ZELab - planning a living lab to educate modern engineering professionals

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ABSTRACT

Buildings are now complex systems that traditionally have been studied in an isolated mode, seeking to respond to a specific need and dealing with a restricted set of variables. The targets established for energy efficient buildings and energy sustainability imply that these new systems are now more comprehensive and combine various independent systems. This new topology requires a new kind of engineering professionals trained in a more integrative and collaborative way. These new engineering professionals need to have not only expertise in a specific area, but also more comprehensive proficiencies that allow them to understand how to integrate their particular project into a wider functional system, and to communicate with experts from different areas. This paper addresses some challenges and issues posed to Higher Education institutions on the educational paradigms of future engineering professionals and proposes the ZELab teaching / research space as an integrative educational tool.

CCS CONCEPTS

• Applied Computing → Physical Sciences and Engineering • Applied Computing → Education • Computers and Education → Computer and Information Science Education – curriculum, problem-based learning, self-assessment.

KEYWORDS

Higher education in engineering, NZEB, ZEB, ZELab, sustainable laboratories.

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1 INTRODUCTION

Every nation's development has historically been based on energy consumption. High population of developing countries causes a faster growth than that of already developed ones. This means that when these countries want to reach a higher state of development, the amount of energy and resources needed are enormous. In addition, huge amounts of effluents, as well as of waste, will be created leading to a need to use much cleaner and more efficient technologies, to reduce the negative impacts caused in the environment. Thus, strategic planning is fundamental to achieve a sustainable growth.

Energy needs can no longer be only based on fossil energy, due to scarcity and environmental issues. Consequently, the associated emissions and environmental impacts are driving scientists and decision makers towards both a new model of development, based on renewable energy systems, as well as on higher energy efficiency. However, both have brought new challenges. This is the

- intrinsic unpredictability that is characteristic of a significant part of renewable energy sources, imposing that only a low share of renewable energy is used, since the present electric paradigm is based in control;
- new appliances that have higher efficiency but are now nonlinear loads, because of the introduction of electronic controllers, causing a negative impact on the electric energy quality.

These examples show that *renewability* does not necessarily mean *sustainability*. Every new solution that has the advantage of being environmentally friendly also brings new problems that need solutions [1]. On the other hand, the non-renewable energy cannot be considered the cause of all problems, as its total elimination from the current energy system cannot be achieved without a deep change of both human behavior and of the energy system performance. The whole system has to be analyzed in a *life cycle thinking perspective*, where non-renewable energy sources must be considered as one essential piece to supply the failures of the renewable sources, and all the appliances that are developed to reduce the energy consumption are submitted to deep analysis of their impacts. Thus, this new model of development relies on a new class of environmental and engineering professionals, who are able to relate their particular expertise with all the other surrounding areas and, at the same time, understand the impacts of such systems.

This paper addresses some challenges and issues posed both to teachers and students who will become engineering professionals and presents the Zero Energy Laboratory (*ZELab*), a laboratory specifically designed for students to train multi-collaborative work, as it would be the case of the Nearly Zero Energy Building (*NZEB*) design.

2 TRADITIONAL HIGHER EDUCATION

Higher education is considered an essential factor for the future success of people in modern society [3]. Its importance is well recognized despite the high cost it assumes for each country. Indeed, the number of people with this level of education has increased dramatically over the past 50 years. This increase in the number of students has, however, brought new challenges not only to national economies but also to educational systems [4]. In fact, more traditional and teacher-centered methodologies have proved to be inefficient when applied massively [5]. This unacceptable situation led not only to an adjustment in teaching strategies, but also to a greater focus on students and teaching / learning methodologies [6,7]. The Bologna process brought with it a reorganization within universities to improve educational resources, [8] but also a tendency to *shorten the duration of degrees* and to focus them on a very *limited area of knowledge* [9,10]. This was done aiming to reduce educational costs, as well as to allow the *production* of a larger number of professionals available faster. Thus, these new degrees have become very focused, while their scope has been greatly reduced. This new scenario has brought advantages and disadvantages, particularly in the case of engineering education [11]. For the specific case of buildings' design, this issue can be summarized as depicted in Figure 1. As can be observed in the diagram, we have essentially three agents:

- the educational system;
- the set of professionals;
- the building design.

The current methodology of the Higher Educational system is training Professionals with a high degree of specialization in a very limited area of knowledge, who have the skills to project a standard Building. Under this model, each professional is responsible only for a single layer in the global design. He does not think about any interaction. This strategy was successfully used until a relatively recent past, before which buildings were essentially systems resulting from the aggregation of smaller projects with very low interdependence between the said aggregates.

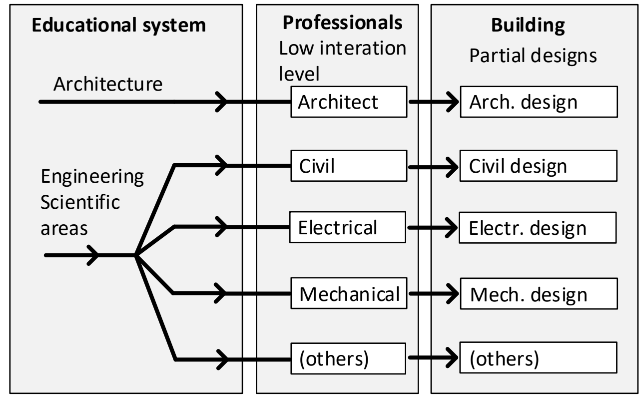

Figure 1. Traditional interaction between Educational system, Professionals and Building design

This educational strategy makes it possible to keep technological and educational development processes closer to each other [12] since the narrower the scope, the easier it is to achieve a higher level of knowledge. On the other hand, the aforementioned strategy has several disadvantages, such as the *reduction of skills* in terms of abstraction to deal with more realistic and complex models, the lack of ability to deal with *multidisciplinary problems* [13] or even the ability to generalize, i.e., the ability to associate the structure of several systems. This latter skill assumes special importance in engineering programs given the fact that solutions to modern problems are *multidisciplinary*.

3 SUSTAINABILITY DESIGN IN HIGHER EDUCATION

The teaching / learning concepts of Control Systems Engineering are of particular importance because they are the basis of the development and application of systems that are intended to be increasingly sustainable. The most quoted definition of sustainability refers:

"...development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [14]

A more direct, technical interpretation for Systems Engineering may be as follows:

"A sustainable system is one that consumes the resources strictly necessary to obtain the desired effect." [1]

It should be noted that this new definition highlights two main factors. On the one hand, it is sufficiently broad to be applied to any system, be it a building system, biological system, educational system, health system and even home appliances. On the other hand, it shows the need for optimization. The optimization of a variable in a system implies that it is controlled. In turn, said control leads to the development of closed-loop mechanisms that allow the controlled variable to remain stable in the presence of disturbances.

Therefore, automatic control is on the basis of sustainability because it allows optimization of the system's consumption. This is a particularly important issue in the European Union (EU), since the sustainability-related objectives of each country are systematically revised, being more demanding. A very visible part of this effort was placed on cars that now exhibit a good performance along with very low pollution rates. However, these results were only possible through the massive use of sensors, actuators, *shared information*, and computation. These are highly multidisciplinary systems that include mechanics, electricity, electronics, chemistry, computers, among others. As an example, older cars have no electronic control units or lines of code, but now even low-end cars can include 30 to 50 microprocessors governing windows, doors, the dashboard, seats, and so on, in addition to the powertrain and vehicle dynamics. Luxury cars can have more than 70 and as many as 100 microprocessors. Analysts seem to agree that a modern premium-class car probably contains close to 100 million lines of software code [15].

The next trend will cover buildings, as they account for about 49% of the world's energy consumption. Away from the ideal situations of the past, the so-called Zero net Energy Building (*ZEB*) and Nearly Zero net Energy Building (*NZEB*) are real demonstrations of this. Recent legislation imposes ever more demanding rules on the performance level of new constructions to be built. As with cars, the new buildings will be multidisciplinary and very complex systems.

As said, in the past, these building's projects were done using independent layers: electricity, water, telephones, alarm, central heating, etc. This methodology of design is no longer suitable for the design of high-performance buildings, where the various layers need to be integrated into a global state observation and control platform, using an *Input/Output Communication Infrastructure*. To do this, and as previously mentioned, we must use the resources strictly necessary to obtain a desired effect. Take lighting as an example. For proper lighting, closed-loop control of this variable is required, i.e. closed-loop (mathematical) concepts are required. It is also necessary to control power (Power + Power Electronics Systems). Thus, the bulbs will provide the exact amount of light to compensate for the one that is not provided naturally. A more complex system would involve controlling room's blinds, further increasing the complexity and multidisciplinary requirements of the system. Air renewal control would measure indoor air quality (chemical / environmental / mechanical engineering) and renew air as needed (HAVAC - mechanical engineering). Inner (winter) and outer (summer) blinds can be provided according to the thermal (mechanical) requirements. The central heating should be used in each room according to the specific needs of each location. Each room must have a controller that depends on the room's use and should identify the presence of users. Infrastructures necessary for monitoring and observing the status of each parameter should be provided (civil / informatics / other engineering). The whole system is interconnected by an information network (computer science). The entire system should have a management component (industrial management and engineering). Figure 2 depicts the actual scenario for modern building design.

Again, we have the *Educational system*, a set of *Professionals* and a *Building* global design.

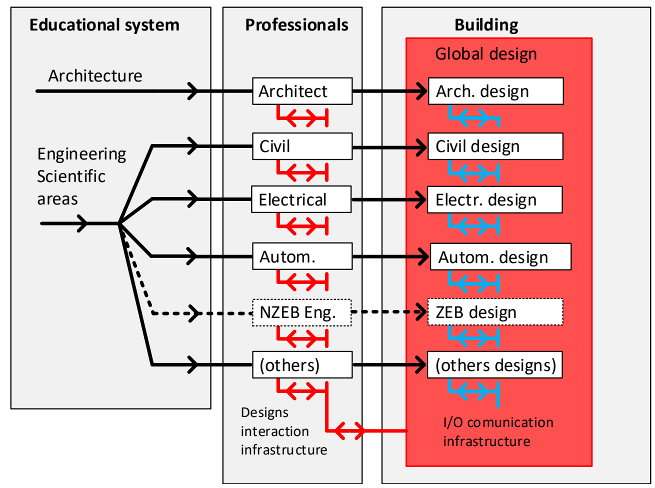

Figure 2. New relation between Educational System, Professionals and Building design

The Building results now from a *Global Design* that is composed by a set of independent designs that should respond to any requirement imposed by each *Professional* through a Design Interaction Infrastructure. We have now an I/O Communication Infrastructure across all designs that allows to monitor and control a huge set of parameters. Therefore, we have two important communication infrastructures; one provides *shared information among professionals* and another that provides *shared information of building data*. Moreover, we have now a new class of specialists on *ZEB* arena that we call *NZEB* Engineers. At a methodological level, we can now perceive that:

- All the subsets of designs are interconnected by an I/O Communication Infrastructure;
- A new class of professionals (*NZEB* Engineers) is needed;
- All professionals must develop their work in a collaborative and multidisciplinary way, with very high level of interaction.

NZEB professionals are now starting to be available through an offer from some universities under MSc degree. The *work in a collaborative and multidisciplinary training method* is the most important aspect of this new way of designing buildings since it is disruptive to traditional methodology. In fact, in addition to the laboratories oriented to the practice of a specific area of knowledge, it is increasingly important that institutions of Higher Education also have laboratories for the practice of collaborative and multidisciplinary work. It is in these new laboratories that future professionals learn that their project is a part of a global project.

4 THE ZERO ENERGY LABORATORY (*ZELab*)

Laboratories are particularly important spaces in engineering education. According to Feisel and Rosa [16] the skills acquired in laboratories are not only technical, but also social. From the thirteen *Fundamental Objectives of Engineering Instructional Laboratories*, there is one (11th) that is specifically oriented for the teamwork:

> *"Objective 11: Teamwork. Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable"*

Furthermore, Ernst [17] stated that laboratories serve essentially three purposes:

> *"In my examination of the undergraduate engineering laboratory, I have identified three roles or objectives as major ones. First, the student should learn how to be an experimenter. Second, the laboratory can be a place for the student to learn new and developing subject matter. Third, laboratory courses help the student to gain insight and understanding of the real world."*

As such, Higher Education institutions must adapt to this new *real world*, by presenting the latest technological advances and including spaces for the integrated NZEBs project, so that this new reality is also covered. If this is not done, Higher Education is seriously at risk of not fulfilling its main mission. There have been some breakthroughs but not all respond to the latest requests. In the Western Balkan Six 2017 monitoring report [18] it was stated there is an urgent demand for more post-graduate trained staff, specialized in renewable energy technologies and energy efficiency. It was also stated that it is important to improve current collaboration with leading EU countries to develop Master and PhD programmes, professional training and laboratories with the aim to prepare a new generation of skilled experts in these sectors. Kamp [19] summarized what trends in engineering Deans in Europe care about most as follows: (1) crossing disciplinary boundaries; (2) societal impact instead of individual achievements; (3) T-shaped professionals; (4) interdisciplinarity; (5) different engineering profiles; (6) students as change agents; (7) integration of skills in disciplinary curricula; (8) makerspaces societal and industrial engagement.

We can identify two main approaches available to a Higher Education institution for dealing with this issue, a *conservative* and a *disruptive*.

The *conservative* approach aims to develop methodologies that *reeducate* the old school of professionals in order to begin working as members of a team. This same approach is currently used to educate the new class of professionals, i.e., there are some courses that are in fact a kind of mixture of courses, which include subjects from several departments. As advantages of this approach, we can point out that it is cheaper, easy and quick to implement.

The *disruptive* approach includes the development of an appropriate environment for training the new class of professionals. This means we should have in the school the same environment that the new-graduation students will face in their professional life. This means that it is important to create spaces in the university where new students, i.e., next generation of professionals, can develop their work naturally as team members (including laboratories) to practice the development of a building as we presented in Figure 2. As main advantage from this approach, we can point out the high quality of new graduates.

Regarding the *conservative* approach, Brunsgaard and collaborators [20] produced a study about the implementation of the Energy Performance of Buildings Directive (EPBD) across several countries in the EU. This study shows the need of *more integrated and cross-disciplinary* approaches to building design through state-of-the-art building sector and educational institutions. Several approaches were taken for post-graduate students in order to fulfil these needs using this conservative approach [21].

In regards to the *disruptive* approach, we can perceive that very little work was done up to date. In fact, and according to Mlecnik [22], the primary critique from various members at Passiefhuis-Platform is that many education arenas and universities have yet to integrate the available *innovations into their curricula*. At an engineering level, as said, one of the most important training space is the so called *laboratory*. It is thus important to have laboratories able to properly support the training of students on how to design a NZEB.

Unfortunately, this approach is much too novel and it becomes difficult to find similar examples. In our research, we found examples of laboratory buildings designed using the latest technology [23,24] but none aimed to be a space for practicing and researching engineering solutions in a didactic way.

It is to fulfill this gap that the Zero Energy Laboratory (*ZELab*) is being developed, a project that integrates all aspects of teaching at the ISEP (School of Engineering of Porto). Its sole objective is to provide a space dedicated to projects that aim to stimulate the development of a sustainable attitude in the future professionals of the various scientific fields of Engineering. The conception of this new space must be integrative to the school community from its embryonic stage, reason why from the beginning one should count on the collaboration of students [25]. Some of the characteristics of this innovative laboratory are summarized in Table 1.

The preliminary proposal of such an integrative laboratory is shown in Figure 3. This proposal is meant to be modular so as to facilitate its growth and the implementation of state-of-the-art solutions.

The eastern wall, because it is facing an existing building, and for whose users it is also intended to minimize the visual impact, should constitute a green wall/cover, which extends to the roof plate of *ZELab*. This green wall/cover will also add permeability to the construction site, and act as thermal insulator/regulator.

Table 1. *ZELab* specifications.

Requirement	Strategy
Energy consumption minimization	Use of efficient materials, energetic integration, solar orientation
Indoor air quality	Natural air renovation
Compressed air network	Pre-installation on key points
Photobioreactors water/air temperature	Heater exchanger + controller
Electrical network	Flexible technology
Hydro sustainability	Rainwater harvesting; Use of efficient toilets
Shared data	I/O communication system
Structural certification	Compliance with the most advanced standards

The western and south walls are specially designed to accommodate modular photobioreactors instead of simple windows. They will act as thermal insulation elements, as well as aesthetic elements, dynamic due to the natural evolution of the microalgae population. The microalgae will perform CO_2 abatement and, in the end of life cycle, can be collected and converted into energy, biofuels, and/or other valuable products.

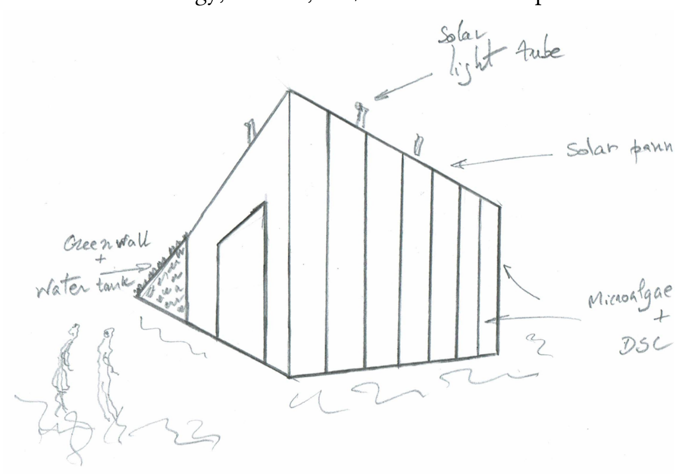

Figure 3. Sketch of ZELab@ISEP, an innovative, multidisciplinary, integrative and sustainable educational laboratory space

Concerning lighting, the use of natural lighting devices (e.g. light tubes), eco-efficient lighting and intelligent lighting will also be favored. The roof should be conceived as to also be used as a solar energy collection space.

As the air conditioning of buildings is one of their largest energy consuming components, the priority will be given to natural air conditioning systems, followed by efficient and intelligent air conditioning, against the usual centralized air conditioning systems. Special attention will be paid to the internal allocation of spaces to specific activities, so that energy is consumed in a more effective way. For instance, refrigerating and other machinery that releases heat should be located outside the rooms that require controlled temperature, in order to minimize the energy costs of air conditioning.

Renewable energy from the sun must be injected into the internal electric grid and excess production stored in batteries. In order to supply the insufficiency of solar energy, the *ZELab* must be equipped with a biomass and / or biogas / biodiesel boiler.

Rainwater must be collected, treated and stored for sanitary use and / or irrigation of the green cover.

The electrical and data network installation must be flexible and allow evolution, with versatile technical rails.

The integration of these energy sources, data and water systems must be done through an intelligent network. This network will also be responsible for monitoring the entire building with regard to users and spaces in use, thus guarantying limited access to spaces, limiting the availability of energy to the essential elements, reducing energy losses and inefficiency.

5 CONCLUSIONS

Buildings that meet the latest standards are highly efficient, highly complex and multidisciplinary systems. Higher Education needs to have laboratories to support teaching of these subjects, and to allow for easy interaction with the surrounding community. The narrowing of the range of skills attributed to students in the various engineering scientific areas resulting from the curricular changes introduced by the reforms performed subsequently to the Bologna agreement can be minimized through collaborative work in a multidisciplinary laboratory environment. This paper framed and briefly presented the development methodology and fundamental characteristics of a Zero Energy Laboratory (*ZELab*) to support teaching, learning and research in the NZEB area.

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REFERENCES

[1] N. Caetano, J. Rocha, J.C. Quadrado, M.C. Felgueiras. (2017). Sustainable energies – the beauty and the beast. In Proceedings of SEFI 2017 – 45th Annual Conference: Education Excellence for Sustainability, Azores - Portugal.

[2] UNFCCC. (2015). Annex: Paris Agreement and Decision 19/CP.21 Extension of the Mandate of the Least Developed Countries Expert Group. Report of the Conference of the Parties on Its Twenty-First Session, Held in Paris from 30 November to 13 December 2015 Addendum Part Two: Action Taken by the Conference of the Parties at Its Twenty-First Session (FCCC/CP/2015/10/Add.1) and (FCCC/CP/2015/10/Add.3).

[3] United Nations. Sustainable Development Goals. United Nations Department of Public Information, New York, NY 10017.

http://www.un.org/sustainabledevelopment/news/communications-material/ (Accessed in April 2017).
[4] E. Schofer, J.W. Meyer. (2005). The worldwide expansion of higher education in the twentieth century. American Sociological Review, 70(6), 898–920.
[5] J. Biggs. (1999). Teaching for quality learning at University, Open University Press, Buckingham, UK, ISBN0335242758.
[6] R. Felder. (1999). How to Improve Teaching Quality. Quality Management Journal, 6 (2), pp. 9–21,
[7] P. Ramsden. (1987). Improving teaching and learning in higher education: the case for a relational perspective. Studies in Higher Education, 12(3), 275–286.
[8] R. Shearman. (2007). Bologna: engineering the right outcomes. International Journal of Electric Engineering Education, 44(2), 97–100.
[9] G. Heitmann. (2005). Challenges of engineering education and curriculum development in the context of the Bologna process. European Journal of Engineering Education, 30(4), 447–458.
[10] J.J. Klemeš, Z. Kravanja, P.S. Varbanov, H.L. Lam. (2013). Advanced multimedia engineering education in energy. Applied Energy, 101, 33–40.
[11] B.R. Williams. (2007). Engineering education, accreditation and the Bologna declaration: a New Zealand view. International Journal of Electrical Engineering Education, 44(2), 124–128.
[12] S. Aslan, C.M. Reigeluth. (2013). Educational technologists: leading change for a new paradigm of education. Tech Trends, 57(5), 18–24.
[13] G. Vega, L. Schlichting, G. Ferreira, M. C. Felgueiras, A. Fidalgo, G.R. Alves. (2015). A remote lab for programmable system-on-chip. Demo Track, within the EXP.AT'15 conference.
[14] United Nations, World Commission on Environment and Development. (1987) Our Common Future, Oxford University Press, Oxford 27. ISBN 019282080X.
[15] R.N. Charette. (2009) This car runs on code. IEEE Spectrum, 46. In https://spectrum.ieee.org/transportation/systems/this-car-runs-on-code (Accessed in April 2017).
[16] L.D. Feisel, A.J. Rosa. (2005). The Role of the Laboratory in Undergraduate Engineering Education. Journal of Engineering Education, 94(1), 121-130.
[17] E.W. Ernst. (1983). A New Role for the Undergraduate Engineering Laboratory. IEEE Transactions on Education, E-26(2), 49–51.
[18] Energy Community Secretariat. WB6 Sustainability Charter: Monitoring Report, June 2017. https://www.google.pt/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwig36vzrbzXAhXLKVAKHaLaCU0QFgguMAE&url=https%3A%2F%2Fwww.energy-community.org%2Fdam%2Fjcr%3A9249f2e6-2fca-4493-b867-8a973f14b78c%2FEnC_WB6_SUS_072017.pdf&usg=AOvVaw205vm26rZ-PU6Z1DmpYBMD (Accessed in April 2017).
[19] A. Kamp. (2016). Engineering Education in the Rapidly Changing World - Rethinking the Vision for Higher Engineering Education, TUDelft, ISBN: 978-94-6186-609-7.
[20] C. Brunsgaard, et al. (2014). Integrated energy design–Education and training in cross-disciplinary teams implementing energy performance of buildings directive (EPBD). Building and Environment, *72*, 1-14.
[21] E. Peñalvo-López, F.J. Cárcel-Carrasco, G.C Christoforidis, A. Nousdilis, A. Riccetti, D. Melandri, G.K. Papagiannis. (2017). Upgrading Qualifications of European Energy Professionals in NZEB – The MEnS Project. Procedia Environmental Sciences, 38, 898-904, https://doi.org/10.1016/j.proenv.2017.03.177.
[22] E. Mlecnik, (2013). Innovation development for highly energy-efficient housing: Opportunities and challenges related to the adoption of passive houses. IOS Press.
[23] A. Li, AIA, A.P. LEED, Payette. (2015). Closing in on net-zero energy for labs. https://www.labdesignnews.com/article/2015/05/closing-net-zero-energy-labs; in November 2017.
[24] B. Glover (2011). The Road to Net Zero. (NREL/PR-6A42-51124); https://scied.ucar.edu/sites/default/files/images/long-content-page/NRELnetZero.pdf (Accessed in November 2017).
[25] S.R.M. Moreira (2017). Contribution for the project and construction of a ZELab (Contributo para o projeto e construção de um ZELab). MSc Dissertation in Mechanical Engineering, School of Engineering, Polytechnic of Porto, Portugal.