Context-Aware Energy Efficiency in Smart Buildings

María V. Moreno, José Santa, Miguel A. Zamora, and Antonio F. Skarmeta *

University of Murcia, Department of Information and Communications Egineering
Campus de Espinardo, 30100 Murcia, Spain
{mvmoreno,josesanta,mzamora,skarmeta}@um.es

Abstract. When talking about energy efficiency at global scale, buildings are the cornerstone in terms of power consumption and CO_2 emissions. New communication paradigms, such as Internet of Things, can improve the way sensors and actuators are accessed in smart buildings. Following this approach, we present an energy efficiency subsystem integrated with a building automation solution that makes the most of the energy consumed, considering user preferences, environmental conditions, and presence/identity of occupants. Through a three-stage approach based on behavior-centred mechanisms, the system is able to propose concrete settings on building devices to cope with energy and user comfort restrictions. The proposal has been implemented and deployed on a smart building. A set of tests validates the system when users are correctly located and identified at comfort service points, and first experimental stages already reflect energy saves in heating and cooling about 20%.

Keywords: Smart Buildings; Energy Efficiency; Context Awareness.

1 Introduction

National governments, industries and citizens worldwide have recognized the need for a more efficient and responsible use of the planet's resources, and new energy and climate goals have already been adopted accordingly, for example the EU's 20-20-20 goals[1]. Due to their relevance in the daily life and their impact on worldwide power consumption, buildings are key infrastructures when talking about the synergy between technology advances and energy efficiency. Indoor environments have a direct relation with quality of life and power consumption both at the work and in citizens private life. Thus, future buildings should be capable of providing mechanisms to minimize their energy consumption, and integrate local power sources improving their energy balance.

* This work has been sponsored by European Commission through the IoT6 Project "grant 288445", and the Spanish Seneca Foundation by means of the Excellence Researching Group Program "04552/GERM/06" and the grant "15493/FPI/10".

[1] www.ec.europa.eu/clima/policies/package/index_en.htm

Last advances on Information and Communication Technologies (ICT) and Internet of Things (IoT) [1] are identified as key enablers for accessing remote sensing units and managing building automation systems. Nevertheless, although there are already works addressing the problem of energy efficiency in buildings, few of them benefit from the boost provided by IoT capabilities in this environment to optimize energy consumption using real-time information or include individual user data. In this sense, the smart energy management system presented in this paper considers an IoT-based building automation platform that gathers real-time data from a huge variety of sensors, and uses behavior-based techniques to determine appropriate control actions on individual lighting and heat, ventilation, air conditioning (HVAC), in order to satisfy comfort conditions of users while saving energy. Most of our IoT infrastructure is composed of wired and wireless sensors and actuator networks embedded in the environment, but individuals play a fundamental role, since the system is able to consider user comfort needs. Moreover, we also show how despite the relatively short time of operation of our system in a real smart building, energy saving is already achieved thanks to consider accurate user location data and individualized control of appliances, in order to provide environmental comfort at specific target locations.

The rest of the paper is organized as follows: Section 2 places the proposal in the literature by reviewing recent related works. Section 3 describes our proposal for intelligent energy management, integrated in a reference building automation solution. Section 4 details the system deployment carried out in a reference smart building where initial tests have been performed for assessing the system operation. Finally, Section 5 concludes the paper with a set of final remarks and presenting future lines.

2 Literature Review

Most of the previous approaches addressing the problem of energy efficiency of buildings present partial solutions regarding monitoring, data collection from sensors or control actions. In [2] an examination of the main issues in adaptive building management systems is carried out, and as the authors state, there are few works dealing with this problem completely. Regarding building automation systems, there are many works in literature extending the domotics field initially focused only on houses. For instance, a relevant example is the proposal given in [3], where the authors describe an automation system for smart homes on top of a sensor network. The work presented in [4] is also based on a sensor network to cope with the building automation problem, but this time the messages of the routing protocol include monitoring information of the building context. The literature about energy efficiency in buildings using automation platforms is more limited. In [5], for instance, a reference implementation of an energy consumption framework is given to analyze only the efficiency of a ventilation unit. In [6] it is described a deployment of a common client/server architecture focused on monitoring energy consumption but without performing any control action.

In this paper, we present a real and interoperable experience on a general purpose platform for building automation, which addresses the problem of energy efficiency of buildings, comfort services of occupants, environmental monitoring and security issues, among others, by means of a flexible IoT platform, which allows to gather data from a plethora of different sources and to control a wide range of automated parts of the building.

3 Intelligent Management System for Energy Efficiency of Buildings

For a building to be considered energy-efficient it must be able to minimize conventional energy consumption (i.e. non-renewable energy) with the goal of saving energy and using it rationally. Optimizing energy efficiency in buildings is an integrated task that covers the whole lifecycle of the building [5], and during these phases it is necessary to continuously adapt the operation of its subsystems to optimize energy performance indexes. However, this process is a complex task full of variables and constraints. Furthermore, the quality of life of occupants should be ensured through at least three basic factors: thermal comfort, visual comfort and indoor air quality (IAQ). But the definition of these factors is not fixed [7], since they depend on user comfort perception with a high subjective load. Therefore, it is necessary to provide users with increased awareness (mainly concerning the energy they consume), and permit them to be an input more to the underlying processes of the energy efficiency subsystem. Bearing these aspects in mind, below we present the base platform for our proposal of building management system, which is described subsequently.

3.1 Holistic IoT Platform for Smart Buildings

Our base automation platform used for integrating energy efficiency features is based on the CityExplorer solution (formerly called Domosec), whose main components were presented in detail in [8]. CityExplorer gathers information from sensors and actuators deployed in a building following an IoT approach and it is responsible for monitoring environmental parameters, gathering tracking data about occupants, detecting anomalies (such as fire and flooding among others), and it is able to take actions dealing with key efficiency requirements, such as saving power or water consumption. The main components of CityExplorer are the network of Home Automation Modules (HAM) and the SCADA (supervisory control and data acquisition). Each HAM module comprises an embedded system connected to all the appliances, sensors and actuators of various spaces of a building. These devices centralize the intelligence of each space, controlling the configuration of the installed devices. Additionally, the SCADA offers management and monitoring facilities through a connection with HAMs. Thus, all the environmental and location data measured by the deployed sensors are first available in HAMs and then reported to the SCADA, which maintains a global view of the whole infrastructure. Sensors and actuators can be self-configured and controlled remotely through the Internet, enabling a variety of monitoring and control applications.

3.2 Energy Efficiency Subsystem in CityExplorer

Our proposal of intelligent management system has capabilities for adapting the behavior of automated devices deployed in the building in order to meet energy consumption restrictions while maintaining the comfort level of occupants. The system is integrated in the back office part of the CityExplorer solution, using the SCADA as both data source and gateway to control automated devices. This way, the decisions taken by the intelligent management module are reflected on the actuators deployed in the building, such as the heating/cooling units and electric lights. We base our energy performance model on the CEN standard EN 15251 [9], which specifies the design criteria to be used for dimensioning the energy system in buildings, establishing and defining the main input parameters for estimating building energy requirements and evaluating the indoor environment. On the other hand, the comfort management algorithms are based on the models for predicting the comfort response of building occupants described in [10]. Taking into account all these criteria, we define the input data of our system, which are showed in Fig.1.

Our building management system for comfort and energy efficiency uses a combination of techniques based on behavior-centred mechanisms and computational intelligence [11] for auto-adapting its operation. This way, it is necessary to consider the data provided directly by users through their interaction, since they can change the comfort conditions provided automatically by the system and, consequently, the system can learn and auto-adjust according to the changes.

As can be seen in Fig. 1, an important prior issue to be solved is the indoor localization problem, since apart from environmental data, user identification and location data are also required to provide customized indoor services in smart buildings. Therefore, information about the number, location and identity of occupants, and even on their activity levels, are needed to adapt the comfort conditions provided in the spaces where occupants stay. Such comfort adaptation is performed through the individual management of the automated appliances in charge of providing their services in such areas. In this way, it is possible to carry out control decisions and define strategies to minimize the energy consumption of the building depending on user presence. For this reason, we have implemented an indoor localization system that provides positioning data of occupants by using RFID (Radio-Frequency Identification) and IR (Infra-Red) sensors deployed in the building [12]. This system is able to provide all user data mentioned as relevant for our problem.

On the other hand, the smart comfort and energy management system is divided in two main modules (see Fig. 1): the subsystem responsible for assuring the environmental comfort on the basis of the user preferences (*Smart Comfort Prediction*), and the subsystem in charge of estimating the energy wastage associated to such preferences and providing the optimal comfort settings that ensure the energy efficiency of the building (*Efficient Comfort Management*). The first module provides the optimum comfort conditions according to the occupants, their activities and their locations, apart from the individual comfort preferences. Once the comfort conditions for each location of the building have been estimated, the second module is responsible for estimating the optimum operational settings for the involved appliances, which ensure minimum energy consumption of the building while considering the previous estimated comfort conditions. For that, it is taken into account a forecast of environmental parameters and the energy generated by alternative energy sources installed in the building.

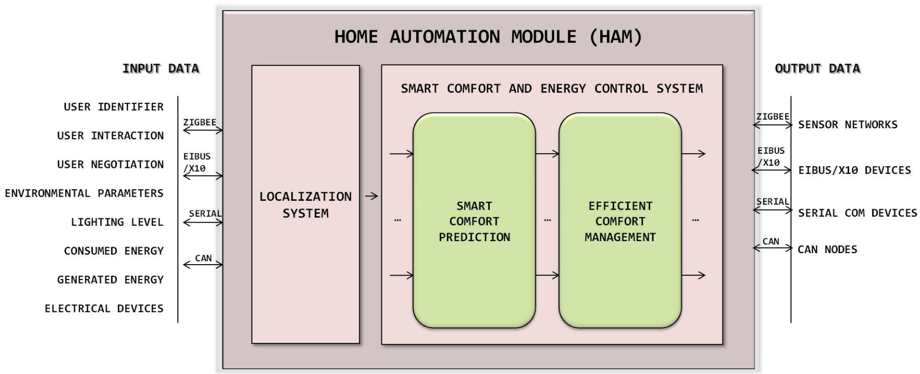

Fig. 1. Schema of the modules composing the management system focused on energy-efficient buildings

4 System Deployment and Tests

The reference building where our smart system has been deployed is the Technology Transfer Centre of the University of Murcia[2], where CityExplorer is already installed and working. All input data involved in our energy and comfort management system are available in real-time through the SCADA access, and the actions for achieving a comfortable and energy-efficient behavior of the building can be performed. All the rooms of the building have been automated (through an HAM unit) to minimize their energy consumption according to the actions suggested by our management system, while user comfort aspects are communicated to the system by user interaction with the system through a control panel or a user restricted access to the SCADA view. In one of the floors of such reference building, we have taken one laboratory as a reference testbed for carrying

[2] www.um.es/otri/?opc=cttfuentealamo

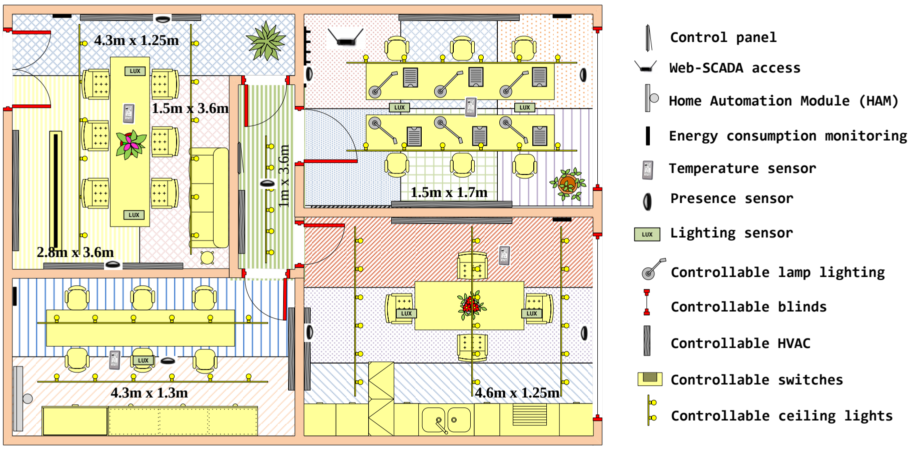

Fig. 2. Different scenarios deployed in a test lab of our reference smart building

energy efficiency experiments. In this test lab we have allocated different room spaces, as can be seen in Fig. 2. In these spaces, separate automation functions for managing lighting, HVAC, switches and blinds are provided, where these devices provide comfort services in different regions. Taking into account such service regions, as well as the features of each space in terms of natural lighting, activities to be carried out, and the estimated comfort requirements (for instance, the case of an individual lamp placed on a desk, the user location must be determined to provide occupants with personalized environmental comfort. These target regions are showed in Fig. 2.

Comfort and energy efficiency services provided in these scenarios are strongly dependent on the location data provided by the localization system integrated in the HAMs of CityExplorer. This system must be capable of providing user location estimation with a mean error lower than the target service regions showed in Fig. 2. A previous work [12] evaluated in detail the accuracy of such localization system. For our current tests, we analyze its accuracy considering the scenarios showed in Fig.2. For that, different user transitions between the different spaces are tracked by the system. According to the obtained results, it can be safely said that the system is able to track users with enough level of accuracy and precision. More specifically, the mean error obtained in this tracking scenario is 1 m., which is enough to offer individualized comfort services to users. In this sense, for instance, among the target service regions here analyzed, the individual lamp light represents the most restrictive case, with a service region of 1.5 m. x 1.7 m., which represents a restriction in terms of location accuracy higher than the mean error provided by our localization system.

Taking as starting point the suitability of the localization system integrated in the building management proposal, we can now demonstrate the benefits of considering such accurate positioning information (including identification) in terms of energy savings by using comfort services. Depending on the user allocated in each target area and the environmental parameters sensed in the room (temperature and humidity in this case of studio), the intelligent management process is responsible for communicating different settings to the appropriate HVAC appliances. All the information sensed is gathered in real-time and is available through CityExplorer. For the comfort management implemented, different comfort profiles for each user involved in the tests were considered. Besides, maximum and minimum indoor temperatures were established as control points for ensuring minimal thermal conditions in each scenario. In this way, customized comfort services are provided to users ensuring their quality of life, and the energy consumed is optimized thanks to the individual user location and identification data. Moreover, any energy wastage derived from overestimated or inappropriate thermal settings is avoided.

It is important to highlight that our energy efficiency system needs a long evaluation period to extract relevant figures of merit regarding energy saves. Furthermore, each simplification or adjustment in the system (different input data, rules, locations, comfort conditions, etc.) requires extensive testing and validation with respect to the environment chosen to carry out the evaluation. In addition, the system validation must cover different seasons in order to analyze its behavior with different weather conditions along the year. Despite all these considerations, we can state that the experiment results obtained until now already reflect energy saves in cooling/heating about 20%, attending to the energy consumption in A/C in prior months without considering our energy management system. It is clear that the environmental conditions are hardly repeatable, but the comparison was performed between consecutive months in the winter of 2013 which presented very similar environmental conditions and context features. Specifically, we consider the month of January without energy management, and February enabling intelligent management decisions. At this moment a constant evaluation is being performed day-by-day for providing further evaluations in future works.

5 Conclusions and Future Work

The proliferation of ICT solutions (IoT among them) represents new opportunities for the development of new intelligent services for achieving energy efficiency. In this work we propose a platform which is powered by IoT capabilities and is part of a novel context-and location-aware system that deals with the issues of data collection, intelligent processing for saving energy according to user comfort preferences, and proper actuation features to modify the operation of relevant indoor devices. An essential part of the energy efficiency module of the proposal is the user location and identity, so that customized services can be provided. The applicability of our system proposal has been demonstrated through a real implementation in a concrete smart building, gathering sensor data for monitoring the power consumption and tracking occupants following an IoT approach to access localization sensors. The localization system has been evaluated and an accuracy of about one meter has been obtained, which is considered more than enough to provide personalized environmental comfort to users for saving energy. Furthermore, using this localization system and the whole energy management platform, an overall energy save of 20% has been recently achieved.

As it has been already mentioned, a longer evaluation period to extract more relevant and precise results is needed. In this line, we are carrying out assessments aimed to analyze individual parts of our system. Several years of experimentation and analysis are needed to tune up the system and leave it ready to operate under different conditions, such as different seasons, people, behaviors, etc. Moreover, we are experimenting on mobile crowd-based sensing techniques for gathering data from occupants' devices, since this information will complement the data obtained by our infrastructure-based system.

References

1. Atzori, Luigi, Antonio Iera, and Giacomo Morabito: The internet of things: A survey. Computer Networks 54.15 (2010): 2787-2805.
2. Stunder, M. J., Sebastian, P., Chube, B. A., Koontz, M. D. (2003): Integration of real-time data into building automation systems (No. DOE/OR22674/611-30050-01). Air-Conditioning and Refrigeration Technology Institute (US).
3. Han, D., Lim, J.: Design and implementation of smart home energy management systems based on ZigBee. IEEE Transactions on Consumer Electronics 56, 1417–1425 (2010)
4. Oksa, P., Soini, M., Sydnheimo, L., Kivikoski, M. (2008). Kilavi platform for wireless building automation. Energy and Buildings, 40(9), 1721-1730.
5. Morrissey, E., O'Donnell, J., Keane, M., Bazjanac, V. (2004): Specification and implementation of IFC based performance metrics to support building life cycle assessment of hybrid energy systems.
6. Escrivá-Escrivá, G., Álvarez-Bel, C., Pealvo-López, E. (2011): New indices to assess building energy efficiency at the use stage. Energy and Buildings, 43(2), 476-484.
7. Handbook, A. S. H. R. A. E. : Fundamentals. American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta (2001).
8. Zamora-Izquierdo, M.A., Santa, J., Gómez-Skarmeta, A.F.: An Integral and Networked Home Automation Solution for Indoor Ambient Intelligence. IEEE Pervasive Computing 9, pp. 66-77 (2010)
9. Centre Europeen de Normalisation: Indoor Environmental Input Parameters for Design and Assesment of Energy Performance of Buildings - Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. EN 15251 (2006)
10. Berglund, L. (1978). Mathematical models for predicting the thermal comfort response of building occupants. ASHRAE Transactions, 84(1), 1848-1858
11. Callaghan, V., et al.: Inhabited intelligent environments. BT Technology Journal 22.3 (2004): 233-247.
12. Moreno-Cano, M. V., Zamora-Izquierdo, M. A., Santa, J., Skarmeta, A. F. (2013). An indoor localization system based on artificial neural networks and particle filters applied to intelligent buildings. Neurocomputing.