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***Abstract*—Energetic sustainability on university campuses relies on the efficiency and smartness of the energy systems, as well as the behavior of its users. The aim of this work is to identify the requirements and propose the design of a Smart Study Room that, besides relying on users' awareness about their energy consumption, might also rely on their feedback about issues that could affect the optimal use of the study room resources. This concept is presented in the paper as *two-way awareness*. To determine the requirements, a survey was conducted among 61 university students to understand: (i) their usual behavior at the study room; (ii) their complaints about the study room; (iii) the set of users' behaviors that, in their opinion, have a negative impact on the energy consumption; and (iv) the information of the study room that they would find useful and interesting to visualize. Based on the results of this survey the design of the smart study room was developed and presented.**

***Index Terms*—Ambient Intelligence, Building Management Systems, Energy Efficiency, Smart Study Room.**

I. Introduction

University campus is a specific environment where energetic sustainability is pursued. Specifically, since 2010, the Politecnico di Torino, in Italy, has devoted several research, educational, and administrative efforts to develop the knowledge and awareness of environmental sustainability. These efforts are founded on the belief that the campus should be used as a *living lab* in which users (students, faculty, staff) and researchers can apply their projects for real. As in many other scenarios, energetic sustainability on the university campus relies on the efficiency and smartness of its energy systems, as well as the behavior of its users. Intelligent Buildings, and specifically, Building Management Systems (BMSs) are considered to be remarkably useful in achieving this efficiency and smartness. An Intelligent Building is defined as "one which provides a productive and cost-effective environment through optimization of its four basic elements including structures, systems, services and management, and the interrelationships between them" [1]. Moreover, Intelligent Buildings are considered to be complex systems that inter-relate people (owners, occupants, users, etc.), products (materials, fabric, structure, facilities, equipment, automation and controls, services), and processes (performance evaluation, facilities management).

BMSs aim at controlling, monitoring and optimizing building services (i.e., lighting, heating, security, audiovisual and entertainment systems, filtration, etc.) [2]. For that purpose, their architecture typically embodies sensory infrastructure, a data processing engine, a user interaction interface, and acting infrastructure [3].

Beyond the technical capabilities of such systems, users' behavior has been recognized as one of the major causes for the gaps in energy consumption and comfort requirements [4]. According to Ghaffarianhoseini *et al.* [5], Intelligent Buildings require "smart users" if they are to be truly inclusive, innovative, and sustainable. Ultimately, occupants, not buildings, are the primary consumers of energy.

In fact, informing users about their current consumption patterns and suggesting them more efficient behaviors can profoundly impact current and future buildings' energy efficiency [6]. Providing appropriate feedback to the users about their energy consumption is the simplest approach to increase their awareness and encourage eco-friendly behaviors [3]. For this reason, several research efforts focused on developing energy efficient Intelligent Buildings by integrating occupants' activities and behaviors as key elements for the BMSs [2].

However, the feedback to increase the users awareness is typically oriented in one way, only, from the BMS to the users. This means that the BMS has knowledge about its occupants' behaviors and provides them feedback when needed. In this paper we present the design of a *two-way aware* study room (Smart Study Room) in which users are also aware of the building issues and are enabled to provide their feedback by reporting these issues and requesting assistance. To this end, users' behavior is characterized through the data that emerges from their interaction with university services and spaces, and their access to the wireless network. In this scenario, the widespread use of laptop computers, smartphones and wearable devices among students is harnessed. The users' awareness of their energy consumption is achieved through the development of real-time visualizations that are displayed on their devices, as well as on a large screen located in the study room. And the users' feedback is captured through a specific system that enables them to request assistance or report damages that would affect the optimal use of the study room resources.

To gain understanding about users' behavior in an actual study room, we carried out a survey addressed to 61 university students with the purpose of identifying: (i) their usual behavior at the study room; (ii) their complaints about other students' behaviors, infrastructure failures, and ambience inadequacies (concerning temperature, lighting, air cleaning); (iii) the set of users' behaviors that have a negative impact on energy consumption; and (iv) the information of the study room that they would find useful and interesting to visualize. Based on the results of the survey, a set of system requirements was defined and the design of the Smart Study Room was developed.

Summarizing, the contributions of this work are: (i) the results from the survey; (ii) the requirements elicitation based on the behaviors, complaints, and visualization preferences reported by the students in the survey; (iii) the system design of a *two-way aware* Study Room, specifying its technology stack; and (iv) the partial implementation of such a system according to the proposed design.

The remainder of the paper is structured as follows. Section II presents some related works concerning Intelligent Buildings and BMS that significantly rely on users' awareness and behaviors to achieve energetic sustainability. Section III describes the requirements elicitation for the Smart Study Room. Section IV presents our design of such a system, while Section V concludes the paper with some considerations and future work.

II. Related Works

Bellagente *et al.* [7] used an "Internet of Things approach" to deploy an Energy Management System aimed at monitoring and supervising the energy production and consumption of the distribution grid at campus of the University of Brescia. The Energy Management System was deployed as an interface between the Distribution Service Operator (DSO) and the sensors and actuators deployed in the campus. In this manner, energy requirements provided by the DSO could be satisfied taking into consideration the users' behaviors and preferences that were gathered by the sensors and the actuators. The integration of the Energy Management System with the sensors and actuators was possible by means of RESTful web services. These web services also enabled the development of new applications by which the users could interact with the devices on the distribution grid.

De Paola *et al.* [8] present *SmartBuildings*, an Ambient Intelligence system aimed at reducing the energy consumption of "legacy" buildings by applying artificial intelligence techniques to heterogeneous sensor networks. The prototype of this system was deployed in the campus of the University of Palermo, Italy. It used machine learning techniques to profile the activities that the building occupants were performing, based on the data captured by Microsoft Kinect devices. Then, relying on a trained predictive controller, the system attempted to find a correspondence between the identified activities and environmental data, captured by sensing devices. Finally, the actuators deployed over the building were managed according to the identified correspondences.

Kusakabe *et al.* [9] discuss a trial case of requirements development aimed at improving the Energy Management System in the campus of the Kyushu University, Japan. For that purpose, software engineering techniques were used under the goal of increasing the awareness and involvement of members for smart energy management. Domain analysis techniques (from software product line engineering) were applied to determine the core requirements of an Energy Management System, as well as to identify the main variable points among different implementations of this kind of systems.

Yu *et al.* [10] propose a Building Management System approach, where user preferences are expressed at a higher level and realized by software agents in an dynamic environment. This approach was intended to deal with the gap between energy consumption goals achieved by a Building Management System with fixed settings and those desired by multiple users in a dynamic environment. For this purpose, users were provided with a web friendly interface that allowed them to control the devices in the room, express their preferences by customizing their predefined desired settings, and visualize statistics about measurements available in the room (such as temperature and power usage readings). However, in addition to user preferences, rules might be added to the room such that appliance actuation adheres to a global policy.

Similarly to [7] and [8], our design integrates an Ambient Intelligence approach to pursue energetic sustainability and contribute to the optimal use of the physical resources in the campus. Moreover, as in [9], we identified a set of system requirements and proposed the design of a Smart Study Room that, like all the works described in this section, significantly relies on users' behaviors to determine its operation. In our work, (i) the system requirements are identified through a survey addressed to the users of the study room; (ii) the proposed system achieves users' awareness about their energy consumption by means of real-time visualizations; and (iii) includes the users' explicit feedback to determine its operation. This explicit feedback refers to reporting or requesting assistance in the occurrence of an event or a situation, that might affect negatively the optimal use of the study room physical, environmental, and energy resources.

III. Requirements Elicitation

A survey was conducted to identify the requirements of the Smart Study Room. This survey was completed by 61 university students that use a specific study room located at the Politecnico di Torino campus. The survey was applied in two consecutive days by polling students at the entrance of the study room at two different times each day (11:00 and 15:00). It was structured around the four general aspects listed below.

1) The **typical behavior** of the survey respondents when using the study room. Specifically, how often they go to the study room during the week, in which time slot they go, and which electronic devices they use there.
2) The **complaints** of the survey respondents concerning other students' behaviors (i.e., improper use of the

seats[1], loud voices, ringing phones, windows/doors left opened), infrastructure failures (i.e., windows/doors that do not close, broken chairs/desks, dirty chairs/desks), and ambience inadequacies (i.e., too high/low temperature, insufficient light, insufficient air recycle).

3) The set of **users' behaviors** that according to the respondents have a negative impact on the energy consumption and the optimal use of the study room resources. Available answers included: heat loss due to opened doors/windows, electric devices charging, prolonged lighting when unnecessary, and intensive use of Wi-Fi connection, or other.
4) The information of the study room that the survey respondents would find useful and interesting to **visualize** on public monitors placed inside and outside the study room. Available answers included: estimate number of present people, noise level, temperature, lightness, Wi-Fi usage, and current energy consumption, or other.

The results and findings of the survey on the aspects outlined above are reported in the following subsections.

A. Typical behavior at the study room

First, students were asked about their attendance to the study room. 36% of the respondents reported to use the study room every day while 37% reported to use the room from three to four times a week.

Concerning the time slots in which respondents visit the study room, 26% of them mostly go to the study room from 8:00 to 11:00, 23% from 11:00 to 14:00, 31% from 14:00 to 17:00, and 20% from 17:00 onward.

Regarding the use of internet-connected devices while in the study room, 79% of the respondents use a laptop computer, the same percentage use a smartphone, and 25% use a tablet. In most of the cases each student uses more than one device.

These results reveal that the study room is widely used by the students. In fact, 73% of them use the study room at least three times a week. Moreover, students use the room several times a day, in no specific time slot, and all of them use one or two internet-connected device.

B. Most annoying issues at the study room

When asked about the annoying issues during their stay at the study room, 59% of the respondents reported that the most annoying issues are related to other users' behaviors. 34% consider that they are related to infrastructure problems, and 7% consider that they are related to ambience inadequacies. Table I presents the three most annoying issues on each category and their associated percentages.

Later, to the question "If you had been able to use a dedicated on-line service, you would have reported these annoying issues to the University's staff?", 47% of the respondents answered *yes*, 33% answered *yes, but anonymously*, and 20% answered *no*.

[1]Refers to the seats that are not occupied by a student, but instead, are occupied by the belongings that someone left there.

TABLE I
MOST ANNOYING ISSUES AT THE STUDY ROOM

Users' behaviors (59%)		
Rank	Annoying issues	Percentage
1	Improper use of the seats	42%
2	Loud voices	29%
3	Doors/windows kept open	22%
Infrastructure failures (34%)		
Rank	Annoying issues	Percentage
1	Broken doors/windows	49%
2	Broken chairs/desks	26%
3	Dirty chairs/desks	26%
Ambience inadequacies (7%)		
Rank	Annoying issues	Percentage
1	Excessively high/low temperature	72%
2	Insufficient air recycle	19%
3	Insufficient light	9%

These results suggest that the most annoying issues are related to users' behavior, much more than to infrastructure failures and ambience inadequacies. Approximately 80% of the respondents are willing to report, through a dedicated service, the occurrence of these annoying issues.

C. Behaviors that negatively impact the optimal usage of the study room resources

To determine the behaviors that have a negative impact on energy consumption, as well as on the optimal use of the available resources at the study room, students were asked to rank a list of suggested behaviors. Table II summarizes the answers to this question. Percentages correspond to the number of times that the given behavior was ranked first or second, respectively. In the following three tables the items are sorted in descending order of the first percentage.

TABLE II
BEHAVIORS THAT NEGATIVELY IMPACT THE OPTIMAL USAGE OF THE STUDY ROOM RESOURCES

Users' behaviors	First	Second
Doors/windows opening to the outside (heat loss)	44%	20%
Improper use of the seats	27%	20%
Electric devices plugged when unnecessary	25%	23%
Prolonged lighting when unnecessary	9%	19%
Excessive use of Wi-Fi connection for non academical purposes	9%	15%

It should be noticed that all the behaviors listed above are easily rectifiable. In fact, many of them do not correspond to deliberate actions. On the contrary, they are due to oversights that would be overcome through timely and accurate notifications targeted to study room occupants.

D. Information about the study room that the students would find useful to visualize

Following the same procedure of the previous question, students were asked to rank the information that they would find useful and interesting to visualize both when they are in the study room and before arriving to the study room. Tables III and IV summarize the corresponding results. While the information delivered inside the room is intended to influence student behavior towards a better use of available resources, the information accessible from outside the study room is intended to help students decide whether they should consider going to the study room.

TABLE III
INFORMATION THAT STUDENTS WOULD LIKE TO VISUALIZE INSIDE THE ROOM

Information	First	Second
Estimate of the number of present people	50%	14%
Wi-Fi usage (used/available bandwith)	21%	20%
Temperature	18%	26%
Noise level	16%	33%
Current energy consumption	5%	7%
Lightness	0%	4%

TABLE IV
INFORMATION THAT STUDENTS WOULD LIKE TO VISUALIZE BEFORE ARRIVING TO THE ROOM

Information	First	Second
Estimate of the number of present people	81%	7%
Noise level	12%	33%
Temperature	7%	36%
Wi-Fi usage (used/available bandwith)	7%	21%
Current energy consumption	4%	2%
Lightness	2%	0%

The estimate of the number of people in the study room was ranked by the respondents as the top information that they would like to visualize both inside and outside the study room.

IV. System Requirements and Design

Based on the results of the survey, a set of system requirements were identified. These requirements aim at transforming a study room at the Politecnico di Torino (the same where the survey was conducted) into a Living Lab in which energy consumption is reduced and the resources of this room are optimally used. Specifically, the concerned study room has 56 seats, 14 desks (each with 4 electrical sockets), 12 windows, and 5 entrances, and the Wi-Fi access is provided by two access points. The identified system requirements were:

- **R1** *Sense environmental variables*: noise level, temperature, humidity, and lighting. Some measurements are used to provide information to users, and some others to feed control algorithms (i.e. comfort estimation).
- **R2** *Calculate specific study room variables*: approximate energy consumption, number of occupants, and Wi-Fi bandwidth usage.
- **R3** *Display real-time visualizations* about the variables sensed and calculated in **R1** and **R2**.
- **R4** *Detect* the occurrence of user-behaviors that could lead to electric *energy waste*.
- **R5** *Notify study room users* in real time about the behaviors that were detected in **R3**.
- **R6** Enable study room users to *report infrastructure failures and damages* that could lead to energy waste, misuse of the physical resources of the study room, or discomfort to the users.

In order to address the above listed requirements, a *two-way awareness* design is proposed. In fact, just as the study room is intended to be aware of the environment and the users' behaviors, also the users are aware of the study room settings and provide feedback if they encounter some failures. In this manner, the study room *"benefits"* from the feedback provided by the users, while the users *"benefit"* from having real-time information that, on the one hand, encourages them to pursue efficient energy consumption and, on the other hand, could help them to decide if going or not to the room based on the sensed variables. Figure 1 illustrates the proposed interactions among the components and the people involved in the Smart Study Room.

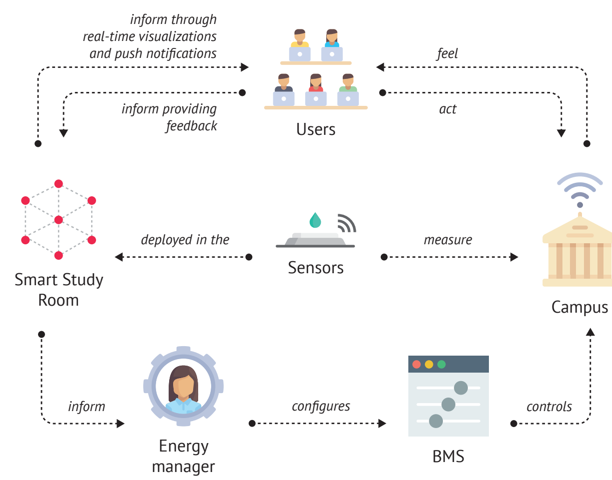

Fig. 1. Smart Study Room two-way awareness (icons were taken from http://www.flaticon.com/)

The overall architecture of the Smart Study Room is illustrated in Figure 2. In general terms, it involves sensing devices whose gathered data is accessible through a Z-Wave gateway[2], an Access point through which the number of users can be estimated, a Gateway that gathers and fusions the data coming from the Z-Wave gateway and the Access Point, an Application server that generates real-time visualizations and receives users' feedback, and the Users' devices through which

[2]Z-Wave the Smartest Choice for your Smart Home. http://www.z-wave.com [Accessed May 18 2017]

they can be aware of the Smart Study Room and interact with it by providing their feedback. The following is a more detailed description of such components.

A. Crowd-sourcing data from the access point

Survey results highlighted the widespread use of several kinds of wireless internet-connected user devices. All the students in the room use at least one device among laptop computers, tablets, smartphones and wearable devices. This fact positions wireless crowd-sourced monitoring [11] [12] [13] as a feasible alternative to estimate the number of occupants in the study room.

The Politecnico di Torino wireless network requires authentication and there is a server deployed for that purpose. This server has records of the campus users, their devices, and the access point to which they are connected in a given moment. However, for privacy reasons, data comprising users' identity and location, cannot be queried. For this reason, to our specific design, the data is gathered directly from the access point deployed at the study room. The number of connected devices is gathered through a Simple Network Management Protocol (SNMP) request.

B. Sensors

The sensing devices deployed in the room are connected to a Z-Wave gateway (RaZberry board). Through this gateway the data gathered by the sensing devices can be queried. The set of sensing devices proposed in our design are: sensors to measure noise levels; amperometric clamps to measure energy consumption; temperature and humidity sensors; connected thermal camera to calculate the number of people in the room; lighting sensors; and sensors to determine if the doors or windows are opened. The communication between the RaZberry and the sensors is achieved through the Z-Wave protocol.

C. Gateway

The Gateway (Raspberry Pi 3 Model B[3]) gathers and integrates data from the access point and the Z-Wave gateway. Data coming from the access point provides information about the number of connected devices and the bandwidth usage. Data coming from the RaZberry provides information about the sensing devices measurements. The gateway invokes a set of RESTful web services exposed by the application server in order to store the gathered data into a database.

D. Feedback mechanism

Study room users would be able to report infrastructure failures that could lead to energy waste, through a web application running on their devices. To achieve this, a feedback system was included in the smart study room design. It consists of a set of RESTful web services by means of which it is possible to report the failures and manage these reports. The web services are consumed by the users' and by the energy manager web applications. In the users' web application, reports about infrastructure failures are posted. In the energy manager web application, these reports are displayed in real-time so they can be quickly solved.

E. Real-time visualizations

Two types of real-time visualizations are generated depending on the users' location. The information provided to the users that are planning to attend the study room would be different from the information provided to the users that are already there. In the first case, information aims at helping users decide if attending or not the study room based on real-time visualizations about the estimate number of present people, the noise level, the temperature, and the Wi-Fi bandwidth usage.

In the second case, when the users are in the study room, besides the aforementioned information, they would be notified in real-time about behaviors that are negatively affecting energy consumption. For example, if based on the information collected by the Gateway, the system determines that a door has been left opened while the air conditioner is on, a notification would be displayed to inform users and encourage them to stop energy waste due to heat loss. In this case, by means of the mechanism previously described, users may provide feedback when the issue is solved.

A third type of real-time visualization is targeted to the energy manager. In this type of visualization, besides displaying information about all the variables that are being measured and the occurrence of behaviors that might be affecting negatively energy consumption, managers are informed about the request for assistance or the reports about infrastructure failures that study room users have made. In this way, they can do something about it.

F. Application server

The application server receives data from the Gateway and from the user devices. Analyzing the data coming from the Gateway, the application server detects behaviors that are affecting negatively efficient-energy consumption in the study room. When these behaviors are detected, push notifications are generated and displayed over the real-time visualizations that are being exhibited in a large screen at the study room.

Since the feedback system is deployed in the application server, the data coming from the user devices corresponds to the reports about infrastructure failures that the users post through a web application. The communication with these two components, the Gateway and the users' devices, is achieved by means of RESTful web services. All the data exchanged with these web services is JSON-formatted.

V. Conclusions

Prior work has pointed out the importance of users' behavior in achieving efficient-energy consumption and satisfy comfort requirements in the context of Intelligent Buildings. Providing appropriate feedback to the users about their energy consumption patterns is the simplest way to increase their awareness

[3]Raspberry Pi - Teach, Learn, and Make with Raspberry Pi. https://www.raspberrypi.org/products/raspberry-pi-3-model-b [Accessed May 18 2017]

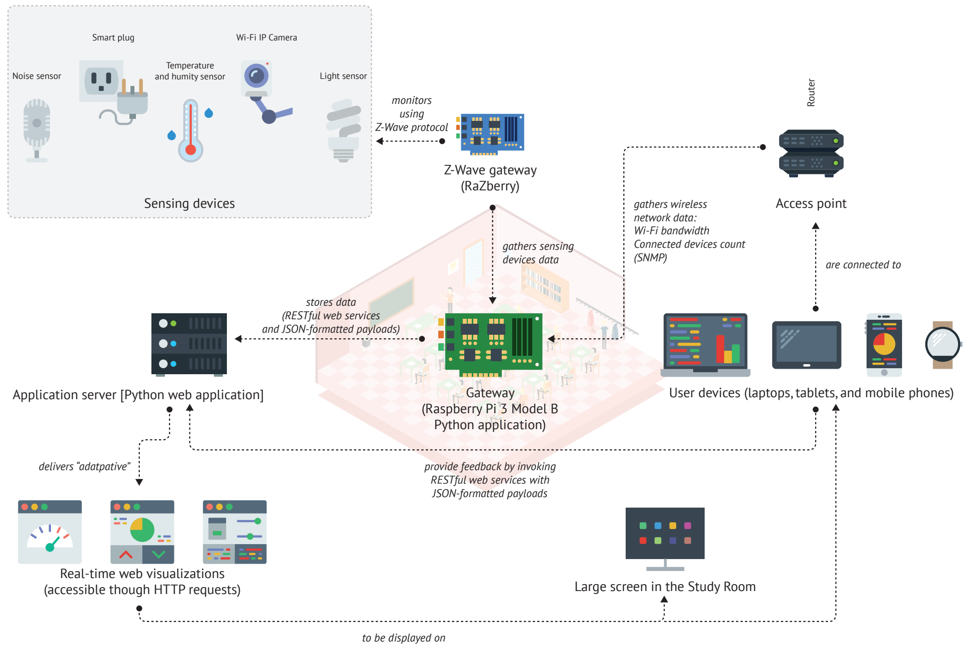

Fig. 2. Overall Smart Study Room architecture (icons were taken from http://www.flaticon.com/)

and encourage eco-friendly behaviors. Ultimately, people and groups are responsible, one way or another, for all energy consumption. For these reasons, several research efforts focused on the users' behavior awareness as a way to significantly increase energy efficiency in Intelligent Buildings.

However, users' awareness is typically one-way directed in the sense that the Intelligent Buildings have knowledge about its occupants' behaviors and can react accordingly. In this study we identified the requirements and proposed the design of a two-way aware study room in which users are also aware of the building issues and are enabled to provide feedback by reporting them and requesting assistance. A survey was conducted to identify the system requirements and the design of such a study room was proposed based on the results of the survey. We are currently refining the implementation and deploying the proposed system and future work will concern its assessment against the objective of decreasing energy consumption, increasing the availability of the physical resources, and raising the comfort level of the users.

VI. Acknowledgments

Roberto Marturano currently works on the design and development of the Smart Study Room as part of his Master's thesis.

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