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Succeeding in Implementing Energy Efficiency in Buildings

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1. Introduction

In this chapter we address a simply stated problem. *How do we motivate and enable energy consumption reduction in the building sector?* Buildings account for about one third of the world's total energy expenditure (UNEP, 2007). This makes them a primary focus for energy reduction strategies. However, building ownership, management and usage extends across the whole population and is not limited to the control of a few international organizations. This diversity of active participants makes the process for initiating change an extremely complex problem. It requires not only technical solutions, but also social and political solutions working together to construct an environment for controlled change.

It is inevitable that policies will evolve in the very near future to penalize excessively inefficient buildings. The motivation will be twofold, an attempt to increase incentives to improve efficiency and to recoup, at a national level, international carbon tax costs. But if these policies are to be made to work, they must be designed to be applied and evolved over a significant time interval, several decades. They will also have to be defined based on inputs from a wide variety of disciplines. We will try here to address the start of this problem in the context of the realities of what is available now and what may be done in the current climate.

There are many technical and political proposals that address some aspects of this problem. Here we will review these contributions and merge them into a novel adaptable energy efficiency rating system. We will focus on the interplay between the technology and policy for enacting energy efficiency. We propose a novel framework which provides incentives to building proprietors to improve energy efficiency. We do so by building upon the three main points of the United Nations Environment Programme (UNEP) sustainable building report (UNEP, 2007): (i) Determine energy efficiency objectives and energy performance standards; (ii) Formulate a methodological tool to verify the reductions on GHG emissions and implement fair comparisons between buildings; and (iii) Establish annual energy performance monitoring systems.

The key to achieving our challenging objective is constructing a unified and planned research line that is composed of a set of developments that address the apparently separate issues that

underlie this problem. Thus the strands works that are described in this chapter should not be seen as separate independent activities, but as interacting elements, whose combined use can start to address this complex problem.

2. Context

Energy is obviously the true engine of industrial, social, and economic advancement that has benefited the developed world in the previous two centuries. This is a fact. However, energy consumption is a significant factor in the catastrophic destruction of the environment, health, and quality of life that we all have suffered during the same period. This is also a fact. This second fact will progressively worsen over the next few decades if nothing is done to combat this horrendous side effect. On the positive side, we are aware of these two facts, and actions have been triggered to address the issues. On the negative side, it is definitely not going to be easy.

The straightforward solution is removing the link between development and energy use. However, in the foreseeable future, this is simply not a possibility. Instead, all efforts focus not directly decreasing energy consumption, but rather on optimizing energy usage such that a similar level of development can be maintained at a smaller overall energy cost. This rather restrictive approach is what is generally call *energy efficiency* and will be the basis of the approach taken here.

There is no real starting point for the emergence of environmental concerns, but the Stockholm Environment Conference in 1972 can be regarded as the point where political attitude began to change. Momentum slowly built up and from the '80s onwards, international organizations and governmental institutions started creating initiatives to promote energy efficiency. Europe has been one of the pioneers, issuing its first Community policy in (European Union, 1986), and subsequently creating an extensive set of Directives and globally focused legislative policies. In the international scenario, the most significant action was the Kyoto Protocol (United Nations, 1998), leading to a limited number of countries agreeing to reduce their GHG emissions to achieve a 5 % reduction from 2008 to 2012 relative to those released in 1990.

Consequently, there is a clear worldwide interest in looking not for *joules* but for *negajoules*, i.e., the “non-consumed” energy. And we try and find those negajoules anywhere, starting from the main consumers: industry, transport, and others, each of which accounts for around a third of the world’s energy consumption (IEA, 2010b), (IEA, 2010c). Buildings are responsible for the vast majority of the *others* category, contributing somewhere between 30 and 40 % of the consumption of primary energy and the corresponding greenhouse gas (GHG) emissions (UNEP, 2007).

Although buildings are a major energy consumer, we have to accept the fact we cannot simply reduce their number. However, they can be regarded as a massive source of potential energy savings (Uihlein & Edera, 2010). In the context of buildings then, the focus is on consumption reduction. The realization that buildings offer this potential is already reflected in policy documents. For instance, in the European Action Plan for Energy Efficiency (European Commission, 2006), 30 % of the priority measures are directed specifically towards buildings.

Buildings are one of the few markets where we have dramatically weak penetration of innovation. Although new buildings can easily incorporate new technologies, the long time scales and significant energy costs of building replacements, means that we will have a legacy environment for decades to come. This provides a remarkable opportunity for development, but it requires the cooperation of a great variety of disciplines: Science, Technology, Economy, and Policy. Together, they could provide a joint solution to achieve energy efficiency and propose novel approaches for succeeding in this ambitious enterprise.

In this work, we aim to propose novel approaches to achieving energy efficiency in buildings. We will follow the three main points indicated in the United Nations Environment Programme (UNEP) in order to succeed in having sustainable buildings (UNEP, 2007): (i) Determine energy efficiency objectives and energy performance standards; (ii) Formulate a methodological tool to verify the reductions on GHG emissions and implement fair comparisons between buildings; and (iii) Establish annual energy performance monitoring systems.

Firstly, we will summarize the legislative framework in which energy efficiency in buildings operates. Then we will describe the present achievements in energy efficiency, following the three previous main points. Finally, we will describe our own novel proposals to fulfill those defined objectives.

3. Legislative framework

3.1 Energy efficiency

Although nowadays energy efficiency is the worldwide accepted keyword to reach the objective of achieving a dramatic decrease in consumption and its consequent positive effect on environment, decades have been needed to come to this point. Among all the significant international efforts, Europe has become a leading actor in the energy field.

As far back in 1986, the European Council issued Resolution 86/C 241/01 (European Union, 1986), a seminal Community policy that fixed an objective of improving the efficiency of final energy demand by at least 20 % by 1995. The Community noticed that the availability of the energy required to fulfill the demand to maintain an optimum economic and social growth was a must. Nevertheless, given the prospects for supply and demand by that time, this availability was seriously uncertain.

In order to achieve such an ambitious objective, the Community adopted a set of innovative ideas that have led Europe in its titanic effort to combat energy consumption and environmental damage. The following list itemizes the most significant of these guidelines:

- It takes into account both the supply and the demand side of the problem. This was a disruptive approach since the majority of measures traditionally focused only on the former. Resolution 86/C 241/01 started considering that every kilowatt that was not consumed accounted for higher benefits than every extra kilowatt that was produced, thus empowering the definition of the term *energy efficiency*.
- It proposes the creation of a continental common framework to coordinate and harmonize efforts in committing to the overall objective. Following this principle, instead of defining rigid planning instruments it inclines for flexible and adaptable objectives. In addition,

it points out the need for the construction of monitoring systems capable of measuring the results of national policies. Finally, it suggests the construction of an internal energy market in order to integrate the different initial available resources to achieve the goal among countries.

- It requires cost effective implementations. Due to the existing direct connection between energy and economy, expensive actions appear as unreasonable to solve the global problem.
- It establishes a link between energy and environment. Despite the original concern regarding the availability of the required energy to keep the same level of social and economic development, the resolution paid also attention to the dramatic consequences of the energy consumption on the quality of life. Huge efforts have been invested in solving this issue during the following decades.
- It acknowledges technology as a key factor for achieving the objective. It points out the need to rely on technology to generate innovative solutions to give answer to the different issues that would arise in all fields related to energy.

In 1991 the European Community realized that the resolution 86/C 241/01 was doomed to fail if no *vigorous* measures were taken. Consequently, it created the so-called *Specific Actions for Vigorous Energy Efficiency* (SAVE programme). SAVE was firstly regulated as the Council Decision 91/565/EEC (91/565/EEC, 1991). 35 million euros were invested in 5 years in order to achieve the objectives fixed for 1995. This decision follows the same original ideas stated in its precedent, focusing efforts mainly on energy efficiency and coordination and harmonization. The former was promoted through the training of end users, creating pilot projects, and building a specific directive regarding efficiency in electricity (89/364/EEC, 1989). The latter was stimulated by the definition of technical standards and the construction of a network to share information among national, Community, and international parties regarding their activities in contributing to achieving the overall objective.

These decisions indicate that the European Community was inclined to set its energy policy on the basis of raising the awareness of the end user to the problem, relying on technology to support the needed innovations, and joining coordinated international efforts to enhance the previous measures and reach the challenging objective.

Decision 91/565/EEC apparently included all the fundamental aspects in its predecessor 86/C 241/01. However, it did not incorporate the relation between energy and environment as one of its pillars. This aspect was considered two years later in the Council Directive 93/76/EEC (93/76/EEC, 1993). It focused on limiting the CO₂ emissions by energy efficiency. It also takes this guideline a step further, noticing that buildings are a key objective for increasing energy efficiency due to: i) they represented a 40 % of the final energy consumption in the Community, and ii) it was an expanding sector. In consequence, this directive explicitly indicates the need for an energy efficiency certification scheme for buildings, as well as energy audits for companies with a high energy consumption. The specific legislation derived from directive 93/76/EEC will be extensively described in subsection 3.2.

External to the European environment, the international community was working in a similar direction. The most relevant milestone was the Kyoto Protocol (United Nations, 1998). The Kyoto Protocol aimed at giving solutions to the tremendous environmental concern through a

dramatic reduction of the GHG emissions. The so called Parties of the Kyoto Protocol, a set of 38 countries around the world, came to an agreement on the objective of reaching from 2008 to 2012, a 5 % reduction on their GHG emissions referred to those in 1990. In order to provide the required flexibility for every member to achieve the overall goal, the Kyoto Protocol allowed the Parties to individually or jointly commit to this objective. In addition, the global objective was not fixed for each Party; instead, a particular percentage of limitation was established for each Party.

Consequently, the Kyoto Protocol included some of the features that had been already considered in the previous European legislation:

- The environmental concern.
- The need for a common framework based on objectives.
- The requirement regarding flexibility and coordination.

Let us go back to Europe and describe how the Kyoto Protocol was transposed into legislation. The first step to be taken for each Party is to legalize their own commitment. Europe performed this step in 2002, through a Council Decision (2002/358/CE, 2002) where the Kyoto Protocol was approved. The European Union agreed to select a joint achievement of its percentage of reduction. The subsequent percentages to be fulfilled for each member of the EU were also listed. Next, the EU issued a second decision (2006/944/EC, 2006), that specified the reference for these percentages, i.e., the levels of GHG emissions to which these percentages should be applied. Following the original guidelines that suggested flexibility and the creation of an internal market, the EU put in place an internal reallocation scheme. The set of the resulting reallocated percentages were defined in Decision (2006/944/EC, 2006). Finally, in this same Decision, the subsequent GHG emission levels allocated to each Member State in the EU for the first period of commitment (2008-2012) were also fixed.

The described first direct implementation of the Kyoto Protocol in Europe led to a decisive political framework to face the environmental and energetic issue in the EU. The final aim was to create a European high efficiency and low emissions economy. This challenging objective, namely the *20 20 by 2020*, was fixed in (European Commission, 2008) and its particularization was based on a set of four compromises:

- A 20 % reduction in GHG emissions with regard to those in 1990.
- A 20 % reduction in primary energy consumption, compared to the projected levels.
- A 20 % energy consumption coming from renewable energies.
- A 20 % increase in energy efficiency.

This overall objective was put into practice through the so called *climate and energy package*. This package was drafted as a Law in June 2009 through four complementary legislative pieces:

- The EU ETS, (EU Emissions Trading Scheme) (2009/29/EC, 2009), aimed at strengthen the European emissions allowances trade.
- Decision 406/2009/EC (406/2009/EC, 2009) in order to share the effort in reducing emissions among those sectors that are not covered by the EU ETS.

- Directive 2009/28/EC (2009/28/EC, 2009) that included the promotion of the use of renewable energy sources.
- Directive 2009/31/EC (2009/31/EC, 2009), to develop technologies for carbon collecting and storing.

In summary, the EU precisely followed the guidelines that were fixed back in the '80s. It built a coordinated continental framework based on a flexible regulation that defined an ambitious objective. This objective jointly considered both environment and energy, even extending the international agreements on the former. In addition, it achieved the committed GHG emissions reduction in a cost-effective way. This cost-effectiveness was heavily supported by mechanisms like the EU ETS with which the EU would fulfill the Kyoto Protocol compromise with an estimated cost below 0.1 % of its Gross Domestic Product. Furthermore, it would also achieve its own European aims for 2020. Finally, through the EU ETS, the EU is contributing to developing clean technologies that can support both its own internal progress and that of developing countries by channeling massive investments to promote energy efficiency.

Even in the realistic context of expecting local difficulties in achieving the objectives and massive international disagreement, the scene has been set. Energy and the associated emission reductions are now a legitimate political concern across the whole population. They are key issues in day-to-day political considerations and building processes that will enable energy reduction has become a topic of crucial importance.

3.2 Buildings

All the previous legislative pieces definitely construct a common framework to achieve the required reduction on energy consumption and its corresponding GHG emissions. On the other hand, specific regulation is needed to adapt the general guidelines to particular problems. Among the whole set of issues concerning energy efficiency, buildings are key as they represent a major energy consumer.

The European Energy Performance of Buildings Directive (EPBD) (European Council, 2002) define the basis of the promotion of energy efficiency in buildings. The EU recast this directive in 2010 (2010/31/EU, 2010) to include a set of amendments on the original legislation.

They take the seminal ideas set in the SAVE programme, which clearly indicated the importance of buildings as a key target for emission reduction through energy efficiency. Following the guidelines included in Resolution 86/C 241/01 the EPBD created a common framework that was particularized for buildings. This common framework specifies:

- A methodology to calculate the energy efficiency of a building.
- A certification scheme to provide meaningful and publicly available information regarding the energy efficiency of buildings.
- A set of minimum requirements to energy performance of existing and new buildings.

In addition, the EPBD fulfills the suggested requirement regarding flexibility through the definition of 30 energy efficiency standards. Each Member State is allowed to adopt a particular subset of these standards in order to construct its own regulatory framework. Despite this flexibility, the EU must guarantee the completion of the agreed commitments,

thus it can make these standards mandatory if the national policies of the Member States are detected as non-compliant to those previously defined.

Finally, considering the individual European objective for 2020, the EPBD establishes an aggressive approach to promote energy efficiency in buildings. As an example, by the end of 2020, all new buildings should be *nearly-zero* buildings, which means that they have to have a very high performance and furthermore, their required energy must be provided by renewable energy sources produced on-site or in the vicinity of the building.

Although definitely promising, the EPBD does not seem enough to face the tremendous challenge of achieving a dramatic reduction of energy consumption and its subsequent GHG emissions. Several lines of action could be put in place to support the EPBD. Among others, due to the fact that building are not currently included into the EU ETS, we believe that doing so we would generate outstanding benefits in reducing their consumption. In Sections 4 and 5 we will analyze the current situation and future proposals, following the three principal guidelines stated in the UNEP to achieve sustainable buildings.

4. Current situation

4.1 Changing standards

The first guideline indicated in the UNEP states the need for determining energy efficiency objectives and energy performance standards. This requirement is essential if we intend to reach a global energy efficiency framework. Some standardization initiatives have arisen in the recent years, which create a common framework for defining energy efficiency in buildings.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has been working for decades on constructing standards, including ones to promote energy efficiency. It published the standard 189.1, that provided a set of minimum requirements for the design, construction, and operation and maintenance of high-performance *green buildings*. The last update of this standard was issued in 2009 (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2009a). The standard includes mandatory prescriptions with respect to the building's envelope and HVAC and Service Water Heating (SWH) systems, in order to achieve energy efficiency, together with site sustainability, water use efficiency, and indoor environment quality. Regarding energy efficiency, it is important to notice that the standard 189.1 states as mandatory that the energy consumption measurements should be captured and stored during at least 36 months. Based on these energy measurements, reports on consumption should be hourly, daily, monthly, and annually generated.

Furthermore, the ASHRAE detailed the energy prescriptions for buildings in a second standard that was first issued in 1975, having a recent update in 2010 (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2009b). Once again it provides the minimum requirements for the design, construction, operation and maintenance, and the use of on-site renewable energy sources to achieve energy efficiency. It includes detailed rules with respect to the envelope, HVAC and SWH systems, power, lighting, and electric motors. In addition, it described the criteria for monitoring the compliance of actual implementations of the standard with the fixed requirements.

Returning to Europe, buildings are included in the European labeling scheme that was set down in law in Directive 2010/31/EU (2010/31/EU, 2010). This directive makes it mandatory for all energy consuming products to be certified in respect to their energy performance. Buildings, as one of these energy consuming products, must commit to this requirement. Consequently, at present all new projected buildings must be certified. A set of software tools, the majority of which are based on DOE-2 (DOE-2, 2010), take as input variables the building's construction materials, geographic location, its operation, its equipment for lighting, HVAC, etc., and the weather conditions at their site. Based on these variables, they predict the theoretical energy consumption of the building. This predicted consumption is then compared to a certain ad hoc reference to produce a ratio that expresses the energy efficiency of the building under study. Classifying this ratio into a set of intervals defined by some predefined thresholds finally produces a label that illustrates the performance of the building.

Including buildings into a labeling scheme provides evident benefits to the promotion of energy efficiency because:

- It shows meaningful information to end users regarding the energy efficiency of the building.
- It adds energy efficiency as a new variable to be considered in the decision on buying a house. Thus buildings that were constructed taking into account efficiency principles are best candidates to be more easily sold and at higher prices.
- It promotes innovation and technology in order achieve sustainable buildings.
- It supports the diffusion of the energy efficiency guidelines to generate public consciousness about the energy and environmental problem.

Nevertheless, on the negative side, we can remark that, to the best of our knowledge, there is no global standard for energy efficiency labeling of buildings. For instance, although Directive 2010/31/EU compels every consuming product to be labeled according to its energy efficiency, there is no fixed procedure on how this labeling process must be implemented. In fact, there is not even a unique number of bands, going from seven in countries like France to fifteen in Ireland. In addition, the required classification of buildings into different types is not standardized, nor does the definition incorporate a set of climatic areas, both key to implement a fair comparison between the building under study and its reference. In consequence, a single and global procedure to calculate an energy efficiency index for buildings and its subsequent label are required.

4.2 Methodological verification framework

Suitable methodological frameworks for the verification of reductions in energy consumption and GHG emissions are key to the construction of national, regional, and worldwide inventories. At present, there are examples of these inventories collected by international agencies, such as the International Energy Agency (IEA) (IEA, 2010a), (IEA, 2010b), or the United Nations Statistics Division, based on the work of the Carbon Dioxide Information Analysis Center (CDIAC) of the United States Department of Energy (United Nations Statistical Division, 2009). Also available are national inventories in many countries around the world. For example, the UK (AEA, 2009) or Spain (Ministerio de Medio Ambiente, y Medio Rural y Marino, 2010) among others. Focusing on buildings, the most detailed

reports are issued by the U.S. Energy Information Administration (EIA) (EIA, 2011). Both the Commercial Buildings Energy Consumption Survey (CBECS) (CBECS, 2011) and the Residential Energy Consumption Survey (RECS) (RECS, 2011) provide data regarding building energy consumption across the US.

These inventories are key in fulfilling the harmonization and coordination requirements. Furthermore, they are also needed to construct a solid reference for the calculation of energy performance. Note, as we will see in Section 5, our proposed certification scheme and its corresponding labeling system are based on a ratio between the consumption of the building under study and that of a reference building. The more information we have, the more accurate and fair the resulting energy efficiency measurement will be.

All the previous initiatives form an interesting basis from which we can start to construct a complete worldwide inventory. Nevertheless, further efforts are needed in order to reach the level of completeness required for such an ambitious enterprise as the one regarding energy efficiency.

The most important pending issue is the construction of a standard and global model to be followed in every energy consumption or emissions inventory. At present it is difficult to construct a fair comparison between building's performances as data could be collected or aggregated following different rules that surely impact on the final energy efficiency measurement. The required model must be flexible in order to be suited for any type of international, national, regional, or local policy. In consequence, it must provide a common framework through which the different entities responsible for energy and environment will be able to construct their particular data structures.

There is also a set of detailed needs regarding different aspects of the common and global energy consumption and emissions inventory. Firstly, inventories must be constructed separating buildings depending on their type. With the exception of CBECS and RECS, inventories do not separate data from different types of buildings. Once again, this fact interferes with a fair comparison procedure because higher levels of consumption may be due to the inherent operation of the building (consider hospitals compared to residential buildings for example) and not to a deviation from the good practices in its use or construction. Secondly, annual inventories could be adequate to identify trends over long periods of time, but they are likely to be insufficient to detect energy efficiency issues depending on season, or use (consider for instance the working days against holidays in an office building). Hence temporal resolution (months, days...) must be added to the collected data in inventories. This temporal separation of consumptions could be key to perform a detailed energy analysis and provide an excellent means of improving energy efficiency. Following the same inspiration, a global and common energy consumption and emissions inventory should include detailed spatial information. Consider for example a residential multi-floor building; its energy efficiency is fully dependent on each householder's use or maintenance. This way, consumptions should refer to flats, areas, floors, or rooms in the building. Consequently, this would allow a better understanding of the building's performance and the underlying problems, making the entities responsible for its operation and maintenance capable of providing solutions and increasing their energy efficiency.

There is never going to be an ideal situation for the data acquisition and waiting for adequate levels of information is not an option. Hence despite the insufficient data to support the

obvious and clear requirements, we need now a procedure that can evolve from the current state of affairs. Simply starting the process and including a mechanism to evolve the structure of the framework against an improved data models has clear and immediate benefits. In fact it will obviously provide the momentum for its own improvement, simply by initiating the process of collecting the data.

4.3 Monitoring system

The development of a monitoring system able to collect data regarding consumption and related emissions, CO₂ levels or any other environmental agent, has been a mature research area since the previous century. Industry has already developed a great variety of devices and they are readily commercially available.

The last decade has seen the introduction of Wireless Sensor Networks (WSN) (Elson & Estrin, 2004), which have greatly extended the applicability of these sensors. The standardization process generated both ZigBee (Alliance, 2002) and IEEE 802.15.4 (IEEE, 2006) standards in 2002 and 2006 respectively. Today, WSN are widely used to monitor the environment and interact with it.

Energy usage has become one of the many applications of this technology and has received increasing levels of attention in recent years. Even so, although most large buildings contain management and monitoring systems, to the best of our knowledge, no monitoring system has been specifically tailored to produce energy efficiency measurements. Hence, to fulfill this objective, a monitoring application framework, that can be adapted easily and cheaply to specific building problems, is needed.

In addition, we believe that a higher temporal resolution is needed in order to detect the source of the eventual deviation of the building from the fixed objectives. The UNEP required annual monitoring reports, but those would not include the precise details needed to perform an energy diagnosis that could point out seasonal or operational issues. Consider for example a highly efficient building in summer with a poorly designed heating system or an optimum performance during working days but not on weekends. Furthermore, this same philosophy should be extended to space allowing to detect failures in specific floors or rooms in the building.

The power of an energy efficiency monitoring system goes beyond its original conception; it obviously can be used to enhance the analysis of a building's performance for maintenance and operation purposes. Additionally different studies, for example (Darby, 2000), have demonstrated how consumption in buildings could be reduced simply by providing understandable feedback to end users. Consequently, the monitoring system appears to be even more significant than initially thought. Also, these monitoring systems could be connected to local, regional, or national governments, so that the collected information regarding energy efficiency could be uploaded to their respective inventories.

5. Novel proposals

This last section is devoted to the description of a set of proposals developed by our team in order to give answer to the previously listed requirements. Some of them are already available for the scientific community and others are being subject of our current work. This

line of research in our group presents two key features. First, the work carefully follows the requirements set out by the associated international organization, such as the United Nations, in order to ensure the proposal is as compliant as possible to current objectives. Second, it is an interdisciplinary piece of work. It incorporates components from a diverse set of disciplines, each of which is designed to provide an answer to specific problems, but always including the requirement of cooperation with other elements of the solution. In this way we believe we can provide a framework for achieving energy efficiency in buildings.

5.1 New standards

The first requirement to accomplish worldwide objectives is to have a homogeneous scheme. This issue includes defining a common measure regarding energy efficiency. In (Rodríguez González et al., 2011) we proposed a universal energy efficiency index for buildings (EEI_B) giving a measure of the energy efficiency to a building as the ratio between its actual consumed energy and that of a reference building. The EEI_B is defined as:

$$EEI_B = \frac{C_{AB}}{C_{RB}}, \quad (1)$$

where C_{AB} is the energy consumption in the actual building (AB) under study and the reference building (RB) respectively.

In the initial stages of the framework we consider only the total energy consumption of the building; these data are readily available from the energy providers. It can also be easily evolved to more sophisticated forms, as more data become available. In addition, if the building under study has not yet been constructed, its energy consumption can also be estimated using any of the available software tools using DOE-2 (DOE-2, 2010) as their simulation engine. The method of obtaining the actual energy consumption of a building (in operation) to be certified based on the energy suppliers reports, avoids the use of complex simulations tools that require a huge amount of input data, which is seldom available. Furthermore, the EEI_B will be calculated from actual values of the consumed energy in the building rather than from estimates.

In order to perform the required ratio that defines EEI_B , we need a reference consumption C_{RB} . We will classify buildings by their type, thus separating hospitals from residences or office buildings as the consumption profiles depend directly on their particular operation. The reference value of the consumptions of all buildings of a particular type is defined as a function of the total constructed area, which again can be built now, in terms of readily available data and can easily be evolved. Using the defined reference, we are accepting an inherent premise: “any square meter of any building of a specific type consumes the same energy”. In consequence, C_{RB} is calculated as the energy consumption per square meter of all the buildings of the same type i , times the floorspace of the AB, S_{AB}

$$C_{RB} = \frac{C_i}{S_i} \cdot S_{AB}. \quad (2)$$

The proposed index is perfectly suitable for a certification scheme based on a labeling system. This labeling system also needs to be defined in a common and accepted format, such as the one we suggest in (Rodríguez González et al., 2011), which is summarized in Figure 1.

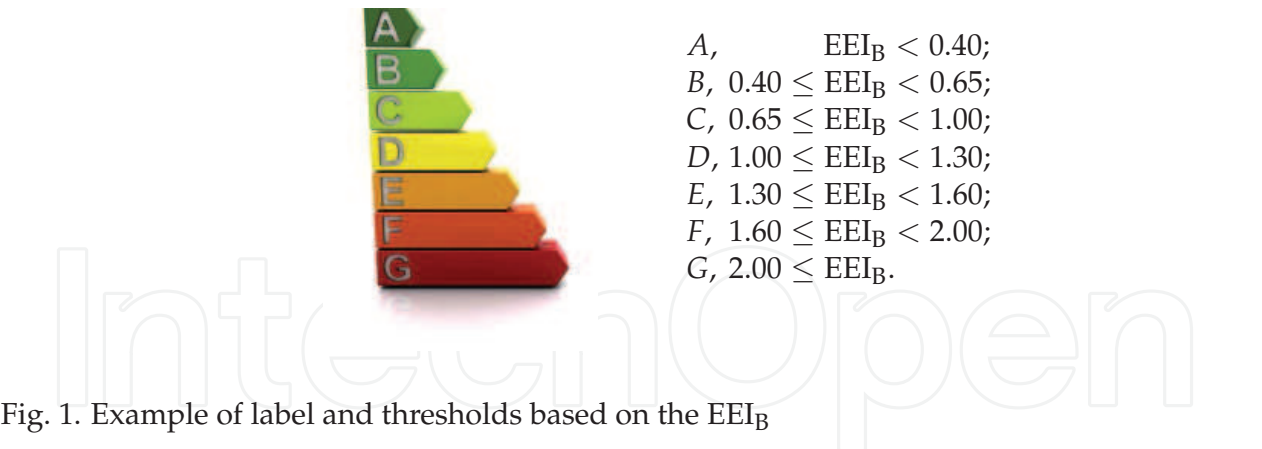


Fig. 1. Example of label and thresholds based on the EEI_B

In consequence, EEI_B provides a flexible means to monitor energy efficiency and update the resulting index whenever a new set of data is collected. Hence it can be used to verify objectives in energy policies. In addition, it promotes energy efficiency in buildings by upgrading the reference values as innovation is incorporated into buildings to increase their energy performance.

The limitation of the scheme is that the index provides an indicator of efficiency, but it does not identify the source of the problem. However it is relatively simple to extend the indexing process into a diagnostic tool.

5.2 Methodological verification framework

All of the previous sections implicitly assume that there is a common means of describing a building. A standardized and universal way of measuring energy efficiency in buildings will not be able to reach the fixed objectives if there is no common definition of those buildings to apply it to. The question is how could we implement fair comparisons of energy efficiency achievements amongst different regions or nations, thus verifying their policies, if we do not have an agreed base reference? Furthermore, how could we generate a worldwide database if the information is not provided in an accepted format?

If we could build a common description, it also could then be used to support information mining from a specific set of measurements that have been applied to it. It is relatively straightforward to define, if the description is limited to type and active surface area. However, if the description is to support a more detailed and extensible description, much more care has to be taken.

This problem of definition is compounded by a need to have a description that can represent an arbitrary set of resolutions. By this we mean that the building may be described simply by its type and its workable surface area, or a more detailed description at the level of floors and rooms. At some later date we may require a more complex description in terms of the materials that are used to construct the walls, or the locations of the heating pipes within the building. This problem of data-representation is twofold; we need a common, but flexible, descriptive language; and we need to actually build the data. The last point is obviously the most costly. Building owners will obviously require something intuitively easy to use. To do this we must define an approach that is extensible. The description model must be: intuitive,

expandable in terms of details of the description, and extensible in terms of being able to incorporate new concepts and new elements within the model.

Fortunately, this type of data description problem is very generic and has been considered in detail by the information technology community. Such an extensible data description can be achieved by the use of an *ontological* model, which can be used to construct a common framework in which to define buildings through their subcomponents and interrelationships between them. An ontology is a semantic specification of a certain domain or context (Gruber, 1993). It includes:

- **Classes:** concepts or abstractions. For example, person, building, floor, room.
- **Individuals:** class instantiation. For example, John, NY Hotel.
- **Attributes:** features of a class and all its individuals. For example, age, name, height, weight.
- **Relations:** interactions and links between the classes. For example: part-of, subclass-of; Hospital or Residential are subclasses of Building.
- **Functions:** relations defined by the user between different classes in the ontology. For example, `isFather(Person, Person)`, `compoundOf(Room, Object)`.
- **Axioms:** theorems that are declared over relations that the elements of an ontology must fulfill. For example: every room must be composed by a Door, a set of Walls, and Corners.

An ontological model of the building provides a perfect framework to define its singular features, create the appropriate relations between its composing elements, and finally connect those to the actual collected data in a semantic form. The very nature of an ontological description also supports evolution of the definition and the standardization of information exchange.

The ontology of a building mainly consists of a structural layer and a functional layer. The former describes the geometric structure of the building (floors, rooms, etc.), the construction materials, its topological representation, and the metrics characterizing the previous elements (length, height, area, etc.). Additionally, it also used to describe the most significant devices within the building and the features they provide. The latter describes the knowledge that has been generated regarding a certain field. For the purpose of this work, this knowledge revolves around energy efficiency. The knowledge can be introduced in the system by an expert or acquired during the operation. These two layers must interact and feedback each other.

The ontological description of a building is currently under the scrutiny of today's research community. One of the earliest examples of a building description ontology can be found in (Bonino & Corno, 2008). Here the ontological model called *DogOnt* is used to construct models of domotic system for home automation from the description of the building itself and the different devices deployed throughout it. Specifically, it includes 7 classes that define the building and its environment, the functionalities of the devices, their state and the network linking them, and commands and notifications for the operation of the domotic system. This work was extended in (Bonino et al., 2011) to add a new *Energy Profile ontology* to *DogOnt* indicating the energy consumption of the devices. This clearly demonstrates how an ontological specification can be extended and enhanced to incorporate new concepts and

functionalities. In this extended model devices are split into different categories depending on their energy consumption profile. In addition, the energy consumption is also divided into different levels depending on the state of the device. Finally, consumption is modeled through the state of the device and its either nominal or actual value, depending on whether real data is available or not.

This particular ontology does provide an excellent starting point for a building description and a starting framework for monitoring processes. However, it does not include the key factors regarding the energetic performance of the building. To do so, we are currently developing an extension of this ontology through a set of modules that incorporate the data components required to describe energy efficiency of the building, as well as the interrelations between the different indices. This process is producing a useful tool allowing a systematic description of a building in terms of its spatial structure, its temporal evolution, and its energy efficiency. Once constructed the ontology is designed to receive data from all the monitoring devices placed around the building. These devices collect information regarding both the environment and the actual consumptions within the building, which can in part be processed in real time, or in its entirety be post processed.

Through the functional layer of the ontology, we are able to obtain information regarding:

- Consumption patterns depending on the user's activity.
- Detection of the user's activity from the data provided by the devices monitoring the environment and the consumptions, coupled with the structure of the building.
- Deviations from usual energy efficiency values in space and time.
- Current status of a specific device.

5.3 Monitoring system

The third and last guideline stated in the UNEP in order to succeed in obtaining energy efficient buildings is the development of monitoring systems capable of providing annual energy performance reports.

The immediate issue regarding a monitoring system is how to collect the required significant data. As we presented in Subsection 4.3, a complete family of devices are commercially available at present. In addition, WSN have paid special attention to this matter in the last decade, thus providing solid solutions for developing monitoring systems able to measure the set of variables needed to study the energy performance of a building (mainly temperature, light, humidity, and consumption). There is still a minor issue regarding the optimum design and deployment of such sensors throughout the building in order to produce the data with the required temporal and spatial resolution.

Nevertheless, under this perspective, monitoring is just a means to collect data, but its true significance resides in the information that can be extracted from them. Consequently, the main reason why this monitoring system is definitely needed is that it is required to construct a complete worldwide inventory of energy consumption that will allow the construction of a fair comparisons between different initiatives and achievements, thus verifying the national and regional policies put in place.

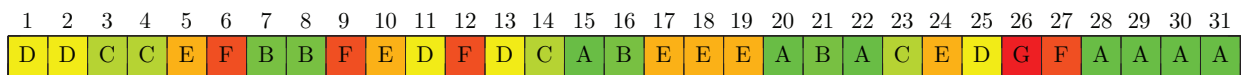


Fig. 2. Daily energy efficiency landscape.

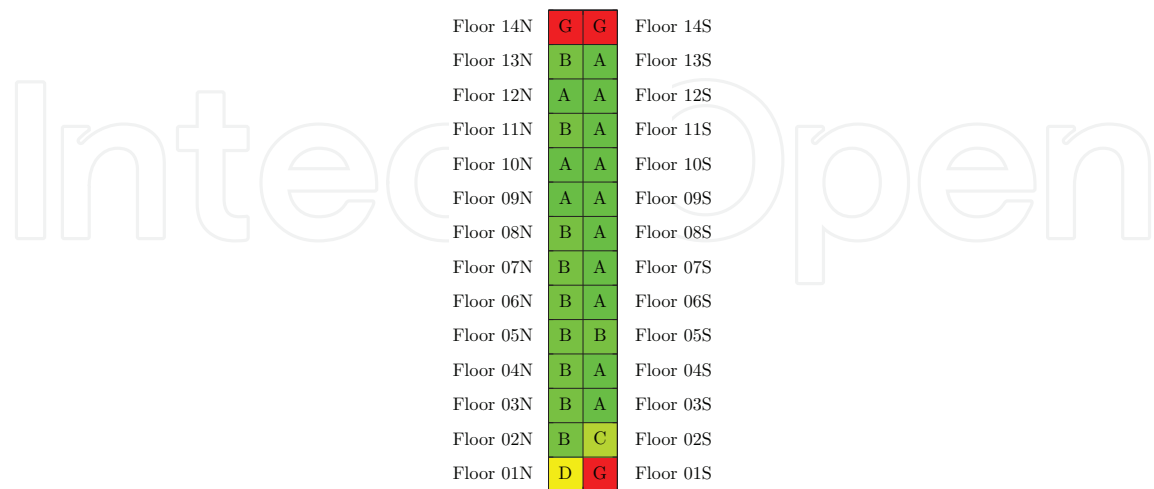


Fig. 3. Spatial floor energy efficiency landscape.

Construction of a basic energy indexing scheme is a must. However, we could significantly extend the benefits of this monitoring system by designing it with a higher temporal and spatial resolution. Doing so, we would be able to provide a powerful tool to implement an accurate diagnosis of the possible sources of failures in the energy performance of the building.

Fortunately this “extension” of the indexing mechanism is perfectly in line with the design and operation of an ontological descriptive language, described in the previous Subsection 5.2. This building’s ontology quote naturally and transparently allows detailed inspection of its energy efficiency to whichever temporal and spatial resolution is required. At this point it is worth remembering that the basic description is simply the building location, its type and its workable surface area. However, an ontological description quite naturally allows us to expand this description to whatever level of detail is required. Additionally, this expansion can be selective, expanding specific parts of the building in detail, whilst having poor resolution of details in the remaining areas.

When this type of decomposition is applied to an index, EEL_B , we call it an *energy efficiency landscape* (EEL_B) of EEL_B . We define an EEL_B as the temporal (days, months...) and/or spatial (rooms, floors,...) disaggregation of the global consumption of every energy source (electricity, gas, etc..), and its corresponding emissions for the building. Some examples of EEL_B are shown in Figures 2 and 3. As it can be observed, they perfectly serve the purpose of detecting temporal and spatial deviations by simple visual inspection.

The level of decomposition is dependent upon need. An energy landscape provides immediately the location and time of anomalies. It is these anomalies that need to be studied, allowing building managers to focus their attention on the relevant areas. Importantly, as the basis for the decomposition is the relative contribution to the overall energy index, comparisons between energy sources are possible and meaningful. The landscaping process

takes us from global policy directly into the local decision making process of building management. It also provides information that could inform future policy, hence we have a system that takes us full circle. In the context of the ontological description, only data that captures details of the area of the anomaly need be added to the model. Hence, workload is limited to only necessary changes, further enhancing the efficiency of the system.

6. Conclusions

Implementing energy efficiency in buildings is a complex problem. It involves different and heterogeneous disciplines such as Policy, Technology, and Science among many others. In addition, developments in any of those must be coordinated with the others and moreover put in place in a real scenario and in a cost-efficient way. Consequently, a well defined and planned strategy is key to achieving this challenging objective.

We accept this premise in the field of research. In order to follow a sensible planning for our research objectives, we chose the three main points of the UNEP to act as guidelines of our work. Hence, we have started analyzing the state of the art that has been reached in defining energy efficiency objectives and standards, developing a methodology to verify accomplishments, and designing monitoring systems to measure energy performance.

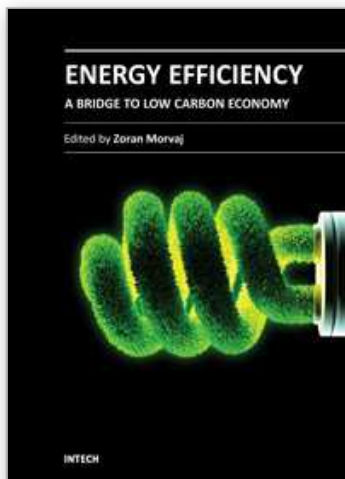
Then we have extended the results obtained in each of these three points through a set of novel proposals developed by our team. This on-going research must be observed as a cooperative framework developed for the overall objective rather than a collection of separate pieces of work. Thus, the definition of a universal energy efficiency index and the modeling of buildings through an ontology will be then used to deploy monitoring systems capable of both constructing a worldwide energy efficiency inventory, and serving as a diagnosis tool for operation and maintenance companies. On the whole, we believe that the proposed framework will significantly contribute to succeeding in implementing energy efficiency in buildings.

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Energy Efficiency - A Bridge to Low Carbon Economy

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Energy efficiency is finally a common sense term. Nowadays almost everyone knows that using energy more efficiently saves money, reduces the emissions of greenhouse gasses and lowers dependence on imported fossil fuels. We are living in a fossil age at the peak of its strength. Competition for securing resources for fuelling economic development is increasing, price of fuels will increase while availability of would gradually decline. Small nations will be first to suffer if caught unprepared in the midst of the struggle for resources among the large players. Here it is where energy efficiency has a potential to lead toward the natural next step - transition away from imported fossil fuels! Someone said that the only thing more harmful then fossil fuel is fossilized thinking. It is our sincere hope that some of chapters in this book will influence you to take a fresh look at the transition to low carbon economy and the role that energy efficiency can play in that process.

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