SMART CAMPUS: Building-user Interaction Towards Energy Efficiency Through ICT-based Intelligent Energy Management Systems

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Abstract. The SMART CAMPUS project, co-funded by the European Commission (CIP-ICT-PSP no. 297251), which started in 2011 and will end in 2015, aims at increasing energy efficiency in public university buildings through a dynamic approach that involves negotiating the building environmental conditions (e.g., temperature, lighting, and ventilation) with the users, by developing ICT-based services and applications that will drive a bi-directional learning process such that both the user and the building learn how to interact with each other in a more energy efficient way. With the proposed approach, the project aims at transforming the behaviour of university campus users towards more energy efficient practices.

1 Introduction

Energy efficiency can be defined as "reducing energy or demand requirements without reducing the end-use benefits". It is one of the most cost-effective methods of enhancing the security of energy supply, and of reducing the emissions of greenhouse gases and other pollutants. Energy efficiency can actually be seen as Europe's largest energy resource.

In 2007, the European Council adopted ambitious energy and climate change objectives for 2020, and these included a non-binding 20% improvement in energy efficiency. This specific target was identified as a key factor towards achieving long-term energy and climate goals. However, although significant steps have already been taken, the EU is still a long way from achieving that target. As buildings account for about 40% of the energy end-use in the EU, making buildings more energy efficient is crucial for achieving the abovementioned target. Another relevant fact is that publicly owned or occupied buildings represent about 12% (by area) of the EU building stock.

Within this context, the SMART CAMPUS project aims at increasing energy efficiency in public university buildings (by reducing unnecessary consumption) through

Oliveira ÃĄ., Nina M. and Medina J.
SMART CAMPUS - Building-user Interaction Towards Energy Efficiency Through ICT-based Intelligent Energy Management Systems.
DOI: 10.5220/0006182900110030
In *European Project Space on Information and Communication Systems (EPS Barcelona 2014)*, pages 11-30
ISBN: 978-989-758-034-5

a dynamic approach that involves negotiating the building environmental conditions (e.g., temperature, lighting, and ventilation) with its users. With the proposed dynamic approach, the SMART CAMPUS project aims at transforming the behaviour of university campus users towards more energy efficient practices.

The dynamic approach of the SMART CAMPUS project is based on the use of innovative ICT-based services and applications supported by a data-gathering platform that integrates real time information and intelligent energy management systems. This integrated approach will drive a bidirectional learning process, in which both the user and the building learn how to interact with each other in a more energy efficient way.

The proposed approach will be implemented in four pilot studies in university buildings located in European countries with distinctive climates and energy consumption patterns, namely Finland, Portugal, Sweden and Italy.

A major requirement for the success of the proposed approach is to engage the users in actively interacting with the building's intelligent energy management system. The innovative ICT-based services of the SMART CAMPUS platform will allow this interaction, empowering the users and providing guidance that is expected to lead to a transformation of their behaviour towards more energy efficient practices.

The implementation of Living Lab methodologies will have a major role in ensuring the engagement of the university campus users from the initial stages of the project, in creating conditions that favour the interaction between the users, and in ensuring that the users accept the transformed behaviours in a sustainable way.

The SMART CAMPUS project is co-funded by the European Commission CIP-ICT-PSP Programme under Grant Agreement no. 297251.

2 Methodology

2.1 Overview of the Methodology

The SMART CAMPUS approach will build upon and improve the approach used in the SAVE ENERGY project: SAVE ENERGY involved a centralized platform for metering energy consumption, providing real time information to the users. This communication was one-way only, i.e. from the building to the users. SMART CAMPUS will also make use of real time information on energy consumption, but the users will have the possibility of actively interacting with the building energy management system that controls Heating Ventilation and Air Conditioning (HVAC), lighting, and other equipment. The SMART CAMPUS approach is thus based on interactive intelligent energy management systems with which the users can negotiate and define the building environmental conditions.

The university campus users clearly play a major role in the SMART CAMPUS project. In fact, the project aims at integrating, implementing and testing new concepts, methodologies and software in four pilot buildings. This can only be achieved if the users of the buildings are engaged and interact from the beginning, contributing to the vision, participating in the development process, and playing a leading role in the validation phase. A Living Lab, user-centric, methodology is thus being implemented (Figure 1).

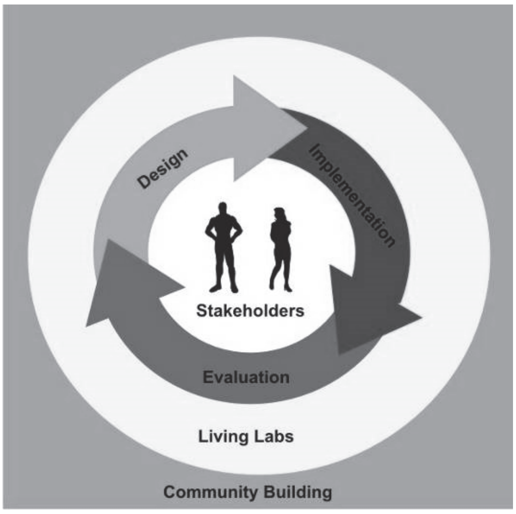

Fig. 1. User-centric approach.

From the above, it is clear that the SMART CAMPUS project has two major components, a technological component and a behavioural component.

Regarding the behavioural component, the lessons learned during the SAVE ENERGY project (www.ict4saveenergy.eu), particularly those related to the living lab methodologies and user behaviour transformation, are taken into account when implementing the SMART CAMPUS pilots.

The main methodological concepts used within the SMART CAMPUS project, the Living Lab methodology and the eeMeasure methodology will be explained.

2.1 Living Lab

A Living Lab can be defined as a user-centric innovation environment built on everyday practice and research, with an approach that facilitates the user influence in open and distributed innovation processes, engaging all relevant partners in real-life contexts, aiming to create sustainable values.

The Living Lab methodology involves co-design, co-creation, testing and evaluation of services or products in real-life environments. By using the Living Lab methodology, researchers can attain a deeper understanding of how people interact with products, finding constraints or new features. This approach leads to the development of better products and services, more adequate to the users' needs and expectations, thus increasing the success and acceptance of those products and services by the users. The Living Lab methodology involves all relevant stakeholders from the very beginning of a new idea, creating the motivation to share and discuss experiences and expectations. This approach provides a trusting collaborative environment, where users are expected to co-create the solutions and become early adopters. The Living Lab methodology also ensures that the users accept the transformed behaviours and the recommended policies in a sustainable way.

The Living Lab methodology within the context of SMART CAMPUS is based upon that used in the SAVE ENERGY project, which is shown schematically in Figure 2.

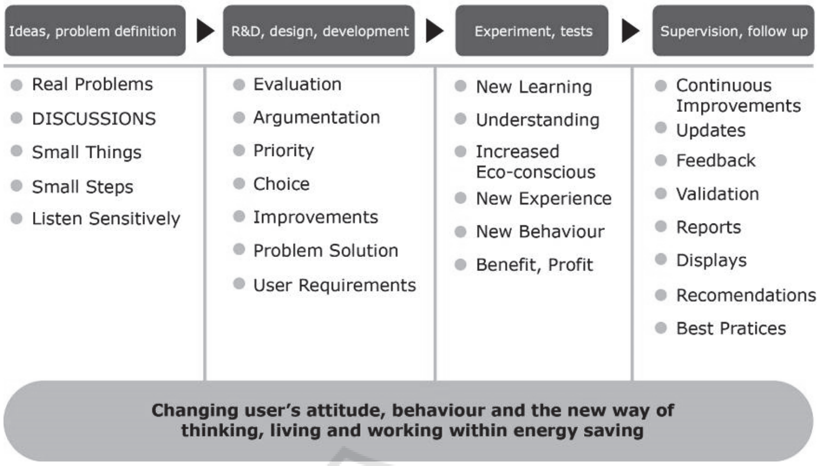

Fig. 2. Living Lab methodology in SAVE ENERGY.

2.2 eeMeasure

eeMeasure is a methodology for calculating and reporting the quantitative project results. According to European Commission recommendations, the eeMeasure Measurement and Verification (M&V) methodology is intended to promote good practice and consistency in the reporting of ICT-PSP project results. The use of the methodology should also assist others to more clearly identify significant future energy saving opportunities, including the development of local and national policy.

The methodology has been produced as part of the eeMeasure project and should be used in conjunction with the eeMeasure software and its integrated online user guide.

It is assumed that all relevant projects have an Intervention to reduce energy Consumption, and that Energy Consumption can be determined both with and without the Intervention.

The eeMeasure documentation is available at http://eemeasure.smartspaces.eu. For the specific pilots of the SMART CAMPUS project, the non-residential methodology should be used ("SMART 2011/0072: Methodology for energy-efficiency measurements applicable to ICT in buildings (eeMeasure) - D1.2 Non-residential methodology" (Version 2.0 August 2011)).

3 Concepts

The SMART CAMPUS approach is built upon several theoretical and practical concepts, among which the following will be further developed in this section:

- Data architecture;
- Real Time Information on Energy Consumption;
- User Engagement and Interaction;
- User Behaviour Transformation;
- User scenarios;
- Bi-directional Learning Process through Energy Management Systems;
- Decision Guidance;
- Data Architecture.

The core of the technical solution of the SMART CAMPUS project consists of Intelligent Energy Management Systems (IEMS) and a Data Platform. The SMART CAMPUS Data Platform for energy efficiency management is constituted by a local intelligent management system and a local data gathering platform installed at each pilot location and the central platform where information for all the pilots are further analysed and compared to energy efficiency models.

The SMART CAMPUS platform has a local intelligent management system and a local data gathering system (both installed locally in each pilot building), as well as a central platform where information from all pilots is further analysed and compared to the energy efficiency models that will be optimized along the project, taking into account the feedback from the users and the energy efficiency policies. Figure 3 and Figure 4 schematically show the SMART CAMPUS platform and its architecture, as proposed during the SMART CAMPUS kick-off meeting.

The platform has a bidirectional communication layer, allowing for better engagement of the users and effective sensing/actuating capabilities with HVAC, lighting and other equipment. The interaction between the platform and the users will take place at the pilot building. The local part of the platform includes the network of sensors and actuators that can be wirelessly connected to a controller, which also receives the information from the smart metering devices and sends information to the users. Besides the consumption of electric energy, the SMART CAMPUS platform will also monitor the temperature inside and outside the building and the natural light luminance, so that these parameters can be included in the evaluation and correlation of energy consumptions. SMART CAMPUS will use devices that can monitor energy consumption in each plug individually. These devices will also enable an automatic power cut through commands sent from a computer, a PDA, or a mobile phone via wireless communications, or by decision of the intelligent management system.

3.1 Real Time Information on Energy Consumption

Real time information can enable energy users to associate specific behaviours with immediate financial and/or environmental consequences. The users will visualize, in real time, the energy consumption on a dashboard that is accessible via computer, mobile phone, PDA, fixed display, etc. The dashboard created at the energy saving server will provide information on energy efficiency, performance against target, etc.

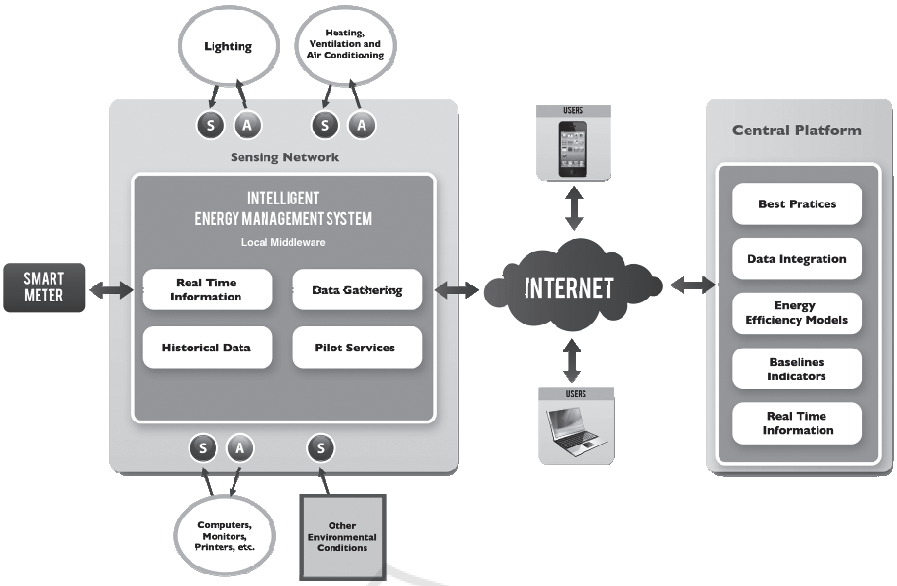

Fig. 3. SMART CAMPUS platform.

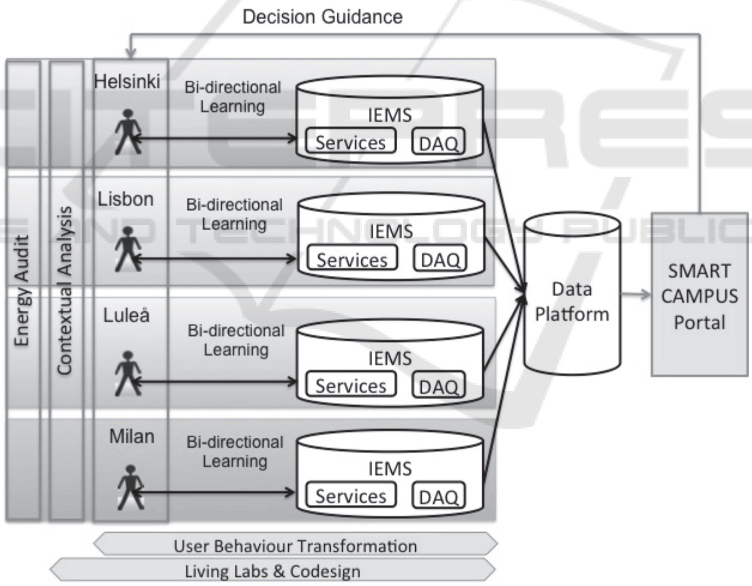

Fig. 4. SMART CAMPUS architecture and conceptual framework.

The impact of the user´s actions on energy consumption is simulated as described in the previous Section, and the simulation results are compared with the real time data. This analysis triggers user's alerts that provide the user with information about the required decisions in order to maximize energy efficiency while keeping pre-defined levels of comfort, cost, load, etc.

3.2 User Engagement and Interaction

Through the implementation of the Living Lab methodology, the SMART CAMPUS users are engaged from the initial stages of the project, and conditions will be created that favour the interaction between them. With this methodology, the users implement decisions in a controlled social environment, where there is close monitoring to assess the impact of their decisions.

Interacting with the intelligent energy management system will benefit the university campus users both by providing them with a feeling of more comfort, according to their own specifications, and by achieving energy savings that translate into economic savings for the university.

Although the level of interaction of a student - "temporary occupant" because he/she may attend the university for longer periods than just a visit, but is not an employee of the university - might be lower than that of the faculty, their level of interaction is nonetheless important, in particular because they can have a strong influence in their homes and living communities, provided that they are well informed and motivated. Thus, students should be engaged and guided through the transformation of behaviour on energy consumption.

3.3 User Behaviour Transformation

Figure 5 schematically shows the SMART CAMPUS integrated approach that aims at achieving user behaviour transformation. Four main blocks are identified:

- SMART CAMPUS Users;
- SMART CAMPUS Pilots;
- SMART CAMPUS Intelligent System;
- SMART CAMPUS Data Platform.

The SMART CAMPUS Data Platform (Knowledge Repository) collects all "knowledge", in particular models, best practice decisions, benchmarking, and real time information from all pilots. The SMART CAMPUS Pilots (Living Labs Universities) are sources of data; for example, the data obtained from the sensors installed inside and outside the building. The SMART CAMPUS Intelligent System will receive data from the pilot, and will actuate according to the pre-settings from the knowledge repository (e.g. pre-set room temperature), but it will also take into consideration the user preferences (e.g. different room temperature preferences). Based on decision-making algorithms, it will make the best decision, trying to influence the user's behaviour towards an efficient use of energy (e.g. actuating on the room temperature system).

The methodology to obtain user behaviour transformation will be similar to that used in the SAVE ENERGY project. It involves three phases and relies on the use of technological tools and behavioural tools. A more detailed description can be found in the SAVE ENERGY Manual.

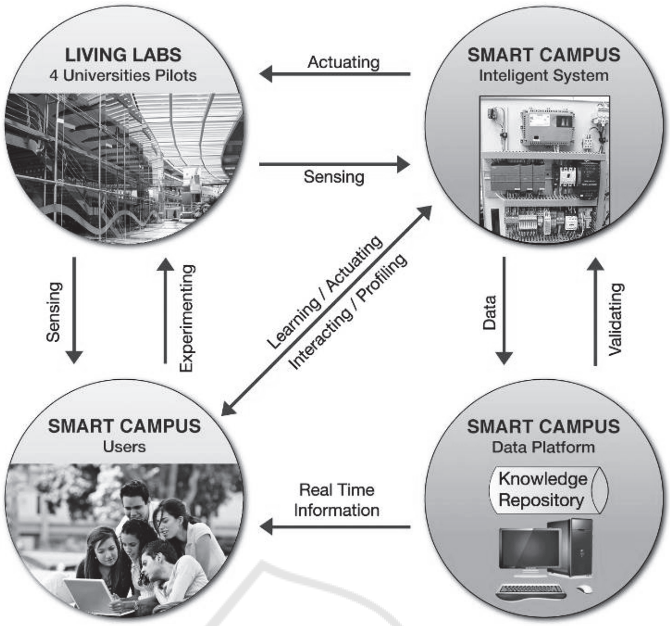

Fig. 5. SMART CAMPUS Integrated approach.

3.4 User Scenarios

A user scenario is defined as a structured description of a situation or event that a potential user is likely to experience as he/she seeks to achieve their goals. A scenario identifies a person as having certain motivations towards a given system, describes the actions taken, the reasons why these actions are taken and outlines the results in terms of the user's motivations and expectations.

Within the SMART CAMPUS project, user scenarios have been developed to better understand the goals and motivations of building users and specific energy-related issues within the different pilots. Ultimately, such scenarios help design and outline each pilot in order to most effectively address user interaction processes towards the construction of more energy efficient and intelligent systems. Consequently, user scenarios will also support the definition of the technical requirements of SMART CAMPUS platform.

3.5 Bi-directional Learning Process Through Energy Management Systems

The Bi-directional Learning Process is a concept that features a constant interaction among an Energy Management System (EMS) and building users, using the information provided by both parties to adapt the control actions towards further energy efficiency as well as to stimulate counteractions by the users.

As computer-aided tools, EMS are expected to monitor, control and optimize the performance of the generation and use of energy. However, the parameters set by

EMS do not usually take into account local conditions and specificities - such as individual preferences and behaviours, occupancy rates of buildings, rooms and offices, dimensions of the control area, differences between the sensors, etc. As a consequence, the local conditions in certain areas of a certain building may be out of the comfort boundaries that the EMS is designed to control and optimize. Therefore, it is important to add learning features to the EMS that would allow the building managers to receive feedback from the users regarding the control actions that are being taken. In this way, the building managers can adjust their control actions to answer better to the users' needs, within the budget and regulation constraints.

Notwithstanding, building users are usually not fully aware of the impact of their actions in terms of energy consumption; neither are they fully enabled to provide a technical description about their comfort levels. In this context, the EMS shall not only provide more tailor-made solutions to the users (according to their preferences), but also help raising awareness about the consequences of their actions and guiding to more resource-efficient and energy-saving attitudes.

The Bi-directional Learning Process thus, on one hand, enables EMS to more efficiently respond to specific local conditions and particular user's behaviour and preferences. It thus intends to go beyond typical and standard parameters that the EMS is designed to control and optimize.

On the other hand, this bi-directional nature intends to foster user behaviour transformation. It means that the feedback provided by the EMS and the control actions adopted - both accordingly to the user behaviour - are not exclusively oriented for information purposes. They are also focused on raising the user's awareness about the impact of their choices in terms of energy efficiency and costs, as well as on regulations compliance, fostering change behaviour towards more energy efficient comfort levels.

In order to trigger this bi-directional learning process, one fundamental milestone to be achieved is the adequate provision of Real Time Information (RTI). The SMART CAMPUS project will measure real time energy consumption in the pilot campus areas and provide this RTI to the users. The information will be presented and visualized in an easy-to-understand format in all the pilots, thus triggering the Bi-directional Learning Process and fostering User Behaviour Transformation.

RTI is understood as a dataflow of some measured variable, shown to the user relatively soon after the measurement. The term "real time" could have a comprehensive scope - either meaning immediately, presently or a couple of days after the actual consumption. Within SMART CAMPUS scope, "real time" will refer to the time lapse of the immediately previous measuring unit. Thus if the energy consumption is measured every hour, real time will mean the energy consumption undertaken in the last hour; if the energy consumption is measured every minute, then real time will refer to the energy consumption undertaken in the last minute. RTI will be provided in a user-friendly manner, in order to most effectively inform the users, enabling a fully-conscious decision making as well as triggering User Behaviour Transformation.

The use of Bi-direction Learning Processes in Energy Management Systems leads to the creation of Intelligent Energy Management Systems (IEMS). Within the SMART CAMPUS project, an IEMS is being developed for each of the pilots to be run in each of the campuses involved - Helsinki, Lisbon, Luleå and Milano. These local IEMS and the Central Platform (eGeneris) that focus on gathering and analysing information from all pilots and comparing them to energy efficiency models - constitute the technical solution provided under the SMART CAMPUS project. The processed information at the Central Platform will then feed the SMART CAMPUS Portal as the primary public dissemination tool of the project.

The IEMS of each pilot run in the campuses will thus be responsible for integrating data from multiple data sources and for supporting the development of distinct applications for energy management, reporting, and user-engagement experimentation. These integration and support development functions will be undertaken through two middleware components - the Data Acquisition System (DAQ) and the Service Layer. Data gathered from different sources by the DAQ is integrated and combined with IEMS and fed to the Services Layer that underlies the functionalities used by distinct stakeholders. The picture below depicts the local data architecture of each pilot to be run within SMART CAMPUS, highlighting each technical functionality abovementioned.

The successful implementation of an IEMS focused on energy savings through User Behaviour Transformation is dependent upon data collection from multiple data sources, both of dynamic and static nature, enabling accurate and real-time information about the location and time of the energy usage, through the DAQ.

Data sources may include the following:

- User actions - commands issued by users to equipment (usually in the form of scenario activations).
- Equipment status data - which can explain how energy is being spent in terms of the operation of the equipment and to provide useful information concerning peak-demand and abnormal situations.
- Ambient sensors - which measure temperature, humidity, CO2, interior and exterior luminosity, as well as occupancy of the analysed rooms.

Although they are traditionally associated with industrial applications, a DAQ can also be associated with intelligent buildings. Usually a DAQ consists of sensors that convert physical parameters to electrical signals, which are then converted to digital values sent to a computational framework that logs and tracks the acquired data.

Within SMART CAMPUS, the DAQ consists of an Application Programming Interface (API) that reads data from adapters and sends it to the IEMS. Its main attributions are thus aimed to cope with different data sources as well as with incomplete, intermittent and inconsistent information, providing unified data representation format through software adapters.

The Service Layer intends to abstract the functionality of the underlying applications (the software that will support the experiments) to be developed for distinct classes of users - namely students, faculty members, energy officers and facility managers. The ultimate goal of the Service Layer is to help in developing specialized control applications and control strategies in terms of energy consumption. Considering the four pilots that will be run within SMART CAMPUS project, it is possible to identify four main types of applications that may result from the Service Layer proceedings:

- Energy data reporting applications aiming at displaying energy data consumption benchmarks;

- User command and control applications enabling individual occupants to interact with energy consuming devices in the space in their working environments and to analyse the energy requirements of different device settings;
- Centralized control and management applications that enable the Facility Managers to compare the performance of different groups of equipment, spaces or groups of occupants;
- Autonomous control applications capable of autonomously driving equipment to improve occupant comfort and to decrease energy consumption.

3.6 Decision Guidance

In order to achieve User Behaviour Transformation it is necessary to exploit the information provided by the IEMS in a more user-friendly language, raising awareness and stimulating counteractions by the users. For this reason, different Decision Guidance tools have been foreseen within SMART CAMPUS project, mostly based on the SMART CAMPUS portal.

A first Decision Guidance tool to be used is the Living Lab Methodology. Users are to be involved in the co-design of the energy saving pilots in their campus. The pilots themselves will act as Decision Guidance tool, as they will make it possible to show, compare and increase the awareness, knowledge and skills on energy efficiency.

Decision Guidance will also be exercised by the "eco-motivators" - skilled people that will be integrated in each user group associated to each pilot. The eco-motivators will use information on the SMART CAMPUS Portal to advise, discuss, train and motivate all the user groups.

Finally, the SMART CAMPUS dissemination and exploitation activities - such as questionnaires, leaflets, project information, presentations, social media, posters, competitions, energy saving tests, workshops and exhibitions - will also help to enact Decision Guidance towards building users involved in the different pilots.

4 Pilots

4.1 Pilot Considerations

The SMART CAMPUS project aims at implementing the previously described methodology and concepts in public university buildings. Because the conclusions and recommendations of the project will be based on the results obtained in these pilot buildings, their adequate choice is crucial for the success of the project.

A large number of different scenarios must be taken into account in order to obtain precise and trustworthy data, which requires the implementation of more than one pilot experiment. Some of the parameters that must be taken into account when choosing the pilot buildings include their infrastructures and their location. Regarding the latter, and in order to address a large number of different scenarios, it is important to consider buildings located in countries with distinctive climates, different energy consumption patterns, and diverse users' habits. Taking into account these requisites, the selected pilot buildings are located in Helsinki (Finland), Lisbon (Portugal), Luleå (Sweden) and Milan (Italy) (Figure 6).

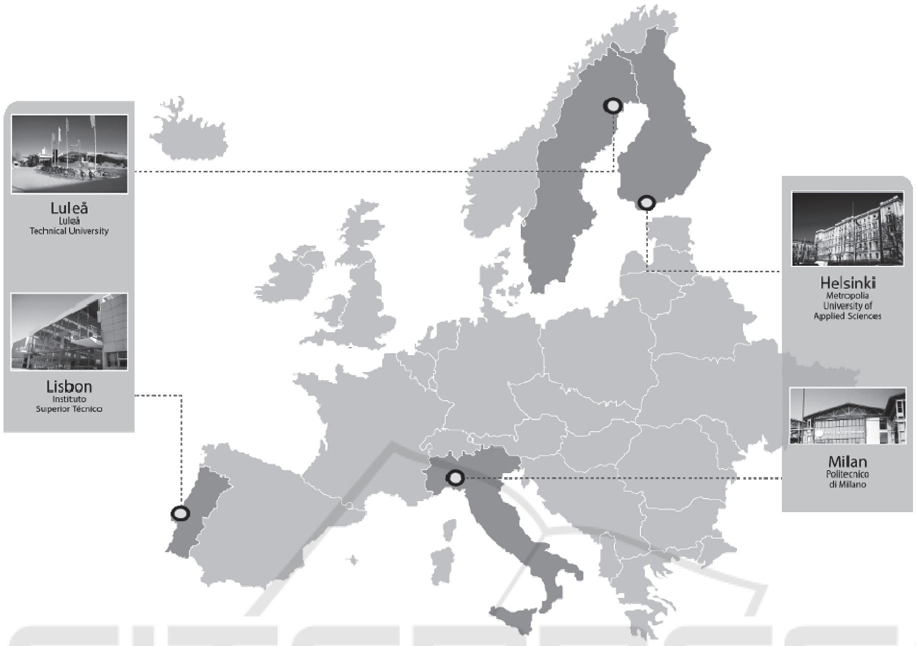

Fig. 6. Location of the SMART CAMPUS pilots.

4.2 Helsinki Pilot

The Helsinki Pilot will be implemented in two campuses of the Helsinki Metropolia University of Applied Sciences - the Leppävaara campus and the Myyrmäki campus.

Metropolia is the largest university of applied sciences in Finland, hosting more than 15.000 students and 1.100 teaching and support staff. It has 600 international degree students and a total of 27 degree programmes, operating on 20 campuses around Helsinki Metropolitan area.

The Leppävaara and Myyrmäki campuses play a key role at METROPOLIA. They have been growing over the last 20 years and are facing many challenges due to a growing interest and limited available space. Currently, the Leppävaara and the Myyrmäki campuses host 2.600 and 2.300 students, respectively, with more than 300 permanent teaching staff.

The Metropolia Pilot energy efficiency ICT system will be based on existing real time measurements, from the local building management and automation system (BM&AS), enhanced with a dedicated wireless network based on special internal measurements of the quality and temperature of the air, in defined applications in the campus buildings. The internet-based ICT system will be operating closely with the eGENERIS EEM system.

The Helsinki Pilot expects to improve energy efficiency by increasing users' awareness of energy use. This will be possible through the development and implementation of an intelligent wireless sensor network and a smart ICT system, connected to the local building automation system; and with local smart pilot application systems for controlling lighting and ventilation.

4.3 Lisbon Pilot

The Lisbon Pilot will be implemented at the Instituto Superior Técnico (IST), the largest school of engineering, science and technology in Portugal, at the Taguspark campus.

The IST has more than 10.000 students, 1300 of which are at the Taguspark campus. The Taguspark campus has 100 teaching staff members and 50 non-teaching staff. The campus itself has one main building with classrooms, offices, laboratories and restaurant facilities.

It is expected that the work of the Lisbon pilot promote energy efficiency in specific locations of the IST Taguspark campus, namely the library, a set of office rooms, a computer room, an energy lab and a classroom. This will be done through the development of an intelligent layer of interaction between the campus users and the building energy management.

The Lisbon pilot contains the platform that will be used to test the development and implementation of new applications that promote the active interaction between the users and the building management systems. In particular, the platform allows the development of a new energy management system for buildings which is able to learn users' preferences and adapt their automation systems to comply with them.

4.4 Luleå Pilot

The Luleå Pilot will be implemented at the Luleå University of Technology - Centre for Distance Spanning Technology (LTU-CDT) in Sweden. LTU-CDT is located close to the Arctic Circle and is therefore exposed to extreme seasonal changes, from +30 °C in summer to -30 °C in winter, and from 24 hours daylight to complete darkness. The pilot will be implemented in Building A of the Luleå campus of LTU.

The Luleå University of Technology is one of the northmost universities in the world and, considering its location, has winters with a great quantity of snow and reasonably warm summers. The University has 17.000 students from 60 different countries, and a total staff of 1.600 individuals. In addition to common offices, class and computer rooms, the University also has a large car parking area equipped with electrical outlets for car heaters which are need because of the cold winter climate.

It is expected that the results from the Luleå Pilot contribute to improving energy efficiency at the University throughout the year. This will be possible through the implementation of ICT solutions used to monitor and adjust energy use in the building in real-time. Also, ICT systems that can learn from and react to user behaviour will be implemented. Applying a Living Lab approach, the Pilot study will involve the campus faculty, staff and students to help develop new ideas on saving energy and new features on how intelligent buildings react with Intelligent Energy Management Systems.

4.5 Milan Pilot

The Milan Pilot will be implemented at Politecnico di Milano (POLIMI). The pilot will be implemented in Building 14 of the Milano Leonardo campus. The building is structured into two main areas: department offices for faculty and administrative staff, and the classrooms used by the students.

A preliminary analysis of consumption has been provided based on monitoring systems and in-field observation with energy management officers and students. This resulted in a mapping of the areas in which there is an opportunity to improve the energy efficiency of users' behaviour. This mapping provides a first identification of the specific locations in which improvements in energy efficiency management may more likely be found. It is expected that the acquired and observed data can promote the necessary behaviour to reduce energy consumption, enabling a mutual learning process between the building and its users, before facilitating similar solutions on other university campuses.

5 Implementation

The four SMART CAMPUS pilot studies serve to test the different projected scenarios in distinctive areas of Europe, each with its associated challenges and specificities regarding energy consumption and users' habits. The implementation process is specific to each pilot. Using the eeMeasure methodology, an energy consumption baseline was determined in each pilot building and the potential energy savings obtained as a result of pilot implementation were calculated. The purpose of this Section is to present an overview of the strategies for pilot implementation in the four locations.

5.1 Pilot Approaches

Helsinki

- Create greater awareness among the users on the impact of their actions on the energy performance of the building while using the Living Lab methodology, through better utilization of the existing monitoring and targeting system (Building management and automation system) and also through new wireless sensor network and web solutions.
- Demonstrate the impact of selected cost-effective energy efficiency improvements with a technical approach that integrates partial IT-solutions and control, and management tools (e.g. remote measurement and monitoring through wireless sensor network integrated with building energy management system).
- Empower the users to participate in the energy management of the building (e.g. as data providers and controllers) through mobile solutions as well as

through advice and experience sharing on energy saving measures in social media networks.

Lisbon

- The capability to interact with IST Taguspark users in a bi-directional manner, capturing user preferences based on past interactions as part of the learning experience and as a way to foster energy efficiency in the campus;
- Actuate in variables like HVAC and illumination for some specific locations based on an innovative intelligence layer that will seek to boost energy efficiency both on user preferences and exogenous variables;
- Provide timely and relevant information to all campus users that may include benchmarking (with the other pilots) and historical information that may positively contribute to foster energy efficiency at the campus;
- Support gamification strategies that will seek to involve all campus users in the effort to reduce energy consumption of the campus.

Luleå

- Implement scenarios with technical "building learning" solutions as well as "user-learning" solutions of User Behaviour Transformation (UBT) enabled by ICT installations;
- Design Luleå Pilot implementations following further end-user participation;
- Engage end-users throughout the project, as openness and communications are important key values;
- Allow Stakeholders to get a detailed view of the energy consumption, in the office area as well as in the car parking area. Furthermore, users are able to dynamically control the car parking outlets.

Milan

- Involve Users as active testers. When using specific applications, they will contribute to energy saving effects derived from the interaction between the building and its occupants;
- In order to monitor energy consumption analyse three different locations for 5 different experiments: classroom (one as experimental and one as test control location), corridor (one as experimental and one as test control location) and professors' offices (two as experimental and one as test control location);
- Implement a classroom reservation system on the web, through a classic and simple Java web application;
- Through a booking and check-in/check-out system, users trigger a warm-up of the test areas, bringing temperatures to comfort levels only when they really occupy the space. Similarly, presence sensors will allow turning on the strictly necessary lights and only in the actually used areas, thus significantly reducing the entire power consumption;
- Through these operating modes, the system will behave dynamically, reacting according to the real needs and behaviours of the users and, at the same time, bringing them to behave responsibly and consciously, changing their habits.

5.2 Implementation Actions & Adopted Solutions

In all SMART Campus pilots, the end users play an important role in the evolution of the implementation process. The implementations of the pilots are characterized by a number of experimental scenarios and adopted technological solutions.

Helsinki

Within the Helsinki Pilot, the implemented technical solutions are based on an extensive analysis of the energy consumption at the campuses, as well as a co-creation and co-design process with the users. From this work, the most relevant test locations and applications that could contribute to a significant energy saving were defined, thereby promoting a better understanding of the current level of energy consumption. The implementation of the pilot has contemplated several test locations on the two campuses, considering the three projected scenarios, namely kitchens, lighting in the classrooms; and need based ventilation.

Globally, the definition of the various test locations and pilot in general has been:

- To demonstrate new technology with smart sensors;
- To replace the old technology with modern eco-technology;
- To improve user - building interactions and learning (adaptation);
- To improve the local environmental conditions (lighting, ventilation) with dynamic control;
- To promote User Behaviour Transformation by training the users (using real time feedback);
- To implement the Living Lab methodology, focusing on the co-operation with students, lectures and staff.

A series of technological solutions have also been considered in the implementation of the Helsinki pilot. These technologies include:

- ICT solutions, including wireless sensors network and eco-technology. These are connected with the local building automation system (BAS). The smart and energy saving ICT based eco technology installed at the test locations will provide the user new knowledge, comparative technical solutions and ability to learn with its interaction;
- Info TV Displays - Two displays (one in the kitchen and one in the lobby hall) are placed on each campus, providing general information on the Smart Campus project, the total energy (electricity, and heat) consumption of the campus, energy consumption in the kitchen and classrooms, as well as the menu of the day;
- Options for dynamic control in classrooms help the users directly control and tune the internal conditions at the test locations (illumination and ventilation), and to learn how it will affect the energy consumption.

Regarding the Intelligent Energy Management System, the Helsinki Pilot IEMS is connected to the existing Building Automation System (Schneider Electric), the controlling sub systems (Glamox, Swegon) at the test locations, the wireless sensor network (WirePas) which collects measurements from the consumption of electricity, and the cameras used in the dining rooms of each campus.

Lisbon

The implementation of the Lisbon Pilot followed global considerations of the project, including the inclusion of users' knowledge and vision in the co-creation process. This stimulates and promotes users' engagement in the project. The process included:

- Internal workshops with students, technical staff, decisions makers, and experts from different areas - engineering, environment and energy management;
- Surveys to identify the perception of the energy consumption of the stakeholders at the university were provided to more than one hundred people;
- Development of mockups for the web and mobile applications developed within the IEMS to integrate user's feedback still in the development stage.

The implementation of the Pilot consists in the implementation of several applications in the various defined test locations. These include:

- Library: Smart automatic control of lighting based on interior lighting conditions;
- Amphitheatre: Automatic scenario management for lighting and video projector, Cooperative HVAC setting;
- PC Rooms: Automatic PC shut down, Smart automatic control of lighting conditions and HVAC conditions through automatic blinding systems based on interior lighting conditions and room occupancy;
- Energy laboratory: Smart automatic control of lighting conditions, Innovative energy visualization tools, Smart management of HVAC;
- Nucleus 14: Smart management of HVAC and lighting systems in some office spaces that takes into account user preferences and also outside and interior temperature conditions and current office occupation, Efficient lighting of the corridors;
- Global campus: Innovative energy visualization tools (the development of several methodologies, in order to promote users' engagement)

Luleå

The Luleå pilot implementation has two main scenarios: the Office and the Car Parking area. In the Office scenario, the objectives are related to saving energy through consumption awareness, which translates into a UBT scenario. In the Car Parking area scenario, the objectives are related to the monitoring and control of energy consumptions for car engine heaters, which translates into a combined UBT and technological scenario. In terms of implementations towards the Intelligent Energy Management Systems, several ideas can be considered:

- Participants in the office areas are made aware of the energy consumption through a visualizing monitor, where the energy consumption is displayed in several ways. This allows the user to always be aware of the current energy consumption and contributes to keeping the consumption below average.
- Further experiments will focus on the individual workplace with, for example, "smart outlets" that switch off equipment when the person is not present.

- Modern, individually controlled car engine heater outlets are installed where the users enter the planned departure time, resulting in efficient use of the electrical energy for car engine heating.

The implementation of the aforementioned ideas required the use of several technological solutions. In the Luleå pilot, the SABER Professional energy measurement device is used to gather energy consumption and display the data on a SABER Visualizer. This data, previously stored in a database, is transferred to Enoro on a daily basis. With the car parking, the heat outlet uses Web-EL equipment, where data is gathered and also sent to Enoro.

Milan

The Milan Pilot implementation counted on the participation of stakeholders which were an active part in the implementation. Meetings were held with multiple stakeholders to discuss aspects of the implementation process.

Regarding implementations on the IEMS, five different experiments have been prepared based on five projected scenarios and in three different locations, namely classrooms, corridors and teachers' offices. Specifically, the experiments are:

- Experiment 1, Classroom: Monitoring and control of air temperature during lessons. Temperature sensors have been installed to monitor the average air temperature in the room during classes.
- Experiment 2, Classroom: Monitoring and control of energy consumptions during hours of individual study. Presence sensors and student counters have been installed and the system will control the turning on of the thermostatic radiator valves according to the progressive occupancy of the room.
- Experiment 3, Classroom: Monitoring and control of electric energy consumptions. Illumination actuators have been installed to control the lamps and the lights will be turned on gradually with the progressive occupancy of the room.
- Experiment 4, Corridor: Monitoring and control of energy consumption. Temperature sensors have been installed to monitor the average air temperature.
- Experiment 5, Teachers' office: Monitoring and control of temperature. Temperature and presence sensors and a HVAC actuator were installed; the IEMS will consider the temperature data in the room to control the HVAC actuator, interrupting hot water flow according to three different temperature levels.

The IEMS system is designed to allow the interaction with the various defined spaces. In the classrooms, this occurs by modifying the lighting and heating setting system, adapting it to specific needs. In the study rooms, this happens by activating the lighting and heating system by booking the specific study room, with a subsequent check-in/check-out. In the faculty office, this occurs by directly interacting with the settings of the lightning and heating system, adapting them to specific needs.

These implementations are possible by using a number of different technological solutions. The hardware architecture designed for the pilot experiment is essentially based on KNX hardware; the interactions with sensors will be done through smartphones, limited to a specific group of individuals using an authentication process; classroom reservation during study hours will be possible via web access, where users are required to complete an authentication step.

5.3 Role of Users in the Pilots

The implementation process of the various pilots contemplated the active participation of a wide group of users in different contexts.

Helsinki
In the Helsinki Pilot, several teachers and students were involved in the pilot implementation, aware of the test locations of the different scenarios. Furthermore, positive reactions have been registered as stakeholders expressed their interest in receiving additional technical information on the installations, being willing to compare lighting systems in classrooms. It is worth noting the active involvement of students in the installation work.

Special attention was also dedicated to cleaners, guards and kitchen staff of the campus. They were engaged in several discussions with the aim of arousing their interest in using the lightning system in a more efficient way (public areas, empty classrooms and laboratories). The kitchen staff has shown interest in energy saving and had positive reactions in relation to the info-TV displays. The staff is now responsible for switching on/off the info-TVs.

There have also been initial discussions with the people responsible for the running of the HVAC machines in the laboratories, with the aim of coming to an understanding on tuning the running hours according to the will of the users. An agreement has been reached regarding the location and installation of the info-TV.

Furthermore, there have been discussions on setting up a network of eco-motivators within each campus. While this work will be done together with the local existing Green Office network, a wide range of stakeholders (the management, teachers, laboratory staff, local student associations) have expressed interest in actively participating in this action.

Lisbon
Within the development phase of the Lisbon Pilot the feedback of user groups was taken into consideration as part of a co-creation process. In this sense, mock-ups interfaces allowed users to test and provide feedback about the interfaces of the IEMS. Several classes of users have been identified within the Lisbon Pilot, namely: top decision makers (Management Board of University, Management Board of the campus of Taguspark, Building managers) technical staff (energy experts, energy initiative staff, energy researchers, IST Employees (professors, supporting staff, service providers) the general public (staff, students and visitors). All classes of users have been engaged to test and provide feedback of the installations.

Luleå
The Luleå Pilot has seen an active participation of a wide range of stakeholders (staff, students, building maintenance, university management) in discussions regarding the implementation of the pilot. Consequently, several solutions have been selected based on reliability, in order to minimize the development effort and to focus on the pilot implementation and the user participation.

Milan
Students and teachers are involved as users of the experimental environments, as well as the interactive applications. They are involved in testing and measuring the effectiveness of the experimented solutions. Both the technical staff (ICT, Logistics, heating and light management stuff), and the top management of POLIMI have been involved as stakeholders in the pilot study. They have contributed to evaluate and co-implement the technical solution that constitutes the experimental environments in the La NAVE building. They have also been involved in defining the future energy policy of the Politecnico University.

6 Conclusions

At this moment (May 2014), all pilots are in the test phase, which will run for one year, and preliminary results indicate consistent savings derived from user behaviour transformation in all the pilots. Future publications will be reporting on field results, lessons learnt and best practices for replication of the project at other public buildings.