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ARTICLE

Design and Development of a New Control System for Improving Energy Efficiency and Demand Response

Guillermo Escrivá-Escrivá*

Institute for Energy Engineering, Universitat Politècnica de València, Camino de Vera, s/n, edificio 8E, escalera F, 2ª planta, 46022 Valencia, Spain

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ABSTRACT

One of the best strategies for improving energy efficiency in any system is using the energy resources in the facilities properly. Using energy systems only when they are absolutely necessary is one of the best cost-benefit ratio strategies, i.e. the best energy saving strategy is, not using it. The aim of this paper resides on introducing a new Energy Management and Control System (EMCS), developed by the authors, which has been installed at the Universitat Politècnica de València. Alongside the paper, the architecture, the components and the installation cost analysis of the EMCS, as well as management actions implemented in the university and the obtained results are presented. Furthermore, this innovative system has been designed to improve demand response in energy systems by providing consumers with a tool for responding actively to energy demands, and also to provide all the different electrical market agents with a communication and business platform for exchanging information.

1. Introduction

Approximately one third of the primary energy supply is consumed in the residential sector, therefore it can be stated that buildings sector is one of the main energy consumers in the actual energy demand mix. In developing countries, buildings account for between 30 and 40% of the total energy consumed [1], a trend that is increasing in energy consumption as well as in carbon dioxide emissions.

Consequently, buildings are primary contributors to global warming, greenhouse gas emissions and ozone depletion.

In order to prevent the global warming effect, and thereby keeping the effects of climate change within acceptable limits, the atmosphere CO_2-equivalent concentrations should be stabilized and CO_2 emissions should be reduced [2]. Considering that the building sector is a significant energy consumer segment due to both, the energy demand required and the long useful lifespan of buildings, anticipated important energy savings may come about if building energy demand is minimized.

Hence, achieving better energy efficiency in buildings has become one of the world's major challenges. As heating, ventilation and air-conditioning (HVAC) and lighting account for the major part of a building's energy use, it is vital to understand a building´s energy trends and its energy systems´ operation in order to optimize their overall

**Corresponding Author:*
Guillermo Escrivá-Escrivá,
Institute for Energy Engineering, Universitat Politècnica de València, Camino de Vera, s/n, edificio 8E, escalera F, 2ª planta, 46022 Valencia, Spain;
Email: guieses@die.upv.es

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energy performance [3].

In general, most of the required energy in buildings is used to maintain acceptable comfort levels. In this regard, lighting and HVAC systems are the largest consumption systems, as it is stated in several studies which indicate that air-conditioning is responsible for between 10 and 60% of the total building energy consumption, depending on the building type [4-7]. This clearly indicates that HVAC equipment is a key system for tackling energy efficiency since it has a large energy savings potential. Furthermore, it is also necessary to consider the implementation of an energy management tool as a cost-effective measure to improve energy efficiency in HVAC systems, without compromising the user`s comfort. Thus, in analyzing the energy behavior in buildings, not only should a good construction design be considered, but also analysis of the correct use of the different facilities in order to demand the minimum energy just when the user requires it.

It is common to find HVAC management control systems in large size buildings, although during the years, these systems have also extended their functioning to the control of lighting-switch circuits and facilities access. There are many commercial brands, such as Honeywell, Siemens, Johnson controls, etc., that provide these equipment [8-10].

The energy management and control system (EMCS) presented in this article have many characteristics in common with other building management systems (BMS), since they are frequent technological solutions based on distributed intelligent processors, each one of them with its own autonomy, but altogether working in concert exchanging data at any moment required.

The application programs dedicated to control the energy systems are located within each distributed intelligent processor. These application programs carry out functions of monitoring, automation, regulation (direct digital control) and energy management at the installed energy equipment.

Data coming from all distributed intelligent processors is stored, via communication cards, in a common database and processed thereafter. This database is operated by a graphical work station to provide the requested information to the energy operators in an easy-to-use format, which also constitutes the main server of the system.

Generally, the operator-system link applications, responsible for making transparent and convenient for the end user to consult the information, analyze the data and generate reports from all the integrated subsystems, reside inside this graphical work station (Figure 1).

In most BMS, the system is based in modular server/client architecture capable to accommodate different configurations: from cases with only one server to configurations that require several servers and workstations interconnected through LANs (local area networks) or WANs (wide area networks, large computer system network capable of covering the whole world). The largest and most known WAN network is the Internet.

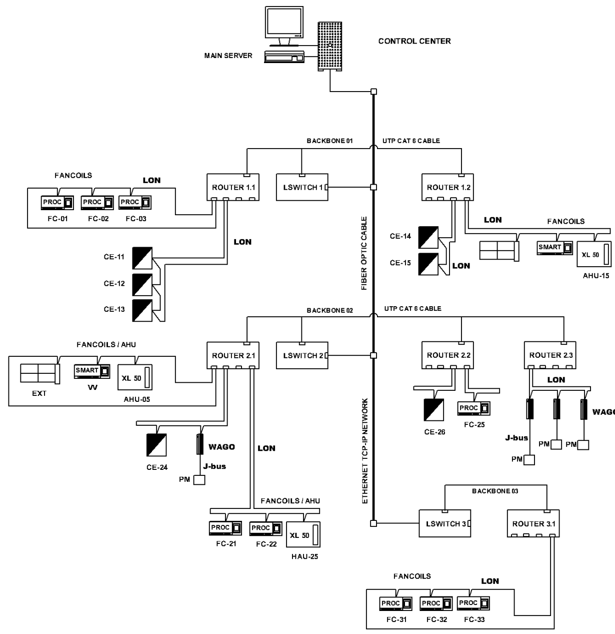

Figure 1. General control system architecture

The application packages for communicating with the distributed intelligent processors reside in the server and update the relational databases in real time. The main server also acts as a file server host, where the graphical information (screens design, images, etc) is stored. End user work station represents the graphical link between the server and the operator.

Industry trends to solve the problem of building control systems integration heads toward open communication protocols that would allow systems integration from different manufacturing companies. Several examples of these protocols are the systems based on TCP-IP, LonWorks, MODBUS, BACnet, OPC, etc. [11, 12].

The described systems have been developed to integrate the different energy installations in buildings and to provide the required functionalities to manage them.

The aim of this paper is to present the definition and implementation of a new EMCS capable to respond to buildings energy efficiency strategies by controlling the BMS and facilitating demand response actions to improve energy savings, fields that have not been tackled so far in the current control systems. Furthermore, the customer use of flexibility strategies in energy consumption is crucial for the effective integration of distributed energy resourc-

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es and CO_2 emission reduction. To achieve this demand response capability, the customers must identify building energy uses and schedules, as well as decide *when* and *how much* energy would not be willing to consume. Active demand-side participation can decrease supply side agents' market power and help these markets to achieve a better operation [13].

This paper is organized as follows: Section 2 is devoted to analyze the new functionalities introduced by the proposed EMCS. Its physical architecture is presented in Section 3 and the software components and applications development are discussed in Section 4. In Section 5 the implementation of the EMCS in the Universitat Politècnica de València is described. The obtained results of the system are described in Section 6 and, finally, some conclusions are drawn in Section 7.

2. New EMCS Features

In the previous section, the architecture and typical features of the current control systems is described, where the effectiveness of these for integrating the different technologies and facilities is shown [6, 7]. However, all these systems have been developed based on market needs such as building facilities integration and control, providing the BMS with the necessary capabilities to achieve this goal.

On the other hand, thanks to the advance of telecommunication in the last decades, today there is a possibility of the necessary hardware to implement a complex control system [14], and powerful software is capable to manage it. Also, nowadays advanced databases exist capable to store and handle lots of data [15].

Nevertheless, the need for defining and developing flexible and useful applications capable of using different systems and taking the most out of them has been detected. New aims can be defined for the control systems: improvement of energy efficiency systems and facilitate users' interaction with demand response programs.

Current control systems present several constraints. This is why it is necessary to raise innovative designs and introduce a new EMCS with additional developments. The EMCS includes the following general features [16, 17]:

● User interaction with the system is set through a web platform, which avoids the need of installing specific software at each work station. The web has been developed to allow the access to different user profiles.

● System architecture uses TCP-IP protocol, so it is not necessary to perform specific wiring to implement the system.

● The system performs and stores electrical magnitude measurements of the different facilities. The EMCS provides a specific application for data acquisition, generating an easy-to-use and extend database. Besides, the software considers anomalous situations such as communication lack with measurement equipment, making a posterior available data treatment. Therefore, it is an important improvement with respect to current BMS which are at the moment not acquiring energy consumption measurements, or if doing so, they are not storing and treating the energy data adequately.

● It is independent of users' geographical dispersion since it enables management by all users from just one and only control center.

● Since the EMCS has been entirely developed at UPV, from its architecture to the applications, it provides an enormous flexibility to the system, thereby facilitating the maintenance and updating of the entire system. The BMSs available in the market have specific applications developed by commercial trademarks, but can not be extended or adapted to the specific needs of new goals. With the comprehensive EMCS development of the system any current or future need could be implemented, as the previously mentioned ones.

● Economic reasons also influence the need for EMCS development. Commercial control systems are purchased by the number of points to be controlled and depending on the available applications; therefore, it is possible that certain desired applications might need to acquire new licenses, at a high cost, for exceeding the number of available points.

Specifically, in order to improve energy efficiency, the system:

● Has got specific applications such as the one for energy consumption surveillance, consumption control, and utilization analysis categorized in periods, etc. (Section 4).

● Has got automatic actions necessary to achieve greater efficiency. The EMCS facilitates setting connection and disconnection times, on holidays, in different operating periods, and so on. Current BMS have significant limitations on the number of different schedules that can be defined and more so they are difficult-to-use by the operator.

● Manages all acquired data and provides the necessary information without additional effort by the system operator, increasing energy efficiency in the utilization of the monitored buildings. It is not necessary for the system operator to wait for certain actions. Once they are defined, the system executes them automatically.

● Develops specific reports on daily consumption, consumption by existing tariff periods, and so on.

Specifically, to improve demand response participation:

● It Integrates all actors that can participate in a demand response program, such as program administrator, aggregators, utilities, electrical grid operators and, most

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importantly, participating customers.

● Constitutes an area of communication between different actors (consumers, suppliers, generators, etc.), which facilitates the interaction and thus, increases trust amongst them. This is a fundamental aspect for the implementation of demand response programs, since it enables energy exchanging products and services in a completely dynamic manner.

● Different participants can react to external variables such as energy or gas price fluctuations, restrictions on networks supply, renewable energy availability, etc., since building facilities are controlled.

In summary, an innovative energy management system developed entirely to meet these objectives presents major improvements over existing ones, both in flexibility and the new features it brings. The goal of the developed system resides on the implementation of new tools and techniques to improve the management of the different energy resources used in existing controlled facilities. The energy efficiency and the control of distributed loads it implies that important energy and economic savings could be achieved, which means a reduction in the environmental impact. These tools allow customer managers to measure energy consumption, to store and manage data, to control energy consumption (i.e. by adjusting the timetable for different loads) and to watch power not to exceed a pre-fixed set point. Additionally, these tools enable obtaining reports and results about energy consumption, so energy demand forecast can be easily estimated.

In conclusion, a new information application to improve energy efficiency and the interaction between the different energy agents has been created (Figure 2).

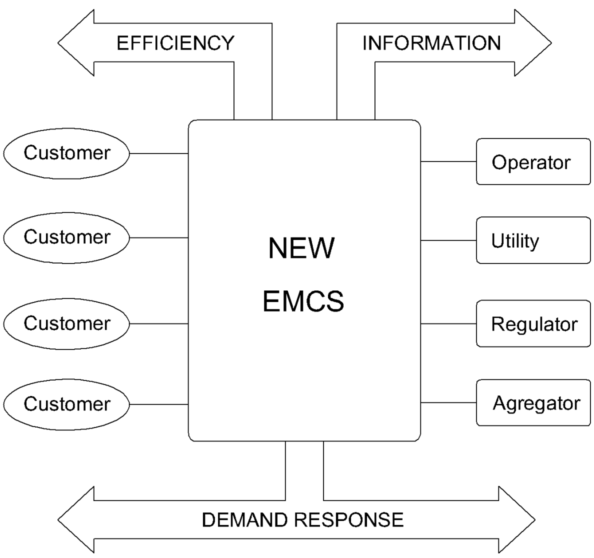

Figure 2. EMCS components

This innovative system brings something new; establishment of orders that building maintenance technicians are not introducing into the system because of it is complex and difficult to them or because they do not have the adequate software.

3. EMCS Physical Architecture

One of the fundamental characteristics of the EMCS is the possibility of communicating with facilities which are far away from each other, and gathering all the information in a central server. TCP-IP Ethernet communication is used, which permits an easy and fast access to the system [16].

Thus, in the architecture of the EMCS, the system components are located in two different sites: one is inside the controlled buildings (the customers), where electrical measurements are taken and control actions are performed. The other one is the control center, where data is stored and a main server manages all the other different applications (Figure 3).

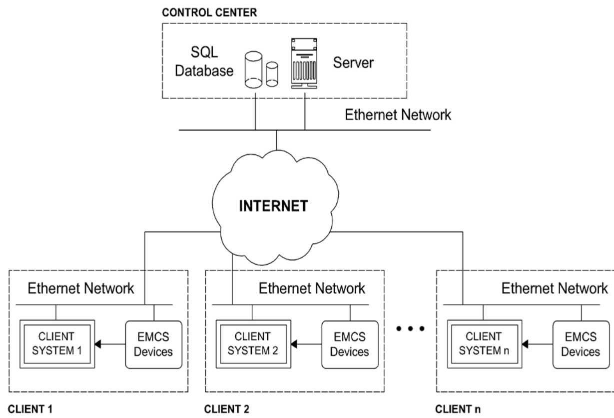

Figure 3. Architecture of the EMCS

3.1 Customers Approach

In order to acquire the necessary measurements and to interact with the facilities, the following devices have to be installed:

● Communication gateway. The gateway sets the communication line between the server and the different measurement and control components. The protocol used between the computer and this gateway is TCP-IP client-server. This device is able to discriminate between components that have permission to access data from others those are not enabled. The commercial device chosen is Telemecanique ETG100 Ethernet gateway [18].

● Data acquisition central unit. This device measures the most relevant electrical magnitude as power, current

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and voltages, as well as other ones related to power quality. It is important to collect the data of the initial status of the site in order to analyze future actions to perform. Additionally, it allows assessment of the success of adopted actions, comparing the final and initial energy status. The commercial device used is the Power Meter 710 Merlin Gerin [19]. Current transformers (I_1A / 5A) selected for the particular point are required (Figure 4).

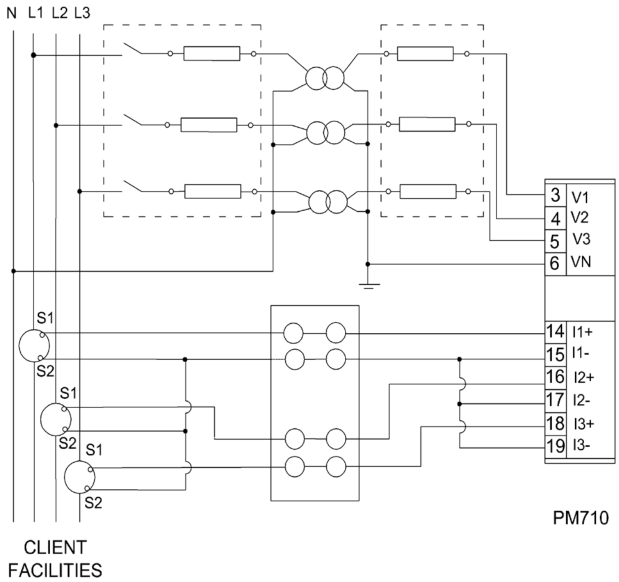

Figure 4. Connection of the data acquisition central unit PM710

● Users performance device. It is necessary to be able to act on the customer with both digital and analog operations. In addition, devices capable of making decisions locally using the instructions from the server, but independent of it, must be used. The commercial element chosen for it is the programmable logic controller-Telemecanique Twido PLC [14, 20, 21]. This will obtain input signals for controlling and certificating the system, and generates the output signals for implementing control actions on the user.

● In the electrical panels, it is necessary to install electrical control devices such as switches, contactors, relays, etc. to adjust the input and output circuits of the PLC to the controlled power system. Relays and contactors installed for the system will be of "normally closed" type to ensure that a supply voltage failure on the control panel does not interfere with the customers' facilities.

3.2 Control Center

Main server. This device works as a database, applications and web server. Gathered data are located in this server, as well as the software used to analyze and manage it. Additionally, the main server works as a web server; therefore it is the support for a secure communication via Internet. The commercial device used in the system is Intel Server System Xeon SR2520SAXR2U with 4 Gb memory DDR2 of 667 MHz, with 2 microprocessors Intel Xeon Quadcore 5405 of 2.0 GHz, 3 hard drives of 320 Gb Serial ATA and 1 DVD. Hard drives are configurated in a mirror backup mode.

Auxiliary server. It is used as a development server, where all the new applications are checked and work data is stored. Its main mission is based on centralizing the information, which implies a higher level of security. Moreover, it stores backup copies of each application in the main server. This is the reason why the auxiliary server is also a redundant station, so it could work as an autonomous server if the main one fails.

Workstations. They will be used to implement the software integrated in the servers, as well as the necessary engineering tasks to perform the different applications.

Besides, the EMCS introduced in this article interacts with the existing BMS, providing these ones with the additional functionalities to perform the required actions to improve energy efficiency and participate in demand response programs. The EMCS must not substitute the existing BMSs but must be complementary on it and should be able to interact with them. The existing BMS systems should be used for the purpose they were designed, controlling the facilities and supporting building operation.

This interaction will take place in a dedicated panel where the actions sent by EMCS shall be performed by the existing BMS (Figure 5). In the case where EMCS does not specify any actions, the BMS should operate as usual [16].

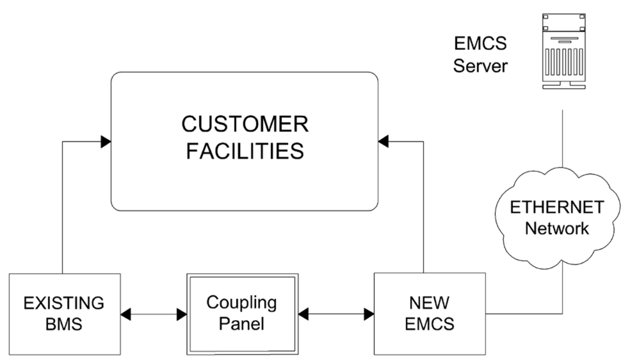

Figure 5. Interaction between the EMCS and the existing BMS

4. EMCS Software Components

As previously mentioned, EMCS is based on a web

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site on Internet, meaning that data could be reviewed in every computer without having to install any specific software. This also enables users to access databases and applications in an easy-to-use way [22-27]. This website is available at the following address: www.derd.upv.es.

The developed EMCS consists of different applications, some of them allow the user a more adequate management of the energy demand; and others are focused on improving the energy efficiency, however all of them are necessary for any considered demand response program:

- Consumption data gathering from customers
- Performance of control actions in facilities
- Storage and management of all the information in a secure database
- Applications development for users

The most promising applications already developed are:

4.1 Building Monitoring (Acquisition)

A reliable monitoring application is used to avoid data losses. For that purpose, adequate maintenance of the measurement devices and databases has to be performed. The existing Ethernet network is used for communication and control purposes, so it is not necessary to do any other specific wiring. For that reason, installation costs are reduced.

This application includes the following features:

- The database system which is implemented in SQL Server that provides a great functionality and has no major technical constraints to the system [22, 24].
- Every hour all measurement points are checked, taking into account their metering intervals. If any loss occurs to some extent, the system notifies through e-mail or the web page.
- Database tables' extension is taken into consideration, so an automatic partitioning is carried out each year.
- It considers the special days of spring time change, with an hour less, and autumn with an extra hour.
- It provides consumer daily report, monthly, tariff periods, and so on.

This application improves the existing control systems in data processing and storage, facilitating the posterior analysis of the information and minimizing the information errors.

Figure 6 presents the stored measurement data for a particular metering point. In the same website it is showed the control lines whose consumption depends on the measuring point represented.

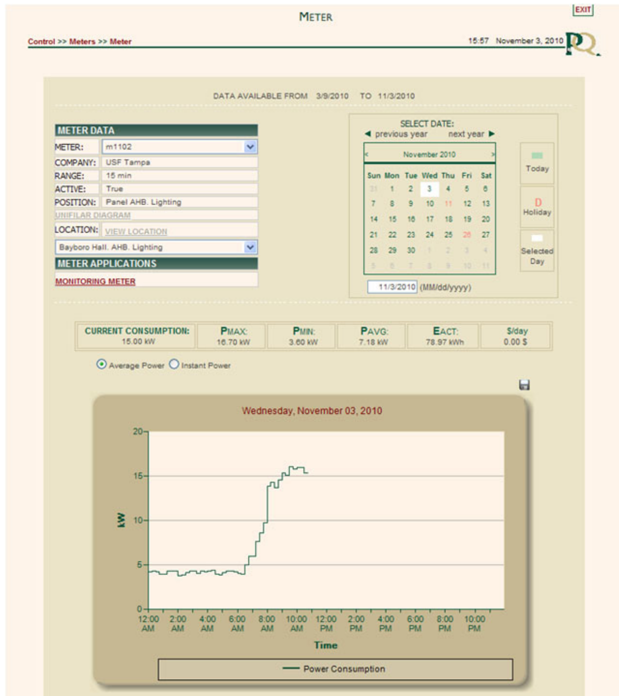

Figure 6. Web site. Meter main page

4.2 Planning Application

This application enables on/off scheduling for each control line of the system. By structuring the lines in measurement point, any on/off action taken in one of them, will be reflected in the meter point where the line hangs.

In this application, two types of planning are possible:

- *Weekly Planning*: operation hours are assigned to different weekdays. It is possible to specify 7 different schedules, one per day, and this schedule is repeated each week. Furthermore, you may define different schedules with different priorities for each period of the year, each time running on the highest priority.
- *Specific Planning*: It is defined as a special operation for a specific date, such as holidays, vacation, etc. There are 3 types of planning for specific days. *Daily*: determined planning is executed only the selected days. *Monthly*: planning for a selected day is executed every month. *Annual*: determined day planning is repeated for the specified date, every year.

This application improves the availability in the BMSs because it is more manageable, and has easier data entry and no limitation on the number of schedules as the existing systems usually present.

4.3 Vigilance Application

The aim of this application is to watch the daily electricity consumption every quarter of an hour at each facil-

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ity. When the tolerance threshold is overloaded, an advice message is sent to the manager´s cell phone or e-mail (Figure 7). It is very important for this purpose to establish the threshold to be applied properly. This information is gathered in specific building audits in order to determine the most adequate values. As this service is carried out permanently, anomalous situations can be detected very quickly, which in turn enables time and cost savings.

It is also possible to define weekly and daily surveillance, considering in a given date (i. e. holiday) where consumption is desired to be different. This application does not exist in the current control systems, since it enables making automatic comparison with historical data.

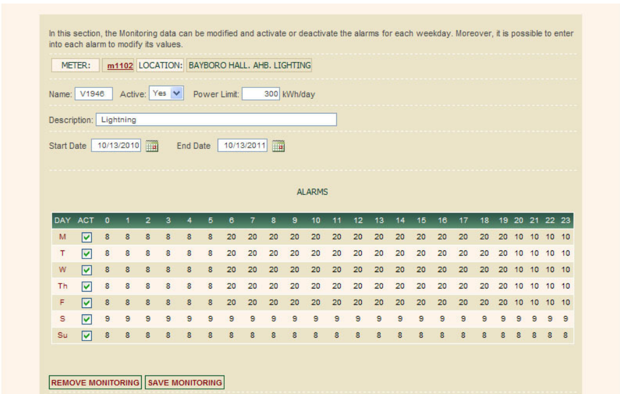

Figure 7. Web page. Vigilance application page

4.4 Peak Power Control Application (PPC)

This software allows controlling the maximum power which is demanded anytime, so penalties due to values higher than the contracted power are avoided. Thus, the client is able to control the electricity bill penalties for power excess, and improve the management of their electricity contracts by optimizing the contracted power.

Maximum power handling is done via a line controlling that have certain permissions. Lines are characterized by a code that defines the feeding loads type (Table 1).

Table 1. Line types in the PPC application

Code	Circuit name	Security level
0	Lighting	10
1	Outside Lighting	10
2	Transit Lighting	10
3	Parking Lighting	10
4	AA Split machine	5
5	AA General	10
6	AA Fan coil / AHU	5
7	AA Production	0
8	AA Parameter	10
9	Extraction	5

The parameters, which must be defined for each line controlled in the application and are necessary for PPC are:

● *Shutting capacity*: Power cut by the system when an active line is turned off, provided that equipment is on.

● *Time off*: It is the longest period that the application PPC sets the line continuously in off-state during a determined event, passing this time the line goes to on-state automatically.

● *Recovery time*: Period in which it is not possible to re-select the line after a shutdown action applied. After this time, the line becomes available to be turned off by the system.

The security level is classified according to Table 2 and used by the application with the following classification:

● Security level 0-4: Lines between these security values consist of the first group of lines which could be select to turn off by the application in case power exceeds the limit set. Any line on this level can be switched off.

● Security level 5-9: Lines with this security level comprise the second group of lines. The lines in this group will only be turn off when there are no more lines from the first group.

● Security Level 10: This third group includes the lines that can not be shut down. Therefore, they are not managed by the PPC application for achieving a power consumption reduction at any time.

Table 2. Security level in the PPC application

Security level	Line action
0-4	First Group
5-9	Second Group
10	Not shutting down

The application estimates in real time which is going to be the active power consumption during the subsequent periods in order not to exceed the maximum contract value within each quarter of an hour. To do so, the system defines two *Operating Modes*:

● *Pessimistic mode*: In this application mode, it starts turning off the lines before reaching the peak power limit defined:

$$E_{LIM} = E_{CONT} - D \cdot E_{CONT}$$

where:

E_{LIM} : Energy limit in which the lines actions start.

E_{CONT} : Maximum energy to be consumed at a given instant according to the contracted power. This value is calculated every minute and reseted every 15 minutes.

D : Deviation parameter, which indicates the energy

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percentage that is added or subtracted depending on which mode is chosen.

● *Optimistic mode*: In this mode the application starts shutting down the lines once the defined peak power limit is reached, expecting an energy consumption reduction in the sequence:

$$E_{LIM} = E_{CONT} + D \cdot E_{CONT}$$

4.5 Baseline Application

For each meter the baseline is calculated every day at 00:00h, considering previous days' measurement data (Figure 8). Currently the system implements a heuristic method which considers historical data of the last year and outside temperature forecast.

It is suitable to integrate this method in the EMCS, since it already has a database with historical measures from all the meters, and a great computation capacity and, since it is connected to Ethernet, it can automatically obtain forecasts of temperature, humidity, etc. from servers that provide such data.

Current control systems do not provide this application and which on the other hand is necessary for managing the actions taken by various participants in a demand response program.

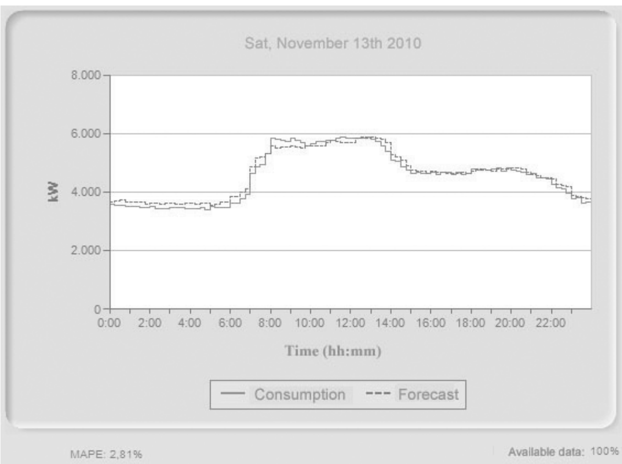

Figure 8. Web Page. Baseline application page

4.6 Maintenance Application

It performs all necessary operations to maintain the system in an adequate state. Thus, every hour it verifies that all applications are active on the server, checks the lines status each 10 minutes, performs auxiliary calculations necessary for the different applications, maintains user permissions, etc.

Other additional services that are provided by the EMCS system are:

● Responsibilities assignation.

● Raising awareness and sensitization on energy saving.

● Interaction between the different users.

5. EMCS Implementation

The project started in February 2007 and since December 2009 savings have been estimated at values of more than 850 k€, while the total cost of the project has been about 2 M€ (Table 3). What is more, it is expected that savings are higher when the EMCS is in full operation. Presently, there are already 67 UPV buildings integrated in the EMCS.

Eighty three control boxes and 236 metering points have been installed, while 2,387 lines are now being controlled.

Table 3. Cost of installed equipments

Device	Description	Cost (€/u)	No. (u)
Power Meter	Installation Power Meter 710 Merlin Gerin with 3 current transformers	654	236
Gateway	TSXETG100 Telemecanique	615	78
PLC	TWDLCAA40DRF 16 outputs, 24 inputs	813	81
Panel	Control box	750	83
Controlled devices	Relays and contactors. Connections and wiring.	250	1,953
Temperature sensor	Sensor TTA-250/F	453	2
Luminosity sensor	Sensor ELV 741	1,853	2

The EMCS carries out more than 2,500 control actions every day.

During the implementation, meters have been installed in the following electrical points:

● Main panel of the electrical system at each building

● Emergency supply main circuit breaker to obtain the total consumption of the building.

● Specific air-conditioning panel, since it is the end-use (independent process) in which control has focused on. This is because HVAC systems present the greatest possibility for energy efficiency improvements in the studied facilities.

● Specific parking panels.

● Some specific panel for interior lighting with several controlled lines.

● Measurement data is obtained out of the transformers´ output.

● Public lighting at specific electrical panels.

For improving energy efficiency in the facilities, it is necessary to perform certain actions in different circuits.

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For example, the air-conditioning installation shall be forced into the air handling units, fan coils, etc., when necessary.

It is also necessary to turn off lighting circuits, flow regulators connection at certain times, etc. Furthermore, the lines, circuits in which some control action can take place by EMCS control, are defined under different types [28]:

● Lighting.

● Outside lighting.

● Public lighting.

● Parking lighting.

● General air-conditioning.

● Air-conditioning production.

● Air-conditioning fan coil.

● Split air-conditioning equipments.

● Extractors.

Also, two sensors have been installed to measure:

● Outside temperature. Outside temperature may be obtained at each point. For this, an external temperature probe has been installed and the PLC has been extended with an analog input module. Specifically, the expansion module selected is the TWD-AMI8HT. The commercial temperature probe selected is the TTA-250 / F model [29].

● Outside Lighting. Luminosity sensor has been installed, in order to acquire data for this variable; concretely the commercial device selected for this purpose is the ELV 741 [30].

With temperature data it may be controlled the actions in the air-conditioning lines while the lighting lines are controlled with luminosity data.

The implementation impact on different system components is described in the following sections.

5.1 Impact on the Facilities Energy Consumptions

Usually, cost of electricity consumption in university premises and similar infrastructures is very high, mainly due to the following causes:

● There is no optimum management. Usually the person who manages the electricity in a building is the same that manages other services (water, air-conditioning, general maintenance, etc)

● Electricity contract is not the optimum (not enough studied).

● There is no place where users and maintenance managers can get in touch.

● Users are not aware of the energy problem.

The development of this system improves the energy management, because:

● Energy consumption is measured, so it can be controlled and reduced. In addition, there is a responsibility assignation that means that the responsible manager is more careful because he knows the building energy consumption levels and he is responsible for energy data acquisition.

● Electricity consumption during out-of-work-hours is perfectly known, so different strategies can be applied.

● New guidelines on energy use may be proposed.

Previous studies carried out about energy management in commercial buildings [3-5] showed that reductions of 8% can be obtained by only watching consumption trends. Total reduction can be up to 20% if additional active controls are performed.

5.2 Impact on Human Habits

Other important impact is the achievement of a social energy commitment. This project promotes the best use of energy by the different people forming the university community (professors, students, resource managers, services and staff) or the facilities. Thus, responsibilities for each collective are promoted in the following areas:

● Maintenance service: Control of air conditioning system and common areas' lighting.

● Students and professors: Air-conditioning and lighting in classrooms and lighting in restrooms.

5.3 Impact on the Facilities

There are two situations, which are: buildings with and without control system that integrates various facilities. In the first case, as discussed earlier (section 3.2), the EMCS provides orders to the BMS, which performs the adequate actions for turning off the necessary equipment. In the second case, EMCS performs the control directly on the facility with the installation of the required equipment (relays, contactors, etc.).

Some proposals about different equipment that is usually not controlled in analyzed buildings are included below. In order to manage these devices some actions have been implemented:

● Autonomous air conditioning (AC) devices (split units, roof-top, etc.):

Problem: Some AC individual devices, installed in offices and little rooms, remained switched on during nights or weekends.

Solution: Permission relays have been installed in series with the control circuit of machines. These relays are connected to the control system, which avoids AC devices to stay connected during nights or weekends. The payback is shorter than 2 years.

● Centralized HVAC systems

Problem: Some HVAC centralized devices remained

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switched on during nights or weekends. Nevertheless, the control of these systems was usually centralized and easy to adjust, but timetables were not optimized.

Solution: Permission orders are given by the EMCS to the local control system installed for chillers/heaters and groups of fans. This option avoids HVAC devices to remain connected during nights or weekends. Moreover, other control options have been performed, for example disconnection of chillers/heaters on peak hours, since fans can use the thermal inertia of the system. The payback is shorter than 2 years.

● Lighting

a) In common areas

Problem: Usually, lighting in common areas was excessive during the day. Additionally, some lights were switched on during the whole day.

Solution: Permission relays have been installed - in series - to main lines of common lighting areas that are switched off from time to time. These lines are switched off when lighting in the area is not necessary (during night, weekends and holidays). In addition, twilight switches have been installed and timetables for connection are now adapted in order to optimize the luminosity level (adaptation of switching timetables in accordance with seasonality).

b) In classrooms/conference halls

Problem: Sometimes there were empty classrooms where lights stayed switched on.

Solution: Presence detector units have been installed in series with switches in order to control the lighting.

c) In restrooms

Problem: Light in restrooms was switched on during all the day.

Solution: Presence detector units or timer switches have been installed. Energy savings of about 60% are being achieved. The payback is not higher than 3 years.

● Electronic Equipment

Problem: Obviously, the electronic equipment (computers, printers, videos) in offices, in general, and in university buildings, in particular, is very important. Energy demand of electronic devices in universities represents up to 15% of overall peak demand [31]. Sometimes, electronic equipment was switched on during the whole day.

Solution: It is analyzed the number of connected devices and the users are made aware to bring them into suspension mode. In the university there are 4,000 computers connected during night period of the 10,000 used during the day.

5.4 Demand Response Capability

Throughout the implementation of the EMCS system, various power lines are controlled. When managing a large number of buildings, the control over the available power becomes very large. As the number of monitored buildings increases, the power to be controlled also increases. Currently, EMCS is managing over 2.5 MW, only in air-conditioning lines. Such power can be used to respond to price signals that reach the system via the Internet or from a FTP server.

The EMCS provides the necessary infrastructure, capable of participating in electricity markets where power disconnection could be offered as a service to the grid. Furthermore, since the consumed energy is perfectly known in the different facilities, the electricity contract can be optimized, so that the electricity bill is reduced.

In this new framework, energy consumers could have influence over the price and quantity of generated energy, so customers may offer energy not by producing it, but by not consuming it. In this way, this system would enable demand response to be monitored by different agents, and price signals may be provided [13].

A common framework for the different energy actors has been created, where real-time information can be accessed according to access profiles. Moreover, the information provided will enable the utility to offer customized contracts to the customers.

Using the Baseline application, an estimation of certain facility consumption is obtained (Figure 9), information that can be used to establish the necessary compensation mechanism required in a demand response program.

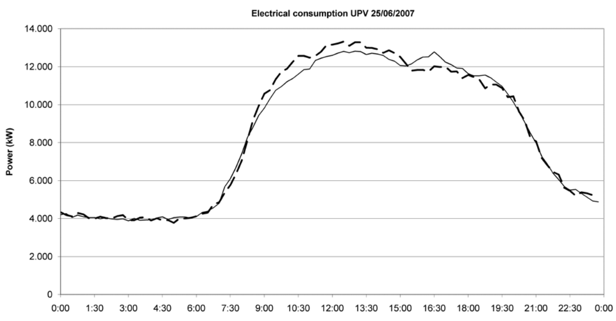

Figure 9. Baseline calculated

This EMCS is expected to contribute to the improvement of operation and management in electricity systems, since the access to centralized and controlled loads through a website provides an environment where the operator of the grid, utilities and the consumer are able to interact.

Management options proposed here may imply the reduction in the necessity of new generation plants and new transport lines, that means a significant reduction of the environmental impact (reduction of 1 Ton CO_2 emissions

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per MWh) and a reduction of needs and costs of electricity transport and system operation.

For example, in Europe there are about 4,000 colleges and universities, so this project has a huge potential for this type of infrastructures [31].

6. Obtained Results

Considering all the proposals in this work as an outcome of the implementation of the EMCS system substantial energy saving has been calculated. This includes:

● Permanent savings in HVAC systems. In conducting the initial audit, prior to the installation of the system in the buildings, set points, schedules, timers, etc. are modified obtaining a permanent better facility operation.

● Savings on lighting. Using presence detectors together with EMCS actions a reduction in lighting consumption in common areas with external lighting has been achieved.

● Savings as a result of daily monitoring of the facilities. The maintenance technicians are more dedicated since the system monitors and stores energy consumption, even in off-working hours.

● Savings in holiday periods by better adjusting the schedule planning.

● Savings by EMCS daily actions: They have been mainly achieved by controlling the HVAC devices. The results are quantified comparing the consumption during a normal day with the EMCS functioning (EMCS ON) and without doing this actions (EMCS OFF). Only implementing this action, consumption reductions in working days for these devices have been calculated in 315 €/day, whereas savings of 636 €/day and 910 €/day were achieved on Saturdays and Sundays or on holidays respectively (Figure 10).

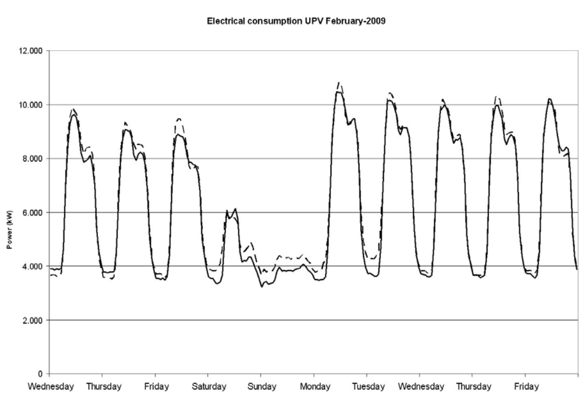

Figure 10. Energy consumption in the UPV with and without EMCS

Savings are very important in common areas lighting, such as restrooms, corridors or halls, where reductions of 18,126€ have been got.

Following, some figures directly obtained from the EMCS reports are presented to illustrate the interesting effects in the load curve of different facilities while are being controlled. These results are used for energy and economic savings calculation, according to the control actions performed by the EMCS.

Taking into account the effect in the whole campus on Saturday days, it could be inferred that consumption during the valley period (mainly on night) has been reduced, unless the total consumption during the day suffers an increment due to construction new buildings in the university.

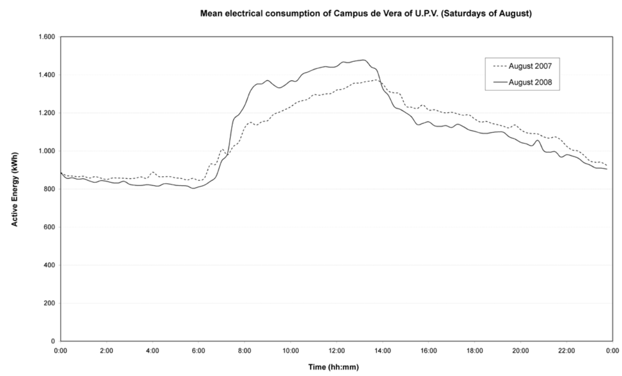

Figure 11. Consumption on Saturdays in August 2007 and 2008

As it is shown in Figure 11, the mean consumption in 2007 on Saturdays was 104,008 kWh and 104,347 kWh in 2008. Nevertheless, when only valley periods (from 0:00 to 7:00 and from 14:00 to 24:00) are considered, it is easy to check that consumption has been reduced in about 5 % (from 69,614 kWh to 66,458 kWh a day) periods in which EMCS action are performed.

A similar effect is obtained in Sundays and vacation periods. Figure 12 represents load curve for the whole campus on a holiday day, August 15th 2006, 2007 and 2008.

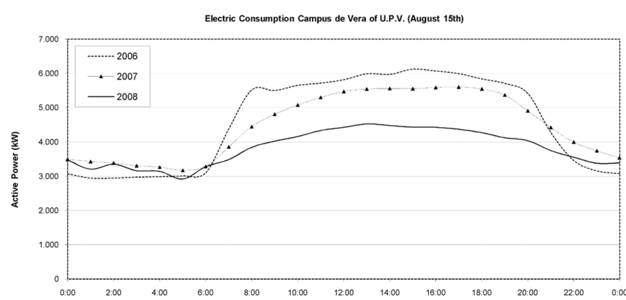

Figure 12. UPV consumption on August 15th

Consumption in 2006 is 111,734 kWh, 108,166 kWh in 2007 and 92,223 kWh in 2008, so a 15 % reduction has been achieved since the EMCS´ implementation. It has been achieved because of the proper space cooling device management, since some HVAC machines were switched on during the whole day on vacation before implementing the EMCS.

EMCS provides significant savings in air conditioning and common areas lighting, allows daily consumption monitoring, facilitates energy bills verification, permits scheduling adjustment for vacations and holidays planning, controls the peak power consumption, and provides air conditioning management on daytime and daily basis.

In Figure 13 there is an analysis of the consumption of a teaching building with 4 floors and 8,323 m^2 area (7B-7E ETSID). It can be noted that there are significant reductions in energy consumption due to switching-off of the cool production 30 minutes in advance at 21:00, so that thermal inertia of the system is used to keep the temperature range under control. Additionally, the starting time is delayed for 30 minutes in the morning and 30 minutes in the evening, which also produced noteworthy energy savings.

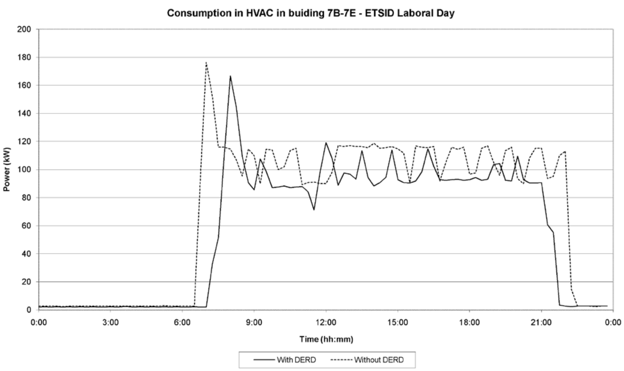

Figure 13. Energy consumption in building 7B-7E ETSID

As it is shown in the figure, consumption is reduced from 1,720 kWh to 1,392 kWh, which implies savings of 19 %. If only periods from 0:00 to 8:00 and from 21:00 to 24:00 are considered (valley periods), savings of 179 kWh are achieved.

7. Conclusions

A new energy management and control systems (EMCS) has been created to help the customer to use energy more properly. This EMCS includes a set of new tools and techniques in order to improve the management of different energy resources used in existing facilitates, resulting in a reduction in energy consumption, increasing overall efficiency and the control of the distributed loads. The university campus is selected to install the developed EMCS since it encompasses many service enterprises including healthcare delivery, sports facilities, businesses in research parks, as well as overall faculty and student services.

The EMCS is based on a secure website to inform and to get in touch with different agents that could be interested in the use of available distributed energy resources, as generation, storage and demand response. It allows the facility managers to measure energy consumption, to store and manage data, to control energy consumption and to watch power not to exceed a pre-fixed set point.

Currently, the Institute for Energy Engineering (IIE) is working on a project with a utility to define a new electricity contract, which values control power available. Within this project IIE is developing the necessary applications to manage the power available through the EMCS as an information exchange platform.

Energy consumption would be measured, so it could be controlled and reduced. As it is shown in this paper, the EMCS is able to achieve decrements of 20% with active control.

Lastly, another impact is the achievement of a social energy commitment towards effective energy control in service enterprises.

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