Title

Optimization of the management of building stocks: an example of the application of managing heating systems in university buildings in Spain

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Abstract [50-200 words: aim, scope and conclusions]

The article presents the implementation of management measures that have reduced the gas consumption for heating of a university building in Spain by 40%. The measures affect the use of the building, e.g., the use of its spaces, and the scheduling of its occupancy. They also affect the management of the heating system: a protocol for turning the system on and shutting it off has been developed.

The work is part of a framework for action by the Technical University of Catalonia covering more areas and for a longer period of time, in which policies have been designed for managing buildings and a number of studies have been developed on the energy consumption of the university's buildings. The article highlights the vision of the research group on the topic, and work methodology proposed. The implementation of these measures in the case, which is explained in detail, from November 2006 until May 2007, has reduced consumption from 113.2 kWh/sqm to 68.7 kWh/sqm a year; thus, the hypothesis has been validated. In addition, it was possible to examine methodological details more closely. Finally, the relationship between the people involved in the process [the building owners, managers and energy users] is a determining factor.

Keywords [max 10]

Energy efficiency, educational buildings, management of heating systems, environmental impact of buildings.

Main Text

1. Introduction

Emissions of greenhouse gases (GHGs) in Spain have increased by 152% compared to 1990 [1]. Energy consumption in buildings (domestic and services) is responsible for around 23% of final energy consumption in Spain. Of these, about 8% of the total (35% of consumption attributable to buildings) is the non-residential sector, on which there are very few data.

Although it has been demonstrated that use and management are determining factors in energy consumption in buildings [2], these factors are not usually taken into account in policies for energy savings and efficiency. Spanish strategic plans focus on new buildings [3, 4] or improvement measures for existing buildings to renew their envelope or systems [5, 6], which assume optimum management [7]. Furthermore, these improvements require large investments.

To optimize the management of existing buildings, knowledge of the characteristics of the current stock is essential for defining strategies for savings and for the calculation of those savings. In general, the descriptions of the surface of the existing stock are only top to bottom [3, 8] or bottom to top [9 - 11], but there is no evidence from various scales. Also there are few actual consumption data on buildings [12]. In the specific case of university buildings, several universities have been monitoring consumption, but not all data are openly available [13 - 16].

This article addresses the following research questions:

a) Up to what point can the ideas on optimization of management be applied to existing non-residential buildings? How far is the theory from reality?
b) What are the process' key points? Is it possible to establish a certain methodology?
c) Who are the determining players?

To answer these questions, we have chosen a case study: the buildings of the Technical University of Catalonia (UPC) in Barcelona, Spain. The UPC has more than 60 monitored buildings in various climatic regions of Catalonia. In addition, the institution has been working for several years on an intense policy of *sustainability* [17, 18] and prior studies have been conducted [19] on the factors that determine energy consumption in buildings. In particular, measures have been implemented on the campus occupied by the *Escuela Técnica Superior de Arquitectura del Vallés* [Vallés' School of Architecture] (ETSAV).

2. Institutional context

The first of the research questions referred to the application of ideas, i.e., the implementation of actions or creation of new patterns of behaviour from a theoretical belief. In this case, the theoretical root of the need to consume less energy sprouts from the awareness of the planet's limitations and the need to manage resources sustainably. There are also some more pragmatic roots, such as the existence of regulations at higher levels (e.g., at the European level) and increased economic costs posed by the indiscriminate consumption of energy. These latter reasons are very crucial at the administrative level.

This section will explain the theoretical and practical engines of the institution under study, the UPC, which is relevant to explaining the amount of theoretical and political effort that has been required before a case could be applied in practice.

2.1. Political framework

After 2 consecutive environmental plans in the periods from 1996-2001 and 2002-2005 [18], UPC has approved the *UPC Plan for Sustainability in 2015* [20], which is divided into five lines, and one of them is *Construction, energy and climate change*.

This line created the UPCO$_2$, the programme for reducing GHG emissions from the UPC [21, 22], which is part of the challenge *Construction, energy and climate change* of the UPC Plan for sustainability. The following are among the plan's activities related to energy savings and efficiency:

- At the end of December 2006, a partnership agreement between the Catalan Institute for Energy [ICAEN] and the UPC was signed in which the parties undertook to carry out a series of measures in relation to savings and energy efficiency, which would be implemented in different campuses of the university. This agreement is part of the collaboration agreement signed on September 12, 2005 between ICAEN and the Institute for Diversification and Saving of Energy (IDAE) for the definition and implementation of the public support activities in the Plan of Action of the Spanish Strategy for Energy Saving and Efficiency (E4) [3], in the territory of Catalonia in 2005.
- The UPC's SIRENA project [System of Information on Consumption of Energy Resources and Water] [23 - 25].

2.2. Practical experiences

Recent experiences carried out within this political framework include:

- The Process of Application of Environmental Criteria in Architecture (ACA2), 2000 [26].
- Research for the Environmental Excellence of the Baix Llobregat Campus (REAL Laboratory), 2001 [27].
- Efficiency Plan for the Consumption of Resources (PECR), 2003 [28, 29].
- REAL Laboratory 2, 2005.

In this second laboratory phase, the strategies that have been developed so far in the UPC for improving the environmental quality of their buildings are collated and analysed, and diagnoses and defining of new objectives are carried out. Having identified the factors that determine consumption of energy resources, the tools that enable a detailed analysis are defined: energy demand and system performance can be calculated either manually or by using a computer program, depending on the level of detail of the analysis and the available data.

The organisational structure of the UPC was analyzed in regard to decisions and actions related to resource management, to make a proposal for an optimal layout diagram for both new buildings and existing buildings.

3. Description of the buildings analysed

A generic description of the characteristics of the UPC's stock of buildings as a whole is given below. As shown in Table 1, the buildings will be described from a management standpoint [surface area, climatic region, management, electricity and gas consumption, type of heating and cooling systems and type of use]. Other parameters considered to be important could not be included in the general description due to the difficulty of collecting such information [U, electrical capacity installed, hours of use], but they are in the description of the building studied. The reasons for selecting the specific building studied will also be explained.

3.1. The UPC's buildings

The UPC has 96 buildings spread over 10 campuses in a total of 7 municipalities in Catalonia. Their total surface area is 404,715.5 sqm. These locations are grouped into a total of 6 meteorological stations of the Catalan Institute of Meteorology (Meteocat) [30]. According to the Spanish Technical Building Code [CTE], they are in 3 different climatic zones [5], as shown in Figure 1.

Data are available on the consumption of 64.2% of the buildings, which represent 75.4% of the total surface area. As shown in Figure 2, the mean annual electricity consumption of these buildings oscillates between 15.1 kWh/sqm and 140.9 kWh/sqm, and the mean annual gas consumption, is between 9.0 kWh/sqm and 113.5 kWh/sqm. The gas is mainly used for heating. The time from which these data are recorded varies for each building.

The physical management of the facilities is centralized, so there are three major operators or maintainers of the buildings [G1 to G3]; figure 2 shows some differences in ranking between the three managers. However, the manager of the unit or centre that the building occupies also has some power of decision.

Figure 2 also shows that the ETSAV building has high gas consumption. In the comparison of the annual CO_2 emissions by campus that can be seen in Figure 3, it is only surpassed by the North Campus [where there are many air conditioning installations, and which has housed the super-computer *Mare Nostrum* since 2005]. Finally, the annual CO_2 emissions of that building are higher than other buildings of the same type and use [2], as shown in Table 2.

In addition, a previous study that analyzed the consumption of buildings over the 2002-2003 season, had determined that the inefficient management of the building's heating plants increased final energy consumption in the building by 30% [2]. Lastly, the centre has a highly motivated administrative team that is willing to investigate in order to reduce energy consumption in the buildings it occupies. For the above reasons, from now on the management of the heating of the ETSAV buildings will be analysed with the aim of optimizing it.

3.2. The Sant Cugat Campus

3.2.1. Description of the building

The campus is located in Sant Cugat del Valles (elevation: 100m, latitude: 41º 29' 40" N, longitude: 2° 2' 6"W), Barcelona, Spain. The climatic features can be found in Table 3.

As shown in Figure 4, it consists of 2 buildings (ETSAV and CRITT) that have been built progressively, so that the total area has varied from 8,746sqm (up to 1999), 9,267sqm up to 2005 and 10,130sqm since 2006.

3.2.2. Description of consumption

During the period from 1995 to 2005, consumption of gas in the ETSAV building grew steadily by approximately 7% annually, with a total increase of 66% within the period. With regard to electricity consumption, it grew steadily by around 4% annually, with a total increase of 44% during the period.

The gas-electricity share in total energy consumption []for the period was 70% -30%, but in regard to total CO_2 emissions the share was 50%-50%. To perform the calculation of emissions, the equivalents of 204g CO_2/kWh of gas [31] and 501g CO_2/kWh electricity were used [32].

The mean annual emissions associated with ETSAV energy consumption for the period were 51.3 kg CO_2/sqm, which is above the UPC's mean annual emissions, which are 40.9 kg CO_2/sqm. All of the data are shown in table 4.

4. .Methodology

This study is part of a larger project that primarily aims to assess the weight of each of the factors determining the inefficient consumption of energy resources and, once identified and evaluated, to identify opportunities for improvement. The factors considered are:

- Energy demand: the structural characteristics of the building;
- System performance: inefficient facilities, lack of control or maintenance elements;
- Use and management: inadequate management and maintenance of facilities, poor utilization by users (e.g., leaving windows open when the air conditioning is running).

The relationship between these reasons is not obvious and is not independent of each other: if the maintenance team cannot properly maintain existing facilities, using new technologies, it is possible that the same thing could happen. Likewise, by reducing demand (by changing the windows, for example) the actions of some irresponsible users continue to minimize savings. In addition, changes in the facilities, renewals of air or the thickness of the insulation will change the demand [33].

Management has proven to be a determining factor in the examples studied [2], particularly with a 30% potential for improvement for the ETSAV building. Accordingly, this part of the project examines in detail the possibilities of optimizing the management and the applicability of the theoretical measures.

In the first section 4.1, the provenance of all data sets laid out in the article are explained, taking into account that attainment of information is already part of the methodology. The second section, 4.2, explains the details of the application of the generic analytical methodology of the factors that determine energy consumption [28, 33]. Section 4.3 explains the actions that were carried out. Finally, the results and conclusions are laid out.

4.1. Sources of information

4.1.1. Climatological data

Climatological data can come from two different sources:

- The Catalan Institute of Meteorology, Meteocat, manages the network of automatic weather stations of the Meteorological Service of Catalonia. Table 1 shows the station closest to each building. The stations recorded hourly variables.
- Private meteorological stations installed in the buildings. In the particular case of the ETSAV, data were recorded with a Davis station [34] belonging to the ETSAV's Department of Physics and Nuclear Engineering. The observatory is called the ETSAV-DFEN and its geographical coordinates are 41° 29'40"N, 2°2'6"E. The station data are read and processed using the Energy Weatherlink Software 1.01 program.

4.1.2. Consumption data

The consumption data may come from two different sources:

- Accounting.
- SIRENA. See section 2.1.b].

4.1.3. Inside temperatures

Data for temperatures inside the buildings can come from different sources:

- Either alcohol or mercury thermometers placed at locations considered representative. In all cases, the instruments were placed at a height of approximately 1m above ground and in a position similar to that of a worker; proximity to radiators and windows was avoided.
  Reading and recording of temperatures was done manually at 8 and 11 a.m., and 2, 4 and 7 p.m. each work day. The data were analyzed in comparison to the recommended temperature range for winter 17-23 °C [35], as shown in Figure 5.
  This type of monitoring was conducted throughout October, November and December 2006.
- Testo 435-2 Multi-function instrument, with probes and 0632 1535 IAQ and 0602 0394 T/P. The probes were in two classrooms of different sizes as of October 2007. Given their location in a crowded locale, they were placed at a height of approximately 2.2m above the ground and in a position away from radiators and windows.
- Data gathering set of Testo-580 with RS232, with Testo 175-H2 temperature and humidity logger. This type of monitoring was conducted as of January 2008, replacing the previously mentioned mercury thermometers in the same representative spaces.

4.1.4. Users' opinions

It was considered essential to take into account the views of users to verify the characteristics of the inside atmosphere, as there were not sufficient measuring tools. The data may come from different sources:

- Personal interviews.
- Posts in the school's online forum.
  Online questionnaire on the ETSAV users' intranet.

4.1.5. Occupancy

Occupancy data can come from different sources:

- Theoretical diurnal profile, with details of student enrolment from the school's academic secretary. To discover the schedules of workers, a face to face survey was conducted in each of the spaces of the buildings because there is no official registration.
- "Off hours" profile with entrance data on people registered by the security guard, from 8 p.m. to 8 a.m. on midweek days and 24 hours a day on weekends.
- People counters. Throughout the months of October to December 2006, two counters were installed [36] at two of the three doorways to the ETSAV. Separate data are available for entrances and exits. This type of device does not give exact counts, but rather serve to detect the amount of movement [33]. As shown in Figure 6, on weekdays people arrive from 8 to 10 am and leave from noon to 3 pm. In the afternoons, there is only 60% movement; people arrive between 2 and 4 pm and leave between 6 and 8 pm. At weekends, they show similar patterns, although the amount of movement is only 20% of the usual and entries occur a little later in the morning.

4.2. Analysis [first phase]

After evaluating the consumption of the building (section 3.3.2) and knowing the potential for optimizing the management of the heating system [37], it was decided to immediately intervene in the building, i.e., implement management actions that would reduce gas consumption as soon as possible. To do so, and in accordance with the analysis methodology defined in previous studies [28, 38], some aspects had to be considered to be able to implement specific actions on the management of the building.

4.2.1. Analysis of the occupancy profile

There were theoretical profiles for the ETSAV building occupancy rate from previous studies [29], which had also been contrasted with random counts in 2005 [37]. The theoretical profile of the occupancy of the different areas of the building during the autumn of 2006 were plotted, taking into account the number of students enrolled in each course, and the areas of the building where the courses took place. With regard to professors, it was deemed that they spent in the department at least the time in which classes took place. Thus, it must be known in advance in which classrooms each course provided by the centre will be given and how many enrolments there are. Similarly, we need to know the allocation of administrative staff and teaching staff in the offices. Therefore, co-operation by the centre’s administration is indispensable.

4.2.2. Characteristics of the heating system

In regard to the ETSAV building, the generic information in previous studies [2] on the characteristics of the heating system and its components was completed using the details from the original 1991 blueprints in paper format of the construction project. But the plans did not include the changes that took place on the construction phase. There were digitalised plans of the CRITT building with the path of the circuit to the boiler room, but the information about the heating vents was incorrect, since the changes made to the project were not shown in the documentation or justified in any way.

Since an integral or comprehensive reading of how the system operated was not possible from the all of the information available, on-site checks were made of the facility’s characteristics, the zoning of the circuits and the characteristics of the components (boilers, pumps, valves, etc.).

4.2.3. Customary running of the heating system

There were two sources of information: the first, because there was no written protocol for managing the heating, were direct talks with the head of building maintenance. Up until 2005, the programming was done manually, so it was directly contingent upon the working hours of maintenance personnel. As of early 2006, there is an automatic scheduler with up to 50 programmes, which regulate only the on-off operation of boilers, i.e., the regulation of each of the circuits must still be done manually.

The second was the online information using the SIRENA tool. Both sources revealed that the system was running continuously from the beginning to the end of the heating season, so gas consumption was the same during the day as at night and on working days as at weekends [25, 39]. The slight variations in consumption corresponded to variations in demand, variations which are minor over the weekend, when there are only students and security personnel in the building.

4.2.4. Climate

Considering that energy consumption for heating has to maintain a relationship with demand and hence with the external climate, we used the concept of degree-days [5]. The degree-day is not directly related to consumption, but can give an idea of the trend that climate should have on consumption. In an ideal situation for optimal management, the same quantity of gas would be consumed for each degree-day.

As shown in Figure 7, a combined analysis of the management system of heating, occupancy and climatic variations was performed [40]. It was observed that there was no relationship between the three factors: the building was heated continuously, without taking into account changes in climate or occupancy.

4.2.5. Discovering the response capacity of the building and its systems

To check the possibilities of modifying the management pattern in the building would have repercussions on interior comfort or the thermal stability of the buildings, so we studied the ability of the heating system to preheat the building and the capacity of the thermal mass of the building to slow the influence of external temperature variations in different indoor spaces.

The *Balanç Energètic* tool [41] was used to estimate changes in the internal temperature every hour. The results of this analysis were used to define the heating season’s nocturnal off time and to reprogramme the system's on and off cycles. The ultimate goal was to reduce the consumption needed to meet the requirements in the building [39]. This could have been done with another tool, but the one we used was useful, simple and quick.

4.2.6. Conclusions of the first analysis

Of course, it became evident that a large amount of money could be invested in replacing the system with a much more adjustable one, but opportunities for action that could be implemented immediately without the need for more financial investment than the dedication of the staff were also identified. It should be noted that the assumption that changes in management require no investment is debatable, and will be discussed again in the section on conclusions.

Regarding the management pattern, some simple changes in turning the system on/off could be made using just the regulation devices already available. As for the circuits, some manual changes could also be made in the periods when the maintenance staff is in the building. Furthermore, the use being made of the building's spaces could be adjusted to the simplified zoning of the system.

4.3. Actions taken

In general, the heating season in this climatic zone is from October to April. The first months are for charging up the building, the central months correspond to the usual heating period, and the final months are the end of the heating season. The research was conducted in three phases (see Figure 7): the analysis was conducted in the first phase (Section 4.2), the first actions were carried out in the second phase, and they were refined in the third phase.

4.3.1. First actions (second phase)

As shown in Figure 7, the months of December and January coincide with the end of the first semester and holiday periods. The analysis has revealed that, although the building is used much less, the consumption is the same.

a) First, the management of the heating was adapted to the building's schedule of use: times when it was minimally or completely unoccupied were identified and shutdowns in the system were programmed without interfering with the operation of the building. In particular, a five-hour shutdown at night in the operation of heating was established as was a reduction in the hours the heat was on at weekends [39]. A management model for specific periods of non-classroom time in the heating season was also established. To this end, we identified the different types of days, which can be seen in Table 5, and a management profile was defined for each of them that included routines for turning the heating and lighting on and off. Each day of the year was classified according to these types.

b) Second, we took into account the influence of variations in the external environment (e.g., whether it was a sunny day or not) in the programming of the heating taking into account the characteristics of the building. That is, the circuits for heating locales with large windows on the south facade were manually programmed differently than those with windows on the north. Similarly, on warm days the system was turned on for less time than on cold days.

c) In addition, preferred use areas were identified, so before using a space heated by a new circuit, all the spaces belonging to a same heating circuit, which was already turned on, were used. Likewise, a work classroom for students to use outside of school hours was set up (until then, all of the classrooms were available and heated 24 hours a day), which represented a reduction of 70% of the surface to be heated outside the normal timetable (from 8 am to 9 pm).

d) Finally, more reasonable temperature values were set. Previously, there were areas where temperatures were very high and, on the other hand, there were spaces that were kept at the same temperature regardless of whether they were occupied or not, as shown in Figure 5.

Internal temperatures measured, as well as the opinions of users were used as a system for verifying interior conditions, and hence the adequacy of the decisions taken. This made it possible to detect the most controversial areas, in which, after a small analysis, other problems were detected, namely:

- Library: several of the windows did not close properly, so there were large losses at workplaces near large windows.
- Computer Centre (CC): along with the library, it belonged to a heating circuit that fed areas with very different uses, so the programming of the circuit was inadequate.
- Concierge: draughts of air, very large space.

- CRITT building: large losses from transmission and filtrations [42].

That is, as soon as the overheating of the building finished, the weak points were found in the architectural, construction and systems design, including the administrative and social weak points. The problems encountered with users and maintenance personnel correspond to that described in the sources consulted [43]. Users' problems are primarily due to differences in thermal sensation and lack of information on how the heating system operates. The problems found with the staff directly involved in the operation are due to lack of time or knowledge of how to operate it correctly [44, 45].

4.3.2. Recording of actions (third phase)

The beginning of the new school semester in February provides an opportunity to regulate the process. The results from the first phase were analyzed to further improve the management of the heating system. Thus, the management profiles of the heating system proposed in the previous phase were adjusted taking into account the occupancy of the building and comments from users.

a) A model was created for recording and monitoring the heating management profile at regular intervals. The model included the following information:
- Recording of maximum, minimum and mean exterior temperatures
- Recording of pumping and return temperature of all of the circuits
- Routines for turning the circuits on and off
- Observations

b) New probes were added to measure and record the pumping and return temperature of the heating system's water circuits and the surface temperature of the vents. New environmental comfort measurement points were added.
When monitoring and recording the various parameters, it was possible to verify aspects that up to that time had only been theoretical considerations, such as the response of the interior temperature to the on and off phases of the heating system, and changes throughout the day both for internal temperature as well as occupancy.

c) Finally, the allocation of classrooms for different subjects was revised, and it was proven that there was a connection with the heating circuits that were on. That is, before assigning a classroom belonging to a new circuit, the occupancy of the classrooms was completed based on the circuits that were already on and, therefore, heated. With the agreement of the professors involved and with the school's administrative team, the classrooms for some subjects were changed to enhance, as explained above, the management of heating and lighting.

The results from this second phase are laid out in section 5.

The investigation is ongoing, and a second analysis is being performed to identify other options for action, such as the management of the building envelope, changes in energy systems and improvements in the regulation of the heating system. In addition, the management model of the heating system that was created during the 2006-2007 period has been transferred to the ETSAV maintenance personnel for the 2007 - 2008 school year as a tool to support decision making in managing the heating system. This management model was created for a specific case, but with the intention that it is adaptable to the characteristics of other buildings of the UPC.

5. Results

In absolute terms, gas consumption for heating during the period from November 2006 to March 2007 inclusive has been reduced [46] to 62.7%. As shown in Table 6, gas consumption per unit area was reduced to 57.5%. Taking into account climatic variations [39], Figure 8 shows that the consumption in the 2006-07 season has not only been reduced to 75.9%, but is also more stable. These savings can be attributed to the change in management, because other relevant variables such as characteristics of the building envelope, facilities or hours of use of the building have not changed significantly from one period to another.

Although electricity consumption was not the main subject of the study, changes in the use of the spaces of the building have involved changes that have affected its lighting. It can be seen in Table 6 that the electricity consumption per unit area has been reduced to 89.1%.

Finally, looking at the results in terms of CO2 emissions per unit area, Table 7 shows that total emissions have been reduced to 70.4%. As there has been more gas savings, it can be seen in the same table that the contribution of consumption of electricity and gas to total emissions has also changed. All the annual (from September to June) values are shown in table 4.

6. Conclusions

An example of application [practical, not theoretical] of optimization measures for the management of heating systems in a university building at the UPC in Spain has been submitted. An explanation has also been given of the long political and theoretical institutional process prior to the intervention. The study has helped verify some hypotheses held by the research team as starting points, deeming that low consumption of energy is a good indicator both of good design and good management, and strictly technical measures do not always solve inefficiency, but must be considered within the context of management and designed to be properly managed throughout the lifetime of the building [33]:

a) As to the applicability,

- It is possible to define strategies for action along the route of energy efficiency based on building management.
- It is possible to reduce the consumption of energy resources (such as those associated with heating in this case) by optimizing the management of the use of a building and its systems. Results can be obtained fairly quickly and with little financial investment.
- In terms of economic investment, if the premise was to act on the management of the building and its facilities without regard to actions on the building itself or its systems, the goal then becomes the most efficient management (in relation to resources consumed) of the building and its facilities, making the most of what there is (regardless of whether improvements can be made to the building and its facilities). This route is very attractive from an economic point of view because it offers the possibility of minimizing the relationship between money invested (because, although lower, there are also investments to be made) and the results obtained. But we need to consider what it means to optimize just one of the factors that determine resource consumption on the premises.
- The results of applying the measures to optimize management have strayed very little from the theoretical calculations [2] for the same building. It was possible to reduce gas consumption for heating by 30%.

b) In terms of methodology, it is based on the combined analysis of consumption, demand and usage. Therefore, access to all necessary information is essential.
In this case, the management strategy was conducted over a very specific time of year and only on the heating system, but the same kind of strategies could be applied to other periods and other energy systems of the building, such as lighting or cooling systems.

c) In regard to the agents,

- The existence of institutional policy is not enough: after making people aware of the need for change, there must be skilled personnel who can translate the theory into practice. The absence of a competent intermediate body may impede transmission and, therefore, success.
- The distribution of responsibilities is not clear: users, those responsible for facilities and administrators of the centre are influential at different times and in different ways.
- Inadequate transmission of information and decision making occurs, so it is important to centralize the process so that responses are appropriate.
- In relation to the adaptation of their response, management staff must be skilled not only in air conditioning systems, but also in the factors that influence the feeling of comfort (air temperature, relative humidity, radiant temperature and air speed). Attention is usually only given to air temperature or user complaints and responses are limited to turning on the heating, without analyzing the causes of discomfort.

The following general conclusions can be written for the Spanish case based on these partial conclusions:

- There should be an administrative unit that would integrate programming of use and systems and monitoring of comfort.

- The management has a social component as important as the technical component, because it has to do with changing patterns of behaviour at all levels.
- Transparency and accessibility to data of the characteristics of buildings and systems, use, and finally, energy consumption are essential for management.

Further work

This study has led to the development of protocols for action so that in the future further action can be undertaken in the building without needing a research team behind it. This guide for the management of buildings is designed to be applicable not only to the building studied, but the UPC's entire stock of buildings. The experience will soon be presented in another article.

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References

[1] Ministerio de Medio Ambiente, Inventario de gases de efecto invernadero de España, Edición 2007 (serie 1990 – 2005), Madrid, 2007.

[2] F. López Plazas, About the use and the management like the main factors that determine the final Buildings Energy consumption. A contribution to reduce the environmental impact of the buildings, Ph.D. Thesis, Technical University of Catalonia, Barcelona, 2006. Available at: http://www.tdcat.cesca.es/

[3] Ministerio de Industria, Turismo y Comercio, Instituto para la Diversificación y Ahorro de Energía, Plan de Acción 2005-2007 de Ahorro y Eficiencia Energética (E4), España, 2003.

[4] Ministerio de Industria, Turismo y Comercio, Instituto para la Diversificación y Ahorro de Energía, Plan de Acción 2008-2012 de Ahorro y Eficiencia Energética, España, 2007.

[5] RD. 314/2006, 17th March, Código Técnico de la Edificación.

[6] RD. 47/2007, 19th January, Procedimiento básico para la certificación de eficiencia energética de edificios de nueva construcción. Boletín Oficial del Estado, (27) (2007) p.4499.

[7] RD. 1027/2007, 20th July, Reglamento de Instalaciones Térmicas en los Edificios. Boletín Oficial del Estado (207) (2007) p. 35931.

[8] A. Cuchí, A. Pagés, Sobre una estrategia para dirigir al sector de la edificación hacia la eficiencia en la emisión de gases de efecto invernadero (GEI), Ministerio de la Vivienda, 2007. Available at: http://www.mviv.es/es/pdf/otros/doc_GEI.pdf

[9] Ministerio de Fomento, Boletin on line, Ministerio de Fomento.

[10] Ministerio de Fomento, Licencias municipales de obra: Construcción de edificios 1990 - 1999.

[11] Ministerio de Fomento, Construcción de edificios 2001 - 2006 licencias municipales de obra.

[12] L.Pérez-Lombard, J. Ortiz and C. Pout, A review on buildings energy consumption information, Energy and Buildings 40 (3), pp. 394-398.

[13] http://www.greencampus.harvard.edu

[14] http://www.upo.es/general/n_servicios/generales/index_general.html

[15] La información en la gestión de las instalaciones, Foro TGU, Valencia, 2003. Available at: http://www.upo.es/general/n_servicios/generales/infr_comunic/doc/web_ponencia_valencia.PDF

[16] B.P. Ó Gallachóir, M. Keane, E. Morrissey, J. O'Donnell, Using indicators to profile energy consumption and to inform energy policy in a university—A case study in Ireland Energy and Buildings 39 (8) pp. 913-922.

[17] I. Capdevila, J.Bruno and L.Jofré, Curriculum greening and environmental research co-ordination at Technical University of Catalonia, Barcelona, Journal or Cleaner Production 10 (2002), pp. 25-31.

[18] D. Ferrer-Balas, Global environmental planning at the Technical University of Catalonia, International Journal of Sustainability in Higher Education 5 (1) (2004), pp. 48-62.

[19] D. Ferrer-Balas, Lopez, F., Díaz, A. Sans, R., Experiences for Improving New and Current Buildings Environmental Performance at the Technical University of Catalunya (UPC) Campuses.

[20] UPC Sustainable Plan 2015, Technical University of Catalonia, Spain, 2006. Available at: http://www.upc.edu/sostenible2015/upc-sostenible-2015/pla_upc_sostenible_2015_esp.pdf [10 June 2008]

[21] A. Cuchí, A. Pagés, É. Mata, UPCO_2: A Program to reduce the GHG emissions in the University, in: Pathways to our common future, in: Proceedings of The Alliance for Global Sustainability Annual Meeting 2007, AGS Office at Chalmers, Sweden, 2007.

[22] G. Ruiz Martorell and A.Cuchí Burgos, Programa UPCO_2 de reducció d'emissions equivalents de CO2 a la UPC, in: 1er Congrés UPC Sostenible 2015, Barcelona, Spain, 2007, p. 201-203. Available at: http://hdl.handle.net/2099/3466

[23] G. Ruiz, About information systems as a key for sustainability strategy. A case on energy efficiency of UPC buildings, in: Pathways to our common future, Proceedings of The Alliance for Global Sustainability Annual Meeting 2007, AGS Office at Chalmers, Sweden, 2007.

[24] G. Ruiz Martorell, F. López Plazas, A. Cuchí, Sistema d'informació del consum d'energia i d'aigua de la UPC (Sirena), in: 1er Congrés UPC Sostenible 2015, Barcelona, Spain, 2007, p. 205-206. Available at: http://hdl.handle.net/2099/3465

[25] www.upc.edu/sirena

[26] D.Ferrer i Balas, N. Granado i Martín, and À.Díaz i Ruiz, ACA2: procés d'aplicació de criteris ambientals en l'arquitectura, Technical University of Catalonia UPC, Barcelona, 2003.

[27] M. Pujades, Laboratori real 1: estratègia de diseny per a un campus sostenible, Ide@sostenible 4, 2004.

[28] M. Bosch, F. López, I. Rodríguez, G Ruiz, Avaluació energética d'edificis. L'xperiencia de la UPC, una metodología d'anàlisi, Barcelona, Edicions UPC, 2005.

[29] A. Cuchí, F. López, Energy consumption indicators for Technical University of Catalonia (UPC) buildings, in: World Renewable Energy Congress VIII: book of abstracts, Elsevier Ltda. Editor. AAAM Sayigh, Denver, Colorado, 2004, p. 210.

[30] http://www.meteocat.com/mediamb_xemec/servmet/marcs/marc_xemec.html

[31] A. Pagés Ramón, A. Cuchí Burgos, Moving the entire building sector towards low CO_2 emissions, in: Proceedings of the Passive and Low Energy Architecture Conference, 2008.

[32] Instituto para la Diversificación y Ahorro de Energía (IDAE). Mix energético español para el año 2005, Programa CALENER versión BETA 3.0

[33] E. Mills, Building Maintenance and Preservation: a guide for design and management. Cap.3: Energy utilization, audits and management [Bordass, W.T. y Field, J.W.] Oxford, Butterworth-Heinemann, 1994 [1^{a} ed.1980].

[34] www.darrera.com/weather.html

[35] R.D. 486/1997, 14th April, por el que se establecen las disposiciones mínimas de seguridad y salud en el trabajo.

[36] Y. Yoshimura, Análisis Urbano. La simulación de la concentración de personas: Multiple Diversity Assessment, Ph.D. Project, UNESCO Chair, UPC, 2007.

[37] F. López, A. Cuchí, About the environmental impact of buildings: Analysis of the incidence of the use of buildings in the energy consumption, in: 3rd Conference on Sustainable Development of Energy, Water and Environmental System, Dubrovnik, Croatia, 2005, pp.450-462.

[38] Diputación de Barcelona, Auditoria energètica II: instal·lacions i edificis, Servei de Medi Ambient, Barcelona,1986.

[39] É. Mata, F. López, A. Cuchí, Sustainable management of existing building stock: a strategy to reduce the energy consumption and the environmental impact, in: Proceedings of Portugal SBO7 Sustainable Construction: Materials and Practices. Challenge of the Industry for the New Millennium. IOS Press, The Netherlands, 2007.

[40] É. Mata, F. López, Monitoring Buildings with Non-computerized Heating Systems: Optimization of Energy Performance by Variations in use and Management, in: Proceedings of the 24th International Conference on Passive and Low Energy ArchitectureDepartment of Architecture, NUS, y Research Publishing Services, Singapore, 2007.

[41] A. De Bobes, Balanç calculation tool, Grup d’Arquitectura i Tecnologia, UPC, Barcelona, 2006.

[42] É. Mata, C. Claret, Applying sustainable renovation policies to buildings: Are we missing a step?, in: Proceedings of the Passive and Low Energy Architecture 2008 Conference. Paul Kenny, Vivienne Brophy, J. Owen Lewis, University College Dublin, Ireland, 2008.

[43] G.J. Levermore, Building energy management systems: an application to heating and digital control, London, E & FN Spon, 1992.

[44] G.J. Levermore, Staff Reaction to BEMSs, 1989.

[45] J.A.C. Brown, The Social Psychology of Industry, 1977.

[46] A. Cuchí, É. Mata, G. Ruiz, F. López, Actuacions sobre la gestió i ús eficient de l'edifici de l'Escola d'Arquitectura del Vallès, 1er Congrés UPC Sostenible 2015, Barcelona, Spain, 2007, p. 197-200. Available at: http://hdl.handle.net/2099/3517

Figures

Figure 1. Map of Spain showing the location of the campus and the climate regions according to the CTE. The region in grey is Catalonia.

Figure 2. Annual mean consumption per surface unit [kWh/sqm year] in UPC buildings. The ETSAV values are in black.

Figure 3. Evolution of the total CO_2 emissions [kg CO_2/sqm] associated with energy consumption for the buildings of each Campus. The dotted line
is the UPC mean. The dotted line and circles refer only to gas.

Figure 4. Plans of the ETSAV and CRITT buildings, on which the heating circuits and placement of the probes for recording interior conditions can be seen.

Figure 5. Sample of the processing of the temperatures taken manually using mercury thermometers in the months of November and December 2006 in representative spaces of the ETSAV building. Legend: Rec = reception, Lib= library, O1:O4= offices, A1-A2= classrooms.

Figure 6. Entries to and exits from the ETSAV, according to the people counter.

Figure 7. Combined analysis of weekly values of consumption, occupancy and climatic variation of the ETSAV building during the 2006 – 07 heating season in which the investigation took place.

Figure 8. Comparison of monthly gas consumption in the 2005 – 06 season with the 2006 – 07 season in which the investigation took place.

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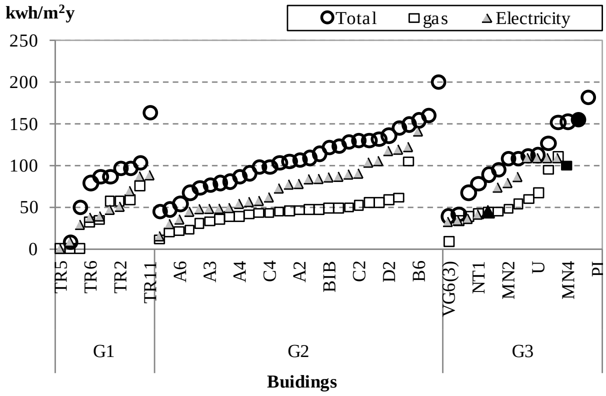

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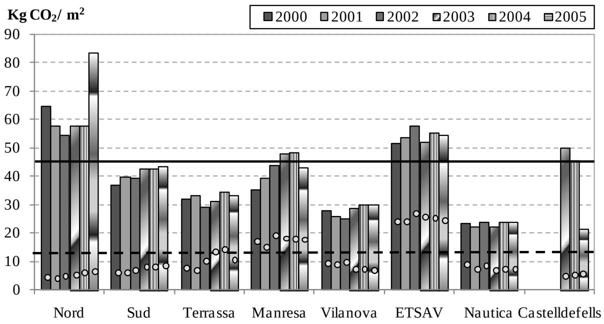

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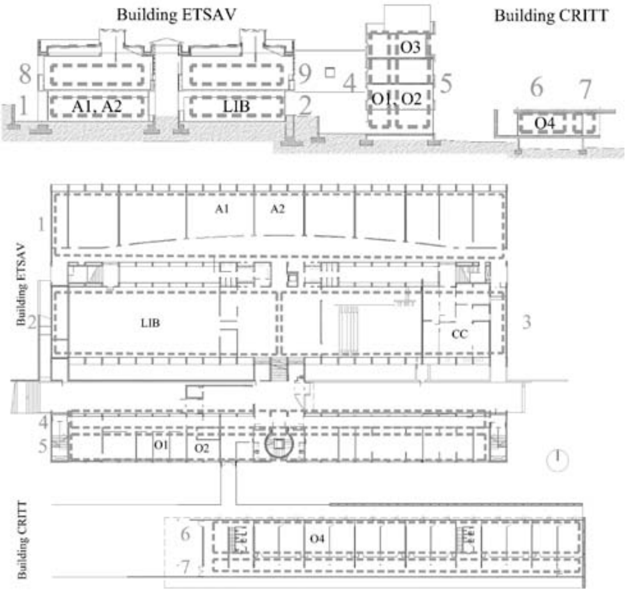

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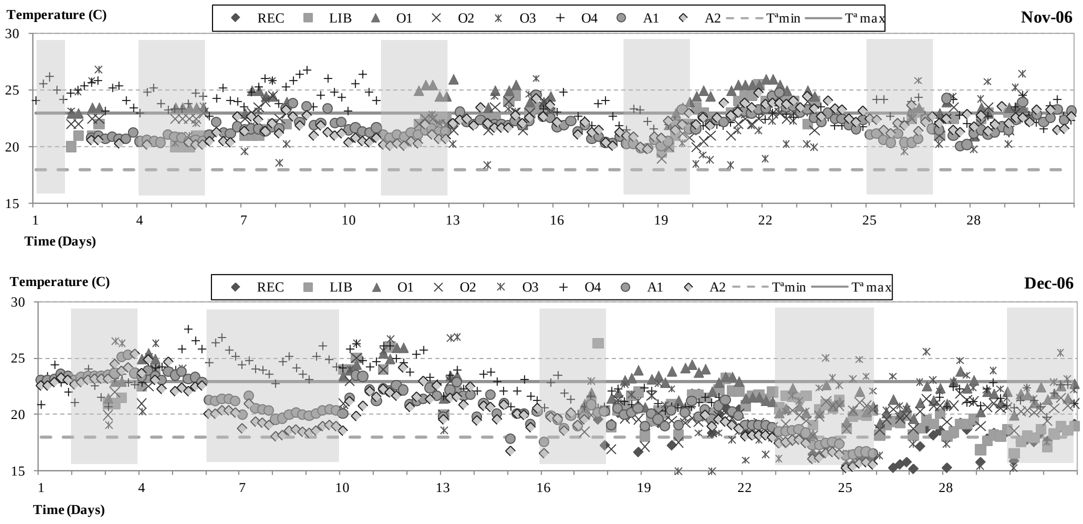

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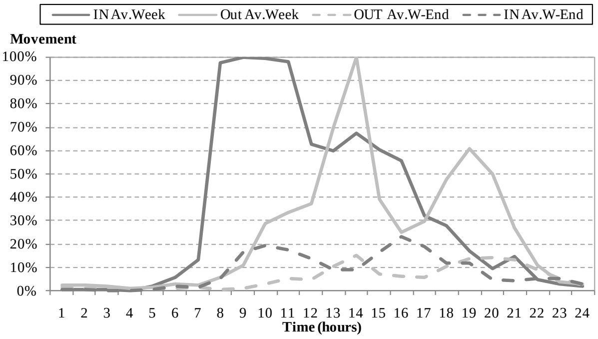

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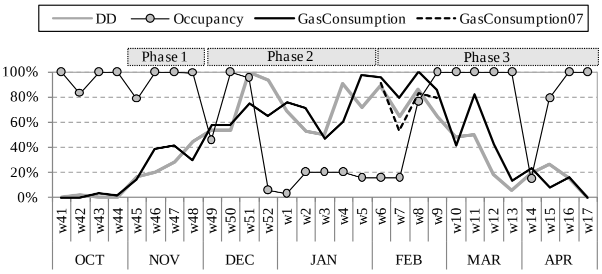

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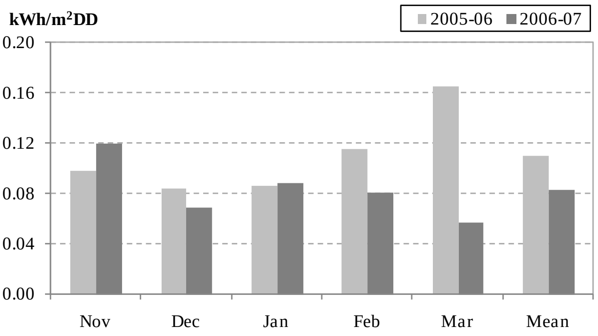

Tables

Table 1. Description of UPC buildings. Legend: W= Meteocat Weather Station, M= manager, C= classroom, O=office, Ci=circulation, S=services, L=lab. Source: www.upc.edu/sirena

Building	Area	W	M	Gas consumption (kWh/sqmy)				Electricity consumption (kWh/sqmy)				Space Use				
	[m^2]			2004	2005	2006	Av	2004	2005	2006	Av	C	O	Ci	S	L
North Campus																
A1	3967	X8	G2	47.0	51.1	57.2	**40.5**	28.2	31.1	27.7	**23.4**	32	20	30	9	9
A2	3889	X8	G2	48.0	52.2	27.2	**32.3**	64.0	63.0	53.1	**46.4**	44	4	32	16	
A3	3783	X8	G2	54.5	29.0	34.8	**30.6**	24.1	42.3	39.9	**28.8**	48	2	31	15	
A4	3795	X8	G2	29.2	43.5	29.6	**28.9**	45.3	48.6	46.2	**37.8**	38	3	36	12	
A5	3886	X8	G2	37.6	33.4	41.4	**25.3**	49.9	55.2	56.9	**43.2**	60	2	31	7	
A6	4216	X8	G2	36.4	24.0	11.1	**16.9**	13.9	16.3	15.5	**12.1**	41	37	20		
B1	2848	X8	G2	56.4	49.4	36.8	**35.8**					14	36	22	5	23
B2	1318	X8	G2	86.1	46.0	28.3	**37.7**	134.8	180.4		**102.4**	23	24	21	16	
B3	2263	X8	G2	42.7	41.0	39.9	**35.9**	71.1	112.8	89.5	**72.3**	19	30	29	17	
B4/5	5919	X8	G2	19.1	21.8		**8.2**	54.0	72.4		**37.9**	8	22	24	8	6
B6	2337	X8	G2	38.6	36.6	30.4	**28.5**	148.0	202.0	77.9	**100.6**	9	35	20	23	
C1	4895	X8	G2	56.0	49.0	37.6	**37.2**	93.1	95.8	84.6	**73.7**	7	41	17	6	29
C2	2475	X8	G2	60.5	54.4	42.1	**40.3**	67.5	90.9	94.4	**70.7**	12	47	28	9	3
C3	4755	X8	G2	25.4	25.4	21.9	**18.1**	92.1	105.7	105.9	**83.6**	6	27	27	8	11
C4	4790	X8	G2	27.7	25.8	18.2	**17.4**	80.5	87.1	92.8	**74.6**	3	24	29	8	16
C5	5280	X8	G2	37.1	28.5	28.2	**23.9**	91.9	91.6	96.7	**81.4**	10	24	32	14	20
C6	4753	X8	G2	107.0	135.0	121.4	**90.1**	42.2	48.2	50.5	**38.2**	17	46	22	13	
D1	5208	X8	G2	53.5	51.3	40.6	**40.1**	46.6	49.0	50.6	**39.4**	8	19	13	19	41
D2	2971	X8	G2	48.5	47.4	36.5	**35.7**	80.3	94.6	95.6	**73.1**	10	42	20	6	22
D3	2969	X8	G2		39.8	32.5	**22.3**	81.6	35.9	25.3	**35.2**	7	29	23	9	32
D4	3049	X8	G2	48.5	44.4	31.7	**32.1**	96.6	118.9	123.8	**97.6**	6	32	23	10	29
D5	3011	X8	G2	64.4	60.1	49.4	**45.0**	66.0	69.4	81.4	**66.7**	11	29	27	8	24
D6	3048	X8	G2	58.1	45.3	40.3	**37.5**	271.8	292.4	253.8	**229.6**	9	41	27	10	12
PO	6766	X8	G2					101.8	102.8	105.3	**83.0**			23	10	
BIB	6644	X8	G2					142.8	137.4		**85.0**	54	6	22	18	
VX	18574	X8	G2	56.58	53.96	52.75	**42.9**	74.3	75.6	87.4	**61.8**	8	28	20	16	3
OM	10083	X8	G2					38.2	116.0	110.3	**92.2**	2	47	26	17	5
South Campus																
A	12168	X8	G3	66.3	63.0	48.2	**47.0**	64.3	61.9	60.7	**48.7**	37	19	24	9	2
C	8679	X8	G3	12.4	12.8	10.3	**9.2**	64.3	61.9	60.7	**45.5**					
P	15992	X8	G3	68.2	50.0	62.3	**45.3**	64.3	61.9	60.7	**44.6**	38	23	20	7	7
U	12097	X8	G3	44.8	31.7	29.1	**26.7**	64.3	61.9	60.7	**56.2**	22	22	28	13	13
PI	6867	X8	G3	46.7	50.5	38.8		73.1	76.5	77.7		32	16	18	17	2
Nautical Campus																
NT1	4254	X2	G3	53.0	46.8	30.2	**35.5**	36.1	38.5	19.6	**45.3**	35	15	31	7	10
NT3	541	X2	G3					46.5	55.9	61.9			73	19	1	7
Castelldefels Campus																
C4C	14962	UG	G3	25.9	25.9		**25.9**	83.3	87.4		**72.3**	17	15	30	18	14
D4C	11943	UG	G3									18	14	31	7	28
D7C	6436	UG	G3									24	26	15	15	20
Terrassa Campus																
TR1	9429	D2	G1	59.3	56.8	59.7	**35.1**	38.2	31.7	30.5	**26.9**	33	20	25	6	14
TR2	2940	D2	G1	59.3	56.8	65.5	**36.3**	35.4	34.0	34.1	**28.2**	9	27	17	5	42
TR3	2573	D2	G1	59.3	56.8	59.7	**35.1**	35.4	25.9	24.1	**21.7**	1	10	9	7	73
TR4	6670	D2	G1	43.1	26.5	53.1	**24.5**	52.7	80.1	73.1	**57.2**	3	16	11	12	58
TR45	3077	D2	G1				**23.2**				**35.4**					
TR5	11589	D2	G1	40.5	22.5	53.1	**20.0**	57.1	40.3	38.1	**18.3**	29	19	24	11	12
TR6	2368	D2	G1	29.0	17.8	53.1		42.2	18.0	15.8		34	20	21	4	21
TR7	2589	D2	G1				**86.0**				**41.3**	7	13	18	16	46
TR8	6494	D2	G1	118.9	115.6	94.0		48.9	51.5	52.5	**63.3**	15	16	29	14	23
TR9	2393	D2	G1				**39.3**	99.6	97.1		**61.2**	53	3	11	7	
TR10	2218	D2	G1	105.5		90.8	**25.4**	101.4	96.9		**22.6**	3	33	13	21	

TR11	2779	D2	G1	31.6	31.5	33.1		56.5	56.5		**22.0**	13	27	19	9	31
TR12	2977	D2	G1					54.3	55.6			27	11	23	12	27
Sant Cugat Campus																
ETSAV	9268	VT	G3	133.8	128.9	95.5	**113.2**	57.8	58.3	58.4	**45.3**	**44**	18	22	10	2
CRITT	863	VT	G3	133.8	128.9	95.5	**113.2**	57.8	58.3	58.4	**45.3**		18	16	2	
Manresa Campus																
MN1	4112	R1	G3				**65.8**	43.9	42.9	41.6	**25.7**	17	25	25	9	23
MN2	1324	R1	G3				**65.8**	43.9	42.9		**25.7**	7	22	13	8	37
MN3	2464	R1	G3				**65.9**	43.9			**25.7**	47	16	21	9	6
MN5	2925	R1	G3				**70.6**	104.5	85.9	96.2	**78.5**	8	25	27	13	27
MN6	1400	R1	G3						90.5	132.6	**44.6**	75	12	2	11	

Table 2. Annual emissions [kg CO_2/sqmy] of the buildings with the same typology as the ETSAV. 2005.

Building	1	2	3	4	5	ETSAV
Emissions associated with gas consumption	9.4	11.4	23.6	24.2	9.1	26.3
Emissions associated with electricity	23.0	22.9	25.0	21.4	29.6	28.3

Table 3. Climate characteristics in Sant Cugat del Valles.

Total accumulated precipitation	550 mm
Mean temperature	15.7 ºC
Mean of maximum temperatures	21.6 ºC
Mean of minimum temperatures	10.3 ºC
Absolute maximum temperature	38.6 ºC
Absolute minimum temperature	- 3.5 ºC
Mean wind speed	1.3 m/s
Dominant direction	W
Mean relative humidity	65%
Overall mean daily irradiation	15.7 MJ

Table 4. Consumption and emissions from the ETSAV building [from September to June]

Consumption [kWh/sqmy]											
Year	95-6	96-7	97-8	98-9	99-0	00-1	01-2	02-3	03-4	04-5	05-6	06-7
Gas	71,8	-	96,2	116,6	122,4	126,0	155,5	123,0	121,3	136,9	114,6	68,7
Electricity	40,7	42,4	47,7	48,1	49,0	50,0	55,8	48,2	52,7	52,5	50,7	49,3
Emissions [KgCO_2/sqm]												
Gas	14,7		19,6	23,8	25,0	25,7	31,7	25,1	24,8	27,9	23,4	14,0
Electricity	21,2		24,8	25,0	25,5	26,0	29,0	25,1	27,4	27,3	26,4	25,6

Table 5. Classification of days according to occupancy

Type of day	Students	Admin+Maint
Weekday classes	Classes during the day, personal work outside regular hours	Work schedule
Weekday no class	Not present	Work schedule
Academic holiday	Personal work outside regular hours	Not present
Non-academic holiday	Not present	Not present

Table 6. Comparison of climatic variation and consumption of gas and electricity in the 2005-06 [prior to the study] and 2006-07 seasons [in which the measures were applied].

GD[15]	Nov	Dec	Jan	Feb	Mar	Total	Percentage
2005-06	175.6	326.3	289.5	222.3	101.6	1115.3	100.0%
2006-07	79.6	242.0	204.4	140.3	148.2	814.6	73.0%
Gas consumption [kWh/sqmy]							
2005-06	17.3	27.4	25.0	25.7	16.8	22.4	100.0%
2006-07	9.5	16.9	18.2	11.4	8.5	12.9	57.5%
Electricity consumption [kWh/sqmy]							
2005-06	6.3	6.0	6.5	4.7	6.1	5.9	100.0%
2006-07	6.0	5.7	5.3	4.0	5.4	5.3	89.1%

Table 7. Comparison of CO_2 emissions in the months from November to March for the 2005-06 [prior to the study] and 2006-07 seasons [in which the measures were applied].

Gas [Kg CO_2/sqm]	Nov	Dec	Jan	Feb	Mar	Mean	Percentage
2005-06	3.5	5.5	5.0	5.1	3.4	22.5	59.4*
2006-07	1.9	3.4	3.6	2.3	1.7	12.9	48.5*
Electricity [Kg CO_2/sqm]							
2005-06	3.3	3.1	3.4	2.4	3.2	15.4	40.6*
2006-07	3.1	3.0	2.8	2.1	2.8	13.7	51.5*
TOTAL[Kg CO_2/sqm]							
2005-06	6.8	8.6	8.4	7.6	6.5	37.8	100.0%
2006-07	5.0	6.3	6.4	4.4	4.5	26.6	70.4%

* Compared to total emissions [gas and electricity] of the same period