Achieving university campus sustainability with nearly zero energy building retrofits

Paula Fonseca
Institute of Systems and Robotics
Dep. of Electrical and Computer Engineering
University of Coimbra
Polo II, 3030-290 Coimbra
Portugal
pfonseca@isr.uc.pt

Pedro S. Moura
Institute of Systems and Robotics
Dep. of Electrical and Computer Engineering
University of Coimbra
Polo II, 3030-290 Coimbra
Portugal
pmoura@isr.uc.pt

Humberto Jorge
Institute for Systems Engineering and Computers
Dep. of Electrical and Computer Engineering
University of Coimbra
Polo II, 3030-290 Coimbra
Portugal
hjorge@deec.uc.pt

Anibal de Almeida
Institute of Systems and Robotics
Dep. of Electrical and Computer Engineering
University of Coimbra
Polo II, 3030-290 Coimbra
Portugal
adealmeida@isr.uc.pt

Keywords
public buildings, energy efficiency improvements, lighting, zero energy buildings, renewable generation

Abstract
University campuses are normally constituted by large buildings responsible for significant energy consumption. Furthermore, Universities face several challenges due to the shrinking budgets and rising energy costs. These pressures are a clear motivation to implement energy efficiency programs. University buildings are also suitable as demonstration sites of sustainable renovation, since they will be directly visible examples for the students that will soon use their knowledge in the community.

In the last five years, the University of Coimbra took several measures to foster energy efficiency, such as energy audits, large-scale retrofit of lighting systems, power factor correction and general improvements in electrical loads. Recently, the University of Coimbra has also started to install PV power in several buildings.

The Electrical Engineering Department has been the testbed for the installation of new technologies. The building was constructed in 1996 and is composed by 9 floors, with a total area of about 10,000 m^2 and an electricity consumption of about 520 MWh/year. During the last 5 years, the lighting (previously mostly based on T8 lamps) was gradually replaced by LEDs. Additionally, the control of the lighting and HVAC by Building Management System also achieved significant electricity savings of about 10 % of the total electricity buildings consumption. The next step will be to transform the building in a nearly Zero Energy Building, by installing PV panels with enough capacity to ensure a large share of the yearly electricity consumption.

This paper presents the building renovation plan, presenting details of the technical design and assessing its impacts. With such renovation plan, 20 % of energy savings were achieved with 37 % of the consumed energy ensured by onsite photovoltaic generation.

Introduction
As one of the oldest Universities in Europe, 726 years old, the University of Coimbra (UC) is composed by historic buildings, as well as by modern and relatively efficient buildings. The Electrical Engineering Department (DEEC) building was constructed in 1996, few years after the first building code requiring minimum thermal performance (RCCTE) was enacted in Portugal (ADENE, 2017). Although the code was important at that time, its performance requirements were not very demanding and therefore, the building offers several opportunities for energy renovation improvements.

Regarding the legal framework for existing buildings, several legislative initiatives have been introduced for building renovation. The 2010 Energy Performance of Buildings Directive (EPBD) introduced the requirement of implementing energy efficiency measures for major renovations in order to encourage more ambitious renovation (EC, 2010a). The EPBD also asked EU Member States to introduce cost-optimal energy performance requirements that can be used for new buildings, as well as for renovation activities. Moreover, the EPBD recast in 2010, introduces the smart integration of nearly Zero Energy Building (nZEB) Renovation measures and deployment of Renewable Energy Resources (RES) in the European renovation market. The Directive requires that by the end of 2020 all new buildings should be nearly Zero Energy, being the deadline even sooner (by the end of 2018) for the buildings occupied or owned by public authorities. Member States shall draw up national plans for increasing the number of nearly zero-energy buildings, which should include a numerical indicator in primary energy expressed in kWh/m^2 year. Portugal has not yet defined such indicator, but in the countries that have defined numerical indicators, they range from 0 to 220 kWh/m^2 year (ECEEE, 2017). Therefore, this work has considered an average of 110 kWh/m^2 year and the conversion factor from electricity to primary energy in Portugal of 2.5 (EDP, 2017), leading to an electricity consumption of 44 kWh/m^2 year.

Even though there is no overall energy efficiency plan nor a specific reduction target defined for the University of Coimbra, there is an increasing consciousness towards energy optimization and a strong commitment regarding a good public budget management. The economic crisis which has significantly shrunk the public budgets and increased energy taxes, namely the rise of electricity VAT from 6 to 23 %, had a major impact in the final energy bill. Driven by the economic constraints and in order to set the example to the community, during recent years, the University took several measures to foster energy savings and energy efficiency, such as energy audits in several buildings, power factor correction or retrofit of lighting systems and electrical systems in general.

There is a strong will in the University of Coimbra to integrate the most advanced technologies for energy generation, storage, and consumption in parallel with a transportation planning strategy, as well as the use of digital tools in order to help transforming this part of the University into a sustainable campus. By promoting a creative participation of all people across campus (professors, staff, students) that directly or indirectly impact energy use, the University of Coimbra is raising a strong commitment and engagement within its community towards an efficient use of resources. Being a public University which relies on state funding and having as its mission both to teach and to research, the University of Coimbra, is in a privileged position to engage people with projects and ideas by empowering future generations towards a more sustainable society. Universities are requested to respond to the need of preparing the skilled workers for the present and future challenges that sustainable development brings to society (Klimova et al., 2016). Therefore, not only leading by example but also educating the future generations with energy related courses included in the curriculum, and promoting large scale participation of students in integrated and structured energy and environmental projects, with the help of available digital tools, is part of a broader strategic goal to transform the University of Coimbra into a Sustainable Campus.

In an electrical engineering department, because of its nature, there is an additional motivation towards raising awareness and students' engagement with sustainability issues. Therefore, the Electrical Engineering Department building has been the testbed for the installation of new technologies. The perception of good conservation of buildings associated with reduced budgets for renovations were the main causes for postponing energy renovation measures. However, some measures have been implemented, and during the last 5 years, the lighting (previously mostly based on T8 lamps with conventional magnetic ballast) was gradually replaced by LEDs. Additionally, the control of the lighting and Heating, Ventilation and Air Conditioning (HVAC) was also improved in the Building Management System (BMS) leading to significant electricity savings. The next step will be to transform the building into a nearly Zero Energy Building, by installing photovoltaic (PV) panels with enough capacity to ensure a large share of the yearly electricity consumption and by implementing additional measures to reduce the energy demand. Therefore, the objective of work described in this paper is the development of a renovation plan for the DEEC building able to ensure an overall net energy consumption reduction higher than 30 % by 2020, in line with the National legislation for public buildings (Eco.Ap, 2011), as well as a high share of renewable generation (higher than 30 % of the consumption) and a low specific energy consumption (lower than 44 kWh/m^2 year).

Other universities have already implemented related projects in their campus. In the Smart Campus at University of Brescia the classroom building is used as demonstrator of the energy strategies to improve the performance of existing buildings toward zero energy goals (Angelis et al., 2015). In the "Sustainable Campus at Técnico" project, with the development of energy audits and the implementation of low cost and awareness-raising measures, a reduction of 15.5 % on the energy consumption was achieved (Ferrão and Matos, 2017). Cornell´s Ithaca campus already reached a 30 % reduction in campus emissions through energy conservation, campus energy supply, and creating a culture of sustainable behaviour and advancing climate literacy. Campus energy neutrality requires engagement from every member of the community: passions of students, faculty and staff in research opportunities, multidisciplinary teaching and living laboratory projects (Cornell, 2016). However, such examples have not yet achieved a low energy consumption and a high share of renewables, as is the objective of the presented paper. Other studies using the university buildings as demonstrators towards zero energy goals, base the improvement measures to reduce energy demand in the envelope refurbishment. The DEEC retrofit did not consider modifications in the building envelope because the relatively new construction and the good thermal properties of the building which walls are made of solid concrete with an outside layer of thermal insulation, giving the building a good thermal inertia.

To achieve NZEBs a wide range of technologies, systems and solutions with varying degrees of complexity and sophistication are required. Energy optimization of the different energy end-uses is the first step to address it and a mix of strategies and collaboration between different partners is required to reach a zero energy building (Habash et al., 2014). Innovative systems to reduce energy consumption (heating, cooling and ventilation, lighting, computers, servers and electric equipment) and smart automation are crucial elements for smart campus. A systems approach is a sustainable design method that integrates across site planning, architectural design, building engineering (Shan and Jones, 2016). The four aspects (three pillars and one transversal action) of the used approach are represented in Figure 1.

This study is based on the conceptualization of a system approach for the whole University Campus focusing four aspects: reduce energy demand, integration of RES and storage, raising-awareness and behavioural aspects and decision making processes. The paper focus on the actions already carried out in the

DEEC and analyses the improvements considered to achieve a nearly Zero Energy Building. Besides the several energy conservation measures that have been implemented during the last five years, the paper presents a local generation energy system based on a PV that has been just installed, and an energy storage system to be implemented in the near future, designed in the context of a tertiary sector building (public University). The objective of such system is to contribute to the reduction of the net energy demand from the grid and to contribute to the matching between the local generation and consumption. Moreover, two different scenarios with measures to be implemented in the near future, in order to achieve a NZEB building, are also presented.

The remainder of the paper is structured as follows. Section 2 presents the current conditions of the building. Section 3 presents the proposed renovation actions for energy demand reduction and Section 4 presents the renewable energy generation and energy storage actions. Section 5 assesses and discusses the impacts. Finally, Section 6 summarizes the paper, emphasizing its main conclusions.

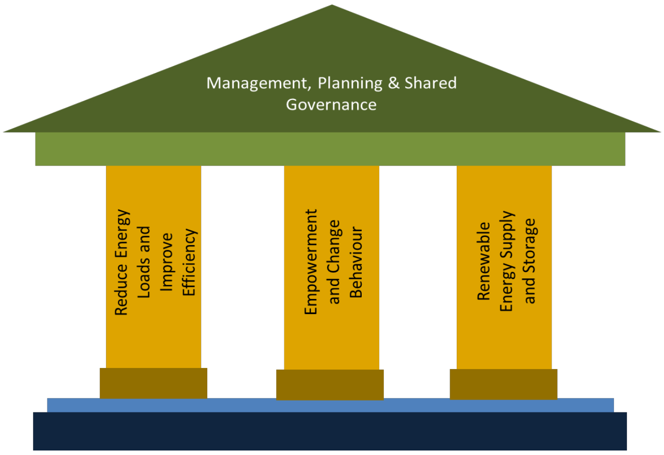


Figure 1. Four aspects of the systems approach.

Baseline characterization

The DEEC building was constructed in 1996 and is part of the new Faculty of Sciences and Technology campus. The building is constituted by two main blocks: one larger block that is composed by 9 floors and divided in 5 towers and a smaller block divided in 3 towers (Figure 2). The building comprises classrooms, Professors' offices, laboratories, administrative services, study rooms, bar, copy shop and garage. Beyond the department services, three private non-profit research institutes associated with the University are located in the building.

Electricity use has been gradually decreasing in recent years (2010–2016), as can be seen in Figure 3. This positive achievement is due, in significant part, by controlling the use of HVAC in classrooms and lighting in public areas as well as due to the energy conservation measures that have been implemented. This was achieved by increasing energy efficiency of the existing loads on one hand and raising awareness towards better energy behaviour on another hand The first aspect was to reduce the energy demand by adjust the existing Building Management System (BMS) to the profile needs of the users, avoiding all types of wasting energy, and also by shifting the loads, whenever possible, to match the night tariffs and reduce peak hours' consumption. Lighting in corridors is centrally controlled and there are also presence sensors installed in some less used areas. In parallel, a software tool was developed in order to show online the actual energy use within the building to occupants and visitors. There is one TV screen in the main entrance hall of the building and another one in the cafeteria with such information.

A second aspect was to reduce the electricity consumption by using energy efficient equipment and lighting. As an engineering department, the main load within the building is Information and Communications Technology (ICT) equipment, namely computers, computers screens, laptops, servers, office equipment (printers, scanners, photocopiers), etc. and the renovation process of such equipment by more efficient ones, not only when the equipment went out of order, but also with massive replacement of ICT equipment, within the budget cap for equipment renovation, has ensured a large consumption reduction.

However, despite such evolution, in order to have a relevant impact, more efforts are needed to achieve a higher decline in energy use and achieve a nZEB level. Hence, a broader energy analysis is underway in order to identify several potential savings in terms of cost-effective efficiency policies and to identify what needs to be done to reach higher energy savings.

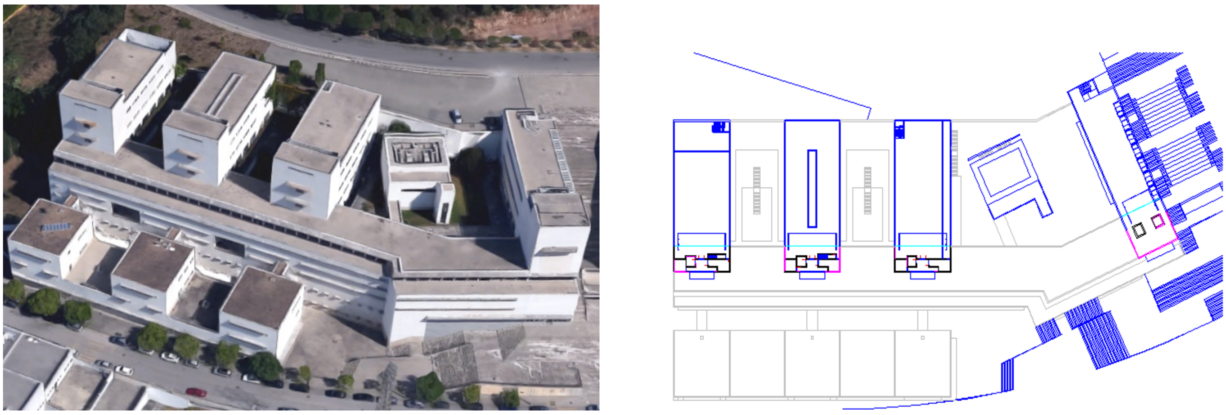


Figure 2. Building and building plant.

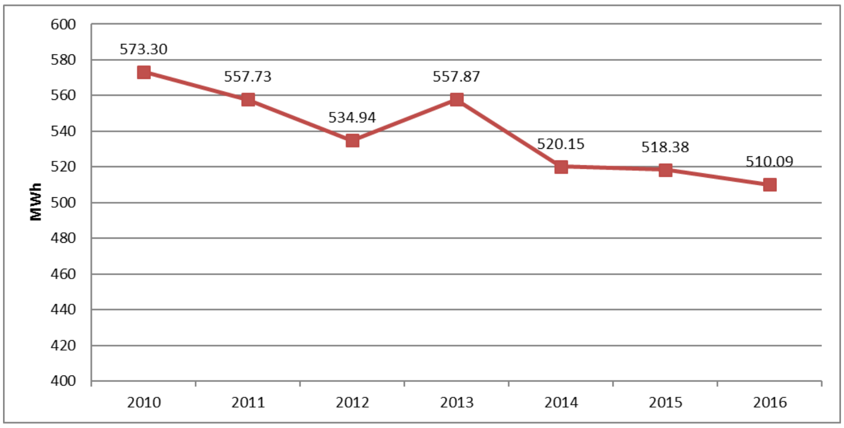


Figure 3. Electricity consumption per year.

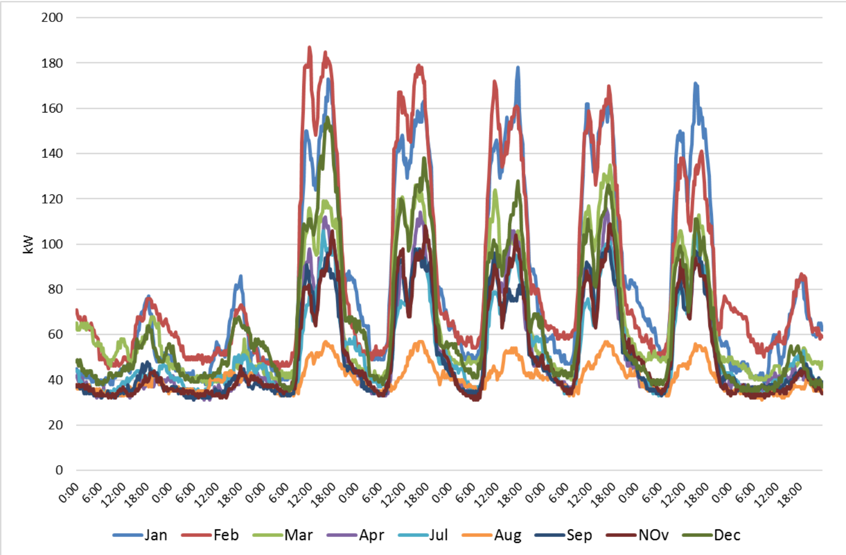


Figure 4. Week load diagrams in several months of 2015.

Reducing energy demand

The baseline considered for the evaluation carried out was the electricity consumption in 2015. Based on light energy audits recently carried out, including a walking thought lighting assessment audit of types of lamps, power and use profile, on the smart metering data delivered by the electricity company operator and on the existing BMS, it was possible to make a better diagnose of the electricity consumption within the building and obtain a better picture of the energy efficiency potentials that exist. A rough estimation of the disaggregation of end-uses indicates that ICT loads represent more than half of the building consumption, followed by lighting. The study did not consider any envelope renovation because the actual envelope presents a good performance and since there is no central HVAC system and the consumption with HVAC devices is low, any improvement measures in the building envelope would not be cost-effective.

ELECTRICITY CONSUMPTION REDUCTION

Further to the overall tendency of electricity consumption decrease after 2010, by analysing the load diagram for the years 2009 and 2015, in Figure 4, a shift of the load curve is noticeable, since the base load moved upwards and the maximum consumption values have generally decreased. These good results are explained by the replacement of part of the Fluorescent T8 lamps by LED lamps in the amphitheatres and in some corridors, as well as the large scale replacement of CRT monitors and inefficient computers in classrooms and laboratories by more efficient equipment.

The night consumption is mostly related to the data centre, ICT equipment and HVAC. However, when comparing one-week consumption in February or January and one-week consumption in August, when the building is closed, or with one-week consumption in December or November, it can be concluded that, on contrary of what was expected, in February and also in January, the night consumption is higher. This phenomenon can be explained by the utilisation of this building by master and PhD students, who are allowed to stay in the building during the night. Looking at the weekly load diagrams in Figure 5 it is possible to see their impact in the total night consumption increase in winter, mostly probably due to the use of individual heating devices.

One interesting result of this comparison is the positive impact of the labelling (EC, 2010a) and eco-design (EC, 2013) policies of products in the electricity consumption. Besides the lighting retrofitting by LEDs, several hundreds of PCs existing in classrooms and laboratories have been all replaced by LCD models, in the last couple of years, with minimum energy efficiency requirements. This was a result of a procurement process within the University, in line with the EU law, imposing central governments and EU Institutions, to purchase office equipment with energy efficiency levels at least equivalent to ENERGYSTAR (EC, 2012). Furthermore, students use more often their own laptop which also use less energy than PCs. Another interesting result is the slope in the load diagram during the two weeks of summer holidays in August 2015, when the building was closed. Although this was a direct result of a human resource management related measure undertaken by the University, its impact in the overall consumption of the building was very positive.

LED LAMPS AND CONTROLS

The actual lighting system is constituted by fluorescent linear T8, compact fluorescent lamps with separate magnetic ballasts, halogen spots and halogen projectors. The retrofitting of lighting in order to replace all lighting within the building was planned for two phases. The first phase, already carried out, was the replacement of the lamps with more operating hours and less efficient lamps. This phase ensured a decrease in the total installed power of 12.7 kW (Table 1) and a reduction on the electricity consumption of 27.1 MWh/year (91.5 % of savings). The impact of this renovation measure is significant because the number of lamps and, in some cases, also the number of luminaires, has been reduced without impact in the quality of the service, since the original lighting system was oversized.

The next phase, already planned, is going to be the replacement of all remaining 1,422 lamps by LEDs, ensuring a decrease on the total installed power of 51.55 kW (Table 2). The energy consumption was simulated considering the actual usage profile for each lamp type and room of the building and the renovation ensures 76.45 MWh/year (62.6 %) of savings.

INDOOR COMFORT

There is no central heating, cooling or ventilation system running. The building has a heating system powered by natural gas, but this system has been out of order for many years. Because of the mild weather of Coimbra, as can be seen by the average temperatures in Figure 6, and short heating season, this load has been neglected. However, analysing Figure 7, it is clear a negative correlation between the average temperature (independent variable) and the consumption (dependent variable). With such data, a correlation coefficient of -0.849 was obtained, showing a good indicative of the dependency between the electricity consumption and the average temperature. Therefore, in relation to the heating loads, there is a need for action. Due to the lack of a central and controlled heating system, heating is based on individual heating devices (resistance and fan-ventilators) and heat pumps, which are controlled manually, according to each individual comfort standard and wish. Moreover,

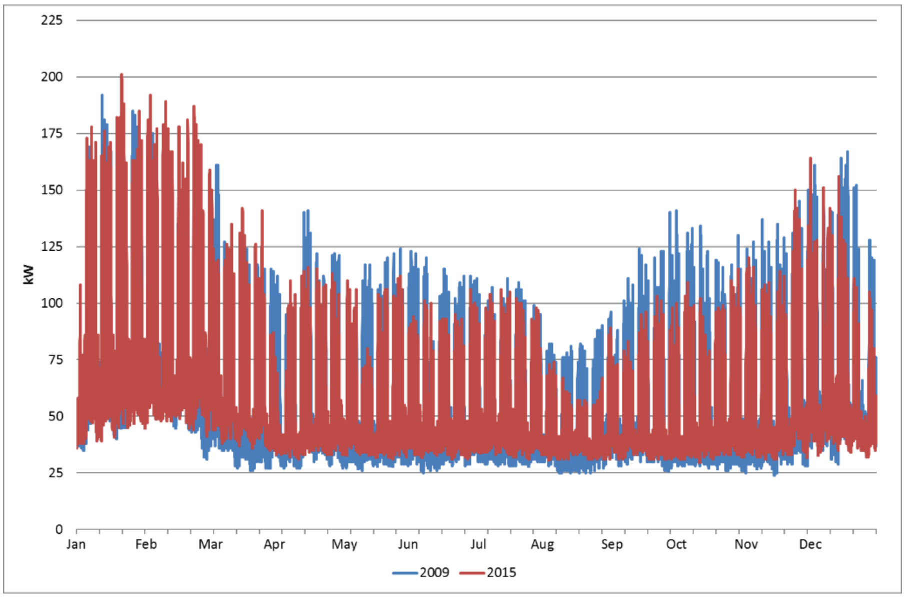


Figure 5. Load diagram for the years 2009 and 2015.

Table 1. Types and quantity of lamps considered in the lighting renovation – Phase 1.

Actual			*Renovation*		
Lamp	***Quantity***	***Power (W)***	***Lamp***	***Quantity***	***Power (W)***
Fluorescent Linear T8 F120	60	2,590	LED Linear F120	36	130
Compact Fluorescent	30	940	LED Spots	20	70
Halogen Spot	72	10,800	LED Spots	72	1,440
Total	**162**	**14,330**	**Total**	**128**	**1,640**

Table 2. Types and quantity of lamps considered in the lighting renovation – Phase 2.

Space	*Actual*			*Renovation*		
	Lamp	*Quantity*	*Power (W)*	*Lamp*	*Quantity*	*Power (W)*
Classrooms	Fluorescent Linear T8 F120	30	1,300	LED Linear F120	30	600
	Fluorescent Linear T8 F150	168	11,690	LED Linear F150	168	4,030
Corridors	CFL13	40	620	LED SPOT	40	140
	HP Sodium Projectors	8	2,400	LED Projector	8	640
	Fluorescent Linear T8 F120	24	1,040	LED Linear F120	24	480
Adm. Services	Fluorescent Linear T8 F120	44	1,900	LED Linear F120	44	880
	Fluorescent Linear T8 F150	4	280	LED Linear F150	4	100
Cafeteria	Fluorescent Linear T8 F120	20	860	LED Linear F120	20	400
	CFL13	28	440	LED Spot	28	100
Prof. Offices	Fluorescent Linear T8 F120	288	12,440	LED Linear F120	288	5,760
R&D Labs	Fluorescent Linear T8 F120	84	3,630	LED Linear F120	84	1,680
	Fluorescent Linear T8 F150	152	10,580	LED Linear F150	152	3,650
Teaching Labs	Fluorescent Linear T8 F120	40	1,730	LED Linear F120	40	800
	Fluorescent Linear T8 F150	368	25,610	LED Linear F150	368	8,830
Other offices	Fluorescent Linear T8 F120	24	1,040	LED Linear F120	24	480
	Fluorescent Linear T8 F150	100	6,960	LED Linear F150	100	2,400
	Total	**1,422**	**82,520**	**Total**	**1,422**	**30,970**

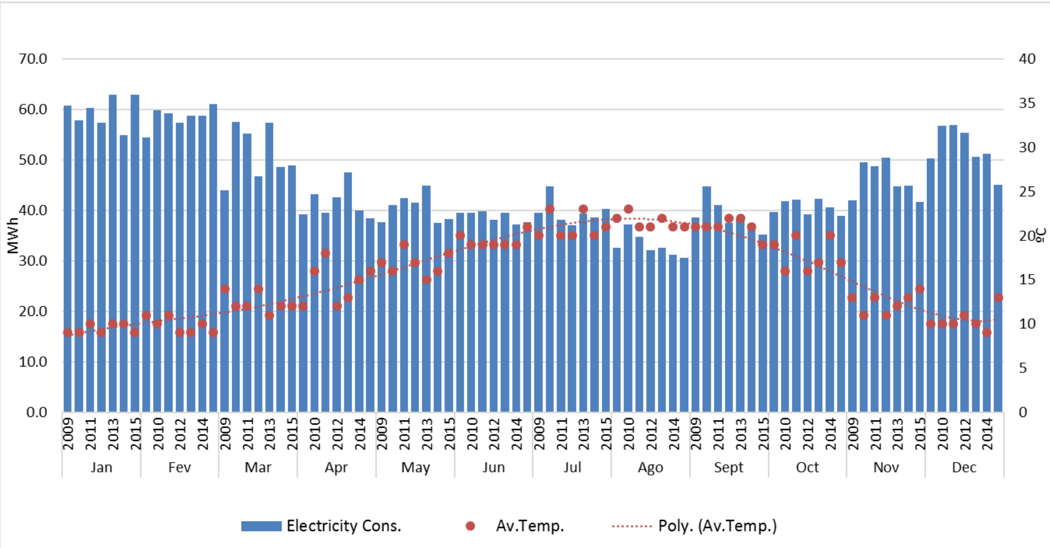


Figure 6. Electricity consumption per month, over the last years, and respective average temperatures.

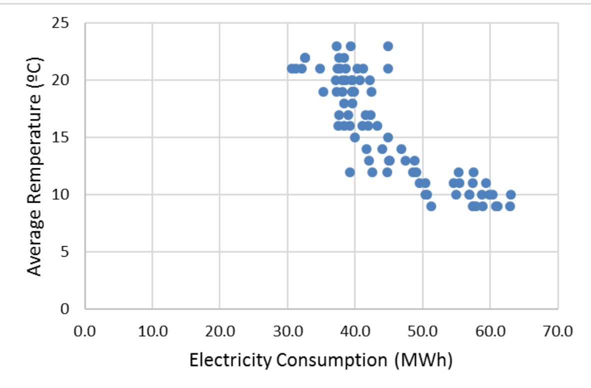


Figure 7. Average temperature versus electricity consumption per month.

the rising in the maximum temperatures achieved in the last years, anticipate a rise in cooling consumption in summer as well.

AWARENESS RAISING CAMPAIGNS

Education has played and continues to play an important role when it concerns to sustainable consumption (Fisher and Rieckmann, 2010). Promoting an efficient behaviour towards energy reduction by advertising campaigns based on the display of current energy use, online information, printed signs close to elevators and lighting switches have long been implemented within the DEEC building. Besides acting on reducing own consumption, as (Álvarez-Suárez et al., 2014) pointed out, the universities can also act at larger scale by introducing cross-curricular teaching modules designed to promote environmentally-aware patterns of consumption. At the DEEC, the inclusion of sustainability issues in engineering curricula is in place for more than a decade, with a significant number of students carrying out their master thesis on energy and environment related subjects.

Actions to take benefit of digital tools and IoT (Internet of Things) through the promotion of behaviour change among students and staff are very important, as well as developing creative ideas to use shared governance to integrate sustainability into higher education buildings. It is well known that shared governance may limit the agility and flexibility of institutions in enabling a transformation towards sustainability (Kurland, 2014), but local authority staff of faculty/departments may have a powerful influence on the legal authority of administrators.

However, there are still challenges and obstacles. Universities play a part in promoting sustainability trough socially responsible actions, but there is still lack of commitment to promote energy efficiency on the part of some university managers, educators and students. Individual sustainability initiatives carried out by university researchers and faculty are of a great value, but this will tend not to have a significant effect on global campus sustainability performance, if detached from the core operations of the campus (Ferrão, 2017). One solution may be to see energy efficiency not only as teaching to start a new business but also, more broadly, creatively making an idea to happen. Moreover, to address the challenges and obstacles of the persistence of savings problem, there is a need for continuous and regular awareness raising campaigns focusing energy efficiency and sustainability. Continuous awareness campaigns are needed to maintain energy conservation behaviours.

Renewable energy generation and storage

The building has a large flat roof with a good orientation. In a first assessment, the main areas without shading and without visual impact (avoiding the front areas) were selected, as presented in Figure 8(a). Considering PV panels with 270 Wp, it is possible to install 732 panels in such area, leading to an installed power of 197.64 kWp. The designed PV system was simulated using Sunny Design 3 (SMA, 2017) being the assessed annual energy generation 282 MWh, representing 54.4 % of the actual energy consumption.

It would also be possible to achieve a higher generation level, since there are several other roof areas that could be used. However, such generation level is only able to ensure a self-consumption of 183 MWh (representing 64.9 of the annual generation and 35.3 % of the annual consumption) cover for the building's own energy need of 518 MWh. Therefore, 99 MWh (35.1 % of the generation) would have to be injected into the grid. Despite the higher consumption in the building during the hours of higher generation, the building has a low consumption during weekends and during July and August, due to the summer vacations, leading to generation surplus during such periods. From the economic point-of-view, this is a problem since the price paid by the consumed energy is much higher than the price received by the energy injected into the grid (MEE, 2017). With the new Portuguese regulation to self-consumption of locally generated electricity, the energy injected into grid is paid only with a price of 90 % of the monthly average price of the Portuguese spot electricity market and the average price paid during 2015 was only €0.0453/kWh. Therefore, a high generation level is possible, but not cost-effective and a new scenario was considered using the areas presented in presented in Figure 8(b).

Areas 1 and 2 are oriented to South and areas 3 and 4 are oriented to South-southwest (with 25 º). In area 2 the PV panels were oriented to south with a slope of 13 º (smaller than the optimum slope of 33 7 º, in order to minimize the visual impact) with a distance between lines of panels of 1.32 m, using the structure presented in Figure 9(a). With such structure it is possible to install 54 PV panels in area 2, ensuring an installed power of 14.58 kWp. In areas 1, 3 and 4, in order to achieve a high density of PV panels and to maximize the energy generation during the early morning and late afternoon, a structure oriented to East-West was used, as presented in Figure 9(b). With such structure it is possible to install 76 PV panels in area 1, 162 panels in area 3 and 100 panels in area 4, ensuring an installed power of 20.52 kWp, 42.74 kWp and 27 kWp, respectively. Therefore, a total of 392 PV panels and a peak power of 105.84 kWp was considered.

Table 3 presents the technical data of the designed PV system. As can be seen the system has an active power of 92 kW and ensures in average a generation of 152.6 MWh/year, with a

(a) (b)

Figure 8. Considered PV Panels Areas in Scenario 1 (a) and Scenario 2 (b).

(a) (b)

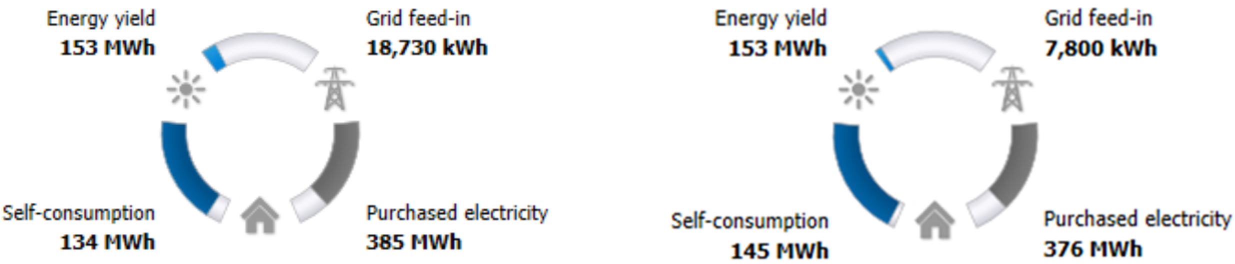
Figure 9. Structure of the PV panels installed in area 2 (a) and in areas 1, 3 and 4 (b).

Table 3. Technical data of the PV system.

Total number of PV modules	392
Peak power	105.84 kWp
Number of PV inverters	5
AC active power	92.00 kW
Active power ratio	86.9 %
Annual energy yield	152.61 MWh
Energy usability factor	99.6 %
Performance ratio	88 %
Spec. energy yield	1,442 kWh/kWp
Battery Capacity	100 kWh

Table 4. Impact with the PV system and energy storage.

	PV	***PV + Storage***
Annual energy consumption	518 MWh	518 MWh
Annual energy yield	153 MWh	153 MWh
Grid feed-in	18,730 kWh	7,800 kWh
Purchased electricity	385 MWh	376 MWh
Self-consumption	134 MWh	145 MWh
Self-consumption (in % of PV)	87.7 %	94.9 %
Self-sufficiency (in % of consumption)	25.8 %	27.5 %



(a) (b)

Figure 10. Distribution of PV energy without (a) and with (b) energy storage.

specific energy yield of 1,442 kWh/kWp. In order to maximize the self-consumption, a battery system using lithium-ion batteries with a capacity of 100 kWh was also included for storage of the generation surplus generated during weekends.

The annual generation of 152.6 MWh represents 29.5 % of the existing energy consumption. As can be seen in Table 4, the energy storage system is able to reduce the energy injected into the grid from 18.7 MWh to 7.8 MWh, therefore increasing the self-consumption from 134 MWh (representing 87.7 % of the annual generation and 25.8 % of the annual consumption) to 145 MWh (representing 94.9 % of the annual generation and 27.5 % of the annual consumption).

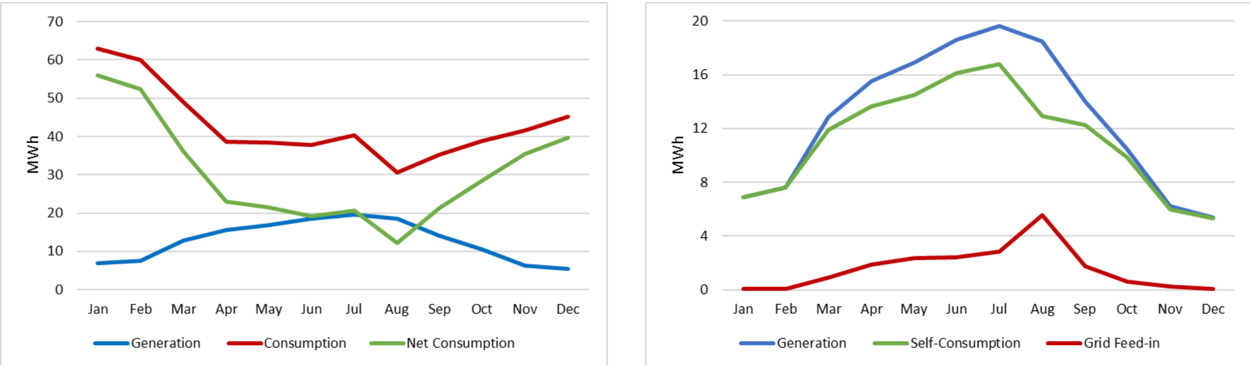
Figure 10 presents the distribution of PV generation (between self-consumption and grid feed-in), as well as the impact on the purchased energy considering scenarios with and without energy storage. Figure 11 presents the yearly variation of the energy generation and consumption, as well as the net-energy consumption, being visible the low net-energy consumption during Summer (mainly in August). It is also presented the distribution between the energy generation used for self-consumption and injected into the grid. As can be seen, during Winter months almost all the generation is used for self-consumption. However, during Summer a high share of the energy has to be injected into the grid, due to the simultaneous increase of solar radiation and decrease of consumption level. The injection of generated energy into the grid is mainly concentrated during weekends, due to the low energy consumption. The impact on the maximum load in each month is also presented in Figure 12, showing not only a lower maximum load, but also a higher impact on its reduction due to self-consumption during Summer.

Figure 13 presents daily average variation of the consumed energy with and without self-consumption. As it can be seen, in August, due to self-consumption, the average energy consumption, between 9 h and 16 h is almost zero. It can be noticed from the daily average variation that most of the impact of the generated energy on the purchased energy occurs between 8 h and 20 h. The self-consumption ensures a reduction of 27.4 % on the annual purchased electricity. However, considering only the electricity purchased between 8 h and 20 h the reduction of the annual purchased electricity is 40.5 %.

Impact Assessment

There are several strategies underlined to progressively transform the DEEC building into a shining demonstrator example. Among the several strategies to manage and control the electricity consumption in the building, the current practice consists on energy consumption assessment and preliminary operational monitoring, by means of collecting raw data from telemetering load diagrams, which are available for the last 6 years (2009–2016). Based on such data, the main cost-effective identified measures to be implemented in large scale were the lighting retrofit and the installation of PV panels.

Table 5 presents the achievable yearly savings, generation and net-energy consumption (difference between the energy consumption and generation) in each scenario (considering the baseline, renovation of lighting, installation of PV, as well



(a) (b)

Figure 11. Yearly variation of the generation, consumption (a), self-consumption and grid feed-in (b).

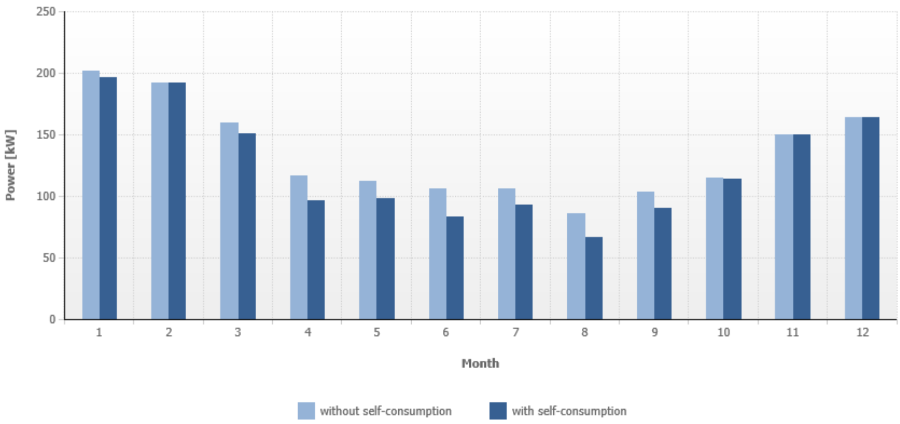
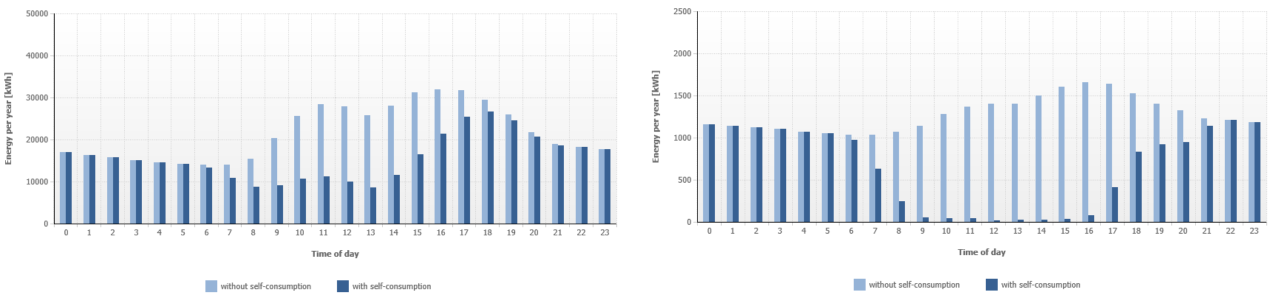


Figure 12. Maximum load in each month with and without self-consumption.



(a) (b)

Figure 13. Daily variation of the consumption with and without self-consumption – yearly (a) and August (b).

Table 5. Consumption, generation and net consumption.

Scenario	Consumption (MWh/Year)	Savings (MWh/Year)	Generation (MWh/Year)	Net-Cons. (MWh/Year)
Baseline	518.00	–	–	518.00
Lighting – Phase 1	490.90	27.11	–	490.90
Lighting – Phase 2	441.55	76.45	–	441.55
PV	–	–	152.61	365.39
Total	**414.45** **80.0 %**	**103.55** **20.0 %**	**152.61** **36.8 %**	**261.84** **50.5 %**

Table 6. Final energy and CO_2 emissions savings.

Scenario	Final Energy (MWh/Year)	Specific Energy (kWh/m²Year)	CO_2 Emissions (kg CO_2 /Year)
Baseline	518.00	51.80	72.463
Retrofit	261.84	26.18	36.628
Savings	**256.16** **49.5 %**	**25.62** **49.5 %**	**35.835** **49.5 %**

as the total renovation considering lighting and PV). As can be seen, with the total renovation of lighting 20 % of energy savings are achieved and the installed renewable generation is able to ensure 36.8 % of the consumption, decreasing the net-energy consumption to 50.5 % of the baseline.

The results were also assessed in terms of final energy, specific energy and CO_2 emissions, considering a conversion factor from electricity to CO_2 emissions of 139.89 g CO_2/kWh (EDP, 2017). As can be seen in Table 6, the tangible improvement measures ensure 49.5 % savings, decreasing the energy density of the building to only 26.18 kWh/m² year.

Conclusions

The best way to improve the performance of existing buildings towards zero energy is an integrated approach of different energy strategies, running in parallel, that tackle behaviour, efficiency of equipment, in site RES generation and energy storage (Ferreira, 2016). Innovative systems to reduce energy consumption, production and storage, as well as smart monitoring, automation and control are key drivers for existing buildings.

This paper presented the renovation plan for a University campus building, designed with the aim to achieve a very low energy consumption, which is met by a high share of renewable generation and a. The baseline was characterized based on light energy audits, on the smart metering data and on the existing BMS data. It was concluded that during the last 5 years, the electricity consumption has been decreasing as result of some implemented measures and the consumption considered to the baseline was 518 MWh/year. This research shows that the EU directives and regulations, in particular MEPs and labelling for lighting and office equipment have a significant impact on the decrease of electricity consumption in University buildings. Although the positive impact of eco-design in the maximum peak load, the typical load diagram of the DEEC shows a high base load which has been increasing due to the increasing number of servers and ICT equipment, indicating the need for further efforts on this particular load. Moreover, new challenges and needs are coming together with on-site electricity generation to pursue an energy balance between generation and consumption.

The main measure to be implemented in the short term is the large scale replacement of remaining lamps by LEDs. This improvement measure will yield significant energy savings of about 63 %, ensuring 76 MWh/year of energy consumption reduction, with a short payback time of 2 and half years. A PV system with 105.84 kWp of installed power was also designed, ensuring a generation of 152.61 MWh/year. In order to maximize the self-consumption, the use of a battery system using lithium-ion batteries with a capacity of 100 kWh was also analysed, ensuring 145 MWh of self-consumption (representing 94.9 % of the annual generation). Higher levels of generation would be possible, but this would increase the level of energy injected into the grid that is paid by the grid with a very low price, therefore decreasing the cost-effectiveness of the PV system. The total impact of the renovation achieved so far was assessed, being the achieved energy savings 20 % with 36.8 % of the consumed energy ensured by the PV system. This will ensure a reduction of the energy density of the building to only 26.18 kWh/m², with 49.5 % savings on the net-energy consumption.

References

ADENE, "Regulamento das Características de Comportamento Térmico dos Edifícios", http://www.rccte.com/, Accessed 06-01-2017.

Álvarez-Suárez, P., Vega-Marcote, P., Garcia Mira, R., "Sustainable consumption: a teaching intervention in higher education", International Journal of Sustainability in Higher Education, Vol.15, N1, 2014.

De Angelis, E., Ciribini, A., Tagliabue, L., Paneroni, M., "The Brescia Smart Campus demonstrator. Renovation toward a zero energy classroom building", International Conference on Sustainable Design, Engineering and Construction, Procedia Engineering, 118 (2015) 735–734.

Cornell University, Senior leaders Climate Action Working Group, "Options for Achieving a carbon Neutral Campus by 2030, September 2016.

EC, "Directive 2010/30/EU of the European Parliament and of the Council of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products" Official Journal of the European Union, 153, p. 101–112, Brussels, 18.06.2010.

EC, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings" Official Journal of the European Union, 153, p. 13–35, Brussels, 18.06.2010.

EC, "Energy Efficiency Directive (EED) 2012/27/EU" Official Journal of the European Union, 315, p. 1–56, Brussels, 14.11.2012.

EC, "Commission Regulation (EU) No 617/2013 of 26 June 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for computers and computer servers" Official Journal of the European Union, 175, p. 13–33, Brussels, 27.06.2013.

ECEEE, "Nearly Zero Energy Buildings, http://www.eceee.org/policy-areas/Buildings/nearly-zero-energy-buildings, Accessed 06-01-2017.

EDP, "Electricity Sources" (in Portuguese), http://www.edpsu.pt/pt/origemdaenergia/, Accessed 06-01-2017.

Eco.AP, "O Programa de Eficiência Energética na Administração Pública , Resolução do Conselho de Ministros n.º2/2011 (.http://ecoap.pnaee.pt/ambito).

Ferreira, M., Almeida, M., Rodrigues, A. and Silva, S.A., (2016), "Comparing cost-optimal and net-zero energy targets in building retrofit", Building Research & Information, 442:2; 188–201, DOI: 10.1080/09613218.2014.975412.

Ferrão P., Matos, M., 2017, "Sustainable Energy Campus: A Challenge on Smart Facilities and Operations", W. leal Filho et al. (eds.), Handbook of Theory and Practice os Sustainable development in Higher Education, World Sustainability Series, DOI 10.1007/978-3-319-47895-1_15.

Fisher D. and Rieckmann, M., "Higher education for sustainable consumption: concept and results of a transdisciplinary project course", Journal for Sustainability Education, Vol.1, Nº.1, 2010.

Habash, G., Chapotchkine, D., Fisher, P. and Rancout, A, "Sustainable Design of a neraly Zero Energy Building by a Smart Microgrid", Journal of Renewable Energy, Hindawi, Vol. 2014, Article ID 725850, 11 pages. http://dx.doi.org/10.1155/2014/725850.

Klimova, A., Rondeau, E., Andersson, K., Porras, J., Rybin, A., Zaslavsky, A. 2016. "An international Master´s program in green ICT as a contribution to sustainable development". Journal Cleaner Production. (135) 223–239. http://dx.doi.org/10.1016/j.jclepro.2016.06.032.

Kurland, N., "Shared governance and the sustainable college", International Journal of Sustainability in Higher Education, Vol. 15, Nº. 1, 2014.

MEE, "Renewable Generation Legislation" (in Portuguese), http://www.renovaveisnahora.pt/web/srm/entrada, Accessed 06-01-2017.Shan, H., Jones, P.,"Near Zero Carbon Care Home Design in the UK", 4th European Conference on Behaviour and Energy Efficiency, Coimbra 8–9 September, 2016.

SMA, "Sunny Design 3", www.sma.de/en/products/planning-software/sunny-design-web.html, Accessed 06-01-2017.