Monitoring and stimulating energy behavioural change in university buildings towards post carbon cities

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Abstract

In recent times, there is a growing recognition around the role universities can play for educating behavioural change in the modern "knowledge society". University activities have traditionally been understood as two missions: teaching and research. Policy makers have been keen to encourage all the other contributions of universities to society of the so-called 'Third Mission' including social engagement as one of the main pillar. The present paper refers to an experience to exploit new solutions for behavioural change. Outcomes of building energy simulations were deployed to foster the educative dimension of building managers and users as the basis for positive regenerating energy saving policies and measures at the campus scale in the path towards carbon emission reduction.

Introduction

Climate change, global population growth and urbanization phenomenon issues are putting great pressure, arising the need for innovative energy policies and sustainable behavioural changes in urban areas (European Commission, 2010).

Policymakers in the EU and worldwide are setting energy efficiency goals for new buildings, as well as for adoption of retrofit measures enhancing existing building stock towards post carbon city. However, in order to meet such aggressive goals, there is a need to scale up the achievement of real energy consumption savings of the existing building stock to the urban level (European Commission, 2011). Furthermore, cities nor buildings use energy: people do. Indeed, technology alone does not guarantee energy reduction in buildings, leading to a mismatch between predicted and real energy saving in buildings. The reasons for this uncovered discrepancy vary, but they are mostly rooted in oversimplifying or ignoring the human factors driving the choice and utilization of end-use technologies as well as efficacy of energy saving measures (Sacari et al., 2007; Menezes et al., 2012; Majcen et al., 2013). In this context, building users' energy awareness campaigns have been widely demonstrated low cost but effective investments for educating occupants towards more sustainable profiles and reducing energy wastes.

Particularly, recently, there has been an increasing attention about energy sustainability of university buildings. Actually, "greening the campus" initiatives started on late 1990s (Velazquez L., 2006), but a special attention to energy-related issues for university campuses has arisen only since the release of the European Directive on Energy Performances of Buildings (EPBD) (Janssen R., 2004). Educational institutions have been early and comprehensive adopters of building energy efficiency and sustainability policies, aspiring at becoming lighthouse examples (Faghihi V., 2014). In particular, one aspect of energy sustainability in university buildings is a demand-side approach by implementing energy savings through low-investment actions. Particularly, they are aimed at increasing users' awareness through behavioural change programs, improvements of energy system regulation and control, real time monitoring and reporting.

In line with these issues, the main goal of this research was to describe the experience of a behavioural change strategy applied at University of Turin by adopting a real-time system of both building sensors and wearable sensors and gathering comfort-related feedback by the users. Building energy simulation was used to connect the energy outcomes to the desired comfort levels.

Campuses towards sustainability: two experiences at a glance

Energy efficient measures represent the key factor towards a sustainable campus framework and effective sustainability programs require an accurate understanding of their interactions. The balance between conservation and efficiency strategies could vary significantly from campus to campus depending on several factors, such as institutions' environmental goals, policies, and available budget. In this section, the cases of Politecnico di Torino and University of Cambridge are presented, highlighting the main on-going actions.

In an ideal sustainable university model, the establishment of a sustainability committee is a pre-requisite of effective sustainability policies.

Politecnico di Torino strengthened its path towards sustainability by enrolling in the ISCN (International Sustainable Campus Network), a global forum to support leading colleges and universities in the exchange of information, ideas and best practices. A "Green Team" was established by the academia, including both student representations and different types of managers and delegates from University departments. University of Cambridge is organised in a federation (Schools, Faculties, Departments and Colleges). The University is a campus in the city, and reducing the carbon footprint of such a peculiar building stock (cutting-edge research centre flank Gothic chapels) is a challenging task. To face this issue, the University of Cambridge established a dedicated Environment and Energy Section (EES) within Estate management, responsible for promoting policies

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and practices aimed at reducing the carbon impact of the University system as a whole.

Both the universities adopted a combined promotion of energy conservation and efficiency measures towards energy and carbon reduction in the campus buildings.

In particular, energy conservation strategies for engaging occupants and changing their energy-related behaviour is applied especially at the University of Cambridge, but also, in a minor measure, at the Politecnico di Torino. These measures are applied by means of awareness campaigns (i.e. "Shut the Sash Campaign" promoted by Department of Chemistry in Cambridge, or the "Switch off the lights" program applied to the whole University of Cambridge campus), incentives (i.e. "Electricity Incentivisation Scheme" in Cambridge), training (i.e. "Empower" for staff and students in Cambridge or "Smart and Green management services" in Turin), and active involvement of the occupants (i.e. Living Lab for Sustainability both in Cambridge and in Turin).

In the following, a research project to exploit new solutions for educating energy behavioural change is presented using the case study of University of Turin.

Engaging campus users towards sustainability

The main goal of the research was to motivate behavioural change by raising consumer awareness and by providing attractive personalized combined pro-active knowledge services on energy use and indoor environment, based on ICT solutions. This goal has been reached by integrating data coming from both building and wearable sensors, and subjective feedback on the perceived comfort by the rooms occupants. Moreover, calculated indicators were provided to the users to give them the basic knowledge on the amount of energy used. Measurable benefits raised behavioural change by the awareness of feedback loops. This awareness should support and motivate end-users to adopt a well-informed and pro-active behaviour towards energy use, empowering consumers and providing confidence of making the right choices.

The combination of awareness on energy and comfort conditions offered consumers more and lasting incentives than only information on energy use. Yet, combining information on energy use and behaviour with other relevant information such as the actual indoor environmental quality (and the relation with energy and behaviour patterns), eventually combined with other attractive life style information could be used to catch the interest of occupants and maintain their new habits and interest on the long term.

Method

An Italian University campus located in Northern Italy represents the test bed for this research project to exploit new solutions for educating energy behavioural change. 18 classrooms and 600 participants have been involved in the experimentation by means of the creation of a Living Lab. This was achieved by making use of ICT monitoring and sharing technologies, social networks, peer-to-peer exchange and social engagement - to educate the university communities in the path towards post carbon cities.

Data gathered from fixed building (indoor air temperature, relative humidity and CO_2 concentration) and wearable (indoor air temperature, relative humidity and illuminance level) sensors are coupled with subjective feedback on IEQ perception, collected via smart-phone application. A Direct Virtual Sensor (DVS) reproduced the subjective IEQ perception based on gathered data. Two monitoring campaigns were realized during wintertime and summertime, for a total of 6 months of data collection.

Energy dynamic simulations of a typical classroom were developed in order to evaluate energy consumption variation (reduction or waste) by changing user comfort scenarios.

Case study

The University campus consists in several buildings scattered throughout the city, which differ significantly in terms of building typology, dimension and construction year. The university comprises many student houses in the proximity of the main building that, however, were not taken into account during the analysis. In figure 1, a floor map of the main building taken as case study for the project is reported.

Thanks to the involvement of the Energy Manager and the staff of the campus, the main problematic issues related to comfort perception by the users were highlighted:

- Not-balanced occupancy patterns in the different building areas (overcrowding or underused zones);
- Discomfort peaks;
- Non-homogenous environments used for several uses (i.e. teaching and studying);

These issues could be referred to a general lack of understanding of the relationship between comfort, energy and environment awareness of the different users. Thus, first the main components of the Living Lab (i.e. people, rooms, sensors, comfort requirements, behaviours, energy) were defined. Then, different scenarios (i.e. personas), ICT requirements and global comfort perception evaluation methodology were identified.

The Living Lab involved both students and professors of the university building. Information desks, seminars, brochures and social media were used to inform people about the on-going project.

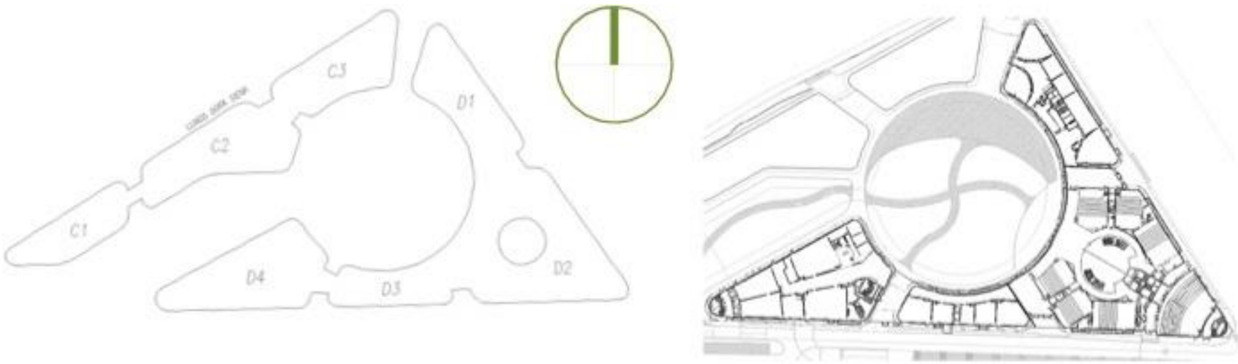

Figure 1: A floor map and a general view of the case study

ICT tools for behavioural change

Parameters collection and data analysis were established for the realization of a Direct Virtual Sensor (DVS) allowing to match systematically objective and subjective measures of comfort and to provide final feedback on comfort conditions to the room end-users and useful indicators to the energy manager. Furthermore, collected data allowed to calibrate dynamic energy simulations of the case study and to exploit alternative scenarios related to user behaviour.

The starting point was the realization of a network of sensors that allowed to measure a representative set of environmental parameters useful for the evaluation of comfort: air temperature, relative humidity, CO_2 concentrations and people density were gathered every 10 minutes. Moreover, wearable sensors were adopted in the project for collecting data on air temperature, air relative humidity and illuminance level to be matched with the data gathered by fixed building sensors.

People localization and crowding were also collected.

To monitor appropriately the environment, the choice of the sensors and of the representative rooms where to gather data (considering the complex characteristics of the environment and the intended use) were crucial.

The second source of information was the smartphone application on which the participants at the Living Lab were able to express the perception of their comfort condition. The reliability of the software and the usability was very important, as well as the choice of questions and the adopted assessment scale.

The objective and subjective data were collected in a central repository.

Different evaluation methods have allowed to analyse information with specific purposes. First, data processing has allowed to obtain both statistics on participation to the Living Lab and real-time measurements. These elaborations were represented by infographics and reported in a project dedicated website, in social media main pages and in a specific application for the energy manager.

Then, the data collection allowed the estimation of a Direct Virtual Sensor, which provided the average comfort level as a function of the measured objective and subjective data. The predictive accuracy of the DVS was characterised by an error of ±1 in 95% of the cases. DVS was useful to give the users information on comfort conditions in all the zones, even if not equipped with sensors. DVS comfort outcomes were directly displayed on the smartphone app that was realized during the first months of the experimentation.

In figure 2 the main assets of the project are represented.

Three different data visualization types have been developed, based on JavaScript, on the main website of the project, in the form of a real-time dashboard:

- display the historical power consumption;
- display of all the data collected during the project;
- display of average values of collected data, referred to a selected time interval and a specific zone in the campus map (Figure 3).

Finally, an estimate of the energy consumption variations and related costs arising from changes in the physical environmental parameters such as temperature, relative humidity and CO_2 were calculated by running energy dynamic simulations of the case study.

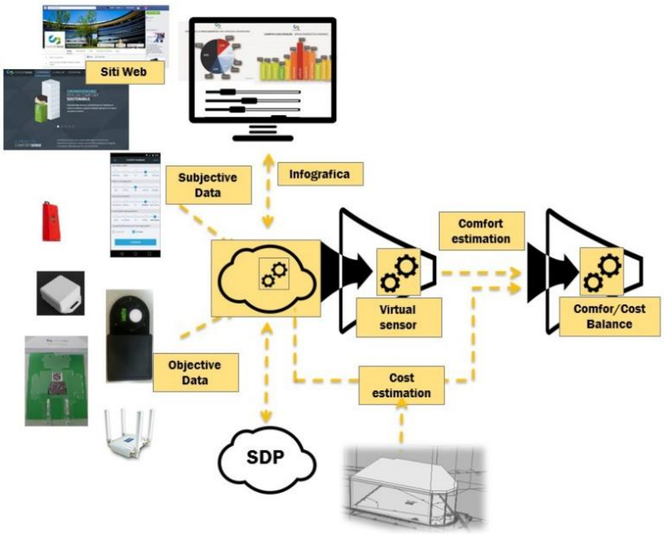

Figure 2: Assets of the project

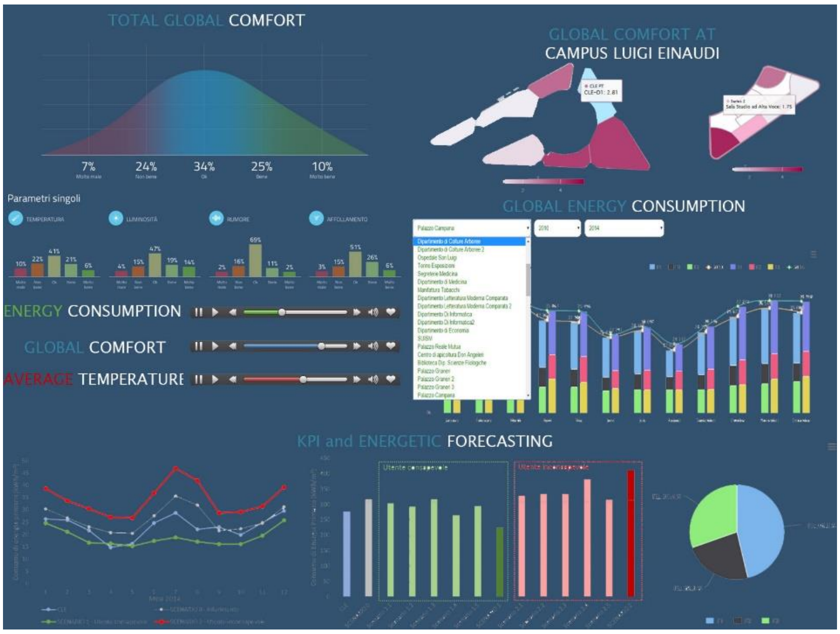

Figure 3: Real time dashboard

Building energy simulation for behavioural change

A dynamic building energy simulation software (IDA ICE, v.4.6) was used to model the monitored rooms and perform energy dynamic simulations (Figure 4). The simulation outcomes were scaled up to the building level to have a benchmark for comparing different user behaviour scenarios. In particular, the simulation inputs were calibrated by taking into account in-field measurements and real consumption data in order to obtain a model close to reality.

Since the purpose of the simulation scenarios was to define different occupant behaviours, three different types of users were simulated: “Standard” User, “Informed” User and “Uninformed” User. In particular, “Standard” user was modelled as defined in the EU standard and policies (i.e. EN 15251); "Informed" and "Uninformed" users are broken down into further sub-categories, each of them characterized by variations in indoor environmental parameters requests having an impact on comfort assessment. User behaviour effect was then modelled by running sequential simulations varying specific physical environmental parameters. The set of performed simulations allowed to verify the effect of each variable separately (From Scenario 1.1 up to 1.5 and from Scenario 2.1 up to 2.5), and the combined effect (Scenario 1 and Scenario 2) with respect to the Standard User (Scenario 0). Table 1 outlines the different values considered for the definition of the simulation scenarios.

Obtained outcomes were then used to define customized feedback for the engaged users.

The following variables were identified for the definition of the simulation scenarios:

- Winter and summer temperature set-point (°C);
- Relative humidity (%);
- Indoor illuminance level (lux);
- CO_2 concentration (ppm).

Since the variability in energy consumption was described by an increase (or decrease) in terms of comfort conditions, the ultimate goal was to match the customized feedback related to the energy consumption with users' perceptions of comfort. In this way, building (or zone) occupants, could provide their feedback on perceived comfort conditions, and at the same time understand the relationship between the comfort and the amount of energy use. Finally, the results obtained from the energy dynamic simulations were useful for other stakeholders, i.e. the energy managers, who could link energy forecast scenarios to optimize the operation of the building plant systems.

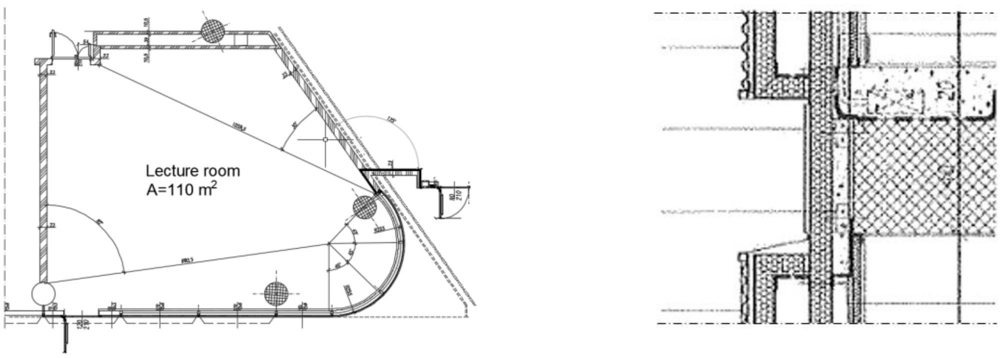

Figure 4: Floor plan of the analysed lecture room and detail of the external wall.

Table 1: Analysed energy scenarios and physical environmental variables

	Set-point Winter	Set-point Summer	Relative Humidity	Illuminance level	CO_2 Concentration
Standard User					
Scenario 0	**21°C**	**25°C**	**40%-70%**	**500-700 lux**	**700-1000 ppm**
Informed User					
Scenario 1.1	**19°C**	25°C	40%-70%	500-700 lux	700-1000 ppm
Scenario 1.2	21°C	**27°C**	40%-70%	500-700 lux	700-1000 ppm
Scenario 1.3	21°C	25°C	**50%-80%**	500-700 lux	700-1000 ppm
Scenario 1.4	21°C	25°C	40%-70%	**500-550 lux**	700-1000 ppm
Scenario 1.5	21°C	25°C	40%-70%	500-700 lux	**800-1300 ppm**
Scenario 1	**19°C**	**27°C**	**50%-80%**	**500-550 lux**	**800-1300 ppm**
Uninformed User					
Scenario 2.1	**23°C**	25°C	40%-70%	500-700 lux	700-1000 ppm
Scenario 2.2	21°C	**24°C**	40%-70%	500-700 lux	700-1000 ppm
Scenario 2.3	21°C	25°C	**40%-50%**	500-700 lux	700-1000 ppm
Scenario 2.4	21°C	25°C	40%-70%	**300-1000 lux**	700-1000 ppm
Scenario 2.5	21°C	25°C	40%-70%	500-700 lux	**500-700 ppm**
Scenario 2	**23°C**	**24°C**	**40%-50%**	**300-1000 lux**	**500-700 ppm**

Results

Each simulation scenario depicted in Table 1 is represented in Figure 5. Here, they were compared to the measured energy consumption of the building ("Real Building"). The results of these scenarios were used to create "what if" scenarios implemented as direct feedback for the users in the mobile application. Indeed, the feedback related to different potential scenarios aimed at raising user awareness by showing them how their behaviour might influence building energy performances, also in terms of thermal comfort and costs. The synergy between ICT tools and energy simulations was therefore a crucial aspect for this research: On one hand, energy simulations were calibrated with collected data from the ICT tools; on the other hand, the results of the energy simulations were implemented to give feedback via mobile application and obtain behavioural change. Results showed that a generic "Informed User" corresponds to significant energy savings and to a decrease of the classic peak of energy consumption for cooling during the summer months. In particular, the "Informed" User defined in Scenario 1 leads to a decrease in terms of annual primary energy consumptions by -29%. As regards the single effect of each variable setting, the highest energy savings are related to Scenario 1.4, in which the illuminance level range was set to 500-550 lux with respect to the "Standard" User (500-700 lux). Scenario 1.3, which regarded the variation of the indoor relative humidity settings, instead, did not lead to any significant changes of the annual primary energy uses of the building. On the other hand, the "Uninformed" User represented as Scenario 2 increased the annual primary energy use of the building up to +30% with respect to the "Standard" User. Similar to Scenario 1, the highest impact is given by Scenario 1.4, in which the range of the illuminance level was assumed to be 300-1000 lux. Among the "Uninformed" User scenarios settings, the variation of the CO_2 concentration ranges (Scenario 2.5) did not alter significantly the outcomes of the simulation results.

In Figure 6, the final annual energy consumption of the main simulated user types ("Standard", "Informed", "Uninformed") are plotted against the real measured primary energy use (blue line) The graph highlights that the modelled "Standard" User (Scenario 0) is similar to the real building energy consumption profile. Indeed, Scenario 0 (grey line) was calibrated according to the current comfort settings in the case study. The simulated consumption profiles of the "Informed" and "Uninformed" users are presented by the green and the red line, respectively. The latter profiles show a significant variation in terms of primary energy consumptions throughout the whole year, and especially during the summer peak.

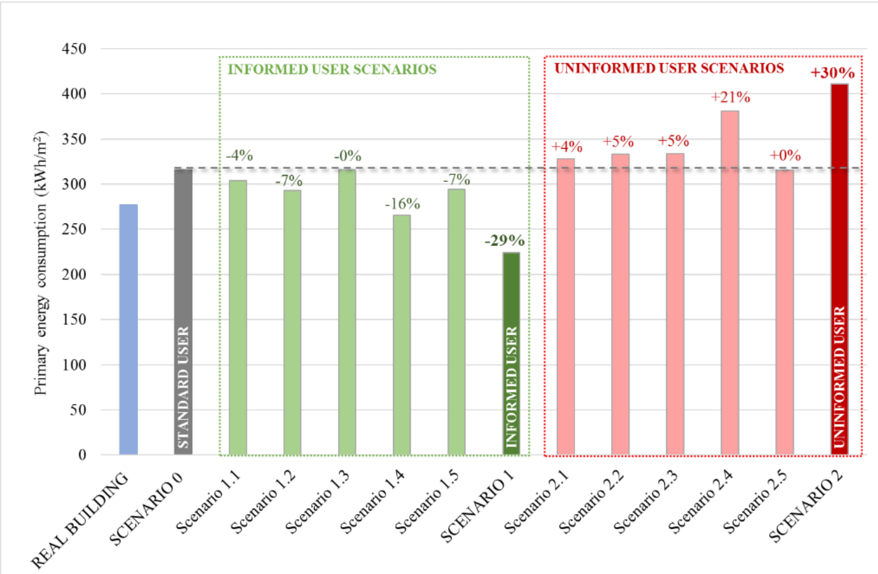

Figure 5: Analysed energy scenarios and related average changes

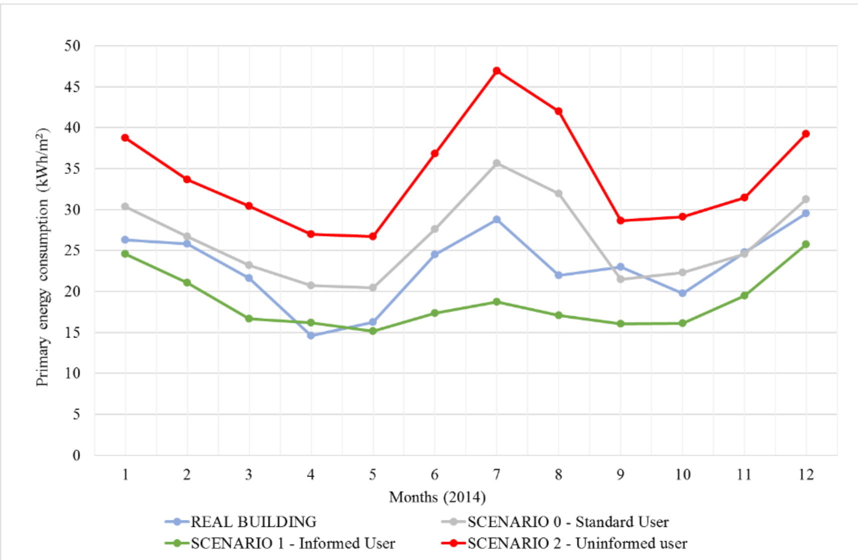

Figure 6: Annual primary energy associated with different user scenarios

Table 2: Simulation results of the main analysed scenarios

			Scenario 0 Standard User	Scenario 1 Informed User	Scenario 2 Uninformed User
Comfort	EN 15251	Category I	23%	16%	31%
		Category II	34%	23%	34%
		Category III	43%	50%	35%
		Category IV	0%	10%	0%
	EN 7730	PMV winter	-0.16	-0.24	-0.11
		PMV summer	0.02	0.08	0
Energy Consumption	Electric	(kWh_{el}/m^2)	117.5	86.6 (-26%)	152.1 (+29%)
	Thermal	(kWh_{t}/m^2)	61.1	36.1 (-41%)	80.7 (+32%)
	Primary	(kWh_{EP}/m^2)	316.1	224.1 (-29%)	410.7 (+30%)

Finally, Table 2 summarises the main simulation results in terms of thermal comfort conditions and energy consumptions (electric, thermal and primary).

As regards the simulated thermal comfort conditions, the authors referred to the European Standard EN 15251 (CEN 2008) and to the Predicted Mean Vote (PMV) Index (EN 7730; 2005) evaluation during winter and summer, respectively. In particular, the table highlights that in Scenario 1 ("Informed User"), the PMV indexes both in winter and summer period are close to 0, corresponding to a neutral thermal condition and at the same time to a decrease of annual primary energy consumption of -29%.

Conclusion

This paper has shown a research project aimed at using ICT tools to raise the end-user awareness in university buildings. Building fixed sensors, wearable sensors and users' feedback were matched together to realize a Direct Virtual Sensor reproducing the environmental conditions in different building zones. A mobile application was realized and deployed to send and gather data from the users. Building energy simulations were implemented to complement the educative dimension of the project by giving to the different stakeholders (building managers and final end-users) the necessary knowledge to understand the consequences of their preferences in terms of comfort settings. This allows to foster energy saving policies and measures at the campus scale in the path towards carbon emission reduction.

Acknowledgement

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