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Sustainable engineering labs - A Portuguese perspective

Nídia S. Caetano[a,b]*, Rafael R. Carvalho[c], Francisco R. Franco[c], Carlos A.R. Afonso[c], Carlos Felgueiras[b]

[a]LEPABE, Faculty of Engineering-University of Porto (FEUP), R. Dr. Roberto Frias S/N, 4200-465 Porto, Portugal
[b]CIETI, School of Engineering (ISEP), Polytechnic of Porto (P.Porto), R. Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal
[c]MED, School of Engineering (ISEP), Polytechnic of Porto (P.Porto), R. Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal

Abstract

Strategies to reduce emissions responsible for greenhouse effect, and contributing to economy decarbonisation, should focus on using renewable energy, increasing energy efficiency both at production, distribution and consumption (equipment efficiency), sustainable mobility, urban renewal and rehabilitation and behavioural changes. Considering that man spend a significant part of their lives inside buildings that represent a significant share of energy consumption, buildings turn out to be an attractive area to invest efforts, aiming to improve efficiency, as recommended in the European Commission reports. However, despite the goals outlined in the Energy Performance of Buildings Directive, there are difficulties in the projection of new buildings that can be classified as nearly Zero Energy Buildings (nZEB). These include legal and financial obstacles, as insufficient formation of professionals (such as architects, engineers and consultants) able to tackle the challenges. This paper aims to point strategies that can contribute to the creation of a nearly zero energy laboratory in a university environment, that works as a tool for raising awareness about nZEB while improving the future engineering professionals' skills towards team work and knowledge sharing – a living lab.

Keywords: living labs; nZEB, multidisciplinary work; team work; sustainable laboratories

* Corresponding author. Tel.: +351-228340500; fax: +351-228321159.
E-mail address: nsc@isep.ipp.pt

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1. Main text

The discovery of electricity has changed the daily life of the population, allowing the introduction of appliances and technologies that simplified and contributed to improve their quality of life. Initially, the electrical energy was produced from fossil resources, like mineral coal and petroleum, then from a new and more effective way to produce energy, nuclear power plants, and currently from a mix that includes renewable energy sources, which are seen as a viable and promising way to produce clean energy, with low payback time. However, if the world's energy demand continues to grow at the same pace, our future and that of future generations will be compromised [1].

About 40% of final energy consumption in European Union is spent on buildings [2], what constitutes an opportunity to improve the reduction of energy consumption, with huge gains. This improvement opportunity in building efficiency was highlighted in the European Directive on the Energy Performance of Buildings (EPBD), that stipulates that from 2018 all new buildings owned by public entities will have to be buildings with zero energy needs (nZEB - nearly Zero-Energy Buildings) and, after 2020, all new buildings built in the European Union (EU) will have the same characteristics [3].

The nZEB buildings are able to provide a significant reduction of energy compared to conventional buildings. A nZEB project, requires an integrated design approach to minimize building energy consumption, and at the same time meet the needs of the occupants. Thus, architects, civil and mechanical engineers, energy experts and installers must know the specificities related to nZEB design (standards and new technologies) and work together in multidisciplinary teams, from the very beginning of the conception stage.

The SouthZEB project, funded by the Intelligent Energy Europe (IEE) program, was born to fulfil de necessity of formation of professionals on nZEB matters; this training and certification system resulted from an international consortium involving nine entities from six European countries (Portugal, Cyprus, Greece, Italy, United Kingdom and Austria) with the objective of training at least 150 trainers and 1500 consultants [4].

In Portugal, the concept of nZEB has not yet been clearly defined; however, there is legislation that provides minimum requirements for new constructions and buildings rehabilitation, both in the residential and in the commercial and services sector and establishes the minimum efficiency for technical equipment [5].

A study about energy efficiency in domestic houses, made by ADENE (Portuguese Energy Agency), inquired several people to understand their position on energy efficiency in buildings: regardless these people apply energy efficiency measures in their houses, about 72% showed receptivity and concern about the theme. The inquired people, when asked to define energy efficiency, could not describe it in a formal way, but they associated energy efficiency to reduced energy bills, reduction of waste, lower environmental impact, better quality of life, satisfaction and comfort inside buildings [6].

Although Portugal is reaching the deadline for implementing the European Directive 2010/31/EU, and despite the fact that people recognize that energy efficiency is the way, there are some issues that have been show as barriers in formation of nZEB, in Portugal: due to the crisis, Portuguese Government extinguished the incentives for renewable energy application; the lack of qualified professionals; the lack of information about energy efficiency projects and the classification as high risk investments and limited access to investments funds [5].

The objective of this paper is thus to alert to: 1) the need to achieve buildings with zero or positive energy balance and turn them into reality, and 2) the creation of a specification with a set of strategies and technologies categorized, which will allow obtaining a nZEB laboratorial space used for educational purposes, where students can learn how to work in a multidisciplinary team.

2. The Portuguese path to achieve nZEB

Following the obligation of EU Member States to adjust their national legislation in line with the EPBD 2010, it was published in Portugal, a legislation that establishes more rigid energy efficiency rules to apply to new buildings (Decreto-Lei n.º 118/2013, of August 20) which was amended by Decreto-Lei n.º 28/2016, of June 23.

The energy efficiency in buildings legislation is organized in such a way to cover 2 separate types of buildings: housing buildings and commercial and services buildings where REH (Regulation of Energy performance of Housing buildings) and RECS (Regulation of Energy performance of Commercial and Services buildings) are applied, respectively. These two integrant parts of legislation (REH and RECS) establish minimum building quality requirements by applying limits to the thermal transmission coefficient (U) of opaque and glass enclosure, as well as minimum energy classes for energy consuming equipment in air conditioning area. These 2 parts of legislation promote the energy efficiency in buildings through an Energy Building Certification (SCE) [7].

The qualitative definition for nZEB arises from the *Decreto-Lei* n. º118/2013, defining nZEB as *"a building with almost zero energy needs, those with a very high performance…where the almost zero or very low energy requirements are largely satisfied using energy from renewable sources namely produced on site or nearby"*. Another aspect that complements the definition of nZEB (point 5, article 16º) is that nZEBs should have *"a component compatible with the most stringent level of economic viability that can be obtained by applying the great cost methodology"* [7].

As Portugal is one of the European Countries with the highest number of sunshine hours a year, the high energy consumption that is currently spent on buildings heating and cooling, is not justified when a significant part of this consumption could be easily minimized using adequate construction techniques and technologies. The awarding of energy certification to European buildings is the first important step to understand the energy performance of existing buildings and to improve energy performance in new construction and refurbishment.

In Portugal, the emission of an energy certificate or pre-certificate assumes the attribution of an energy efficiency class that varies from A+ (more efficient) to F (less efficient) by qualified experts. As there is differentiation between the regulation for residential buildings and for commercial and services buildings it is noted that the calculation formula for obtaining the energy class also change. However, there is a common link between the two expressions: the energy class of the building is always obtained in relation to a reference building with well-defined characteristics in the national legislation and taking into account the thermal behavior of the building and the installed equipment (for thermal energy production in REH and thermal energy production and large consumers such as elevators, escalators in RECS). The quotient obtained in both expressions translates the amount of energy consumed by the existing building or in the design phase in relation to the reference building: thus, a building at the design stage, new or subject to refurbishment at most can obtain an energy class of B-, which means that the energy consumed by the building is equal to the reference building [8].

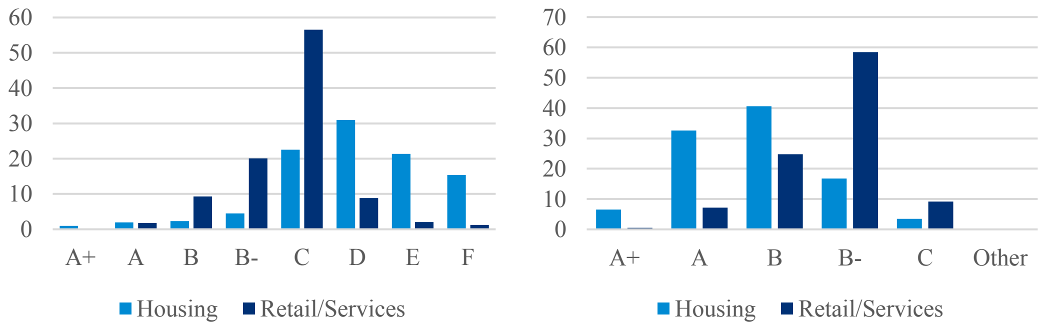

Fig. 1. (left) Energy certificates issued until 2016; (right.) Pre-certificates issued until 2016 (adapted from [8]).

From the graphs in Fig. 1, it is possible to conclude that the predominant energy class attributed to residential buildings is C and D, whereas that for commercial and services buildings is C (both lower than the current legal minimum). Regarding the emission of energy pre-certificates in Portugal until 2016, there was a trend towards the assignment of energy classes A and B for residential buildings and B- (the legal minimum) for commercial and services buildings.

To support the emergence of sustainable buildings, a few voluntary certification systems have been developed worldwide, being the most known LEED [9], BREEAM [10], SBTool [11] and *Passivhaus* [12]. In Portugal, there are also some voluntary systems to certificate buildings: LiderA [13], Domus Natura [14] and the application of SBTool to Portuguese reality, $SBTool^{PT}$ [15].

3. Proposal of a demonstration Zero Energy Laboratory

According to the European Directive, EPBD 2010, as of 31 December 2018, the new buildings belonging to the state must be nZEB and as of 31 December 2020 all buildings constructed must also be nZEB.

Our proposal, the *ZELab* (Zero Energy Laboratory) [16], is an integrated building in a Higher Education Institution, and as such it is mandatory that it is a nZEB, it is expected to be a reference building in the construction of nZEBs in Portugal, used in professional qualification and in teaching of engineering graduates and master students.

Initially the building will be organized into 3 main areas, the utilities unit (compressed air, steam, hot water, etc.), a common space area (meeting rooms, work rooms, sanitary facilities, storage area) and a microbiology and environmental research laboratory. Modular construction was chosen so that prefabricated modules with dimensions 2.5 x 2.5 m^2 can be combined, with the possibility of being added according to the needs of each working area. This decision has advantages in the transportation and construction speed, while allowing a diversity of configurations and constructive solutions.

To achieve a building with almost zero energy needs, in the first phase it is essential to consider the effective energy needs of the building and the possibilities of its reduction; it is also needed to invest in adequate systems with efficient equipment and lighting. The incorporation of technology that guarantees optimization, both thermal and solar gains, and strategic thinking with passive systems and the use of natural factors such as lighting and ventilation, are fundamental. In a second phase, to meet the remaining energy needs, local energy production, using existing technologies, is an option.

The building will be installed in the ISEP (School of Engineering of the Polytechnic of Porto). According to the legislation and considering the local climatic characteristics, the buildings are subject to minimum standards of energy efficiency, air conditioning systems and indoor air quality. Given the climatic zone I1 and V2, an altitude of 113 meters, an average winter temperature of 9.8 °C and an average summer temperature of 20.6 °C, the requirements of the quality of the enclosure are: the maximum thermal transmission coefficient of vertical elements is 0.50 W/(m^2.°C), the maximum thermal transmission coefficient of horizontal elements is 0.70 W/(m^2.°C), the maximum thermal transmission coefficient of glazed spans is 4.30 W/(m^2.°C) and the maximum solar factor of glazed spans is 0.56.

The main energy consumers in buildings are installed equipment, lighting and HVAC systems (heating, ventilation and air conditioning). The thermal behaviour and the consumption related to the climatization depend on the building's architecture, the thermal quality of the constructive solutions, the behaviour of its occupants, the undesirable internal loads, the use regime (permanent or intermittent), the local climatic conditions, geographical location and orientation of the building.

Most buildings are currently designed with the dominant concern of aesthetics, sacrificing energy efficiency. The architecture of buildings, namely the area of glazed spans, distribution and their exposure to direct solar radiation, has a significant influence on energy consumption. In addition to the correct positioning of the building, shading solutions should be used which maximize the direct exposure of the solar rays to the glazing facades in the cooling station and minimize the same gains in the heating season. Wherever possible, elements such as solar chimneys should be included in order to favour natural ventilation.

Regarding the constructive solutions of the opaque envelope, these must contain high quality insulating materials to restrain the thermal loss by the enclosure and to pay special attention to linear thermal bridges. There are also other innovative solutions such as vertical gardens that can be applied and contribute not only to the aesthetic component but also to reduce thermal loads.

Inevitably buildings, and especially the type of building we are dealing with, use a wide variety of equipment, such as office supplies, laboratory equipment, and others. Due to the high density of equipment, in order to achieve the nZEB objective, it is urgent to reduce these consumptions, either by their rational use or by using higher energy efficiency class equipment. In addition to the recurring energy consuming equipment of the activity, the energy consumption of HVAC systems must be reduced. Systems for heating and / or cooling must be of high efficiency, selected from a seasonal efficiency perspective, but without neglecting the energy performance of the equipment under full load. In addition to mechanical air conditioning systems, natural ventilation must be considered, and as such the building must be provided with architectural solutions that allow one to take full advantage of its use.

To achieve the nZEB goal it is necessary to minimize the energy consumption of lighting systems with the application of efficient technologies, such as LED technology. Lighting systems must have a distribution, location and power supply adequate for their function, together with an architectural design to maximize natural lighting with automatic control strategies.

Energy consumption is inevitable, so in a nZEB it is mandatory to produce enough energy, for a time period, usually annual, to satisfy most of its consumption. In relation to energy produced through renewable sources, the issue becomes ambiguous, as there are several sources of renewable energy, such as solar thermal, solar photovoltaic, wind, biomass, biogas, biofuel, geothermal, hydro and tidal, but not all are feasible for application in the building or nearby. In terms of thermal energy from renewable sources, the most viable are solar thermal, biomass and, geothermal energy systems; in terms of electricity produced locally or nearby, the photovoltaic and wind systems are the most recommended. Both cogeneration systems (simultaneous production of thermal and electrical energy from the same source) and trigeneration (use of the rejected heat from cogeneration to produce cooled water, allowing the use in absorption chillers for applications in ambient cooling) currently operate almost exclusively on natural gas, which is a fossil fuel and therefore does not fit as renewable energy. However, there are technologies available on the market such as thermal and hybrid solar concentrators that are used for steam and electric power applications, and the excess heat energy can be used in domestic hot water (DHW), as well as solar / gas hybrid or biomass cogeneration. Thus, combining cogeneration with the use of renewables presents energy, environmental and economic benefits, contributing to the significant reduction of CO_2 and increasing the security of energy supply by reducing the import of fuels and the beneficial use of local energy resources. Other complementary and still embryonic systems can be considered, such as the production of microalgae as raw material for biofuels. They are cultivated in photobioreactors that can be inserted in one of the facades of the building and, if well dimensioned, they can help reduce thermal loads with the absorption of radiation.

Finally, during the use of the building, it is not enough that a building has a passive component of excellence, it is also required that its use and its equipment are rational, to be considered nZEB. Users should behave appropriately to reduce energy consumption and consumer systems and energy producers should be controlled by a system that allows the optimization of energy consumption, thus it is necessary to install a management system. There should be a user manual that covers not only the above-mentioned topics, but also safety standards, maintenance procedures and internal audits.

4. Discussion

The first analysis that needs to be done is the current legislation deriving from European directives: it is pointed out, that the main concern is reducing energy consumption and consequently the emission of greenhouse gases. Having in mind the concept of sustainability, building a *ZELab* demands a radically different way of thinking and require integration of experiences in architecture, design, civil engineering, environmental engineering and other sciences, in particular social sciences, since it considers aspects environmental, socio-economic and cultural dimensions. The construction of the *ZELab* should include the implementation of life cycle assessment, ranging from raw material extraction and material processing for manufacturing, distribution and use, to final waste disposal.

The adoption of the concept of sustainability in buildings is fairly well known in Portugal, with a concern for energy efficiency, however, economic barriers, legal barriers and lack of knowledge make it difficult to implement some energy efficiency measures. The main idea is that this *ZELab* is used not only as a final use laboratory, but also as a multidisciplinary space where engineers from different specialities can work together in a collaborative way, discussing their problems while practicing the team work skills.

Regarding the construction of the *ZELab*, only its location and construction technique have been defined. Its location has been chosen to allow easy access to students. However, there may be some challenges of air conditioning due to the external pavement being tar, which in summer absorbs all solar radiation and thus increases the average temperature nearby, which imposes two problems: the external average temperature will be higher due to the radiation emitted by the tar and at nightfall the heat from the tar is released and the use of natural ventilation may be compromised. Vertical gardens may be the solution to solve this problem.

The decision to use modular construction refers to the ease of construction, diversity of constructive solutions, reduction of construction costs, ease of transport provided that the dimensions of the module are maintained within the maximum measures required for the transport of goods by legislation (using reference is made to the dimensions of a marine container), and to the possibility and facility of increasing the working space, if necessary, in comparison with traditional constructions.

Regarding the other technologies in this building, they need to be technologically advanced, with the integration of passive systems whenever possible and their absence covered by mechanical systems, controlled by a centralized management system. It is also important that the choice of consumer equipment and energy producers demonstrates energy concern. But a more important sub-theme is human behavior: building procedures must be created, space by space, contain security rules and which behaviors to adopt, so that the human being interacts as little as possible in a negative way with the *ZELab*.

Education of engineering professionals towards sustainability has commonly been diverted from the main objectives of Higher Education. In fact, each curricular unit aims to provide its students with the tools to solve engineering problems. However, there is not much consideration or problem thinking towards preventing the occurrence of sustainability issues, which is only possible by analyzing the whole chain, not only one single process.

This laboratorial space will allow engineering students to learn by the practice the scientific aspects of several curricular units, while they are integrated in one complex problem. One of the advantages of such a living lab is to provide all the academic community with the tools to interact in a multidisciplinary way, taking into consideration the aspects of sustainability, from the very beginning of the Higher Education of engineering professionals. Furthermore, this kind of common space is potentially interesting to integrate multicultural educational practices.

5. Conclusion

Firstly, this paper intends to draw attention to the need to create study and research spaces in which teamwork can be encouraged and to create working methods that allow teaching the concepts of nZEBs. From the proposal comes one of the conclusions that justifies it: the diversity of work areas that are or could be involved in the project and construction of such a building with almost zero or even zero energy needs. Secondly, this paper does not aim to point out the final characteristics (insulation, technical solutions, etc.) of a nZEB, but to define the way to plan the project of a *ZEBLab,* with the identification of its specifications.

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