Emerald International Journal of Sustainability in Higher Education

Energy efficiency of higher education buildings: a case study

Journal:	*International Journal of Sustainability in Higher Education*
Manuscript ID:	IJSHE-11-2013-0147.R2
Manuscript Type:	Research Paper
Keywords:	Sustainability, Green campus, Higher education, Energy audit, Energy efficiency, Sustainable behaviours

Energy efficiency of higher education buildings: a case study

N. Soares (nelson.soares@dem.uc.pt)

MIT-Portugal Program, EFS Initiative, University of Coimbra, Coimbra, Portugal

ADAI, LAETA, Department of Mechanical Engineering, University of Coimbra, Coimbra, Portugal

ISISE, Department of Civil Engineering, University of Coimbra, Coimbra, Portugal

Luísa Dias Pereira (luisa.pereira@uc.pt)

MIT-Portugal Program, EFS Initiative, University of Coimbra, Coimbra, Portugal

ADAI, LAETA, Department of Mechanical Engineering, University of Coimbra, Coimbra, Portugal

João-Pedro Ferreira (joao.ferreira@fe.uc.pt)

MIT-Portugal Program, EFS Initiative, University of Coimbra, Coimbra, Portugal

GEMF, Faculty of Economics, University of Coimbra, Coimbra, Portugal

Pedro Conceição (pedroconceicao86@gmail.com)

Department of Electrical and Computer Engineering, University of Coimbra, Coimbra, Portugal

Patrícia Pereira da Silva (patsilva@fe.uc.pt)

MIT-Portugal Program, EFS Initiative, University of Coimbra, Coimbra, Portugal

INESC-Coimbra, Faculty of Economics, University of Coimbra, Coimbra, Portugal

Submitted: 05-Nov-2013

Revised: 17-Sep-2014

Structured Abstract:

Purpose - This paper proposes an energy efficiency plan (with technical and behavioural improvement measures) for a Portuguese higher education building - the Teaching Building of the Faculty of Economics of the University of Coimbra (FEUC).

Design/methodology/approach - The study was developed in the context of both the "Green Campus - Challenge for Energy Efficiency in Higher Education" and the Energy for Sustainability Initiative of the University of Coimbra, Portugal. An energy audit was conducted based on the analysis of the energy consumption profiles. A monitoring campaign was carried out to measure and disaggregate the electricity consumption. The consumption of natural gas and water were also assessed. The building envelope and the heating and lighting systems were also evaluated. Some patterns of energy-environmental behaviours of the academic community were investigated through a web-based survey.

Findings - The energy efficiency plan contemplates short-term tangible/intangible actions. It also considers the investment and payback period of the tangible measures. The implementation of three improvement measures in the lighting system would lead to a consumption reduction of about 26123 kWh/year, avoiding the emission of 3704 $KgCO_2$/year, for an initial cost of 9920 € (payback period of 3.7 years).

Research limitations/implications - Results are restricted to the case study and there are limitations in their generalisation outside of their context. However, they show some broadly implications and trends that have relevance for the higher education sector. This paper highlights the importance of engaging students, faculty and technical staff for working together on the assessment of the energy efficiency of the buildings where they study and work.

Social implications - The higher education sector holds important functions in educating the next generation of professionals for a sustainable culture. The categories of activities described in this paper are a good examples of what can be done within the academic community for acting towards sustainability. The results also pointed out that making users aware of their energy consumption is a priority towards the energy efficiency in higher education buildings.

Originality/value - Reductions on energy consumption are expected if the energy eficiency plan would be implemented. The results of the behavioural study were presented to the FEUC's board of directors to be integrated in the "*Good Practices Manual on Water and Energy Management*".

Keywords: Sustainability, Green campus, Higher education, Energy audit, Energy efficiency, Sustainable behaviours.

Article Classification: Case study

1 Introduction

The energy efficiency in buildings, appliances, transport and industry is one of the broad areas that the International Energy Agency was asked for policy advice through the G8 Gleneagles Plan of Action. In their work, Jollands *et al.* (2010) explain how this plan can be important by expanding energy efficiency activities through the use of international-level recommendations. The authors also pointed out that addressing the many barriers to energy efficiency can create the necessary conditions for improving energy efficiency itself. According to the authors, the energy efficiency barriers described by the International Energy Agency (2003b) can be grouped into three main categories: (*i*) the information and behavioural barriers; (*ii*) the market organisation barriers, and (*iii*) the technological barriers. Other studies have pointed out the importance of changing energy-use behaviours, imposing new policy measures and providing technological development as part of the main required changes to improve energy efficiency (Egging, 2013; Cansino *et al*., 2011; González *et al*., 2012). Indeed, energy efficiency is considered as one of the most cost effective ways for society to enhance security of energy supply and reduce emissions of green house gases and other pollutants (European Commission, 2011).

Regarding the building sector, the Energy Efficiency Plan of the European Commission (European Commission, 2011) recognized that the greatest energy saving potential lies in buildings. Therefore, the European Union (EU) policy has identified the promotion of energy efficiency in buildings as a key objective of its energy and climate policy (Commission of the European Communities, 2006; Ekins and Lees, 2008; Raslan and Davies, 2012). The EU regulators have published the Directive on Energy Performance of Buildings (EPBD) (EPBD, 2003) and its recast (EPBD recast, 2010). The EPBD has become the major channel for the process of adopting performance-based energy standards for buildings by all the member states. As stated by Egging (2013), the EPBD outlines measures that required all member states to set minimum requirements and develop methods for determining the energy performance of buildings. Ambition levels vary by building type and sort of project. The implementation of the EU Energy Efficiency Plan in the building sector in different member states is reported in several papers (Andaloro *et al*., 2010; Travezan *et al*., 2013; Raslan and Davies, 2012). An important target is that by the end of 2018, all government occupied and owned buildings should attain a nearly zero energy consumption. Public owned or occupied buildings represent about 12% by area of the EU building stock (European Commission, 2011). Therefore, energy savings in public buildings is imperative to achieve EU's 2020 established goal of reducing 20% of the greenhouse gas emissions and another 20% increasing in energy efficiency by 2020 (European Commission, 2011).

The reduction of the energy consumption in buildings depends on users' awareness of their energy consumption. Several studies have been exploring how occupants' behaviors may influence the energy consumption in buildings, for example, Fabi *et al.* (2012) and Fabi *et al.* (2013) evaluated how different behavior patterns influence indoor climate quality and energy consumption. In the first study, occupant behaviours (namely occupants' window opening and closing behaviours) are related to the building control systems; in the second study a probabilistic approach is proposed and applied to simulate occupant behaviors realistically. As stated by Dahle and Neumayer (2001), one of the most important measures that need to be undertaken to overcome barriers to "greening" is to raise the environmental awareness within campus communities. Therefore, user's behaviour becomes decisive in the development of a sustainable culture. As suggested by Barata *et al.* (2011), university campus may constitute an important laboratory to test and implement new strategies leading to reductions in infrastructure costs and less negative impacts on the surrounding areas. These authors also pointed out that one aspect frequently disregarded is the potential of academia to influence not only the student's behaviours, but also the environmental awareness and habits that they can develop in the long term, i.e., they can become powerful forces to reshape the future society's patterns (Barata *et al*., 2011). As remarked by János (2011), «energy lectures stand as long term measures that influence students' intention to engage in energy saving measures (…).They have stronger influence on students' energy saving intention than the television campaigns», i.e. higher education plays a critical role in sustainable education and it is a perfect environment to get people involved in multi-disciplinary activities, promoting the education for sustainability. An example of such kind of activities is the *Green Campus - Energy Efficiency Challenge in Higher Education*. It is the biggest competition on energy efficiency being carried out in university campuses in Portugal. The main goal of this competition is to challenge students, faculty and office staff of the Portuguese higher education network to work together on the assessment of the energy efficiency of the buildings where they study and work, proposing actions to reduce energy consumption.

Nowadays, the issue of sustainability in higher education is within many educational programs and curricula worldwide. An excellent example is the Energy for Sustainability (EfS) Initiative of the University of Coimbra (UC), Portugal. This initiative aims at developing its postgraduate students' abilities to contribute to interdisciplinary interventions in areas such as the efficient use of energy, centralizes or decentralized energy production and distribution of energy, always under a sustainable development perspective. Batterman *et al.* (2011) presented recommendations for competencies for postgraduate education in two subareas of EfS that have been implemented at the University of Coimbra, namely *Buildings and Urban Environments* and *Energy Systems and Policy*. These competencies constitute the bulk of both UC doctoral and master of sciences programs under the EfS Initiative. As stated by Batterman *et al.* (2011), the view of energy in the context of sustainability, called EfS, follows from the perspective that energy is a basic ingredient for life and future sustainability. Furthermore, the authors pointed out that energy/sustainability education and activities involve a complex framework characterized by numerous stakeholders and multiple time and spatial scales, which range from the global/international level down to the local/subnational supply and demand level. Mochizuki and Fadeeva (2010) also recognized the multilevel complexity of the education for sustainable development (ESD). Jones *et al*. (2008) highlighted the locally embedded socio-cultural factors, and the multilevel complexity of leading with worldwide ESD organizational and pedagogical changes. The benefits of ESD were also strongly recognized by Rusinko (2010), Sherman and Hansen (2010), Shephard (2008) and Thomas (2004).

Mochizuki and Fadeeva (2010) evaluated the competences required for implementing ESD into higher education successfully. They also highlighted that ESD has a transformative role in terms of the localized relationships between individual and group agencies, and more macro-socioeconomic and inter-institutional structures. Recently, Naeem and Neal (2012) provided some information about the extent to which sustainability is integrated into business school education and learning in the Asia Pacific region. These authors found that there was a lack of systematic approaches to the integration of sustainability in business curricula in the Asia Pacific region, and significant barriers to the integration of sustainability into programs remained. Littledyke *et al*. (2013) investigated EfS practises and perceptions in three university contexts in England, Australia and Greece. Their study aimed at identifying a suitable systems model for effective EfS across university contexts. Is was found that clear vision, shared understanding about the importance, nature and purpose of the EfS, leadership, support and collaborative practises, were considered vital to achieve effective EfS across the university environment. Alshuwaikhat and Abubakar (2008) proposed some strategies to ensure more sustainable campus, namely: the implementation of an university Environmental Management System; the public participation and social responsibility, and the promotion of sustainability in teaching and research activities. János (2011) also analyzed the application of energy efficiency measures at universities. Departing from the *Theory of Planned Behavior* (Ajzen, 1991), several hypotheses were formulated and the students' intention to save energy was compared between different groups. Several suggestions were designed to encourage energy savings at the University, namely: a competition between different departments of the University; a competition between different university residences, and the implementation of Energy Saving Days (also designated as One Hour Switch Off days). This author evokes the experience held at the University of Leeds, such as Earth Hour Campaign or Heater Amnesty - «during one hour students are advised to switch off their computers, laptops, printers, phone chargers etc. to save energy». In 2011, this hour experience resulted in 12442 kWh energy savings.

The study herein presented was developed in the framework of both the UC's EfS initiative, and the first edition of the Portuguese *Green Campus* competition, which main goal was to contribute for the implementation of target measures towards energy efficiency of Portuguese university campuses (Cravo *et al*., 2012). This study proposes an energy efficiency plan, including measures related with the lighting system and behavioural measures, for a Portuguese higher education building – the Teaching Building (TB) of the Faculty of Economics of the University of Coimbra (FEUC). It aimed at giving FEUC's directory-board the first document reflecting the energy efficiency of the TB, including both technical and behavioural patterns. The specific goals are: (*i*) to evaluate the contribution of the TB regarding the total energy consumption of the campus; (*ii*) to assess the energy consumption profile of the TB identifying energy conservation measures (ECM); (*iii*) to investigate the energy consumption linked to the cafeteria activities; (*iv*) to evaluate the TB lighting system proposing measures to rationalize electricity consumption, quantifying the required investment and determining the simple payback period; (*v*) to assess how the characteristics of the building envelope affect indoor thermal comfort, trying to identify improvement measures; (*vi*) to investigate the influence of the heating system on the energy efficiency of the campus; (*vii*) to characterize water consumption; (*viii*) to engage the academic community for sustainable education, and (*ix*) to characterize energy-environmental standard behaviours.

This paper highlights the importance of engaging students, faculty and office staff for working together on the evaluation of the energy efficiency of the buildings where they conduct their daily activities. It also emphasizes how academic studies, such as the one now presented, can be useful for higher education institutions on promoting the education for sustainability in higher education environments.

Nomenclature

AE	Active Energy	ESD	Education for Sustainable Development
AP	Active Power	EU	European Union
CL	Casa dos Limas	FEUC	Faculty of Economics of the University of Coimbra
EC	European Commission	NG	Natural Gas
ECM	Energy Conservation Measures	PF	Power Factor
EEI	Energy Efficiency Indicator	RLB	Research/ Library Building
EfS	Energy for Sustainability	TB	Teaching Building
		UC	University of Coimbra

2 Research approach

2.1 Case study

The TB is part of the FEUC's campus (Figure 1) which is composed by three buildings: the Teaching Building - developed in 4000 m^2 spread over 4 floors; the Research/Library building (RLB) - 4410 m^2 spread over 5 floors, and the administrative building *Casa dos Limas* (CL) - 860 m^2 spread over 4 floors. The campus is located in Coimbra in the centre of Portugal, 40 km away from the Atlantic coast. The project of the TB dates back to 1988. Located in the S/SW of the campus, the TB is developed according to a NW-SE longitudinal orientation. The 17 classrooms are mostly flat rooms NE oriented while the 5 rooms/amphitheatre are SW facing. The TB is also equipped with an auditorium, located under the multipurpose room and the cafeteria. The predominant activities include lecturing and the actions associated with the cafeteria itself. The occupancy rate is continuous from Monday to Saturday. It is vacated on Sundays and only partially occupied during holidays, as it is most common in higher education buildings worldwide. FEUC's community is composed by 2200 students, 130 teachers and 40 non-teaching staff.

a) b) c)

Figure 1. a) Limits of the FEUC's campus (dashed line) and the TB (continuous line) [Google Maps (2012)]. b) SE façade of the TB and c) NE façade of the TB.

2.2 Methodology

The study was divided into four phases, each one at a different scale approach. The first phase is linked to the campus scale, the second one to the TB scale and the third phase to the lighting system scale. To identify standard behaviours and savings opportunities, a web-based survey engaging the entire academic community was carried out during the fourth phase. Two kinds of technical actions were identified and reported in the energy efficiency plan: the tangible and the intangible ones in a short-term period (considering a budget of 10000 €). The lighting system was identified as one of the systems in which some immediate straightforward improvement measures could lead to significant energy savings. Therefore, during the third phase of the study, some tangible actions were offered along with the quantification of their respective costs. The simple payback period and the energy savings achieved by implementing the energy efficiency improvement measures in the lighting system were also estimated. The behavioural actions were considered free of charge. Several intangible short-term improvement measures were also reported in the study, mainly those related with the building envelope, heating system and water management. As stated above, these measures were considered intangible in the short-time period because of the pre-established budget. More information on the approach carried out can be found in the literature (Conceição, 2012), including the description of the equipments used, an extensive explanation of both case study and methodology, all measured data and further results.

3 Phase I - Campus scale

Figure 2 sketches the methodology followed during the first phase - FEUC's campus scale. An energy audit was carried out based on the analysis of the energy consumption profiles and bills. A monitoring campaign was conducted to measure the electricity consumption. The consumption of natural gas (NG) and water were also evaluated.

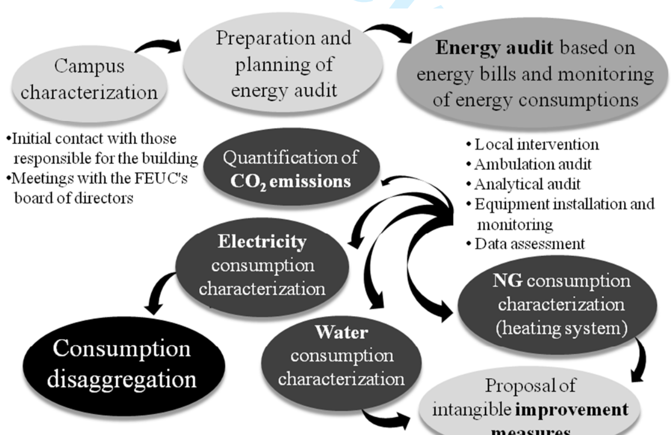


Figure 2. Work methodology of phase I – FEUC's campus scale.

The energy performance of a building is frequently stated in an Energy Efficient Indicator (EEI), expressed in final energy units per useful area per year. This EEI can be determined based on the average consumption of the three years previous to the energy audit or estimated from the real consumption data of the building for one year. The energy consumption of the building is then multiplied by a global conversion factor, determining this way the EEI. In the present case, the EEI value is equal to 16.45 kgep/m^2.year, which is higher than the reference value for existing teaching buildings (15 kgep/m^2.year) according to the national regulation at the time of the study (RSECE, 2006).

3.1 Disaggregation of electricity consumption

It is to notice that the disaggregated monitoring of electricity consumption at the campus was inexistent at the time of this study. Therefore, since the activities and occupancy of the three buildings are different, it was challenging to predict what was the consumption which was allocated to the TB. In order to measure the disaggregated consumptions of electricity, a monitoring campaign was carried out between 24 and 31 January 2012. It was found that the building presenting higher consumption was the RLB (53 %), followed by the TB (33 %) and the CL (14 %). However, these results were related to an exams week. It is reasonable to expect that the electricity consumption in the TB would be higher during the lecture term. The opposite is expected to happen in the RLB since its occupancy decreases during the lecture term. The central heating system runs on NG. However, in the RLB (including faculty offices) some electrical heating devices were found, which may have contributed to an increase in the electricity consumption during the analyzed period.

Figure 3 shows the Active Power (AP) evolution and the AP evolution by phase during the measured period. The Active Power corresponds to the real power resulting in actual work done. The highest consumption was found for the weekdays. The results were consistent with buildings occupancy. The consumption remained constant during nights and Sundays (the TB is unoccupied) and it was due to the cafeteria equipments (refrigerated cabinets, freezers, among similar appliances), other standby equipments, some lighting (including exterior lighting) and some heating devices.

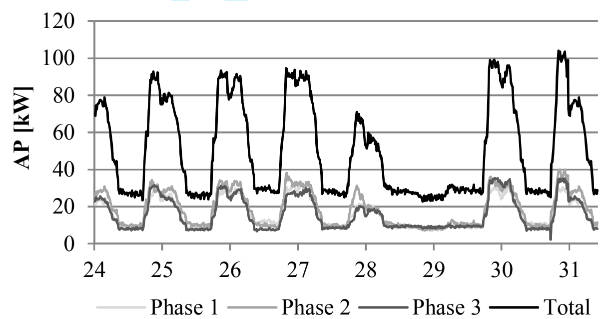


Figure 3. Active Power evolution between 24 and 31 January 2012 - campus scale.

3.2 Evolution of the Active Energy consumption

With non-linear loads applied to power lines the Active Energy (AE) does not represent the total energy delivered (apparent power expressed in kVA), hence monitoring the AE is essential to understand how the energy in the installation is really used. The AE consumption evolution was obtained through the analysis of the electricity bills ranging from 2007 to 2010 and it is presented in Figure 4. This four years data collection allows the comparison between the different annual profiles and the definition of a pattern: it was verified that the AE consumption was not constant throughout the year - it was higher during the heating periods.

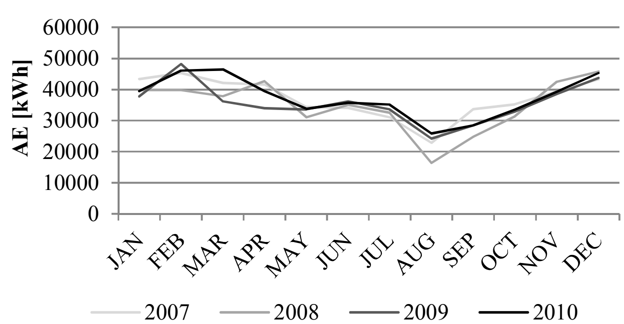


Figure 4. Active Energy consumption evolution from 2007 to 2010.

Figure 5 shows the AE disaggregated consumptions for different load tariff periods (regular-low, super-low, peak and high periods) from 2007 to 2010. These periods are taken by the energy supplier, accordingly to the electricity contract that foresees different energy prices for different periods of the day and different contracted power. The same AE consumption trend was verified for the analyzed years. Most of the consumption occurred during the high and peak load hours due to the higher occupancy of the building. The AE consumption during the regular-low and super-low periods (no school activities) was higher than expected. As stated above, this consumption is due to standby and permanently turned-on equipments (heating devices, lighting, ventilation, computers, freezers, etc.).

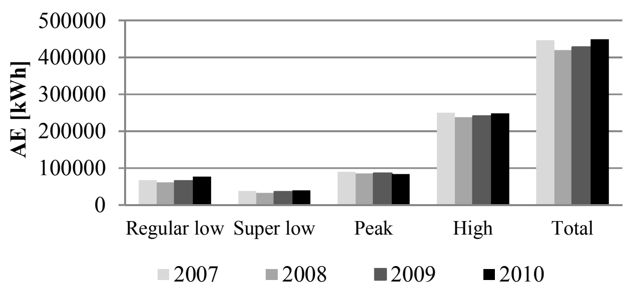


Figure 5. Active Energy disaggregated consumption by time period from 2007 to 2010.

3.3 Natural gas consumption

Figure 6 shows the evolution of the NG consumption from 2009 to 2011. The NG heating system is centralized and shared by the TB and the RLB. Hence, it was not possible to disaggregate consumptions by building. Moreover, it was found that it is extremely difficult to manage the operation of the system. Several aspects that reveal the low energy efficiency of the heating system were found: (*i*) it works continuously with very high boiler temperatures even during nights; (*ii*) the full length between the heat production and the final heat release is too long and evidences several problems of inadequate insulation of the hot water pipes; (*iii*) the NG consumption during the heating period is significant; (*iv*) the level of occupants' complaints is quite considerable; (*v*) there are overheating problems in the offices of the RLB, and cold temperatures in the TB classrooms, and (*vi*) there are considerable heat losses through the building envelope which is poorly insulated. The last aspect was confirmed by testing the building envelope with infrared thermography. Some intangible improvement measures aiming the NG consumption reduction are highlighted in Table I.

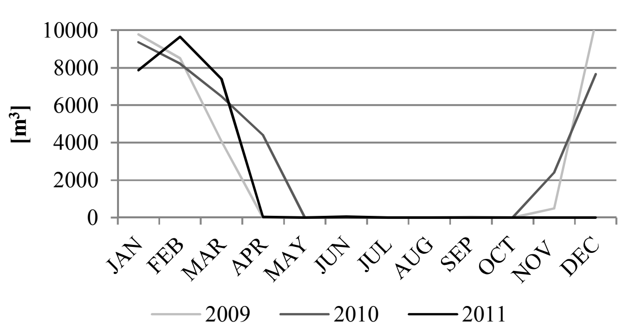


Figure 6. Evolution of the natural gas consumption from 2009 to 2011.

Table I. Summary of the intangible ECM identified and measures to improve the energy efficiency of the Teaching Building.

System	Measures / Description
Envelope	1. Replacement of the existing windows by double-glazing ones with thermal cutting frames. 2. Increase of the thermal resistance of opaque exterior envelope elements by placing thermal insulation on the roof, insulation on the inside surface of concrete exposed facades and ETIC insulation systems on both the non concrete exposed facades and outdoors exposed pavements. 3. Increase of the thermal resistance of the opaque envelope elements (reducing heat losses to the technical spaces) by placing insulation on the walls. 4. Improvement of the energy efficiency of the heating system by placing insulation on the concrete walls that form the boundary surface between the outside and the technical space which contains the heated water pipes. 5. Efficient solar gains management through the correct use of shading devices: by taking advantage of solar gains for heating during winter and mitigating solar gains during summer (avoiding overheating).
Heating system	1. Insulation of the heated water pipes. 2. Disaggregation of the centralized system. 3. Development of an integrated management model for the heating system based on the daily/weekly occupancy of the building.
Water use	1. Replacement of the water meter. 2. Installation of water flow regulators in WCs. 3. Development of an integrated management plan for gardens irrigation. 4. Development of an efficient irrigation plan considering retention and rainwater use.
Others	1. Energy consumption disaggregation and monitoring by building. 2. Energy consumption disaggregation and monitoring by sector in the TB.

3.4 Water consumption

Just like for electricity and NG consumption, the campus did not provide disaggregated water level consumptions. Water is used in WCs, cafeteria, irrigation, and cleaning and maintenance activities. It was found that higher consumption occurs during the cooling season when garden irrigation is more frequent. There was neither an irrigation system management providing water savings, nor a retention system which allows rainwater catchment to support some irrigation periods. Regarding water savings in WCs, there was no kind of water saving fixtures such as temporized taps, urinal water flow regulators or dual flush toilets. Some intangible improvement measures regarding reduction in water consumption are highlighted in Table I.

3.5 CO_2 emissions

Table II summarizes FEUC's annual consumptions of electricity, water and NG, between 2009 and 2011. All energy consumptions were converted into CO_2 equivalent emissions. The CO_2 equivalent emissions of the TB associated to electricity consumption represent 33 % of the total value. Regarding NG consumption, it was not possible to disaggregate consumptions and to quantify the TB's contribution in terms of CO_2 equivalent emissions.

Table II. Electricity, water and natural gas consumptions and CO_2 equivalent emissions from 2009 to 2011.

Year	Consumption			CO_2 equivalent emissions ($kgCO_2$)		
	Electricity (kWh)	NG (m^3)	Water (m^3)	Electricity	NG	Total
2008	419543	-	-	220092	-	-
2009	427323	33332	-	224174	78791	302965
2010	448620	38537	2658	235346	91562	326908
2011	-	25005	882	-	59770	-

4 Phase II - TB scale

Figure 7 sketches the methodology followed during the second phase of the study - TB scale. A monitoring campaign was conducted to measure and disaggregate the electricity consumption in the TB. The characteristics of the building envelope were also evaluated in order to identify improvement measures.

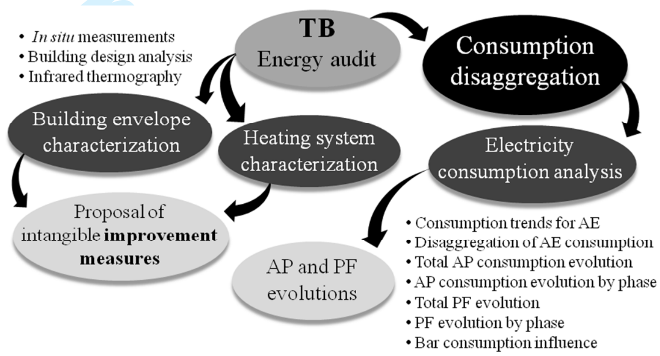


Figure 7. Work methodology of phase II – TB scale.

4.1 Electricity consumption

A monitoring campaign was carried out during three different periods to evaluate the electricity consumption in the TB: (*i*) between 16 December 2011 and 17 January 2012; (*ii*) between 24 and 31 January 2012, and (*iii*) between 3 and 23 March 2012.

Figure 8 shows the AP evolution between 16 and 26 December 2011. The highest intakes occurred on 16 and 17 mornings due to school activities. After 17 afternoon (following the end of lectures) there was a significant decrease in the electricity consumption. Moreover, its value remained stable during Sundays and night periods. This consumption was mainly due to cafeteria equipments, some standby devices and lighting. Despite the holidays period between 19 and 23 December, there was some activity of the staff and students. During higher occupancy periods, from 7 am to 6 pm, it was verified a rise in the electricity consumption. During 24 and 25 December the electricity consumption remained stable because of Christmas day. On Monday 26 the electricity consumption was again at the same levels the days before Christmas day. The base AP remained stable (≈ 6 kW) during the week. Regarding the consumption by phase it was verified an unbalanced profile, being phase 2 the most utilized.

Figure 9 shows the evolution of the total Power Factor (PF) and the evolution of the PF by phase during the analysed period. The PF-value was considered satisfactory since it was never lower than 0.7. Between 26 December 2011 and 1 January 2012 the electricity consumption profile was similar to those of the period before holidays. The measured results confirmed that the nonexistence of lectures implies a sharp reduction in the electricity consumption.

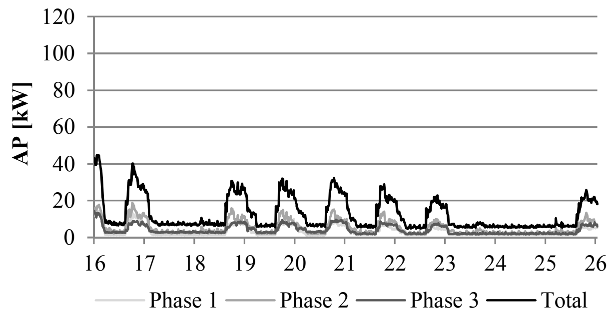


Figure 8. Active Power evolution between 16 and 26 December 2011 - TB scale.

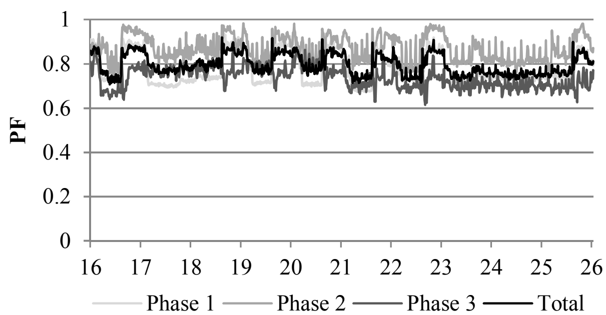


Figure 9. Power Factor evolution between 16 and 26 December 2011 - TB scale.

Figure 10 shows the total AP evolution and the AP evolution by phase between 2 and 10 January 2012. Figure 10 shows the evolution of both the total PF and the PF by phase during the same period. The results evidence that there was an increase in the energy consumption and in the peak-values during the analyzed period due to higher activity/occupancy. A remarkable increase was noticed in the morning peak, between 10 am and 11.30 am as a result of the meals preparation in the cafeteria. Another difference from the week before was the night-time energy consumption profile. Regarding the base AP-value, it was verified a significant increase of 5 kW in its value. Between 10 and 17 January 2012 the measured results were very similar to the results obtained over the previous week since the occupancy profile of the TB was also similar.

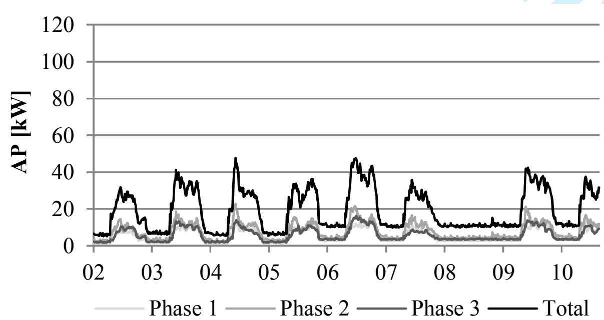


Figure 10. Active Power evolution between 2 and 10 January 2012 - TB scale.

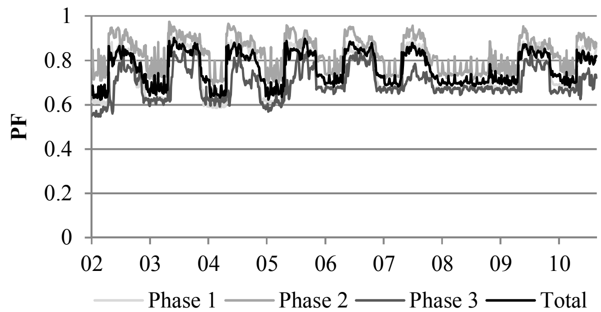


Figure 11. Power Factor evolution between 2 and 10 January 2012 - TB scale.

4.2 Analysis of the building envelope

Regarding the building envelope performance, only a brief analysis was carried out (a complete energy audit was not performed). It was found that none of the horizontal or vertical opaque elements of the building envelope have a thermal insulation layer associated. The refurbishment of the building envelope through the application of external thermal insulation materials may significantly contribute to increase the thermal resistance of the construction elements and to reduce the thermal bridges effect. It can also contribute to improve the energy savings relating to heating and cooling (Abreu and Corvacho, 2010). The placement of a thermal insulation layer on the external walls of the classrooms (mainly in those connected with the technical closet that contains the heating system hot pipes) may also improve the energy efficiency of the heating system. According to DOE (2013), in some cases, some actions as repairing the insulation of the pipes and increasing the insulation level may pay for themselves in less than six months. Additionally, insulating the pipework and valves on heating systems may lead to heat gains by up to 90% (Carbon Trust, 2011).

Regarding glazing facades, the majority of the windows are single-glass panes with metallic frames without thermal cutting. It was verified the damaged state of some frames (e.g. warped frames and blocked windows). Concerning shading devices, they were damaged in most cases. In other cases, they have disappeared or have never existed (mainly in the SW facade). Large North oriented windows are associated to great heat losses during winter. The characterization of the building envelope was complemented with infrared thermography, mainly to evaluate the thermal bridging effect. Some intangible improvement measures regarding the energy efficiency of the building envelope are highlighted in Table I.

5 Phase III – Lighting system scale

During the last decades some small interventions were made in the lighting system. Therefore, old and new technologies coexist in the TB. During the energy audit some non-efficient situations were identified, such as the existence of ferromagnetic ballasts (Class D) and low efficient T8 lamps lighting fixtures which were working all day long. In classrooms, lighting fittings are well distributed (parallel to the windows facade). In the corridors/circulation areas it was verified that some lighting systems were on even under good natural lighting conditions. The most obsolete systems were found in WCs. Like in corridors, lightings were on besides favourable natural lighting and the absence of users. Figure 12 sketches the methodology followed during the third phase of the study - lighting system scale.

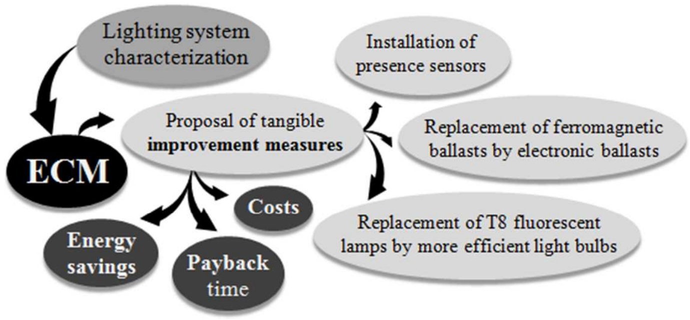


Figure 12. Work methodology of phase III – lighting system scale.

5.1 Tangible improvement measures

Regarding the lighting system a refurbishment project was sketched. It consists in the replacement of the fluorescent T8 conventional lamps by more efficient light bulbs - PHILIPS MASTER TL-D ECO type, and in the replacement of all ferromagnetic ballasts by electronic ballasts. The economic viability of these two measures was evaluated considering the equipments costs (9537 €) and the average price of 0.1016031 €/kWh. The installation costs were not considered in the analysis. Energy savings of around 24513 kWh/year could be reached with the joint implementation of these measures.

Table III. Savings and simple payback period from the combined replacement of the T8 fluorescent lamps and ferromagnetic ballasts.

Building zones	Investment (€)	Savings		Payback
		kWh/year	€/year	(years)
Classrooms	6716.4	16856.6	1712.7	3.9
WCs	482.2	1210.5	123.0	3.9
Circulation areas	1045.5	3034.3	308.3	3.4
Auditorium	704.5	1650.6	167.7	4.2
Cafeteria & multipurpose room	506.7	1678.6	170.5	3.0
Administrative & services	82.0	82.0	17.3	4.7
Total	**9537.3**	**24512.6**	**2499.5**	**3.8**

Moreover, it was estimated that energy savings of about 40% could be reached by considering the existence of presence sensors in WCs. The installation of presence sensors in all WCs would lead to energy savings of about 1611 kWh/year. The implementation of the three improvement measures in the lighting system would lead to an electricity savings of about 26123 kWh/year (2663 €/year), avoiding the emission of 3704 $kgCO_2$/year, for an initial cost of 9920 € and a payback period (using the simple payback method) of 3.7 years.

6 Web-based survey – assessment of user's behaviour

The web-based survey was available online between March and May 2012. The survey aimed at characterizing behaviours of the academic community related with environmental and energy issues, such as: (*i*) users' relationship with the academic buildings; (*ii*) how users perceive campus' energy efficiency; (*iii*) their level of commitment with environmental questions; (*iv*) commuting pattern profiles; (*v*) meals habits; (*vi*) waste management, and (*v*) energy consumption at home. The survey was divided in two parts. The first one aimed at characterizing the survey population, and the second one at evaluating the energy efficiency of the campus from the users' perception.

6.1 Characterization of the population

The data collected from the first part of the survey provides a description of the demographic, educational attainment and environmental awareness context of the population. In total, 394 persons participated voluntarily in the survey, 56.7 % females and 43.3 % males. 18.1 % were under 20, 40.5 % were aged 21-25, 10.9 % were aged 26-30, 14.8 % were aged 31-40, 10.4 % were aged 41-50, and 5.3 % were over 51. The demographic distribution reflects the institutional links of the respondents: 87 % were students; 9.7 % were faculty; 2.8 % were office staff, and 0.5 % had another type of link with the institution. Among the 343 students, 48.2 % were undergraduate students and 51.8 % were postgraduate students (38.6 % were masters students, 7.6 % were PhD students, and 5.6 % were in another type of postgraduate degree). As far as the students' field of study, 32.9 % were students of economics, 32.1 % of management, 13.4 % of sociology, 9.5 % of international relations, and 12.1 % were students of others fields of study. When asked about the existence of courses within their curricula related to "environment" and "sustainability" issues, 35.9 % of students stated they had attended at least one course on the subject. In addition, 25.6 % of students answered that they had attended at least one course on the theme "energy for sustainability". When asked to indicate (on average) the number of days per week spent at the building (during the lecture term) 12 % answered less than or equal to 1 day, 18.8 % 2 days, 12.7 % 3 days, 34.9 % 4 days, and 21.6 % 5 or more days. When asked to indicate (on average) the number of hours during a day spent at the building (considering the same period as above) 1.8 % answered less than 2 hours, 20.5 % 2-4 hours, 41 % 4-6 hours, 30 % 6-8 hours, and 6.7 % more than 8 hours.

The next set of questions aimed at understanding the commuting behaviour patterns of the populations, by assessing the distance from their homes to the campus and the means of transportation used in commuting. 31.5 % stated their homes are at a distance less than 2 km, 22.8 % 2-5 km, 12.5 % 5-10 km, 8.7 % 10-20 km, and 24.6 % more than 20 km. 44 % stated they drive their own car to the campus, 33.3 % walk, 18.3 % use public transportation, 3.6 % are driven in someone else's car, and 0.8 % use other means of transportation.

The next set of questions were meant to obtain a measure of the importance of the electricity bill in the individual's monthly expenditures. 51.7 % stated they pay for the electricity bill in their homes, while 48.3 % stated they do not. 75.4 % of those not paying for the electricity in their homes indicated that their parents pay for the electricity bill, 20.9 % the landlord, and 3.7 % other family members.

As to where the individuals have their lunch meal during the lecture term, 35.1 % stated they have lunch in the university's restaurants, 33.3 % in their homes, 17.8 % in FEUC's cafeteria, 5.1 % in a restaurant, 1.3 % in another cafeteria, and 7.4 % in another place.

Finally, to obtain a measure of the level of energy-environmental awareness of the population, the individuals were asked about their concern about this issue. 24.7 % stated they are highly concerned about it, 40.6 % stated they are very concerned about it, 31.4 % stated they are concerned about it, 3.1 % stated they are little concerned about it, and 0.3 % stated they are not concerned about it.

6.2 Energy and environmental awareness of the population

The data collected from the second part of the survey provides information about the energy and environmental awareness of the population. The first question aimed at understanding the users' perception of some inefficient situations that can be found in the TB: (*i*) lights on in unoccupied rooms; (*ii*) water wastage in WCs; (*iii*) electronic devices on in unoccupied rooms, and (*iv*) low efficiency or malfunction of the heating system. A five-levels scale was used to evaluate the users' perception of the frequency of each situation: 1 - never; 2 - rarely; 3 - sometimes; 4 - often, and 5 - always. Table IV lists the inefficient situations investigated and the frequency of their perception. It was found that the frequency of the inefficient evaluated situations was low from the users' perception point of view.

The second question aimed at investigating individuals' concerns about sustainable behaviours related with electrical devices, lighting, and water and waste management. A five-levels scale was used to evaluate the users' concerns: 1 - not concerned; 2 - little concerned; 3 - concerned; 4 - very concerned, and 5 - highly concerned. Table V lists the main sustainable behaviours investigated and the individuals' concerns about them. Results showed that users were particularly concerned about turning off the taps after use; turning off the lights when leaving rooms; closing windows and doors to improve indoor thermal comfort, and putting waste in the right place for recycling. On the other hand, users were not so concerned about turning off electrical devices (computers, projectors and heating devices), and opening curtains to allow solar heating during winter. It should be remarked that turning off the projectors is a task imputed to lecturers. Therefore, 93 % of the faculty persons stated that they were very or highly concerned about it. Results also highlight that users are less concerned about alerting the office staff of a damaged tap or a blown lamp. An important improvement measure can be the definition of a "*Reporting Inefficient and Wastage Situations in the Campus Plan"*. This plan should contemplate an office or a member staff, which are responsible for collecting inefficient situations reports. All the academic community should be familiar with this plan.

Table IV. Inefficient situations detected in the TB and frequency of their perception.

Inefficient situation		**Proportion of responses for each level**				
		never	rarely	sometimes	often	always
1.	Lights on in unoccupied WCs.	11.0%	33.5%	27.4%	18.4%	9.7%
2.	Lights on in unoccupied rooms.	22.4%	59.0%	13.0%	5.1%	0.5%
3.	Taps running in unoccupied WCs.	24.3%	42.2%	22.8%	9.7%	1.0%
4.	Water wastage in toilet flushing.	14.8%	48.6%	25.4%	10.2%	1.0%
5.	Computers on in unoccupied rooms.	16.4%	36.0%	26.1%	17.7%	3.8%
6.	Computers on in the public ITC room when it is unoccupied.	6.2%	23.5%	31.4%	26.8%	12.1%
7.	Projectors on in unoccupied classrooms.	37.5%	47.1%	11.8%	3.3%	0.3%
8.	Windows are opened or it is impossible to close them even if it is cold inside and the heating system is on.	19.0%	44.0%	21.3%	13.9%	1.8%
9.	Overheating with the heating system on.	26.4%	41.0%	18.5%	12.3%	1.8%
10.	Cold inside with the heating system off.	10.5%	27.3%	30.9%	23.4%	7.9%

The most important behavioural improvement measure suggested with this study is the implementation of a "*Good Practices Manual on Water and Energy Management*". The results of the web-based survey were presented to the FEUC's board of directors in order to be integrated in this manual. Afterwards, this manual should be delivered to the academic community to make users awareness of the behavioural patterns found. The "*Good Practices Manual on Water and Energy Management*" should also integrate a list of efficient situations towards energy and water savings. Figure 13 shows the structuring lines that must be considered when preparing this manual.

Table V. Individuals' concerns about sustainable behaviours.

Sustainable behaviour	Proportion of responses for each level					Mode
	Not concerned	Little concerned	Concerned	Very concerned	Highly concerned	
1. Turning off the tap after use.	0.5%	2.3%	11.8%	22.3%	63.1%	5
2. Alerting staff of a damaged tap.	4.9%	18.4%	37.1%	21.2%	18.4%	3
3. Turning off the lights when leaving the WC.	6.1%	16.4%	20.7%	25.3%	31.5%	5
4. Turning off the lights when leaving the classroom.	8.8%	21.0%	19.7%	22.0%	28.5%	5
5. Alerting staff of a blown lamp.	25.1%	39.8%	19.6%	8.8%	6.7%	2
6. Checking if the computer is off when leaving the classroom.	13.7%	22.5%	22.8%	18.7%	22.3%	3
7. Checking if the projector is off when leaving the classroom.	16.8%	29.8%	19.7%	14.8%	18.9%	2
8. Turning off the computer when it is no longer necessary in the classroom.	12.4%	27.7%	30.6%	16.8%	12.5%	3
9. Turning off the projector when it is no longer necessary in the classroom.	16.0%	28.3%	25.9%	16.2%	13.6%	2
10. Turning off the public computer in the ITC room after using it.	12.7%	21.7%	28.4%	17.0%	20.2%	3
11. Opening curtains to allow solar heating during winter.	17.2%	28.3%	26.2%	17.8%	10.5%	2
12. Closing windows if it is cold inside.	1.3%	5.8%	18.8%	38.1%	36.0%	4
13. Closing windows if the heating system is on.	2.9%	9.1%	26.4%	33.2%	28.4%	4
14. Closing doors if the heating system is on.	2.3%	10.1%	27.7%	31.6%	28.3%	4
15. Turning off the heating devices at the end of the day.	33.6%	27.8%	18.5%	10.8%	9.3%	1
16. Putting waste in the right place for recycling.	7.9%	10.2%	20.5%	26.1%	35.3%	5

Figure 13. Structuring lines that must be considered when preparing the "*Good Practices Manual on Water and Energy Management*".

7 Conclusion

The energy efficiency of the TB of the FEUC's campus was partially evaluated in this paper. An energy efficiency plan was also proposed considering short-term tangible/intangible technical and behavioural improvement measures (considering a predefined budget of 10000 €). The study was developed in the framework of both the UC's EfS Initiative and the *Green Campus* Portuguese competition. Therefore, this paper highlights the importance of engaging students, faculty and office staff for working together on the assessment of the energy efficiency of the buildings where they study and work.

An energy audit was conducted based on the analysis of the energy consumption profiles and bills. A monitoring campaign was carried out to measure and disaggregate the electricity consumption by building (considering FEUC's campus scale) and by sector in the TB (considering the TB scale). The consumption of NG and water were also analysed. The building envelope and the heating and lighting systems were also evaluated. A set of intangible measures to improve the energy efficiency of the TB were proposed considering a set of identified ECM regarding the building envelope characteristics, the heating system characteristics and management, and the water and electricity consumptions.

As far as the lighting system, a refurbishment project was proposed. It consists in the implementation of three different tangible measures: (*i*) the replacement of fluorescent T8 type lamps for more efficient light bulbs; (*ii*) the replacement of all ferromagnetic ballasts by electronic ones, and (*iii*) the installation of presence sensors in WCs. It was concluded that the implementation of these improvement measures would lead to a consumption reduction of about 26123 kWh/year (2663 €/year) in the cost of electricity, avoiding the emission of 3704 kgCO_2/year, for an initial cost of 9920 € and a simple payback period of 3.7 years.

To identify energy-environmental behaviour patterns, a web-based survey was carried out engaging the entire academic community mailing list. In total, 394 persons have answered the survey. The data collected from the survey provided information about the energy and environmental awareness of the population. Results showed that the frequency of inefficient situations in the TB was low from the users' point of view. They also showed that users are relatively concerned about sustainable behaviours related with electrical devices, lighting, water and waste management. The results of the survey are very important towards the development of the "*Good Practices Manual on Water and Energy Management"* of FEUC’s campus. This manual was the culmination of this work but it has not been implemented yet. Further work must be done in the near future for implementing and monitoring the application of this manual in order to quantify how much the campus is becoming greener by implementing the proposed energy efficiency measures. Additionally, the building construction characteristics’ can be further explored in the future – by means of simulation e.g., thermal losses through the envelope could be rigorously determined and the "economic impact" versus "energy savings" of implementing different insulation solutions can be investigated.

Acknowledgments

The first author acknowledges the support provided by the Portuguese Foundation for Science and Technology (FCT) under the PhD scholarship SFRH/BD/51640/2011 in the framework of the MIT-Portugal Program. The second and the third authors acknowledge the support provided by FCT under the PhD scholarships SFRH/BD/77105/2011 and SFRH/BD/76357/2011, respectively. This study was partially supported by FCT under the project grant PEst-C/EEI/UI0308/2011 and the Energy for Sustainability Initiative of the University of Coimbra. It was also supported by the project Energy and Mobility for Sustainable Regions - EMSURE (CENTRO-07-0224-FEDER-002004).

References

Abreu, I. and Corvacho, H., 2010. "Conforto Térmico. Os novos desafios tecnológicos na reabilitação energética de paredes exteriores em edifícios", *Construção Magazine*, Vol.35, pp.23-28.

Ajzen, I. (1991). "The theory of planned behavior", *Organizational Behavior and Human Decision Processes*, Vol. 50 No.2, pp. 179-211.

Alshuwaikhat, H.M. and Abubakar, I. (2008), "An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices", *Journal of Cleaner Production*, Vol. 16 No. 16, pp. 1777-85.

Andaloro, A.P.F, Salomone, R., Ioppolo, G. and Andaloro, L. (2010), "Energy certification of buildings: A comparative analysis of progress towards implementation in European countries", *Energy Policy*, Vol. 38, pp. 5840-5866.

Barata, E., Cruz, L. and Ferreira, J.-P. (2011), "Parking at the UC campus: Problems and solutions", *Cities*, Vol. 28 No. 5, pp. 406-13.

Batterman, S.A., Martins, A.G., Antunes, C.H., Freire, F. and da Silva, M.G. (2011), "Development and application of competencies for graduate programs in energy and sustainability", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 137 No. 4, pp. 198-207.

Cansino, J.M., Pablo-Romero, M.P., Román, R. and Yñiguez R. (2011), "Promoting renewable energy sources for heating and cooling in EU-27 countries", *Energy Policy*, Vol. 39, pp. 3803-3812.

Carbon Trust. (2011). "How to implement thermal insulation to HVAC services - CTL145", available at: http://www.carbontrust.com/media/147159/j8052_ctl145_how_to_implement_thermal_insulation_to_hvac_services_aw.pdf (accessed 23 July 2014).

Commission of the European Communities (CEC) (2006), Action Plan for Energy Efficiency: Realising the Potential, EUR-OP, Luxembourg.

Conceição P. (2012), "Auditoria Energética à Faculdade de Economia da UC", Master's Dissertation, University of Coimbra, Portugal.

Cravo, A., Fumega, J., Carvalho, M., Pina, A., Silva, C. and Ferrão, P. (2012), "The Green Campus Challenge - an inclusive approach towards fostering energy efficiency in university campuses", paper presented at Portugal em Conferência para uma Economia Energeticamente Eficiente, 22 June, Coimbra, Portugal.

Dahle, M. and Neumayer, E. (2001), "Overcoming barriers to campus greening: a survey among higher educational institutions in London, UK", *International Journal of Sustainability in Higher Education*, Vol. 2 No. 2, pp. 139-60.

DOE, Department of Energy US. (2013). Advanced Energy Retrofit Guide - Practical Ways to Improve Energy Performance: K-12 Schools.

Egging R. (2013), "Drivers, trends, and uncertainty in long-term price projections for energy management in public buildings", *Energy Policy*, Vol. 62, pp. 617-624.

Ekins, P. and Lees, E. (2008), "The impact of EU policies on energy use in and the evolution of the UK built environment", *Energy Policy*, Vol. 36 No. 12, pp. 4580-4583.

EPBD (2003), Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, in Official Journal of the European Union, L1/65–1/71.

EPBD recast (2010), Directive2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), in Official Journal of the European Union, L153/13–153/35.

European Commission (2011), "COM(2011) 109 final - Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the committee of the Regions - Energy Efficiency Plan 2011", Brussels

Fabi, V., Andersen, R.V., Corgnati, S. and Olesen, B.W. (2012), "Occupants' window opening behaviour : A literature review of factors influencing occupant behaviour and models", *Building and Environment*, Vol.58, pp. 188–198.

Fabi, V., Andersen, R.V. and Corgnati, S.P. (2013), "Influence of occupant's heating set-point preferences on indoor environmental quality and heating demand in residential buildings", *HVAC&R Research*, Vol. 19 No. 5, pp. 635–645.

González, A.B.R., Díaz, J.J.V. and Wilby, M.R. (2012), " Dedicated tax/subsidy scheme for reducing emissions by promoting innovation in buildings: The EcoTax", *Energy Policy*, Vol. 51, pp. 417-424.

International Energy Agency (2003b), Creating Markets for Energy Technologies. OECD/IEA, Paris.

János, L.M. (2011), "Students Energy Saving Behavior - Case study of University of Coimbra", Master's Dissertation, FEUC - University of Coimbra, Portugal.

Jollands, N., Waide, P., Ellis, M., Onoda, T., Laustsen, J., Tanaka, K., de T'Serclaes, P., Barnsley, I., Bradley, R. and Meier, A. (2010), "The 25 IEA energy efficiency policy recommendations to the G8 Gleneagles Plan of Action", *Energy Policy*, Vol. 38, pp. 6409-6418.

Jones, P., Trier, C.J. and Richards J.P. (2008), "Embedding Education for Sustainable Development in higher education: a case study examining common challenges and opportunities for undergraduate programmes", *International Journal of Educational Research*, Vol. 47 No. 6, pp. 341-50.

Littledyke, M., Manolas, E. and Littledyke, R.A. (2013), "A systems approach to education for sustainability in higher education", *International Journal of Sustainability in Higher Education*, Vol. 14 No. 4, pp. 367-83.

Mochizuki, Y. and Fadeeva, Z. (2010), "Competences for sustainable development and sustainability: significance and challenges for ESD", *International Journal of Sustainability in Higher Education*, Vol. 11 No. 4, pp. 391-403.

Naeem, M. and Neal, M. (2012), "Sustainability in business education in the Asia Pacific region: a snapshot of the situation", *International Journal of Sustainability in Higher Education*, Vol. 13 No. 1, pp. 60-71.

Raslan, R. and Davies, M. (2012), "Legislating building energy performance: putting EU policy into practice", *Building Research & Information*, Vol.40 No.3, pp. 305-316.

RSECE (2006). Decree-Law no. 79/2006. (2006). Regulation for the energy and HVAC systems in buildings (in Portuguese: Regulamento dos Sistemas Energéticos de Climatização em Edifícios— RSECE), Official Gazette of the Portuguese Republic, Series A, No. 67.

Rusinko, C.A. (2010), "Integrating sustainability in management and business education: a matrix approach", *Academy of Management Learning and Education*, Vol. 9 No. 3, pp. 507-19.

Shephard, K. (2008), "Higher education for sustainability: seeking affective learning outcomes", *International Journal of Sustainability in Higher Education*, Vol. 9 No. 1, pp. 87-98.

Sherman, P. and Hansen, J. (2010), "The new corporate social responsibility: a call for sustainability in business education", *International Journal of Environment and Sustainable Development*, Vol. 9 Nos. 1-3, pp. 241-54.

Thomas, I. (2004), "Sustainability in tertiary curricula: what is stopping it happening?", *International Journal of Sustainability in Higher Education*, Vol. 5 No. 1, pp. 33-47.

Travezan, J.Y., Harmsen, R. and van Toledo, G. (2013), "Policy analysis for energy efficiency in the built environment in Spain", *Energy Policy*, Vol. 61, pp. 317-326.

About the authors

Nelson Soares is a PhD student in Sustainable Energy Systems at the University of Coimbra (UC), Portugal, in the framework of the MIT-Portugal program. He holds a 5-years degree in Civil Engineering and a master's degree in Civil Engineering in the specialization area of Constructions, both from UC. He also holds a master's degree in Energy for Sustainability in the specialization area of Indoor Climate and Comfort from UC. He is a researcher member of

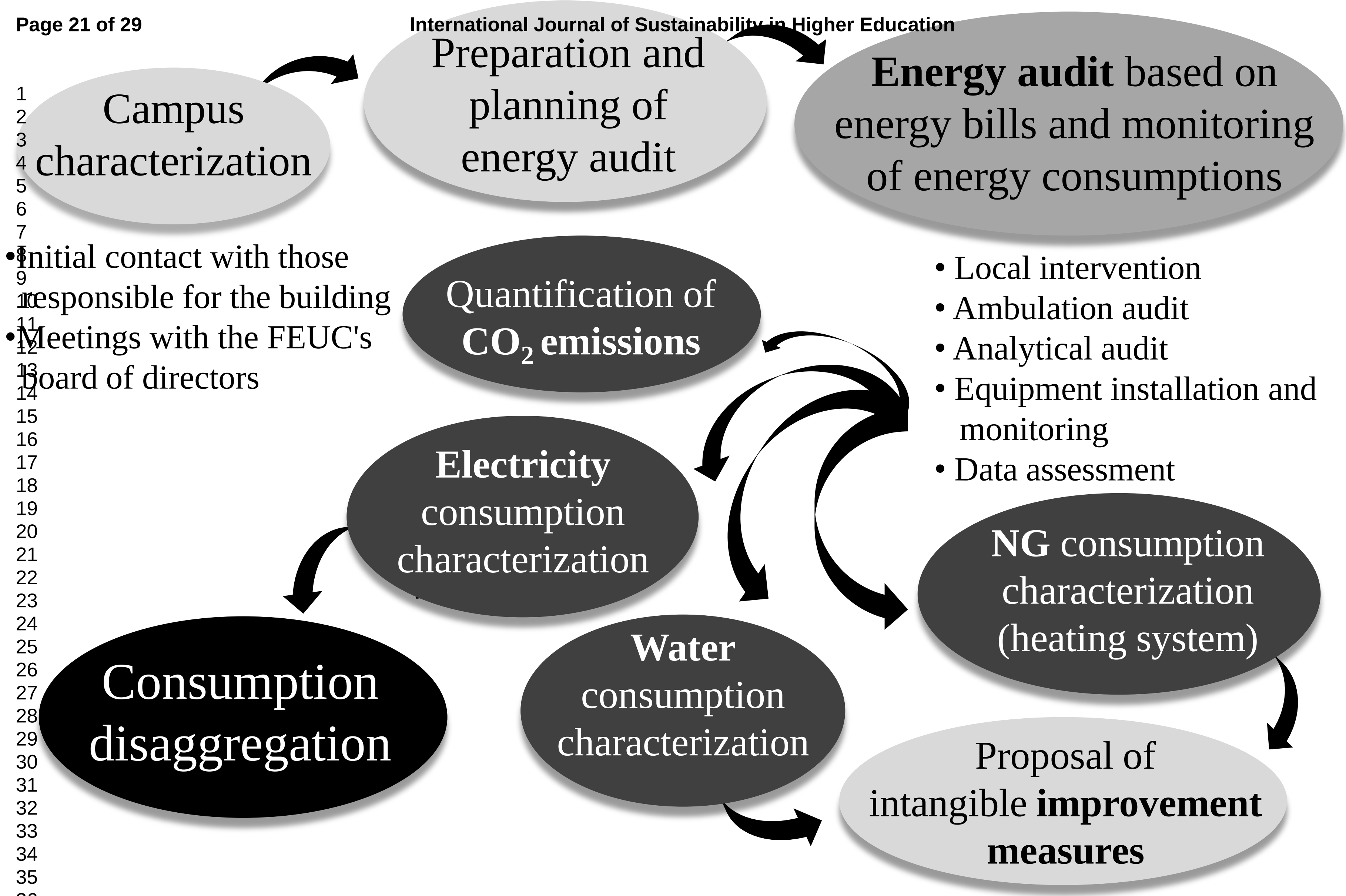
both the ADAI,LAETA and the ISISE research centers. His research is focused on the study of renewable energy based applications of phase change materials (PCMs) in construction solutions towards the improvement of the energy efficiency of buildings. He is co-author of several publications in the field.

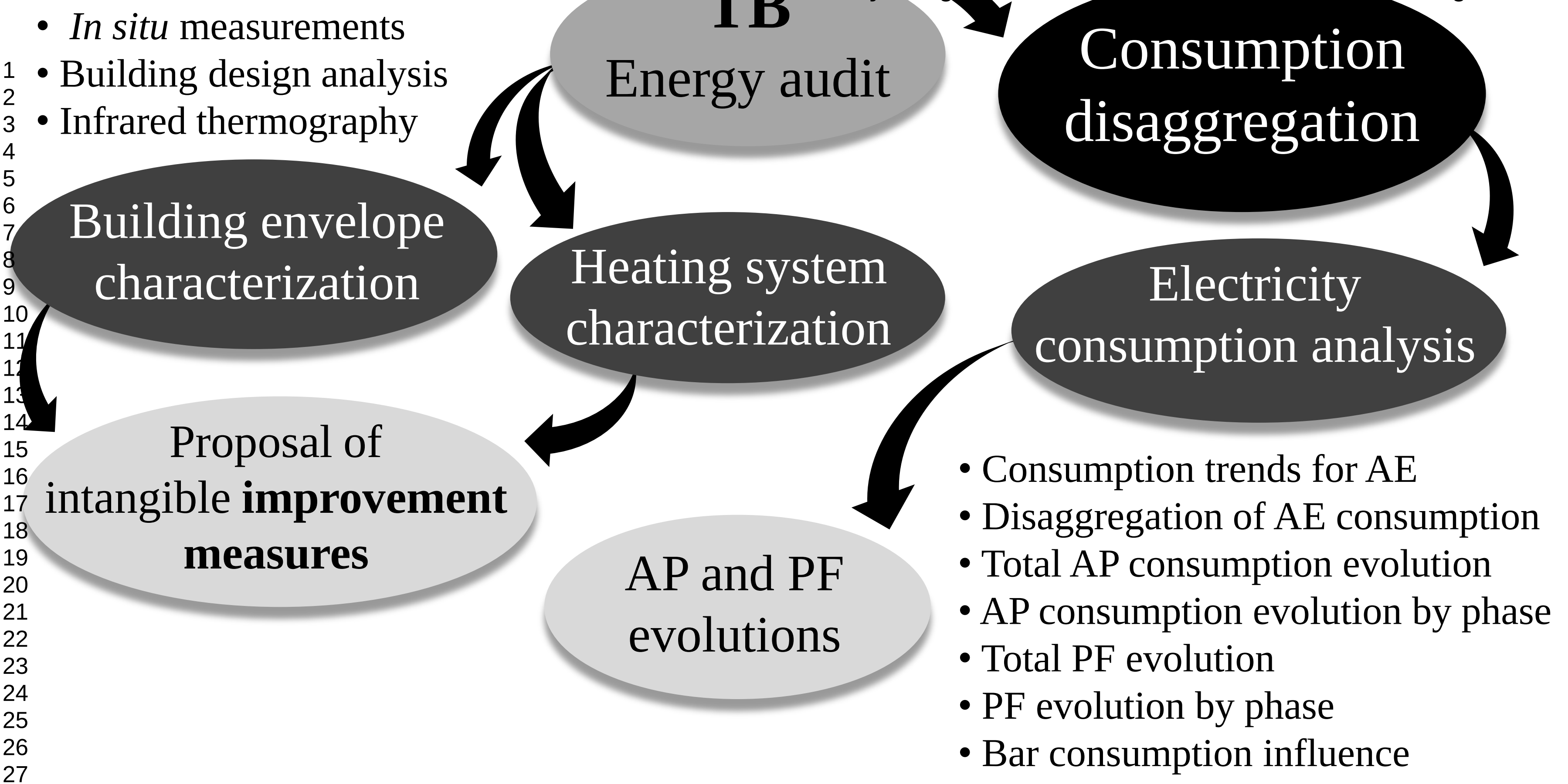
Luísa Dias Pereira is an Architect graduated from FAUP (Porto, Portugal) and holder of a Master degree in Energy for Sustainability from UC. She is finishing her PhD research in Energy Efficiency Plans for Schools at FCTUC under the MIT Portugal Program in Sustainable Energy Systems, and has been author, co-author and reviewer of scientific publications and conference papers in the field. Previously, she was a visiting researcher at TEBE Research Group, in the Department of Energy of the Politecnico di Torino.

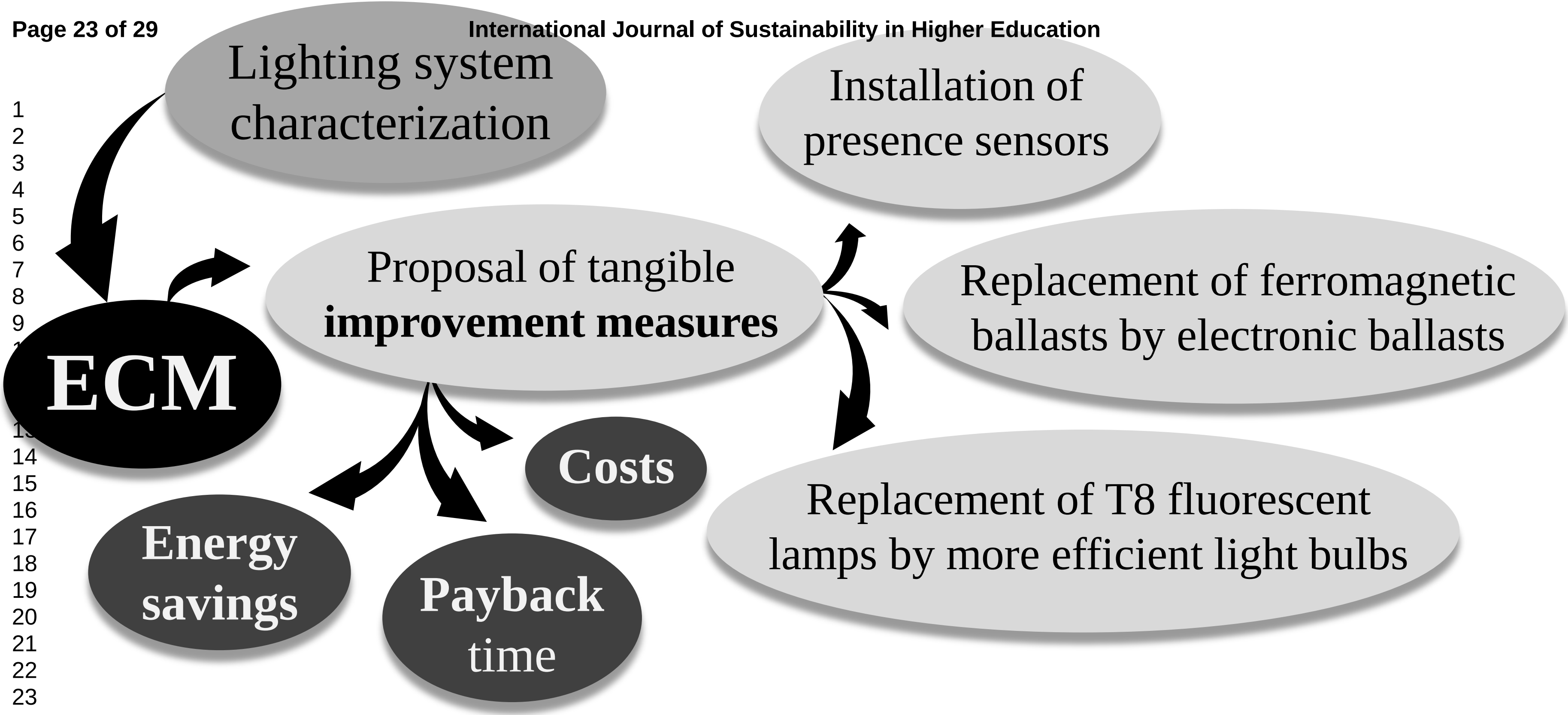
João Pedro Ferreira is an Economist graduated from the Faculty of Economics of the University of Coimbra and holder of a Master degree in Local Economics from the same institution. He is finishing his PhD research in Socio-Economic-Environmental Assessment of Commuting at UC under the MIT Portugal Program in Sustainable Energy Systems, and has been author, co-author and reviewer of scientific publications and conference papers in the field of Regional Economics and Input-Output Techniques.

Pedro Miguel Conceição is an Engineer graduated from the Faculty of Science and Technology of the University of Coimbra and holder of a Master degree in Energy from the same institution. He has been author and co-author of scientific publications and conference papers in the field.

Patrícia Pereira da Silva holds a PhD in Finance from UC. Her research interests, conducted at INESCC, are in the areas of energy economics, energy finance and markets. She is a Professor at the Faculty of Economics and at the Energy for Sustainability Initiative from UC, and also at the MIT-Portugal program within the field of sustainable energy systems.


Campus characterization
Preparation and planning of energy audit
Energy audit based on energy bills and monitoring of energy consumptions
•Initial contact with those responsible for the building
•Meetings with the FEUC's board of directors
• Local intervention
• Ambulation audit
• Analytical audit
• Equipment installation and monitoring
• Data assessment
Quantification of CO_2 emissions
Electricity consumption characterization
Water consumption characterization
NG consumption characterization (heating system)
Consumption disaggregation
Proposal of intangible improvement measures


TB
Energy audit
In situ measurements
Building design analysis
Infrared thermography
Building envelope characterization
Heating system characterization
Proposal of intangible improvement measures
Consumption disaggregation
Electricity consumption analysis
Consumption trends for AE
Disaggregation of AE consumption
Total AP consumption evolution
AP consumption evolution by phase
Total PF evolution
PF evolution by phase
Bar consumption influence
AP and PF evolutions


Lighting system characterization
ECM
Proposal of tangible **improvement measures**
Installation of presence sensors
Replacement of ferromagnetic ballasts by electronic ballasts
Replacement of T8 fluorescent lamps by more efficient light bulbs
Costs
Energy savings
Payback time

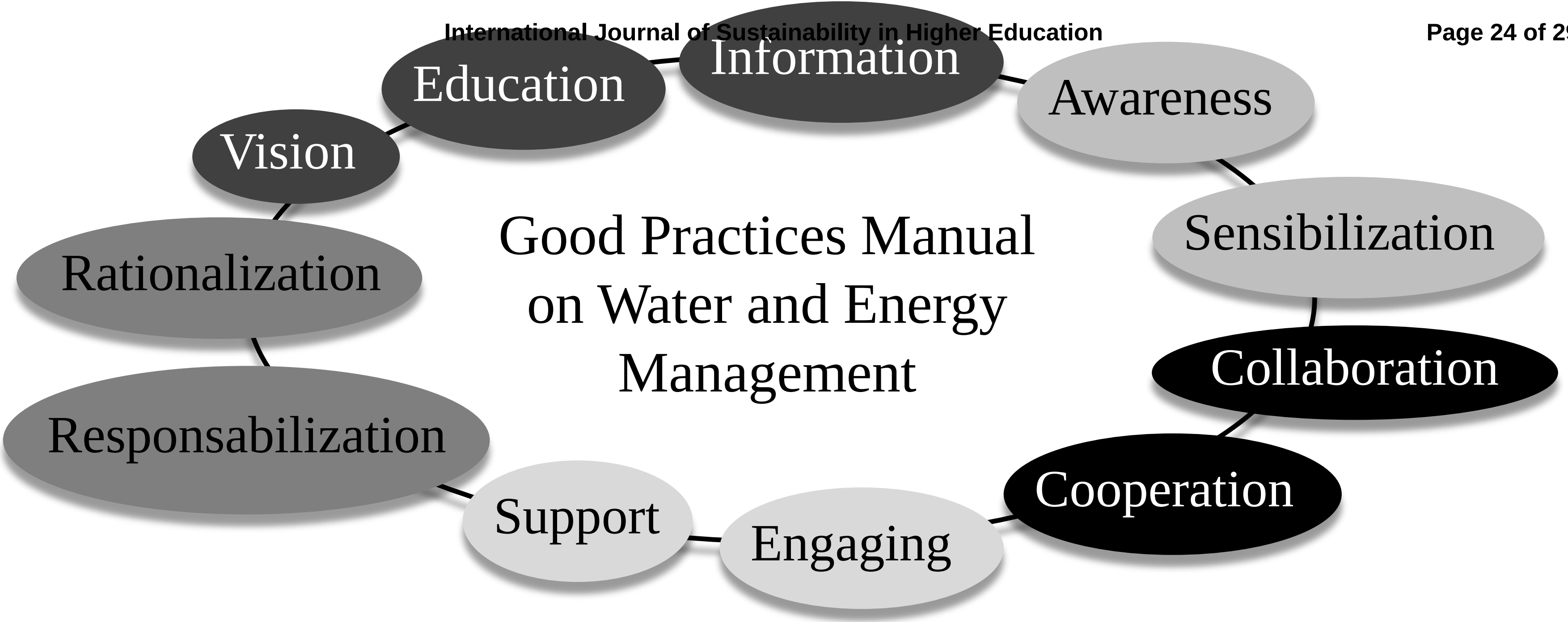

Information
Education
Awareness
Vision
Good Practices Manual on Water and Energy Management
Sensibilization
Rationalization
Collaboration
Responsabilization
Cooperation
Support
Engaging

Table I. Summary of the intangible ECM identified and measures to improve the energy efficiency of the Teaching Building.

System	Measures / Description
Envelope	1. Replacement of the existing windows by double-glazing ones with thermal cutting frames. 2. Increase of the thermal resistance of opaque exterior envelope elements by placing thermal insulation on the roof, insulation on the inside surface of concrete exposed facades and ETIC insulation systems on both the non concrete exposed facades and outdoors exposed pavements. 3. Increase of the thermal resistance of the opaque envelope elements (reducing heat losses to the technical spaces) by placing insulation on the walls. 4. Improvement of the energy efficiency of the heating system by placing insulation on the concrete walls that form the boundary surface between the outside and the technical space which contains the heated water pipes. 5. Efficient solar gains management through the correct use of shading devices: by taking advantage of solar gains for heating during winter and mitigating solar gains during summer (avoiding overheating).
Heating system	1. Insulation of the heated water pipes. 2. Disaggregation of the centralized system. 3. Development of an integrated management model for the heating system based on the daily/weekly occupancy of the building.
Water use	1. Replacement of the water meter. 2. Installation of water flow regulators in WCs. 3. Development of an integrated management plan for gardens irrigation. 4. Development of an efficient irrigation plan considering retention and rainwater use.
Others	1. Energy consumption disaggregation and monitoring by building. 2. Energy consumption disaggregation and monitoring by sector in the TB.

Table II. Electricity, water and natural gas consumptions and CO_2 equivalent emissions from 2009 to 2011.

Year	Consumption			CO_2 equivalent emissions ($kgCO_2$)		
	Electricity (kWh)	NG (m^3)	Water (m^3)	Electricity	NG	Total
2008	419543	-	-	220092	-	-
2009	427323	33332	-	224174	78791	302965
2010	448620	38537	2658	235346	91562	326908
2011	-	25005	882	-	59770	-

Table III. Savings and simple payback period from the combined replacement of the T8 fluorescent lamps and ferromagnetic ballasts.

Building zones	Investment (€)	Savings kWh/year	Savings €/year	Payback (years)
Classrooms	6716.4	16856.6	1712.7	3.9
WCs	482.2	1210.5	123.0	3.9
Circulation areas	1045.5	3034.3	308.3	3.4
Auditorium	704.5	1650.6	167.7	4.2
Cafeteria & multipurpose room	506.7	1678.6	170.5	3.0
Administrative & services	82.0	82.0	17.3	4.7
Total	**9537.3**	**24512.6**	**2499.5**	**3.8**

Table IV. Inefficient situations detected in the TB and frequency of their perception.

Inefficient situation	**Proportion of responses for each level**				
	never	rarely	sometimes	often	always
1. Lights on in unoccupied WCs.	11.0%	33.5%	27.4%	18.4%	9.7%
2. Lights on in unoccupied rooms.	22.4%	59.0%	13.0%	5.1%	0.5%
3. Taps running in unoccupied WCs.	24.3%	42.2%	22.8%	9.7%	1.0%
4. Water wastage in toilet flushing.	14.8%	48.6%	25.4%	10.2%	1.0%
5. Computers on in unoccupied rooms.	16.4%	36.0%	26.1%	17.7%	3.8%
6. Computers on in the public ITC room when it is unoccupied.	6.2%	23.5%	31.4%	26.8%	12.1%
7. Projectors on in unoccupied classrooms.	37.5%	47.1%	11.8%	3.3%	0.3%
8. Windows are opened or it is impossible to close them even if it is cold inside and the heating system is on.	19.0%	44.0%	21.3%	13.9%	1.8%
9. Overheating with the heating system on.	26.4%	41.0%	18.5%	12.3%	1.8%
10. Cold inside with the heating system off.	10.5%	27.3%	30.9%	23.4%	7.9%

Table V. Individuals' concerns about sustainable behaviours.

Sustainable behaviour	Proportion of responses for each level					Mode
	Not concerned	Little concerned	Concerned	Very concerned	Highly concerned	
1. Turning off the tap after use.	0.5%	2.3%	11.8%	22.3%	63.1%	5
2. Alerting staff of a damaged tap.	4.9%	18.4%	37.1%	21.2%	18.4%	3
3. Turning off the lights when leaving the WC.	6.1%	16.4%	20.7%	25.3%	31.5%	5
4. Turning off the lights when leaving the classroom.	8.8%	21.0%	19.7%	22.0%	28.5%	5
5. Alerting staff of a blown lamp.	25.1%	39.8%	19.6%	8.8%	6.7%	2
6. Checking if the computer is off when leaving the classroom.	13.7%	22.5%	22.8%	18.7%	22.3%	3
7. Checking if the projector is off when leaving the classroom.	16.8%	29.8%	19.7%	14.8%	18.9%	2
8. Turning off the computer when it is no longer necessary in the classroom.	12.4%	27.7%	30.6%	16.8%	12.5%	3
9. Turning off the projector when it is no longer necessary in the classroom.	16.0%	28.3%	25.9%	16.2%	13.6%	2
10. Turning off the public computer in the ITC room after using it.	12.7%	21.7%	28.4%	17.0%	20.2%	3
11. Opening curtains to allow solar heating during winter.	17.2%	28.3%	26.2%	17.8%	10.5%	2
12. Closing windows if it is cold inside.	1.3%	5.8%	18.8%	38.1%	36.0%	4
13. Closing windows if the heating system is on.	2.9%	9.1%	26.4%	33.2%	28.4%	4
14. Closing doors if the heating system is on.	2.3%	10.1%	27.7%	31.6%	28.3%	4
15. Turning off the heating devices at the end of the day.	33.6%	27.8%	18.5%	10.8%	9.3%	1
16. Putting waste in the right place for recycling.	7.9%	10.2%	20.5%	26.1%	35.3%	5