Public Building Energy Efficiency - an IoT Approach

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Abstract. Buildings play an important role in energy consumption, mainly in the operation phase. Current development on IoT allows implementing sustainable actions in building towards savings, identify consumption patterns and relate consumption with space usage. Comfort parameters can be defined, and a set of services can be implemented toward the goals of saving energy and water. This approach can be replicated in most buildings and considerable savings can be achieved thus contributing to a more sustainable world without negative impact on building users' comfort.

Keywords: IoT, Sensors, Sustainability, Building Efficiency, Energy.

1 Introduction

Electric power grids in Europe - and worldwide - are gaining intelligence and becoming "smart grids". The increase electricity consumption in developed countries, caused by a larger number of more powerful and diversified power-connected devices, creates consumption peaks, which lead to the need of integrating new ways to produce, distribute and consume energy with more efficiency. Also considering a constant increase in fuel prices, threats of global warming, implications of carbon and other emissions from traditional fuels, there is a growing interest in improving energy efficiency. One of the most important elements in ensuring energy efficiency is energy management and monitoring. Energy monitoring is an energy efficiency technique based on the standard management axiom stating that "you cannot improve what you cannot measure". It implies the necessity of measurements and data organisation [1]. But measuring is just the first part of the journey. There is also a need to transform collected data into correlated and usable information using a sustainable, well designed, and upgradable energy efficiency monitoring system [2].

Effective energy management requires chronological knowledge of both the relevant energy uses and the main influencing factors such as operational requirements (e.g. production data) and environmental data (e.g. external temperature, humidity, etc.). This activity concerns all types of energy (electricity, gas, steam, chilled water, compressed air, etc.) [2]. Some important questions are to determine which parameters should be monitored, define the optimal number and position of meters, choose the suitable frequency of collecting data (annually, monthly, daily, hourly or less). It is essential to identify main, independent, factors to reduce the number of monitored parameters. Creating a suitable database is essential to analyse energy use of buildings properly [1].

Sustainability initiatives at university level falls into three categories:

1) research-based sustainability - there is a proliferation of masters and doctorate's courses adopting the environmental angle on traditional disciplines, from environmental economics to climate modelling;

2) operational-based sustainability on the university itself. The focus is the reduction of deleterious environmental effects, cutting carbon and energy bills. Less common, but still important, is the role universities have in contributing to their local environment - socially, culturally, economically and ecologically;

3) "Universities of Sustainability", where the focus is on the education of environmentally and socially responsible citizens, on improving course curricula to ensure that courses include useful contentsdevelop skills for a world altered by climate change and post-peak oil [3].

These levels are not indepent. For example, sustainability research (level 1) will be converted into content for sustainabilty courses (level 3). Campus energy or water saving efforts (level 2) must involve the population thus educating them (level 3).

Several universities around the world are working on making their campuses sustainable, and one of the aspects is smart energy management - which is the main focus of this work, therefore aligned with the second level. Energy waste in various space types, such as teaching auditoriums, working areas (offices, laboratories, computer rooms, etc.) or residential buildings (dormitories) can be found [4]. The energy and environmental impact of universities could be considerably reduced by applying organisational, technological and energy optimisation measures [5][6]. Actions can be taken and aimed at improving the production, distribution and consumption of energy within the campus, to increase buildings energy performance, improve energy management and educate people about efficient and sustainable energy use [7].

2 Energy Efficiency project

ISCTE-IUL has a global community of ca. 10000 people, of which 9234 students from undergraduate, master, PhD and postgraduate programs. In 2017 it had a budget of 38.5 M€ of which 54% were self-generated. Four main buildings compose the campus: 1) Building Sedas Nunes (also known as Building I); 2) Building II; 3) Ala Autónoma; and 4) Building INDEG. These buildings are 20 to 40 years old and have a total gross built area of 48,500 m^2. ISCTE-IUL also has a multi-sports field, a parking lot and an off-campus student residence. In 2017, ISCTE-IUL started a Strategic Program on Sustainability. A formal sustainability specific organizational structure is managed by the Director of Sustainability to implement several projects, namely: 1) Campus Operations, such as water, energy and waste management; 2) Core Activities, like research and education; and 3) Outreach to the community, meaning in this context, activities to connect to society and share knowledge and expertise.

The objective of the university is to become the most sustainable university in Portugal. Under the Sustainability Program, the work described in this paper is focused on the Energy Efficiency Project which includes four topics: 1) Replacement or improvements of the HVAC systems; 2) Upgrade of electric lighting; 3) Installation of photovoltaic panels; and 4) Refurbishment of the Sedas Nunes building's roof to improve thermal insulation. The university believes there will be an average saving of one third on the energy consumption and CO_2 emissions. To accomplish these, there is a need to study energy efficiency and monitor energy consumption – the main focus of this work. What makes IoT interesting is the ability to save ISCTE-IUL a considerable amount of financial resources by optimizing processes. This is possible through the installation of sensors and the respective data analysis which, in turn, allows to take decisions on building operations and influence user behaviour.

3 Related Work

There is a considerable number of theses and research on IoT related to energy efficiency. In Portugal, there are already several smart grids and consumption control pilot-projects, such as, 1) in 2010 Galp company started the development of an energy management system pilot – SmartGalp – which monitors energy consumption through a platform that interacts with domestic users, from electricity and natural gas, to fuel. The installation of devices in houses or cars of the end users allows to follow the effective consumption and establish reduction goals to save on the energy bills. Through the monitoring of results, the company verified that this tool allows for effective savings, being able to reduce up to 8% in the energy consumption [8]. EDP electricity company launched in 2011 the InovCity Project, a program where it is possible to be energetically efficient [9]. Within the scope of this project, Évora became the first Iberian metropolis to test a new way of thinking about electricity production and distribution. The first stage focused on the automation of electric grid management to reduce operating costs. With the smart grid, any citizen can know in real time its energy consumption [10]. The project had a very positive impact regarding energy efficiency since 60% savings in electricity costs were attained with the implementation of LED and AI technology. Parque Escolar, a public company in charge of modernising Portuguese public school buildings, implemented a system that allows it to track and control energy consumption on all of installed equipment. This technology is already implemented in several schools' buildings in Lisbon controlling air conditioning, lighting and even IT devices. The pilot-project reduced the use of energy consumed in IT in 25% - including computers, IP phones, wireless access points or video cameras. This system is complemented with an easy to read information presentation that has become a teaching tool in schools encouraging "green" individual behaviour [11]. This is an example of what ISCTE-IUL university may achieve through integrating institutional strategic goals with researchers and students' cooperative work. By 2020, the prediction is that IoT will be a trillion-dollar industry in selling solutions [12]. Specifically dedicated to smart campus, there are already several companies creating custom-made solutions for the university campus market, such as Huawei [13] and Cisco [14].

Many universities throughout the world have set in motion projects aimed at achieving a smart campus. Most also created labs to work specifically in smart environments. An example is the European Commission-funded project aiming at the development of services and applications supported by a data gathering platform that integrates real-time information systems and intelligent energy management systems that drive a bi-directional learning process. The user learns how to interact with the building, and the building learns how to interact with the user in a more energy efficient way [15]. This was applied to chosen universities in Lisbon, Helsinki, Luleå and Milan. This project reached 30% in energy savings through use of ICT, Living Lab methodologies and gamification to promote user behaviour transformation on public building users [16].

4 Proposal

We have developed a Sensor Network to create smart environments: temperature sensors control the classroom temperature, and BLE beacons track user movement and emit sustainability-related information.

Fig. 1 shows our vision for the problem. The sensors installed on the campus provide data to a central cloud server, where information is manipulated towards the desirable goal. A service-based approach is used to provide flexibility and allow the reuse of algorithms towards knowledge extraction. The proposed architecture is composed of four layers: 1) **Data layer**, which comprises data collection from installed sensors; 2) **Information layer,** where data is manipulated towards achieving desirable information, based on data mining algorithms (out of the scope of this paper); 3) **Knowledge layer**, where this information can be used for campus management, and specific functional roles act on infrastructure and systems to optimise operating conditions; and 4) **Services layer,** which feeds main applications in a service-based approach, where information can be incorporated in the related service. For example, the info about the number of empty spaces at the parking facilities can be used to increase the number of persons using them.

From the gathered (big) data, patterns can be extracted and analysed. It is thus possible to make predictions about the physical or social phenomena being observed. The task of identifying patterns from big data is related to the application domain and oriented to a specific usage. In a university, the information to be collected and analysed has the main objective of allowing an improved operations management that leads to savings and therefore to more a sustainable performance. Nonetheless, in this type of institution, the ability to have data and detect patterns should also be related to research and teaching goals. In fact, these big data sets are also a major opportunity in the search for models relating several levels of information: external environmental conditions (temperature, relative humidity, solar radiation, wind speed, noise pollution, and air quality); internal environmental conditions (air temperature, radiant temperature, relative humidity, air displacement, noise level and air quality); time, date and location-related occupancy patterns and rate; resource consumption and waste and emissions generation.

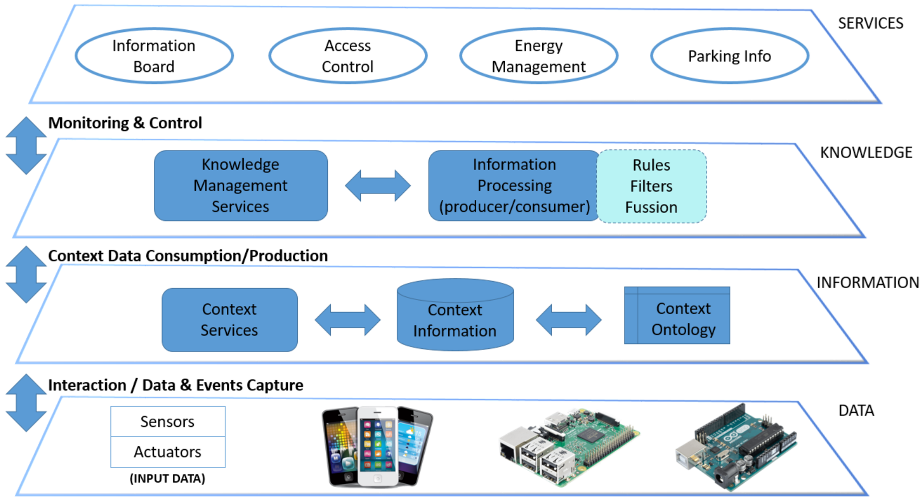

Fig. 1. A general overview of the proposed architecture of our IoT smart campus system.

4.1 Data Layer

This layer is mainly composed of a sensor array on a Lora communication network linked to a cloud IBM server, Bluemix. The following sensors are installed: 1) Electricity measurements - Current sensor: YHDC SCT013-000, current transformer, 100A:50mA and a Receiver - Raspberry Pi 3 Model B + LoRa Module; 2) Temperature and relative humidity measurements based on Texas instruments CC2650STK; and 3) Beacons – Bluetooth Beacon from Estimote which emit data through Bluetooth that is received by a smartphone app linked to a cloud-based backend that calculates users' position as they move through the campus. Sensors are installed in classrooms; data is being sent through Lora network using the MQTT protocol to publish messages to the IBM server.

Sensors are calibrated and specifically used to collect data such as electricity consumption and temperature. Lora network was installed in the university, allowing the sensors (if connected to a hardware device with Lora technology) to transmit the data captured by the sensors. A gateway which receives this data will send it to other similar gateways if needed until the data arrives at a central server which manages the whole network and communicates with the internet [17].

4.2 Information and knowledge layers

Data collected from the sensors will be stored in a database within Bluemix platform; then, through IoT services, we can correlate information and create knowledge from the raw data. Stored data can also be interpreted to identify patterns and create reports. We use the Bluemix platform, from IBM, which provides templates to overview collected data. Rules and alerts based on sensor data in the platform better monitor all the variables. An example for electricity consumption is the identification of residual consumption in empty classrooms leading to corrective actions towards its elimination, or consumption can be correlated with room occupancy and external temperature.

4.3 Service layer

Based on extracted data and knowledge, diversity of automatic actions can be implemented based on a service approach. Heating and cooling are activated based on sensor temperature data correlated with the presence of users in each space. Light intensity can be controlled based on luminosity information and presence. Water flow in bathrooms can be correlated with human presence. These services perform actions based on sensor input using node red platform easily. Manual inputs available from mobile devices can complete these actions [18].

We develop services oriented to room comfort temperature control because there is a connection between environmental temperature and cognitive performance [19]. Higher room temperatures can increase heartbeat to above 100 beats per minute. On a higher cardiac frequency, students end up consuming more calories diminishing their cognitive performance. Our service used input pre-defined temperature and, based on external weather conditions (exterior temperature), adapts the interior conditions to these pre-defined values. In winter, the temperature comfort should be around 18, while during the summer it should be around 26. Several factors need to be considered to actually achieve a comfortable environment, such as the number of students in the classroom - if there is a high number of students within the room, temperature will be higher due to more internal gains, and therefore we need to adapt the heating and cooling system; the insulation of the building will also affect the temperature, and since in ISCTE-IUL we have buildings with different construction materials, there is a possibility of studying systems operations more suitable to each type of external envelope; also due to the university having different buildings, which have rooms with a great diversity in spatial orientations, we can study the impact of room' solar orientation, and adjust the systems operations accordingly. With this, we see it is fundamental to regulate temperature and thermal comfort, so classrooms provide the conditions for students to learn in a comfortable environment.

Available information regarding external climate conditions can be used to predict near-future thermal comfort constraints. Further correlating this set of data with sensors-collected data provides very useful management information to predict future needs regarding heating and cooling. It is, therefore, possible to better manage the relationship between energy supply and demand taking better advantage of renewable energy produced on-site.

5 Results

Experience at ISCTE-IUL shows a significant saving potential. For the last five years, the learning management system included online information about room occupancy based on class schedules. By manually analysing this information on a weekly basis, it was possible to prepare custom-made routines to supply the systems management contractor so that HVAC systems were activated based on actual occupancy predictions. This process led to energy savings of 12%, based on actual consumption determined through energy invoice analysis.

With the implementation of this new sensor-based automatically processed information collection, we foresee a considerable improvement in how the energy-consuming systems are managed. It will be possible to improve occupancy rate-based systems activation at two scales further: the space scale, fine-tuning where heating or cooling should be supplied; and timescale, reducing weekly-based definitions to daily-based information. This is possible putting together the real-time low-frequency data collection with an integrated digital management system.

Also, detailed information on the facilities, such as the building geometry, wall, floor and roof composition, room door and window type and size and room size, type, identification, functions, etc. are stored in Building Information Model (BIM) models. BIM models are 3D descriptions of buildings which associate information with the geometry of the building and its contents. ISCTE-IUL's facility management office has been developing and maintaining a BIM model which is being used to feed maps, room listings and locations. This model has been linked to the academic management system to gather and display information such as room capacity, office occupancy and other parameters. Its visualisation capabilities are used to represent sensor location and results, provide info on which to base thermo-hygrometric simulations and to display gathered data in a geo-referenced, visually rich environment. This visualization platform is important when insights on the occupants and buildings systems response are sought for. Spaces occupancy, building materials, solar orientation and other factors can easily be understood, supporting data interpretation.

6 Conclusions

This work describes ISCTE-IUL approach towards building energy efficiency services where context information from locally installed sensors can be manipulated to identify consumption patterns and later implement actions in a service basis to save energy or water in a building. Usage of external information, like local maps, building materials, external weather conditions and room occupancy can be used to improve further saving actions. In spite of this work being a local dedicated approach to our campus, the service basis approach allows an easy deployment to other cases. In the near future, we will also add to this IoT platform a gamification approach to encourage users in saving energy and water.

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