A Serious Game to Reduce Consumption in Smart Buildings

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Abstract. The research described in this paper presents a social system where intelligent management helps control energy consumption in buildings. In this work we used the CAFCLA framework, which makes it possible to combine various technologies that simplify the creation of context-awareness and social computing systems. The created system is capable of influencing user behavior in a way that favors the efficient management of energy resources in the workplace. This is achieved by merging a number of techniques; Wireless Sensor Networks and Real-Time Locating Systems, along with the use of Collaborative Learning and Virtual Organizations of Agents. These artificial intelligence (AI) techniques provide a great potential for the development of serious games that foster the acquisition of good energy saving habits among workers and users in public buildings.

Keywords: Intelligent systems · Virtual organizations · Distributed systems · Context-awareness · Serious games · Smart cities · Smart buildings · Energy efficiency · Social computing

1 Introduction

The idea of a Smart City is an increasingly common concept nowadays and it is addressed in many technological projects. The balance between the environment and the natural resources is key for these paradigms, their objective being, to reach a level of comfort for citizens and institutions, based on sustainable development. In this respect, achieving better energy efficiency is paramount, not only for the reduction of energy costs, but also to foster environmental and economic sustainability.

Unlike in the past, today many works focus on the measurement of energy consumption in buildings and households, these projects attempt to develop advanced hardware and control systems, these solutions have been proven to be technologically available and sustainable [7]. In this regard, one of the biggest challenges is controlling energy consumption in public spaces and workplaces [28]. However, energy waste in these areas is elevated due to a number of reasons. Old buildings usually lack systems that could aid the efficient use of energy, also it is difficult to model the comfort level of

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users because of the disparity of needs among them [29], and another big factor is the users' carelessness with the energy resources, since in public buildings they are not responsible for the energy costs directly. The goal of serious games is to change user behavior through educating users, motivating them and encouraging participation. At present, the creation of an effective serious game is still a challenge, in this work we decide to make use of Context-aware Learning, which provides the environmental characteristics of the place in which the game is taking place, which provides real-time data through Real-Time Locating Systems (RTLS) and Wireless Sensor Networks (WSN) [6].

The work presented in this paper is focused on new ways of triggering behavioral change in users with the aim of improving energy efficiency. Specifically, this paper presents a serious game that aid behavioral change in users in a public building, creating more energy saving habits. The technical and social features of the game are developed by means of the CAFCLA (Context-Aware Framework for Collaborative Learning Applications) framework [26]. A social computing perspective has been adapted for the design of the framework and for this social and contextual information is used. Contextual information is gathered by the WSNs, providing access to data on energy consumption, the presence of users in rooms and the use of electronic devices. Furthermore, the RTLS determines the behavioral habits followed by users and provides guidelines on how to improve these habits in their workplace. A VO (Virtual Organization) supports the framework, providing intelligence to the game and the learning process [33] by managing the process of the game, updating contextual information, monitoring users' actions and providing players with information. The use of these technologies within the paradigm of social computing has generated an innovative game by customizing it for each user and offering the possibility of interaction among them; working together to achieve a common goal. The article is structured as follows: the background Sect. 2 reviews the current state of the art presented in projects and research conducted in the field of smart cities and energy control. Section 3 describes the created system, its operation and details of the techniques used. Finally, in Sect. 4 results and conclusions drawn from this work are presented.

2 Background

The concept of smart cities, smart buildings, or smart homes [1] itself is still an emerging idea in our society. Building a "smart" city is currently one of the most popular objectives in research, often approached as a strategy of mitigating the problems caused by rapid urban growth. The lack of resources, pollution, traffic congestion and deteriorating infrastructure are some of the many challenges faced by the increasingly large urban communities [10]. One of the many definitions of Smart Cities is: "*The use of smart computing technologies to make city services more intelligent, interconnected and efficient - which includes administration, education, health care, public safety, real estate, transportation and utilities.*" [34]. It seems clear that the purpose of these is sustainable economic development, based on new technologies (ICT) to provide better quality of life and wise management of natural resources through the engagement of all citizens. Today, more and more cities around the world, including Spain, are committed to the development of pilot projects related to this movement. Some of the examples in Spain are, SmartSantander[1]: for now the city has a great display of parking sensors that indicate free parking spaces to drivers. They also have a local Wi-Fi network which can be accessed in the entire city, and augmented reality applications that boost tourism. Málaga Smart City[2]: the goal of this projects it to save energy by micro power management: the storage of energy in batteries for use in buildings, street lighting and electrical transport, promoting the use of electric cars, etc. Smart City Valladolid-Palencia[3]: is concerned with the two cities, where the problem of transport between them is considered. It has a smart meter network, which integrates electric cars, energy efficiency in buildings and traffic organization, etc.

In this section we briefly describe the main goals of this project and the techniques that were involved in this research; serious games, WSN, Context-aware Learning and Social Computing. Firstly, we will discuss the necessity of behavioral change as a basis for efficient energy management.

Buildings are responsible for the largest share of European final energy consumption and they present the greatest potential for reducing our energy spending. Buildings are long-term assets expected to remain useful for 50 or even more years and 75–90% of those standing today are expected to remain in use in 2050 [14]. Energy efficiency investments in public buildings are unique in that the public owner can perceive both the energy savings, productivity and value improvements, as well as the public benefits of re-employment rise, reduction of emissions and improvements on public accounts. Recently, various energy policies concerning the efficient use of energy have been implemented [14]. For these initiatives to be effective, many require a direct change in the behavior of users and energy saving habits. In this sense, many studies are inclined to give more importance to changing user habits than to the technical implementation itself [12].

Therefore, it is necessary to model the behavior of users to determine how they do things. The design of models that promote the user behavioral change differs depending on whether it is for domestic or non-domestic users. While home users have a direct responsibility for the energy costs, the policies implemented in the non-domestic sector are made at the organizational level, lacking a direct relationship with the behavior, habits and benefits for users or workers. For this reason, motivating users to save energy in public buildings is a hard task that requires the use of attractive tools which support and assert the acquisition of these habits [14].

Research on energy efficiency has recently produced ast literature on the topic. However, due to the direct relationship between users and their energy expenses at home, most research addresses the domestic area [17]. Among the proposed solutions within households are those based on providing feedback to users on their consumption by using smart meters or displays reporting energy use in real time [2], and some

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[1] http://www.smartsantander.eu/.

[2] http://www.lacatedralonline.es/innova/system/Document/attachments/12351/original/IDCCiudadesinteligentes.pdf.

[3] http://www.valladolidadelante.es/lang/modulo/?refbol=adelante-futuro&refsec=smart-city-vyp&idarticulo=79302.

proposals extrapolate the solutions used in homes to offices [4]. However, promoting behavioral change in users requires their awareness of the benefits of saving energy, as well as the efficient use of the most frequently used resources, such as MELs (Miscellaneous Electric Loads, including PC, scanners, printers, etc.), which consume more than 25% of energy in offices [5].

Serious games are presented in this work as an alternative technique that has the optimal characteristics which enable it to trigger behavioral change in users for more energy efficient behavior in the public sector and in the working environment. They have been used in different areas to promote this change [1]. Serious games are a broad trend in which traditional mechanisms of games are used in multiple environments such as public policies, business management, healthcare, or energy saving [7]. The objective of these games goes beyond entertainment, paying special attention to the educational purpose, allowing users to acquire skills through play-based activities by using their inherent playfulness and interactive characteristics. They also make it easier to motivate, train and engage participants who improve their habits through the acquisition of new knowledge and skills.

Various approaches to serious games in the energy sector are being piloted or commercially deployed, each adopting differing gamification techniques and having different key objectives. A common factor is their use of granular and real-time energy data, which allows them to provide instantaneous feedback. The use of serious games in office environments is rarely used and are mostly based on making users aware of energy consumption and promoting energy savings.

Despite the multiple solutions and researches that have been analyzed, the use of supporting technologies is not fully. One of the main weaknesses is the underuse of Wireless Sensor Networks when designing and deploying serious games for energy efficiency. Although some technologies, mostly smart meters, are used to obtain power consumption, WSNs offer a great potential of collecting parameters that affect the behavior of users during the game and create richer activities. Thus, the contextual information provided by the sensors becomes a great source of information that helps monitor and customize the game, giving feedback and encouraging awareness among users. Dey in 2001 refers context to “any information that can be used to characterize the situation of an entity” while “an entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves” [3]. Context-aware Learning arises from the inclusion of context-awareness in the learning process [32]. Thus, the educational process takes advantage of the flexibility provided by the use of real-time environmental information within the process. Moreover, the use of technologies that obtain contextual information, such as WSNs and RTLSs enriches the learning process [25].

Furthermore, serious games benefit when contextual and location data is included in their design and development, as multiple lines of research have proven [8]. This gives us an idea of the potential that contextual information offers in the design of games, whose objective is that the participants acquire habits which enable them to make use of the energy in a more efficient way. However, many games developed for the encouragement of efficient energy use do not consider the use of sensor networks and real-time location of users to enrich the learning process.

From a novel viewpoint, sensor networks help obtain an accurate “energy picture” of the environment in which the game is played [22]. Likewise, sensors act automatically on the environment once the parameters of user behavior are determined. In addition, the ability to locate users in real time enables the game to launch challenges that promote and enhance both energy saving and the acquisition of good habits. Otherwise, the use of intelligent management techniques is not taken into account in the researches; these techniques improve the game and trigger behavioral change through prediction, adaptation and anticipation of users’ actions [11]. Finally, the behavioral change pretended with the solutions mentioned above is not addressed from the point of view of social computing.

Regarding behavioral change for energy efficiency, there are a number of proposals that address the problem by using serious games through social networks [9]. However, human-machine interactions are not deeply addressed in these solutions leaving aside, for example, contextual information that may be useful in the field on which we are focused. In addition, none of the proposals have a complete view as to social computing, they do not offer functional infrastructures that would allow to integrate different technologies, communication protocols or diverse ways of encouraging social relations based on the needs that arise in the game. Our work presents a framework based on social computing and context-awareness that allows the creation of learning scenarios, such as serious games, which encourage a change in users’ behavior in public buildings, to actions which are more energy efficient.

Recent trends have led to the social computing paradigm for designing social systems that have helped us build such sociotechnical tools. Thus, it is possible to design tools where humans and machines collaborate to resolve social problems. These tools have a high level of complexity and require the use of artificial intelligence to manage artificial societies, but provide the necessary capacities for effective collaboration between humans and machines [23]. Agent technology, which makes it possible to form dynamic virtual organizations of agents, is particularly well suited to act as a support for the development of these open systems [13, 18, 30]. Modelling an open multi-agent organization makes it possible to describe structural compositions and functional behavior, and it can incorporate normative regulations for controlling agent behavior, the dynamic entry/exit of components and the dynamic formation of agent groups [21].

3 Proposed System

This section describes the proposed system, which aims to deploy a serious game in a public building, encouraging users to use energy resources more efficiently, by changing their behaviors and habits. The system integrates WSNs and RTLSs in order to manage the relations among humans and between humans and material resources. The work depicted here uses the CAFCLA (Context-Aware Framework for Collaborative Learning Activities) [26] framework, designed by the BISITE research group and focused on collaborative learning through the use of contextual information. The aim of CAFCLA is the mixing of several technological resources to simplify the development and design of learning actions based on social computing and contextual information.

The users of CAFCLA have at their disposals numerous which simplify social interactions and contextual information. Moreover, this mixing not only makes it easier to design learning activities, but also decreases the development time enabling the game to start faster.

CAFCLA has been used for collaborative learning activities that use contextual information in museums [27], gardens [26] and other educational settings [25]. In the present work, CAFCLA is used in a non-academic environment with a specific purpose: to educate, raise awareness and trigger behavioral change for the efficient use of energy in public buildings. To this end, a serious game has been designed and developed, with the aim of making users aware of their energy use so that they naturally acquire good habits and change their actions to those that benefit energy saving. The game developed under CAFCLA has been aimed at the users of the research laboratory to test whether the game succeeded at reducing energy consumption and acquiring good energy habits. By means of a WSN the use of lighting is monitored, the energy consumption at the work site of each user (whether they turn off or suspend their computer), their location is also monitored continuously (and even if users use the elevator or the stairs to get into the lab). All these data will help verify whether users meet certain energy efficiency targets and good habits. Depending on their performance, users are either rewarded or penalized with virtual coins.

The game designed using CAFCLA requires the integration of different physical devices and technologies. CAFCLA has been designed as a layer architecture. Each layer includes a set of technologies that fulfil the requirements of the game. These devices and technologies will support data collection, communication, contextualization of the environment even facilitate the development of the application used by the users.

(1) Physical Layer. At the lowest level of the CAFCLA layers is the physical layer, which includes all devices that will be used by the framework. An important part of this layer is the infrastructure necessary to collect all the contextual information. More specifically temperature on/off, luminosity sensors and consumption sensors are integrated into plugs that monitor the power consumption of each job site. Location beacons are also used to obtain the position of users and each of them will wear an identification tag. Tablets, laptops and smartphones have been integrated into CAFCLA. Through these devices users access and use the game interface. Furthermore, communication between devices requires some physical infrastructure. In this case, Internet access points via Wi-Fi and Ethernet, as well as data collectors and hubs that send, via Internet, the data collected by sensors and the RTLS. In addition, the system requires a server to store data and run the application. All these technologies are integrated by CAFCLA transparently to users, making an appropriate use of each depending on the needs raised by the game at any time of its performance.

(2) Communication Layer. In order to send and receive information between different physical devices, CAFCLA integrates different communication protocols. In this case of use, the framework integrates the following wireless communication protocols: Wi-Fi, ZigBee and 4G/3G/GPRS. On the one hand, Wi-Fi and 4G/3G/GPRS protocols are mostly used to transmit data to players or for the communication between mobile devices. On the other hand, ZigBee is the protocol used by the WSN that transmits the

data from any sensor (including RTLS detection of tags by beacons) to the collectors and hubs that forward it to the server.

(3) Context-awareness Layer. Within the game designed using CAFCLA, contextual information plays a key role. Through this information we find out about energy consumption, which resources are being used and whether this use is being done efficiently is known at all times. This information allows players to better understand the challenges they face and, through incentives generated by the rules, they can make more efficient use of energy resources they have in their work environment. In turn, the behavioral change of players occurs transparently through the acquisition of good energy habits and awareness of not wasting energy unnecessarily. To develop effectively the features explained above, CAFCLA has carried out the integration of a WSN and RTLS platform. This technology allows to know at all times, on the one hand, the physical quantities that permit the system to determine the contextual status of the environment (temperature and luminosity sensors), instant and historical energy consumption of each job site (electricity consumption sensors), the status of lighting and, on the other hand, the location of the participants of the game. Thus, the system is able to determine the number of people in the rooms, use of the elevator or if they are at their work site. The platform selected to deploy the wireless sensor network is n-Core [24], which allows integration of all the sensors used in this case of use. The n-Core platform uses the ZigBee communication protocol (IEEE 802.15.4), which enables communication of the sensors (n-Core Sirius RadIon along with IOn-E devices, shown on Fig. 1) with the other devices of the system in a very simple way: the sensor data are sent through the ZigBee network to data collectors which, in turn, send the information collected by these to the server hosting the database through the Wi-Fi protocol. All the data collected and stored and the states generated are used for the development of the game. The n-Core platform also facilitates the deployment of the indoor location system that allows locate each user in real time. In this case, CAFCLA integrates n-Core Polaris [24], which is also based on the ZigBee wireless communication protocol that allows to determine the position of users up to one meter accuracy. To carry out the location, n-Core requires the deployment of a set of beacons that collect the signal sent by tags (n-Core Sirius Quantum devices, see Fig. 1) that are worn by the players. That signal, and its associated data, is sent to the server that implements the location engine that calculates the position of each player. Players wear a n-Core Sirius Quantum tag responsible for sending that signal and provided with an accelerometer that determines whether the user is moving. The beacons (n-Core Sirius RadIOn devices) forward these data to the server in the same way that the sensor data are sent, through Wi-Fi data collectors. n-Core allows the deployment of the wireless sensor network and the location system using the same platform and physical infrastructure. Thus, the sensors integrated in the ZigBee network can act themselves as beacons for the location system, reducing costs and energy consumption. Furthermore, both systems share data collectors for forwarding data to the server. For the game, the location system can distinguish several areas where players can be found: personal job sites, meeting rooms, elevators and stairs, in order to define the context in which each player is at a given time towards the development of the game. As we can see in Fig. 2, during the design of the game different points that measure temperature and luminosity have

been defined, consumption sensors have been placed at each position, on/off sensors which determine the state of the lighting and HVAC (Heating, ventilation and air conditioning) system have been placed and the different areas where the game is taking place have been defined (two meeting rooms, working area, 2nd and ground floor stairs and 2nd and ground floor lifts).

Fig. 1. n-Core Sirius RadIOn device, n-Core Sirius Quantu, device, n-Core Sirius Ion-E device

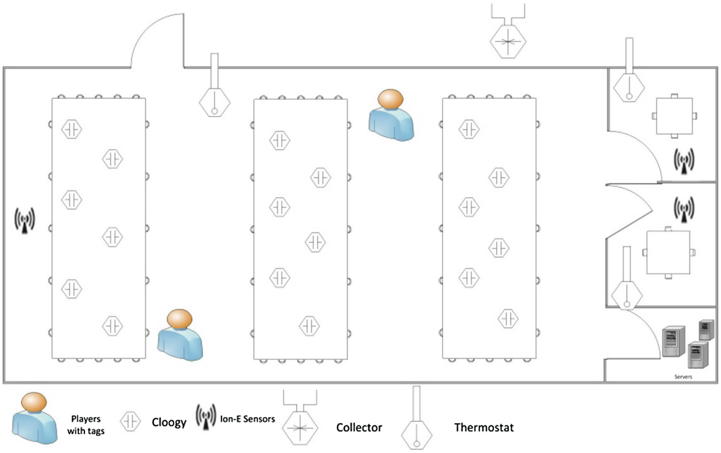

Fig. 2. Distribution of sensors in the laboratory.

(4) Management Layer. This layer integrates the social machine which is in charge of context-awareness and operation of the communication layers in a distributed, effective and predictable way. One of the biggest challenges that the development of Social Computing systems has to face is the communication and coordination between the participating entities, whether human or machine [31]. To address this challenge, current trends recommend the use of Virtual Organizations (VO), that can be defined as a set of individuals and institutions that are needed to coordinate and manage, across institutional boundaries, services and resources [16]. This work considers that a VO is an open system composed of heterogeneous entities that collaborate with each other and whose different forms and functions are required in order to define the behavior of each one. Moreover, VO agents (VOs) technology has facilitated the resolution of challenges related to autonomy, training, collaboration or management of communication between

groups [15] because it allows the creation of dynamic agent organizations, especially useful for the development of the game presented here. Its use favors the description of functional behaviors such as schedules, tasks or services and describe logical structures and interactions, relationships or roles. The main purpose of the management layer is to implement the social machine using VOs. Those VOs will support the context-aware game. The proposed architecture includes different organizations:

- Data Gathering Organization: This organization is responsible of the data that the system has available come from different sources that require a thorough control. The data available to the system come from different sources that require a thorough control. This organization is responsible for managing these heterogeneous sources, such as sensor networks, the location system or even information published or consulted, among others.
- Data Management Organization. This organization is responsible of maintaining the integrity of data during the game. It makes the decision of what data should be developed and stored at all times. The game performance depends on data availability, so this issue is determined during the process. It is related with the Data gathering organization, that gathers new information, and the Game organization that makes the decision of what information has to be stored or requests a concrete data. This VO also classifies the information to be delivered, depending on the context and social information that surrounds the player at a particular time while developing the game.
- Context-aware Organization. This organization manages the information collected by the sensor network. It needs to be coordinated with the Data management organization in order to keep updated the information from any physical service implemented by the sensor network.
- Game Organization. The whole activity is under the control of this organization (management and coordination). All the information from the social machine (players, contextual data, information, etc.) is received and managed by this organization. It finally decides what information is provided to the player according to the stage in which the game is.

Social Machine Organization. This organization is responsible for performing analyses that extract socially relevant information related to the interaction of different agents. Player agents: grouped in organizations, they store all the information related to the game process. This organization enables the player-player interaction and player-machine interaction. Configuration agent: this agent creates, modifies and monitors the development of the game and establishes the social rules of the social machine organization. Collaborative agent: grouped in organizations, this agent monitors the process of the communication with the Context organization and the Activity organization.

- Challenges and Recommendations Organization. This organization produces engaging personalized actions for the players to meet the objectives set in the Activity organization.

(5) Application Layer. The top layer in CAFCLA schema is the application layer. This supports the game development and provides the interface for players and game

organizers, as well as for other components that are part of it, such as the configuration of different devices. To determine the features that this layer may have, as well as for the integration of the necessary technologies, it has been considered a social and serious games approach. Thus, firstly the game is defined and designed using CAFCLA and then technologies that support it are chosen. In this case, a specific game where players will be rewarded or penalized depending on their energy use at work. The scenario in which the game takes place is one of the working laboratories of the BISITE research group in the R&D&I building at the University of Salamanca. This lab has 18 workstations in a common working area and two separate meeting rooms. It is located on the second floor of the building, which can be accessed by a lift or the stairs. Through the various technologies implemented by CAFCLA contextual information of the working environment are controlled at all times, as well as the position of each of the participants. Contextual information is given by the following parameters: temperature and luminosity of each of the zones (working area and meeting rooms), status (on/off) of lighting and measurement of electrical consumption of each work site and the position of each of the people working in the laboratory. All workers are involved in the game (18 in total) whose main objective is to get virtual coins through energy efficient behaviors. To encourage participants, 250 virtual coins permits players to grab a coffee or a soft drink for free. Actions that helped to win or lose virtual coins are as follows:

- The use of light in the meeting room: if one or more users are in the meeting room they should not use artificial light if natural lighting is greater than 200 lx, each of the users gets 10 virtual coins. Otherwise, he/she is penalized.
- The use of the HVAC system in the meeting room: if users do not make use of the HVAC system to change temperature in the room if it is above 18°C in winter or below 25°C in summer, each of them will be rewarded with 10 virtual coins. Otherwise, he/she is penalized.
- Use of the elevator and stairs: every time a player goes up or down the stairs he/she will be rewarded with 10 virtual coins. The use of the lift is penalized.
- If the last user leaving the laboratory turns off lights and HVAC system, he or she receives 10 virtual coins.

Energy consumption: all player whose consumption of electricity during the day is below the average of the previous day, they will receive 10 virtual coins.

A Cloogy[4] power plug was installed at each workstation, a total of 18, to check the progress of energy saving. All sensors were part of the ZigBee network in which real time power consumption data for each position was transmitted. The plug has ZigBee communication capabilities and contains an electrical consumption sensor, with an accuracy of ±1% ±0.5 W. With intervals of 15 min, consumption data was sent to the server. This data is brought together by a crawler integrated within the agents of the Data Gathering Organization from the web page on which the consumption is published. The players could check their consumption history, as well as their electricity consumption throughout the day, and its 466 comparison to the consumption of other

[4] http://www.cloogy.com/media/30958/brochura_cloogy_residential_en.pdf.

users; these acted as an encouraging factor, since the results of others incited competition in energy savings. Moreover, with these data is possible to establish which users were above and below the average consumption each day. It was intended that users were aware, for example, of the times they should turn off or suspend their computers if they were not going to be used for long periods of times.

To encourage a more moderate use of HVCA and lighting systems, four IOn-E devices were deployed along the same wireless sensor network (see Fig. 1). Two of these devices collected data in the shared work environment and one was located in each of the two meeting rooms. Furthermore, users could check the lighting and temperature on demand, they had knowledge of the data collected by these sensors and so could evaluate whether the use of artificial lighting or HVAC systems was necessary or not. The 18 BISITE research group employees in the laboratory participated during 30 days. The data obtained from the desktop monitoring showed that the average total consumption per day of all the users in their workplaces was 2.875 kWh, and the hourly energy consumption per player in his workplace was 0.1597 kWh. These results establish that there has been savings between 6.6% and of 6.9% with respect to the measurements made before the game.

4 Conclusions and Future Work

This paper presents a serious game based on the social computing paradigm that integrates advanced technologies through the framework CAFCLA, including WSN and RTLS. This integration enables to resolve the human-machine interaction and context-awareness issues so that users acquire energy saving habits in public buildings. The use of wireless WSN and RTLS displays a great potential for the development of systems that promote behavioral change in users' energy consumption habits. In this case, players are informed at all times on the energy consumed at their work site. In this way, they are motivated and can interact with others to reduce their energy consumption a, the system will also provide real-time recommendations to users on how they can improve savings and acquire good habits. CAFCLA has added value in comparison to other solutions as the integration of multiple technologies and communication protocols can substantially improve context-awareness, covering a larger number of potential cases of use to be implemented.

Future work includes developing an experimentation stage at the BISITE Research laboratory in order to test the system, observe the changes in the users' behaviors and measure the derived reduction in power consumption, in comparison to other systems.

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