Sustainable Construction: Energy Efficiency in Residential Buildings

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ABSTRACT: The high consumption in the buildings sector, in Portugal, implies an obstacle to the accomplishment of the purposes intrinsic to sustainable construction.

To change this situation we must encourage the construction of energy efficient buildings based on a set of solutions that strive to reduce the energy consumption of buildings throughout its life cycle, while ensuring comfort for its occupants.

The main objective of this article is to analyze proposals that improve energy efficiency in residential buildings, based on the calculation of energy savings associated with the use of air conditioning (to assure a certain comfort temperature) and their payback period. To this end a case study was established. The energy performance assessment, before and after the implementation of the improvement strategies, was done trough a dynamic analysis with the EnergyPlus software.

The use of the considered strategies improves the energy efficiency of buildings, such as the case study, with different payback periods.

Introduction

Today, concerns about the process of sustainable development are increasingly important. The concept of sustainability as we know it today emerged in the early 80's through the Brundtland Report, which stated that sustainable development was the one that "meets the needs of the present without compromising the ability of future generations do meet their own needs" (Brundtland, 1987),

Following the creation of the sustainable development paradigm, the concept of sustainable construction emerged, in 1994, whose main aim is "the responsible development and management of a healthy built environment, based on the efficient use of the resources and on the ecological principles" (Kibert, 2008).

One of the biggest barriers to a global sustainable development is the growth of global energy consumption and the impact of its use on the environment, particularly in terms of climatic changes and the usage of fossil fuels. The problems related to the price of energy, energy efficiency and the energy performance of buildings have been increasingly the subject of political debate (Peréz-Lombard et al., 2008).

Part of the solution is to change the way energy is consumed by prioritizing an efficient use of energy. Solving the problem is not only to produce more energy with renewable sources, but also to use energy wisely (Rezaie et al., 2011).

On average, the buildings sector consume about 25% of the total energy, but that number approaches the 40% mark in large cities, which also concentrate the majority of the population (Guedes, 2009). Because of this, and given the increasing pace of building construction, the buildings sector presents a great potential in terms of energy savings.

One of the main causes of high energy consumption of buildings, in Portugal, is that they present a dissipative behavior due to the lack of efficient insulation solutions, which leads to an inappropriate use of air conditioning systems.

Therefore, it becomes particularly important that professionals from the sector contribute to reverse this trend by adopting a sustainable design for buildings, through the use of passive or active techniques in order to improve their energy efficiency, yet without contributing to a significant increase of building production costs.

Overview and Background

The rapid population growth worldwide increases the need for housing, transport infrastructures, communications, water and energy. This growth confers special relevance to the building industry and is therefore considered, together with the management of the built environment, a key area to achieve the principles of sustainable development in a society (CIB, 1999).

Buildings, infrastructures and environment are closely related, as energy, water and soil are consumed in the construction, use and maintenance of buildings. The uncontrolled consumption of natural resources result in environmental impacts that in some way affect the life, welfare and health of the populations.

Portugal is a country that can be characterized by growing energy consumption, a low energy production and, consequently, a strong dependence on imported energy sources. In 2008 the dependence on foreign energy was 83% of the total primary energy consumed in the country, which puts Portugal in sixth place in the European Union countries with greater external energy dependence, 37% above the average of the other countries (EUROSTAT, 2011).

Energy consumption in buildings represents approximately 29,5% of total consumption in the country, with 17,69% associated to household consumption and 11,64% to non residential building consumption. Although domestic consumption represents 17,69% of total primary energy consumption, this figure rises to 29% when referring strictly to the electricity consumption (ADENE, 2010).

In terms of energy use throughout the life cycle of a building, the construction phase is only responsible for 12% of total energy consumption. The use given to the buildings, including heating, ventilation, water heating and electrical equipment, is responsible for most of their energy consumption (WBCSD, 2009).

The high energy consumption observed in the usage phase of buildings is due, in part, to the increased standard of living of the population and consequent demand for more comfortable environments, especially when it comes to thermal comfort.

In recent years, there has been a widespread use of air conditioning systems, especially in more developed countries. With the occurrence of increasingly higher temperatures during the summer and lower temperatures during the winter, especially in the Mediterranean countries, we can only expect a higher use of this type of devices (Santamouris, et al., 2010).

Thus one should favor the adoption of active and, preferably, passive strategies that promote energy efficiency during the usage phase of the building, in order to counter this trend.

Generally, the promotion of energy efficiency and sustainable construction has better results when the problem is approached by a multidisciplinary team from the beginning of the building life cycle. The use of energy performance simulators is a key factor to support decision during the design phase, as it provides relevant information about the influence of certain options in the future performance of the building (Tavares, 2006).

In order to ensure the sustainability of buildings during their entire life cycle, assessment systems and tools have been created, enabling the evaluation and recognition of sustainable construction, making possible a better integration between the environmental, social, functional and economic parameters (Amado et al.,2011).

Sustainable construction assessment is based on a series of indicators and parameters that fit in the different dimensions of sustainable development. An indicator allows one to evaluate the behavior of a solution against one or more goals of sustainable development, and a parameter is a measurable or observable property that provides information about a phenomenon, environment or area (Bragança et al., 2006).

These indicators and parameters are associated with different weighting factors, which depend on the political, technological, cultural, social and economic context of each country or each region. Several countries have developed their own assessment system for sustainable construction, so that they can consider their local laws, regulations and building solutions based on local materials and/or techniques.

From a general point of view, the various existing assessment systems focus on the analysis of the following indicators: Local and integration, environmental impact, resources, indoor environment, planning, applicability and adaptability, energy, environmental management and political and socioeconomic aspects.

By analyzing the weighting factor corresponding to each of these parameters, it appears that the ones related to energy assume a higher weight. Taking as an example the LiderA system (Portuguese assessment system), the parameters that relate to energy have the highest weighting of all the parameters, corresponding to 17% of the total (Pinheiro, 2011).

We can also use the Lucas' study as an example, in which the author has developed a thorough evaluation of various systems, studying the relevance of various parameters and their applicability to the Portuguese context. The author considered water consumption as the most important parameter, with 18%, followed by indoor comfort and energy consumption with 15% and 14%, respectively (Lucas, 2011).

This demonstrates the importance of energy efficiency as a means of achieving a more sustainable construction.

Analyzing the Portuguese housing conditions we can see that age is a key indicator of its state of degradation. It can be pointed out that 39,2% of the residential buildings have over 40 years of age, while only about a quarter of the existing buildings were built after 1991 (INE, 2009).

Regarding the condition of the housing stock, the 2001 Census data indicates that about 32% of dwellings need small or medium-sized repairs, while about 10% require major repairs. Note also that, at the time of the 2001 Census (March 2001), 9,4% of the homes built between 1996 and 2001 already needed some kind of repair. These values report the lack of construction quality in Portugal (INE, 2002).

Until the publication of the first version of the Portuguese thermal building legislation (RCCTE), in 1990, the building components related to the thermal performance of buildings were often not included in the projects. This regulation introduced thermal and energy aspects in the study and design of buildings, setting minimum requirements for their building envelope (DGE, 2002).

In 2006, acknowledging the European Directive that promotes building energy certification, the SCE (Portuguese energy certification system) and an updated RCCTE were created.

RCCTE uses these main calculation parameters: the heat transfer coefficients of the envelope, the solar factor of glazing, the class of thermal inertia and the rate of air exchange in order to calculate energy requirements of the house. These requirements are compared with reference values in order to obtain an energy class.

The energy performance of housing can also be evaluated by a dynamic tool such as the EnergyPlus software.

The main difference between the RCCTE methodology and the EnergyPlus software, regarding the analysis of some factors influencing the energy performance of buildings, are summarized in table 1 below:

Table 1 - Some differences between RCCTE and EnergyPlus

	RCCTE	***ENERGYPLUS***
Internal Gains	Assumes a value for internal heat gains per unit floor area of pavement, depending on the type of use of the building, which is constant throughout the year (4 W/m^2 for residential buildings)	Variable to the habits of the inhabitants regarding the occupation and use of the equipment and lighting. Inserting in the programs the patterns of use and energy emitted by the equipment, lighting and residents, it's possible to obtain a more accurate and realistic value for internal gains
Solar Gains	Assumes generic values that are based on the incoming incident radiation	Variable throughout the day and year, depending on solar radiation and its intensity. It's also possible to define patterns for the use of mobile shading
Ventilation	Adopts a constant value for the hourly rate of renewal, based on the stipulated in the norm for natural ventilation NP1037-1, which takes into account, for example, the framing class, exposure of the building facades to the wind and the existence of devices for air admission on the facades	A constant value for the hourly rate of renewal can be defined (like in the RCCTE). You can also set a schedule for the rate variation throughout the day and/or year, and you can define solutions and patterns for natural ventilation, such as night ventilation patterns during the summer

The application of the RCCTE and consequent obligatory energy certification has introduced a greater demand in the construction sector, which translates into a change in buildings constructive solutions.

Only by assessing the level of energy efficiency in buildings it became possible to identify the shortcomings of the Portuguese housing stock. That knowledge may lead to an improvement of housing thermal comfort combined with lower costs in terms of energy use.

It's possible to build environmentally comfortable houses with less energy consumption by intervening at the various stages of a habitation life cycle, using essentially passive actions, supplemented or not with suitable active systems. (Amado, 2002)

The viability of the application of sustainable solutions in households also depends on its costs, both for the developer and for the ultimate purchaser. A solution with good environmental performance but with a cost of construction that greatly exceeds the cost of the conventional construction solution might not be considered financially sustainable, which constitutes a barrier to their implementation. Therefore, it’s important to know the payback period of the proposals.

Case Study

The approach to the process of sustainable construction in the sense that this work has been developing requires that the various solutions presented are evaluated in order to prove their value.

For the purpose of this study it was considered an existing building already assessed and certified by the Portuguese energy certification system. This allows obtaining base values in terms of energy requirements, important for comparison with the subsequent analysis.

The building under study is a multi-family residential building, with 271,3 square meters as an area of implementation, composed of six residential floors and two underground parking floors. The main façade of the building is oriented southeast. The roof is terraced, which facilitates the application of solutions such as solar panels or a rooftop garden, having also an enclosed area of support which can be used for activities for the apartment owners.

The coating materials are predominantly white, although there are gray colored elements occasionally. The building unit considered in the study is on the 3rd floor right. It has 3 bedrooms and four inhabitants. The total floor area of this fraction is 110,89 square meters.

The ultimate goal of this study is to optimize the energy efficiency of the dwelling, using sustainable solutions that allow a saving in the energy costs. The original solutions of the base model and the proposals for improvement considered are presented in table 2.

This study only takes into account the energy performance for the acclimatization of the dwelling, as it is the kind of performance that is assessed by the chosen software.

Table 2 - Solutions in the base model and improvement strategies

	BASE MODEL	**PROPOSALS FOR IMPROVEMENT**
Exterior walls	Double wall without therm insulation and structure in reinforced concrete without thermal correction	Double wall with insulation (3, 4 and 6cm EPS) Single wall with ETICS (3, 4 and 6cm EPS)
Paving	Reinforced concrete slab, insulated with 3 cm of XPS and variable coating	n.a.
Elevator wall	Reinforced concrete wall with projected plaster	n.a.
Common areas walls	Single wall masonry	n.a.
Windows	Double low emissivity glass, with coated aluminum frames without thermal cutoff	Double low emissivity glass with PVC frames and introducing na inert gas in the cavity
Solar orientation	Southeast	South and North
Fixed shading	Upper floor balcony at the top of the living room window	Existing + Horizontal fixed shading device at the top of the bedrooms Windows, on the facade oriented Southeast
	BASE MODEL	**PROPOSALS FOR IMPROVEMENT**
Natural ventilation	One air renewal per hour	Night ventilation in the summer with 1,44 air renewals by night and 0,66 air renewals by day
Electric equipment and lighting	Medium efficiency (1000W of lighting; 21740W of equipment)	High efficiency (500W of lighting; 15180W of equipment)

As stated before, the simulation program used for this analysis was the EnergyPlus version 5.0.0. Data characterizing the fraction was introduced in the program, such as its location, environment, usage patterns and other information. With this data it becomes possible to the program to simulate the dwelling energy performance. Output data, resulting from the simulation, were defined according to the desired final evaluation. This process is described in the figure below (fig. 1).

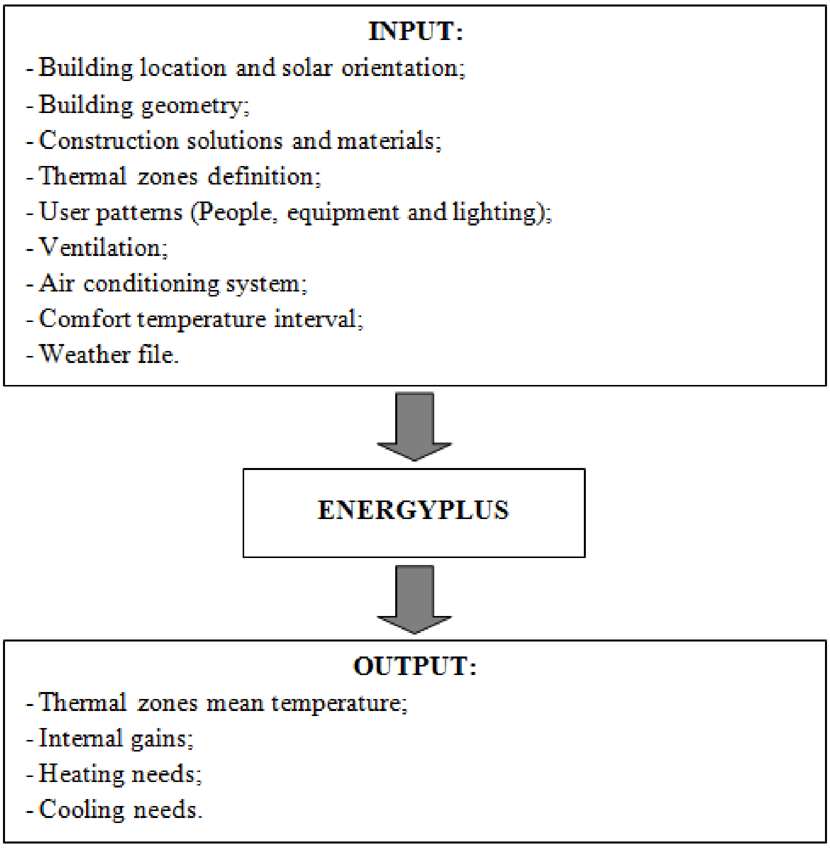

Figure 1 - Simulation process in Energyplus

For the purpose of this study it was considered the use of a fictitious equipment with na efficiency of 100%, that does not produce any internal gains and maintain the temperature within the target range.

The base model created served as a standard for comparison from which to apply the proposed improvements. The dwelling under study was divided into two "heating zones", in order to better represent the actual situation since these two zones show distinct characteristics of use and sun exposure, which greatly influence their thermal behavior.

Table 3 - Energy needs for acclimatization in the dwelling

NEEDS (kWh/year)	"Bedroom Zone"	"Living room Zone"	Building Unit
Heating	880,6	795,8	1676,4
Cooling	617,8	1876,5	2494,3
Global	1498,4	2672,3	4170,7

By observing table 3 one can see that there is a greater need for heating in the "Bedroom Zone" but this trend is reversed when it comes to cooling needs. In terms of the global needs for air conditioning for the whole autonomous fraction the cooling needs are predominant, in a large part due to the amount of cooling requirements in the "Living room Zone", caused largely by the internal gains in this area.

When comparing the internal gains in each of the zones under study, divided by type of source (lighting, electric equipment and people), presented in figure 2, one can observe that the major contribution is made by the use of the electric equipment in the "Living room Zone", with 70% of all the internal gains.

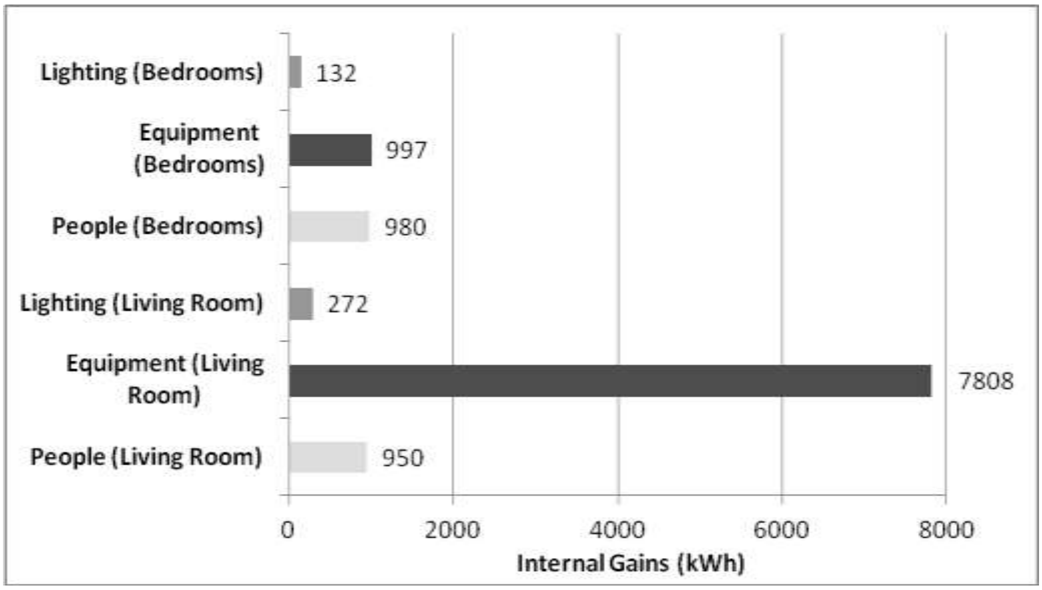

Figure 2 - Internal gains by source

The results were analyzed after creating the case study's base model and applying the different proposals to improve the energy efficiency in regard to the air conditioning needs.

The analysis of the added value of the proposed improvements focus mainly on two parameters: The savings on energy consumption in terms of air conditioning and payback period (if applicable).

The following table shows the main results obtained through this case study, regarding the percentage of improvement on overall needs for air conditioning (which reflects the savings in energy costs) and the payback period from the introduction of new measures.

In order to calculate the payback period it is necessary to know the price paid to the energy distribution company, in this case it's 0,149€/kWh, and the additional cost of each proposal in relation to the base solution. The costs for the installation of the various solutions were calculated based on the commercial costs of the materials and manpower.

Table 4 - Main results of the case study analysis

PROPOSALS FOR IMPROVEMENT APPLIED	GLOBAL NEEDS IMPROVEMENT (%)	PAYBACK PERIOD (Years)
Application of thermal insulation inside the wall cavity	4,5 (3cm) 5,6 (4cm) 7,4 (6cm)	12,0 (3cm) 11,0 (4cm) 10,7 (6cm)
ETICS application	8,8 (3cm) 10,0 (4cm) 11,6 (6cm)	18,5 (3cm) 17,1 (4cm) 16,6 (6cm)
More efficient windows system	1,4	43
Solar orientation of the main facade	0,1 (North) 19,1 (South)	-
Fixed shading	1,2	40,7
Natural nocturnal ventilation	8,4	-
More efficient electric equipment and lighting	0,3	-

Conclusions

Based on the study developed, it was intended to evaluate different proposals for improving the energy performance of a dwelling, with special focus on the application of passive solutions which can be applied in the design stage or in a situation of rehabilitation.

The main conclusions of this study are:

- The best proposal, in terms of energy bills savings, is to change the building's solar orientation, so that the main façade be oriented to the south;
- The application of thermal insulation is a more cost effective solution than the use of more efficient glazing spans or a fixed shading on the main façade;
- The placement of thermal insulation is more favorable the longer the lifetime of the dwelling, in which case it is preferable to adopt the ETICS system because, although representing a more substantial initial investment, allows for greater savings later in the energy bill;
- The application of better glazing and fixed shading spans, assessed in this case study, are for the most part unfeasible proposals financially speaking, in that its simple payback period exceeds 40 years;
- There is only energetic advantage with natural nocturnal ventilation, if behavioral standards are set and applied by users;
- The introduction of more efficient equipment and lighting does not induce any difference in the energy needs for air conditioning, and its added value is only in reducing energy consumption of said equipment.

The evaluation of each proposal was made in a singular fashion and its simultaneous application on building units has not been the subject of study. This simultaneous application could boost energy savings, especially when we combine proposals that do not involve additional costs to implement.

Although we must emphasize that the behavioral study of the population is variable and in this case it may not translate reality faithfully, it was found that internal gains have a great influence in determining the need for air conditioning. So it’s important to proceed in its reasoned assessment, in order to avoid under or overvaluations of said parameter.

The analysis of this case study allowed us to assess the proposals with greater potential for improving energy efficiency. It is not, however, possible to completely extrapolate the results obtained in this case for the reality of all the building stock.

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