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Reducing energy consumption in public buildings through user awareness

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ABSTRACT: Building sector is contributing to the 36% of the CO2 emissions in Europe, and consuming the 40% of final energy consumption. In this context this paper presents a new approach developed under the ENCOURAGE project to carry out the user awareness. The proposed user awareness is based on a set of KPIs, and done at two levels: energy mangers and university campus users. The KPIs are displayed to the energy managers using a web-platform. With that information energy managers are able to identify actions and control algorithms to reduce the energy consumption. In the other hand, the university campus users awareness it is done sending messages to the user through the Twitter platform. A set of messages are defined, and an algorithm decides which messages have to be published in each moment. The aim is to promote good practices in the use of public buildings.

1 INTRODUCTION

Buildings worldwide consume more than 20% of total energy produced (Pérez-Lombard et. al 2008). In Europe nearly 40% of final energy consumption and 36% of the green house emissions are in the buildings (EC 2013), and is expected that this percentage is bound to increase (Gangolells et. al 2012).

According to the Buildings Performance Institute Europe (2010), residential buildings comprise the largest portion of the European buildings stock (75%) and they are responsible for 68% of the total final energy use in buildings. In the other hand, Non-residential buildings account for the remaining 25% of the total stock in Europe, being responsible for 32% of the total final energy use in buildings.

Within this context, the need for achieving high energy and greenhouse gas emissions savings in the buildings sector has been widely advocated. In this way, the ENCOURAGE project aims to develop embedded intelligence and integration technologies that will directly optimize energy use in buildings and enable active participation in the future smart grids and achieve 20% of energy savings. The overall strategic objectives defined in the ENCOURAGE project are: a) Increase energy efficiency at device-level, building-level, district-level; b) Effective in-teraction with external actors; c) Effective monitor-ing and control; d) Good user comfort levels; e) Economic optimization; f) Raise awareness.

The primary application domains of the ENCOURAGE project are non-residential buildings and campuses, but the project has relevancy also to residential buildings and neighborhoods. This paper presents the experiences of ENCOURAGE project in the UPC campus demonstrator, whose challenges focus on the energy efficiency improvement in buildings. It is intended to increase university campus users and building managers' energy awareness by means of an energy information platform that will provide to the users detailed figures about the carbon footprint, the energy consumption and the energy costs derived from their own activities in the campus.

Although energy efficiency is a central target for energy policy and a keystone for sustainable development, an accurate enough, robust and repeatable set of energy efficiency indicators does not exist. This fact affects significantly the success of such policies and cause no little confusion and speculation on this field (Pérez-Lombard et al. 2012).

Different methodologies are proposed to define energy efficiency indicators. Escrivá-Escrivá et al. (2011) used the expertise of the authors to define a set of energy indices to enable identification of inefficient and unsuitable building use. Bunse et. al (2011) firstly carried out a state-of-the-art analysis and secondly used a set of interviews and industrial workshops to define a set of energy efficiency KPIs (Key Performance Indicators). Pérez-Lombard et. al (2012) systematized the process to define energy efficiency indicators with the following sequence of actions: i) setting service quality, ii) identifying aggregation levels, iii), defining energy use indicators, and iiii) choosing demand indicators. Marr (2010a) proposed a methodology that uses the business performance approach of defining strategic objectives before the design of metrics and includes an intermediate step of identifying Key Performance Questions (KPQ) that need to be answered. Starting with KPQs ensures that all subsequently designed performance indicators are relevant. The EN-COURAGE project used this last approach to define the project KPIs.

This paper presents the KPIs developed for the UPC campus demonstrator and shows how these KPIs are used to carry out the user awareness. The user awareness it is done at two levels: energy man-ager and university campus users.

2 URBAN CAMPUS SCENARIO

The urban campus is located in Terrassa city (Barcelona). UPC campus Terrassa has 5400 students and a great number of buildings. The ENCOURAGE project is focused on one building (named TR5), Terrassa School of Industrial and Aeronautical Engineering. TR5 is mainly devoted to academic uses with 2600 students, 240 lecturers and administrative staff. The building floor area is 11,600 m^2 distributed in 3 floors. Three different types of spaces can be identified: i) Lecture rooms, ii) PC rooms, iii) Lecturer and administrative offices and iiii) Laboratories.

The consumption of electricity, water and gas is centrally monitored. In addition the electricity consumption of one lecture room, one PC room and one lecturer office are monitored. These rooms also include temperature, light and the humidity sensors. Finally each space has 2 movement sensors.

3 CREATING KPIS FOR THE ENCOURAGE CAMPUS SCENARIO

The ENCOURAGE project adapted the methodology proposed by Marr (2010a) to define the KPIs. The methodology was divided in 3 steps:

3.1 *Step 1: Define the main strategic objectives and scenario requirements*

Overall objectives defined in the ENCOURAGE Project are:

- Enable energy optimization of buildings
- Focusing on optimal control of internal subsystems
- Providing adequate mechanisms for effective interaction with the external environment
- Integration of heterogeneous data coming from sub-meters and sensor networks
- Efficiently monitor and control appliances and subsystems
- Increase energy efficiency of appliances and subsystems, with optimization at device-level, building-level, and district-level.

This can be translated into the following, more general, strategic objectives:

- *OBJ-A-EFF:* Increase energy efficiency at device-level, building-level, district-level
- *OBJ-B-EXT:* Effective interaction with external actors
- *OBJ-C-MON:* Effective monitoring and control

Taking into account the user point of view, three more strategic objectives can be added to the general ENCOURAGE project objectives:

- *d) OBJ-D-COMF:* Good user comfort levels
- *e) OBJ-E-ECO:* Economic optimization
- *f) OBJ-F-AWA:* Raise awareness

The objective of this paper is to present the KPIs used to carry out the user awareness. For this reason this paper only presents those KPIs related with OBJ-A-EFF, OBJ-D-COMF and OBJ-E-ECO. OBJ-F-AWA is not taken into account because this objective seeks to evaluate the raise awareness.

The challenge is to create a set of indicators to perform the building energy characterization. The indicators should allow users to identify the excessive energy consumption due to the inadequate usage of facilities or premises that have a higher consumption in comparison with similar ones. Furthermore the indicators should allow the comparison between different sized buildings or premises with different amount of users, and the hours of use of the buildings or premises. Finally, in the indicators development it has to be taken into account that some users do not have enough knowledge to understand advanced energy concepts.

3.2 *Step 2: Identify the questions to answer*

Marr (2010b) defines a KPQ as a question that captures exactly what managers need to know when it comes to each of their strategic objectives; hence each strategic objective will lead to one or several KPQs. The KPQ has to be designed involving everyone in the organization as well as relevant external stakeholders.

The KPQs should be open questions to invite the respondent to think, reflect and provide explanations, opinions or feelings. Another aspect to take into account is that the KPQs should focus on the present and future. This helps with the interpretation of data and ensures data collected helps to inform the organization decision making processes. Moreover, KPQs should be short, clear and unambiguous, avoiding any jargon or abbreviations that outsiders might not understand. Finally the KPQs should be refined through usage.

In order to identify the KPQs two different strategies were conducted. To catch the manager opinion and expertise, five interviews with different UPC employees involved in the buildings university management were carried out. Of these interviewees, 2 were building managers, 2 were maintenance managers and one was a UPC professor expert in facility management. In parallel, to catch the building users' opinion, a survey was conducted to 234 students, 19 lecturers and 12 members of administrative staff. The results of this survey were presented by Gangolells (2012).

As a result of this process 7 KPQs were identified. Table 1 summarizes the results.

Table 1. Strategic objectives, KPQs and KPIs for the ENCOURAGE campus demonstrator.

Strategic objective	KPQ	KPI
OBJ-A-EFF	Are we increasing energy efficiency of the building/macro cell?	Energy savings Energy savings rate
	Are we increasing energy efficiency of the appliances?	Stand-by power Hours of stand-by Appliances consumption per category
	Where can we improve energy optimization?	Consumption/m2 Consumption/occupant Consumption/DD Consumption/(occupant·m^2·DD) Optimizable part of consumption Appliances time of use
	Are the consumption patterns consistent?	Consumption per hour type Consumption per day type
	Are we increasing overall sustainability?	CO_2 savings
OBJ-D-COMF	Is he user comfort being compromised?	Internal temperature variability Internal humidity variability
OBJ-E-ECO	Are we decreasing the total costs?	Costs savings Costs per kWh consumed

DD: Degree day

3.3 *Step 3: Design KPIs that will answer the former questions*

In order to define the KPIs, based on Marr (2010a), the following criteria were used: i) Performance data have to be converted into relevant information and knowledge, ii) qualitative and quantitative metrics, iii) Common definitions, and iiii) actionable.

Table 1 summarizes the defined KPIs.

4 USING KPIS IN THE CAMPUS SCENARIO

4.1 *Energy managers' awareness*

The building energy managers' awareness is done displaying the different KPIs in a web-platform. The tests are still in progress. To this date the energy managers used the first web-platform prototype to evaluate the different KPIs. This section includes the results of the first experiences using such proposed KPIs.

The KPIs were calculated for each type of space and for the whole building for the June-July period in 2013, and displayed to the energy managers.

The results show the PC room as the room with the higher energy consumption per square meter per day (185 Wh/m^2 per day), followed by lecture room (92 Wh/m^2 per day), and the lecturer office (51 Wh/m^2 per day). These values indicate that the major contributors to the building energy consumption are the PC rooms.

Using the web-platform the energy managers' identified that during periods where the PC room is empty (from 10 pm to 8 am and weekends, where university is closed) the room power is near 0.5 kW (standby power indicator). This power is due to all PC that are connected to the grid in the room. In the PC room there are 30 computers, this means that the standby power for each computer is on average 16.67 W. Sahin & Koksal (2014) estimated the standby power of a desktop PC as 3 W on average, and maximum as 15 W. This means that these computers may be obsolete. The energy managers verified that is planned to change these computers during the next year.

During a 9-days period, the PC room's energy consumption was 3420.91 kWh. The use of an algorithm to cut electricity during closing periods could have saved more than 916 kWh (26% of reduction). Estimating the savings for the whole year, the potential reduction only for one PC room is of 35%. The impact of this measure in the whole building is a reduction of 1.02% of the energy consumption. If this strategy is applied in all building PC rooms, the potential energy consumption reduction is about 6% of reduction.

This strategy was implemented in one PC room during 2 month achieving the expected energy savings.

Another aspect that was arisen during the analysis is that the indicator "hours of standby" in the PC room is 15 hours on average during the working days. This value is higher than 10 hours. This fact suggests the PC room is not used during the whole opening hours, and this space is underused. In this way the building energy managers' suggested to rationalize the opening hours of each space with the aim to reduce the energy consumption.

The indicator "standby power" for the lecturer office is on average 100 W. The energy managers decided to not apply the same strategy than in the PC rooms, because sometimes lecturers carry out automated long experiments during the night. However, this is a big issue that energy managers will study in the future.

The indicator "standby power" is close to 0 in the lecture room. This is an expected result because in these rooms there no device is plugged in. In this room the whole energy consumption is due to lighting. However in this room the energy managers detected that during alleged non-lecture hours that, the energy consumption is the same as the hours with lecture.

Energy managers checked that usually this consumption is due to the last student or lecturer that used the room and left without turning the lights off. It is difficult to calculate which the wasted energy is because sometimes the students use these rooms to carry out meetings, or to do group work. For this reason energy managers see potential and want to try the user awareness system proposed in the ENCOURAGE project.

The calculation of the indicator "energy consumption per user" was not possible to perform, because the number of persons is not monitored. During the development of the scenario the need to determine the occupation of a room in each moment with cheap and reliable sensors was arisen.

The calculation of the indicator "energy consumption per degree day" was irrelevant in this case because the HVAC system is commanded by the central services and all the rooms are in the same building.

4.2 *University campus users' awareness*

The university campus users' awareness is carried out using a twitter account. The aim is to promote good practices in the use of public buildings, and as a consequence reduce the energy consumption of these buildings.

A database with different standard messages was created with associated rules. An algorithm decides which messages have to be published in each moment, depending on the calculated KPIs and the rules that evaluate them.

Two types of messages were defined: messages reporting historic events, and messages reporting real time events.

Messages reporting historic events are those messages that are sent after an algorithm evaluates past events with the current events. The process followed by the algorithm starts with the evaluation of a set of KPIs during a period of time. Then these KPIs are compared with the reference values. If the rule is accomplished then the algorithm publishes the message to Twitter. The messages do not have more than 140 characters because Twitter limits Tweet length to this amount. Some rules have more than one message; in these cases the algorithm selects randomly one message.

In the following example one rule has two possible messages:

- *Rule:* PC room energy consumption from this week **IS** higher **THAN** 1,05*PC room energy consumption from last week **THEN** send one of this messages.
- *Message 1:* Dear PC room users, the energy consumption has increased in [*value*]% this week. Remember to make the most of solar light whenever possible.
- *Message 2:* Dear PC room users, the energy consumption has increased [value]% this week. If you see any unnecessary light turned on, please turn it off.
- *Periodicity: Weekly*

Not all messages are negative messages. If the energy consumption has decreased during a period of time, the platform sends positive messages such as:

- *Rule:* **IF** PC room energy consumption from this week **IS** *lower* **THAN** 0,95*PC room energy consumption from last week **THEN** send this messages.
- *Message:* Dear PC room users, the energy consumption has decreased in [value]% this week. Thanks for using the PC room in an efficient way.
- *Periodicity:* Weekly.

The database includes similar messages for the lecture room. However, for the lecturer office the messages are private. These types of rooms are only used by a limited number of known people. The energy managers suggested in these cases sending the messages in a private way using email would be a most suitable solution. The energy managers want to avoid public accusations of misbehaviors.

An example of this issue is when in a lecturer office the people forgets to turn off the desk computer at night. If this event occurs then the indicator "standby energy consumption" of this day is higher and the algorithm sends the message.

- *Rule:* **IF** lecturer office standby energy consumption from yesterday **IS** *higher* **THAN** 1,05*lecturer office standby energy consumption from the day before **THEN** send this messages today one hour before the workday end.
- *Message:* Dear lecturer room users, the stand by energy consumption has increased today in [value]%. Remember to shut down your computer at the end of the day.
- *Periodicity:* Each day.

When the user carries out good energy efficiency behavior practices the platform sends positive messages:

- *Rule:* **IF** lecturer office standby energy consumption from last week **IS** *higher* **THAN** 0,95*lecturer office standby energy consumption from last week **AND IS** *lower* **THAN** 1,25*lecturer office standby energy consumption from last week **THEN** send this messages.
- *Message:* Dear lecturer, your office standby energy consumption has remained in the standard values this week. Thanks for using your office in an efficient way.
- *Periodicity:* Weekly.

In a similar way, when the standby energy consumption is reduced to a good energy efficiency behavior practices the platform sends other positive messages.

The platform also asks to the user if he has done something to reduce this consumption. This feedback allows energy managers to learn about new energy reduction options:

- *Rule:* **IF** lecturer office standby energy consumption from last week **IS** *lower* **THAN** 0,95*lecturer office standby energy consumption from last week **THEN** send this messages.
- *Message:* Dear lecturer, your office stand by energy consumption has reduced in [*value*]% this week. Thanks for using your office in an efficient way. Did you carry out a special action to reduce the standby energy consumption?
- *Periodicity:* Weekly.

The messages also include real time reactions. An example of these messages is:

Rule: **IF** not scheduled lecture **AND** current lecture room energy consumption **IS** *higher* **THAN** 1,05*lecture room energy consumption per type of hour **AND** Not movement detected during the last half hour **THEN** send this messages

Message: It seems that lights in the lecture room [*name of the room*] are turned on, and nobody is inside. Please if anyone is nearby, turn off the lights.

Periodicity: Event

In addition a tweetgroup is created to allow campus users' to propose measures to reduce the energy consumption. The aim is to increase the campus users' participation in the objective to reduce the building energy consumption. Furthermore, the communication between the building energy manager and the university campus users will be improved.

The ENCOURAGE project is currently in the last year. It is planned to start the validation of this university campus users' awareness strategy in April 2014. Consequently, the impact of this measure is not quantified yet. It is difficult to determine which will be the impact of the measures. Matthies et al. (2011) estimates that between 5% and 20% of the whole public building consumption is related to consumer behavior and influence. Ueno et al. (2006) reported that installing Energy Consumption Information helped the users reduce 9% of the power consumption. In this way, the expected energy savings are at least 9%.

5 CONCLUSIONS

The paper outlines design considerations and the development of a set of KPIs to carry out the energy user awareness. The KPIs are defined using a standardized methodology. First the strategic objectives are defined, secondly KPQs are identified. Finally the KPIs that will answer the KPQs are designed. This procedure ensures that all subsequently designed KPIs are relevant.

This paper proposes to use the developed KPIs in different ways depending on the target user for the user awareness. For the energy managers a web-platform is developed to help identifying and prioritize which building areas are suitable to improve in terms of energy efficiency. Moreover, the KPIs helped managers to identify which control algorithms can be implemented to reduce the energy consumption.

In the other hand, the University campus user awareness is done using the Twitter platform. A set of messages with associated rules based on developed KPIs are presented. An algorithm calculates the different KPIs and decides which message needs to be published in each moment.

Future work will focus on the implementation and experimental evaluation of the University campus user awareness.

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