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Sustainability in buildings – a teaching approach

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Abstract

Energy consumption in buildings is responsible for an important share of global consumed energy. The current electric energy paradigm carries important consequences both at economic and environmental levels. The so called Zero Energy Buildings' strategy provides some guidelines in order to achieve better results in buildings energy demand. This scenario is a highly multidisciplinary engineering issue, and poses several challenges at the higher education level, that is taught in separate areas. This paper presents some higher education teaching limitations to address new technological challenges in new buildings design.

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Keywords: Buildings; education for sustainability; energy consumption in buildings; sustainability

1. Introduction

Energy consumption in buildings is responsible for an important share of global consumed energy with all associated environmental issues when using the current electric energy paradigm. Global development, particularly in the so called BRIC countries (Brazil, Russia, India, China), will contribute to deteriorate the already concerning situation.

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To overcome this issue, several aspects were put in perspective, such as the energetic performance of systems and appliances, the use of renewable energy, the decentralized production of energy, among others. However, every time we try to solve one problem, new ones arise. Optimal performance only occurs while systems are working under the optimal conditions and those depend on many factors such as the adequate maintenance specified by the manufacturer or the user occupancy behavior. The use of renewable energy can be a difficult process and only feasible for a relatively low share of the total energy involved. The decentralized energy production can bring problems at the level of energy quality.

Far from simple, the energy subject poses serious challenges to be solved that involve all players, from consumers to producers, using several layers, from hardware to communications. Important achievements have been reported at several levels all over the world. Some keywords such as *sustainability* and *smart grids* are frequently used, yet they correspond only to generic concepts. One challenging topic is the absence of a structured and accepted infrastructure developed specifically for energy management. This structure will take some time to be designed but will probably change and modify the current electric energy production paradigm.

Probably the biggest obstacles in this whole process are the design difficulties. In fact, the division of the education system into several areas of specialization allows acceleration of the courses since it permits removal of all subjects that belong to other areas. This type of approach worked with the traditional unidirectional energy production paradigm. However, the new type of project that responds to directives and standards is much more complex and multidisciplinary, and is often opposed to the traditional design methodology. As an example, in the past, electrical engineers should choose if they wanted to make *energy production* designs or *energy demand* designs. The first was typically focused on power plants. The second corresponded, for instance, to the electrical building design. However new directives impose a new type of design that involves demand and production in the same design.

This means that the new paradigm of energy consumption production entails a new teaching paradigm, bringing new and complex challenges issues for both teachers and students.

2. Energy demand in buildings

Buildings are crucial to a sustainable future from their design to their operation. Besides that, all activities in buildings are considerable contributors to energy-related sustainability challenges. As such, reducing energy demand in buildings plays an important role in answering these challenges. Buildings and their activities correspond to approximately 31% of global final energy demand, around one third of energy-related CO_2 emissions, approximately two thirds of halocarbon, and approximately 30% of black carbon emissions. Furthermore, energy-related problems affecting human health and productivity occur in buildings, including mortality and morbidity from poor indoor air quality and/or inadequate indoor temperatures. Therefore, improving buildings' design and their equipment answers one of the entry points to addressing these challenges [1].

The global energy demand is frequently grouped in areas such as *transports*, *industry*, and *other*, the latter including the energy spent in buildings. The portion of energy used in each area is continuously changing. Nevertheless, we can recognize that the share of energy used in buildings is consistently increasing. Energy in buildings alone is assuming such a large importance that it is currently identified as one independent area. Therefore, energy efficiency in buildings is today a prime objective. In the EU, the total amount of energy produced is mainly consumed by three sectors as represented in Fig. 1 [2].

In the USA, every year, approximately half (48%) of all energy produced is consumed by the Building Sector, i.e. near the same amount of energy consumed by the combined sectors of Transportation (29%) and industry (25%). The share of energy consumed in buildings represents about 40%. Accordingly to [3], the global contribution from buildings towards energy consumption, both residential and commercial has progressively increased reaching values between 20% and 40% in developed countries. The U.S. Energy Information Administration (EIA) now reports that, in coming years, *Buildings* sector energy consumption will rise quicker than that of industry and transportation, [3,4]. To reverse this situation, it is necessary to use new technologies and techniques that point the ideal situation, i.e., an energetically self-sufficient building. In fact, this scenario is no longer as far as it has been in the past. The so called Zero Energy Building (ZEB) [5, 6] is under strong research at the present. One important step was done by the Energy Performance of Buildings (EPBD) Directive (2002 and reintroduced in 2010). The EPBD addresses new buildings and those undergoing major renovation (which amounts to 40% of the EU energy use, 36% CO_2 emissions).

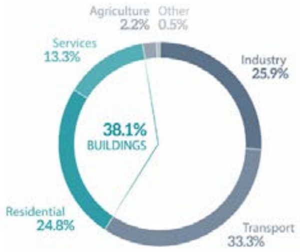

Fig. 1. Share of the energy consumed by household and services in EU [2].

Both its transposition and implementation have been slow. Its reintroduction has strengthened the Directive but less than hoped, in particular regarding to existing buildings, financing and urgency of deadlines [7]. "Nearly zero-energy buildings" (NZEB) have very high energy performance. The low amount of energy that these buildings require comes mostly from renewable sources. The new Energy Performance of Buildings Directive requires all new buildings to be nearly zero-energy by the end of 2020. According to the EU regulations, the Energy Performance of Buildings Directive requires that all new buildings are nearly zero-energy by the end of 2020, and all new public buildings must be nearly zero-energy by 2018 [8]. As seen, the new buildings' design is complex and involves lots of assessing from the architecture to the end use. The process also involves working on the design and overall shell (roofs, walls, windows) of the building to the use of efficient appliances and equipment.

3. Electric energy issues

The modern life style has been associated with the use of an important amount of energy. The fast growing energy consumption has also raised concerns about resources, environmental impacts on ozone layer depletion and climatic changes. To revert this situation, several actions have been proposed. Kyoto protocol assumes special importance as it was probably the first agreement planned at and followed by several actions at a global scale. The European Union (EU) approved a first set of targets that will be followed by a second set of new ones in the so called Europe 2020. This is a 10-year plan proposed in March 2010 to recover the European economy. It aims at smart, sustainable, inclusive growth with greater coordination of national and European policies. These policies identify five several headline targets and one of them refers to the previously agreed target to reduce greenhouse gas emissions by at least 20% compared to 1990 levels or by 30% if the conditions are right. This should be done by increasing the share of renewable energy in final energy consumption to 20%, and reach a 20% increase in energy efficiency. The 20-20-20 plan consists of an emissions and renewable energies target which is legally binding, while the energy saving target is not. The Europe 2020 process which can help promote efficiency and a sustainable growth agenda should not be used to replace national targets and plans, especially at a time when greater transparency, comparability and commitment is required [7]. The treaties related to sustainability, regulations and targets have had a very dynamic action in societies, particularly in economies. According to the UNEP [9], the investment in renewable energy had a growth until the year 2010, when a decline is noticeable, as shown in Fig. 2. This decline in investment has several origins but one in particular relates to that of the paradigm of electric power production. New trends aim to lower the level of energy used without jeopardizing the achieved modern life style quality. Those include several procedures that can generically be divided in two sets of objectives that are the increase on the use of RES from the production side and the rational use of energy on the consumer side. These measures have limitations stemming from the current paradigm of electric power production. One of the current limitations at the level of education is transmitting notions that belong to several different domains.

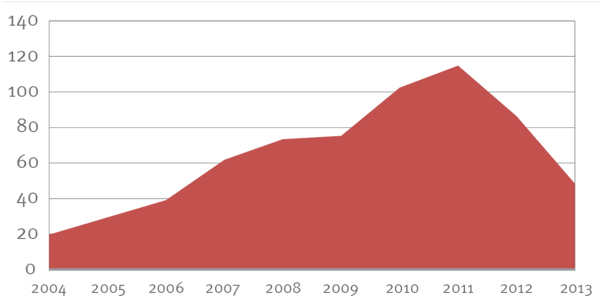

Fig. 2. Annual investment ($BN) in Renewable Energy

This issue and the complexity associated are perhaps the biggest obstacles to the development of engineering solutions.

3.1. Increasing the use of RES

This set of objectives had as an outcome several measures from numerous countries around the world, including EU, to implement and to increase the efficiency and the share of RES in order to raise the sustainability level [10]. The major drawback in the use of RES is its intrinsic unpredictability. This poses huge problems when using an electric energy production paradigm based on the control paradigm that is presented in Fig. 3.

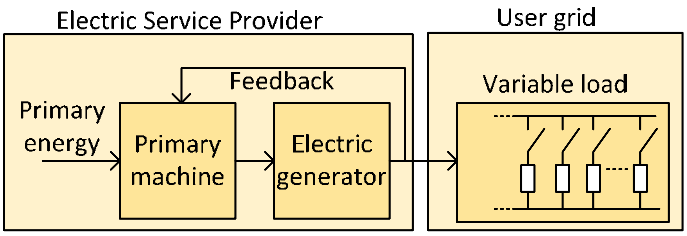

Fig. 3. Electricity paradigm production model.

In fact, every time one consumer turns on a device (e.g. a light) the demand increases and the electric service provider should dynamically and in real-time balance the demand with the production. A simplified diagram is presented in the Fig. 4.

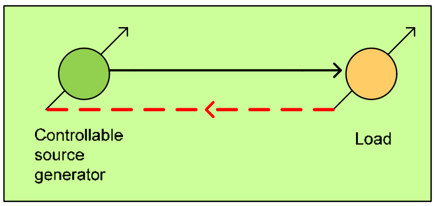

Fig. 4. Electricity paradigm production model.

In Fig. 4 we can see a variable Generator that represents the Centralized Production from the production side and a Variable Load that represents the equivalent load form de demand side. Every time a user switches on or switches off a given load, the total equivalent charge changes. If the equivalent charge were lower and if no corrective action was taken on the production side, then the generator voltage and frequency would rise, possibly beyond acceptable limits. If the equivalent charge rises, the opposite would happen and the voltage and frequency may fall below the acceptable limits in much the same way. To prevent these situations, it is necessary that production is constantly regulated, adapting in real time to the demand. In short, according to the present paradigm of production, it is the charge that imposes the general state of the system. The imposition of this system state is represented by the dashed line in Fig. 4. In order to achieve this, the use of primary controllable energy sources is crucial. Except for hydro-storage energy, all controllable energy sources are fossil derived. In this scenario, the use of RES energy, such as wind-based, brings serious constraints because they are non-controllable sources.

Fig. 5 presents the scenario of a system in which there is now the inclusion of energy from RES that cannot be controlled and that is usually injected into the electric network with a higher priority.

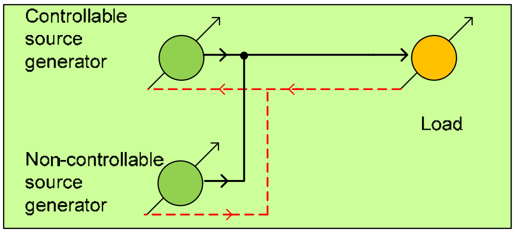

Fig. 5. Non-controllable renewable energy sources in the traditional electricity paradigm production model.

If we assume that the charge is constant, then the energy generated from controllable sources must constantly adapt to fluctuations from uncontrolled sources. If we overlap the load variation explained above, we note that the controllable source has to ensure two variations. The imposition of the state in this system is represented by the dashed line in Fig. 4, so it is now seen that the state imposition arises from load and uncontrollable sources.

As a consequence of the previous explanation, power values from the non-controllable sources (e.g. wind-based energy) are typically injected in the grid at a lower value than 25% of the total power installed [10]. This percentage remains approximately constant even when higher values of wind-based energy are available from wind-energy farms. In this case, we have available energy that is not injected in the grid mainly because of the growing risks associated with the continuity of service. The higher the over percentage, the more often associated wind-cuts occur, i.e. the refuse in the use of wind-based energy due to the associated risks. The solution for this issue includes the use of a different electric energy production paradigm that will take advantage of the use of Information and Communications Technology (ICT). This could partially explain Fig. 2. In fact, the first investments in RES were a huge success. However, we can perceive now the limitations from the traditional electric energy paradigm model. Another possibility consists of a change into another energy production paradigm such as the one presented in Fig. 6.

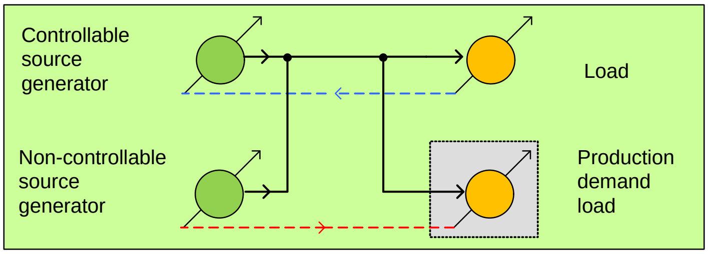

Fig. 6. Non-controllable renewable energy sources in an alternative electricity paradigm production model.

In this system we have the overlapping of two paradigms of energy production. At the top we have the traditional paradigm including controllable generators and user dependent loads. Below we have an alternative production paradigm in which there are Production Demand Loads that are controllable by the electric power supplier. It should be noted that in this paradigm it is the production that controls the loads and not the other way around. The loads associated with this alternative paradigm would be the ones connected with high inertia systems and therefore able to be disconnected for relatively short periods of time (e.g. fridges, air conditioners, etc.).

The big issue in this kind of system is the communication between energy service providers and users. We are talking about the so called *Smart Grids* and the issue that we are far from a solution, since we do not have any kind of standardized network. According to [11], the concept of *Smart Grids* was developed in 2006 by the European Technology Platform for Smart Grids, and contemplates an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economical and secure electricity supplies. According the International Electrotechnical Commission (IEC) [12] *Smart Grid* is used today as a marketing term, rather than a technical definition and, for this reason, there is no well-defined or commonly accepted scope of what *smart* is and what it is not. It is worth noticing that, according to the IEC definition, a *Smart Grid* is not a grid but a concept.

As seen, all presented issues and specifically the migration to a different energy paradigm able to accommodate a bigger, and possibly virtually unlimited, amount of electric energy from RES, are currently under development and, consequently, not feasible at short-term.

3.2. The rational use of energy

This feature includes several aspects, such as device/equipment performance, user behaviors, equipment use conditions, and so on. All efforts to increase the efficiency relate to all industrial and household appliances. The most perceptible face of this change is the use of Light Emitting Diodes (LED) in lighting, TVs, Personal Computers (PC), and a range of new and more efficient appliance devices. In general, we can observe that for any performance increment there is often an associated increment in complexity. As an example, in the past, traditional power supplies generically used in all electronic devices were based on the topology of the so called Linear Power Supply (LPS), in which the first block was a power transformer used to adapt the 110 V or 230 V voltages from the electric power grid to voltages required by electronic devices, (e.g. 5 V, 12 V) typically used in electronic circuits, such as mobile phones. Due to this, those power supply devices were heavy (due to the presence of the 50 Hz transformer) and presented an efficiency value of around 50%. Progressively, those equipments have been replaced by a new generation of power supplies based on the topology of the Switch-Mode Power Supply (SMPS). These devices that are used with the new smart phones are much lighter and present a global efficiency almost always around 90%, but also a considerably higher level of complexity.

Generically, we can perceive that the electronic technology and ICT areas have a rising importance in modern equipment. In fact, they are crucial if high performance and low consumption is wanted. As an example, if we compare modern cars with their old counterparts, we can observe that they present higher efficiency but also, due to the use of massive electronic sensors and control systems, higher complexity. The same conclusion is obtained for several others devices/utilities. When comparing new and old light bulbs we can perceive higher efficiency but also higher complexity. However, the introduction of electronics carries also disadvantages, as traditional linear loads are often transformed into non-linear ones. This has a negative impact on the electric grid because increases the Total Harmonic Distortion (THD) and increases energy losses [13].

In general, electronics and ICT play an important role in systems, increasing their efficiency but also complexity. The very same situation will be taking place in the new buildings' design, which integrates electric design, electronic design, system design and informatics design, among others. This means that the buildings' design will rise very significantly in complexity and, as such, a new generation of highly skilled engineers will be required.

3.3. Zero Energy Building

The ZEB are buildings where it is intended that, the necessary configurations are used so that in each activity that spends resources, only the amount of resources strictly necessary for adequate performance of the desired function are spent. This means that monitoring and controlling infrastructures have to be foreseen in both consumption and energy as well as in local production. At the energy level, a ZEB can be represented in a simplified way as shown in Fig. 7.

As previously stated, the greatest difficulty to transpose remains that of the communication infrastructure. However, now the problem is simplified because it is confined to the building.

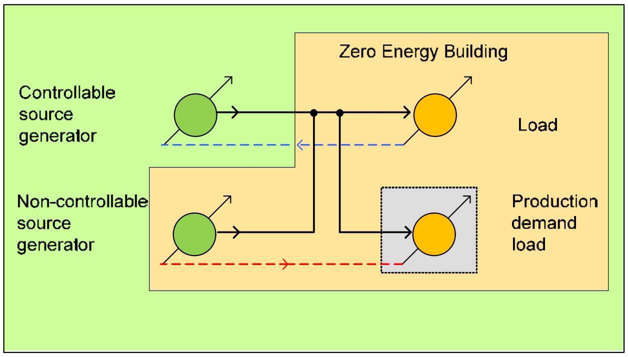

Fig. 7. Energy management in a Zero Energy Building.

3.4. Teaching issues

As said, the design of a ZEB is a complex task since it involves knowledge from various areas. The design now becomes more complex in that it is multidisciplinary and not fully implementable in batch mode, i.e., an independent set of tasks that take place in a successive and independent manner. In addition to the passive actions related to the materials to be used, we have Control Engineering, Electrical Energy Engineering, Electronics Engineering, Network Engineering and Communications. It is important to develop methodologies that allow the development of skills at the level of each specialization but also at the multidisciplinary level. As an example, electronics students have a great deal of ease in designing a LPS, but are not at all aware that the upstream side current waveform is impulsional and that this has a highly negative impact at the voltage waveform level on the electrical grid. The same goes for a very high set of other modern non-linear loads connected to the mains. The THD concept is particularly useful for quantifying how a voltage waveform in the mains distances itself from the ideal situation. This concept is based on the Fourier Series decomposition, but these matters are usually taught by teachers with a mathematical background and are taught transversally to all teaching courses and in practically the same way. As such, this subject isn’t adapted to the course in which it is being taught. At a first glance, this situation causes a certain disinterest. When students really understand that these subjects are fundamental, they are presented in a light manner.

In fact, the design of very specific courses allowed for the reduction of the respective times of duration, but made them too narrow when it comes to the amount of knowledge gained. Given that the solutions of the future are essentially multidisciplinary, it is necessary to implement within the educational institutions mechanisms that allow for their development. Such mechanisms can take the form of Sustainability Laboratories where multidisciplinary problems are developed collaboratively by students from various areas.

4. Conclusions

In this work, a set of current challenges was contextualized. On one hand, we have a set of rules that require that new buildings become highly sustainable and, therefore, have a very low energy consumption. They even have to include a significant amount of locally generated energy. On the other hand, these problems are multidisciplinary and have to be solved by a set of engineers with a far too specific type of training. An essential part of the problem revolves around understanding it. It is necessary to adapt educational institutions to this new reality of multidisciplinary solutions.

Acknowledgements

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