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Sustainable Heritage: Analysis of Building's Thermal Behaviour

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Abstract

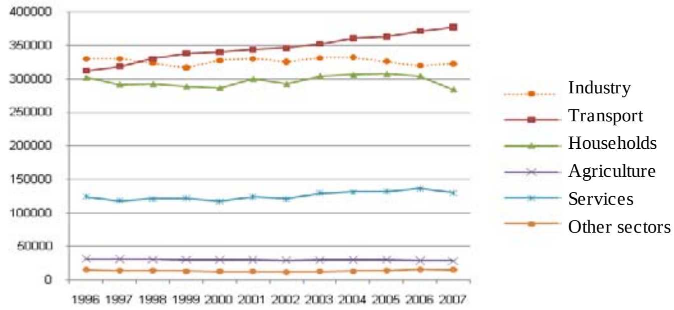
The energy consumption of buildings has presented a steady growth in face of the global energy consumption. This fact is related to a variety of factors, including the increased demand for comfort by the inhabitants, the low quality of construction of buildings and their inadequacy to the climatic and environmental context in which they are included. Reversing this tendency includes the necessary intervention in the built environment, promoting the attainment of comfort through interventions that respect the principles of sustainability in construction, namely in resource consumption over the building's life cycle.

Energy rehabilitation can be accomplished by enhancing the envelope's thermal protection using strategies in terms of i) strengthening insulation in the opaque envelope; ii) strengthening insulation of the glazing and iii) control of solar gains. The use of passive solar systems and the improvement of energy systems are other approaches for improving the thermal performance of dwellings.

This study examines the constructive characteristics and the pathologies found in approximately 700 buildings located in Coimbra's downtown ("Baixa"), the historic sector of the city. From this analysis it was possible to assess the present-day performance of these buildings, attending to the existing code and the application of DesignBuilder software, and to define the desired levels of performance resulting from rehabilitation procedures. The definition of these levels allows the superintendence of the process of intervention, taking into account the solutions to adopt with regard to the principles of sustainability.

1 Introduction

The Sustainable Construction consists of a Sustainable Development approach in the subject of the construction industry, and allows individualizing the overall concept, requiring an interdisciplinary vision among environmental, social and economic aspects. The construction, the buildings and the physical infrastructure are the major consumers of resources. In the European Union, in 2007, homeowners were responsible for about 25% of the total energy consumption (Figure 1), but recently this figure shows a descending trend as a result of the implementation of directives more stringent in terms of the energy consumption of electrical equipment in housing.



Source: Eurostat (July 10th, 2009)

Figure 1. Energy consumption in EU-27, by activity sector (1000 toe)

The environmental impacts caused by the construction industry can be reduced and the role of the construction technology may be important to limit those impacts [1]; sustainable construction corresponds to the construction sector response to the challenges of sustainable development (Figure 2).

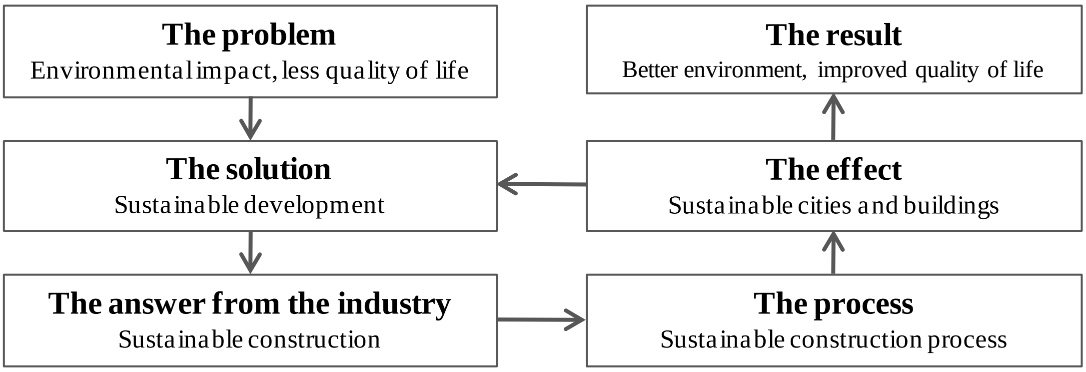


Figure 2. Simplified pathway for sustainable construction [2]

2 The Built Environment

2.1 Context (The Sustainable Construction)

The role of the built environment in the context of sustainable development and construction is essential, considering the extension of the existing built areas and its impact on everyday human existence. Taking into consideration the variety of efforts made to find extremely efficient buildings, searching for the zero consumption or the possibility to even produce its own energy, the existing built environment has (still) significant weaknesses, including the basic principles of hygiene and health.
In considering the need to renew the existing after the world wars, particularly since 1945, with the urban structures renewed, or some new paradigms that arose, such as the modernist movement, it

appears that much of what took place is not covered in the basic principles of sustainability construction, presented in Table 1 [3].

Table 1. Laws and principles for sustainable buildings

Law		Principles
1ª	Resource consumption compatible with the natural ability to its replacement.	Minimize the consumption of resources; Maximize the use of renewable resources and recyclable products; *Do more with less* – efficient resources.
2ª	Create systems aiming to maximize the pairing energy consumption and quality.	Use of solar resources; Energy use with a large number of small steps rather than a few major stages; Minimize waste.
3ª	Create materials that reverse in nutrients or raw materials for the production of resources.	Elimination of pollution; Use of biodegradable materials; Reuse of components and buildings.
4ª	Improve the adaptability and functional and biological diversity.	Life cycle's conscious application; Allow access to easily recyclable materials without destruction of the materials difficult to recycle; Protecting and improving biodiversity.

Within this context, it is necessary to rethink the built environment. This paper discusses the old buildings located in historic areas of Portuguese cities. These urban areas were abandoned during the period when the flow of new urban areas, with new construction, prevailed in the country. The need for controlled urban development, attending to the conservation of land that enable the development of agricultural activities or the preservation of the environment, caused the change in attitudes and awareness about the need to safeguard and maintain the built heritage, restoring degraded urban areas.

2.2 Coimbra downtown ("Baixa")

As previously mentioned, the purpose of this study has its *locus* in the central area of the city of Coimbra, which is an ancient site that was the former suburbs by the 10th century [4]. The urban morphological and physical characteristics are similar to other old areas in several Portuguese cities that therefore will be considered as a pattern for the characterization of their thermal behaviour.

These constructions were used for commerce and housing purposes by low income families, which explain the low quality of the housing. These buildings are mostly two-storey and two facades (front and back) executed in stone, with two walls between buildings ("frontais") that separate them from neighbouring buildings. The roof structure of wood shows a configuration of pitched roofs (two slops) and is covered with clay tiles. The interior walls are formed by partitions in "tabique fasquiado" (a traditional technique with a wood structure).

The characterization of the area was carried out starting from the analysis of the data collected under a protocol signed between the University of Coimbra and the Coimbra City Council, which allowed groups of students, graduates and teachers to perform an exhaustive survey of the area, particularly in the areas of Engineering (construction, conservation status and pathologies, users satisfaction levels), Architecture (survey and architectural design of all buildings in the area) and Social (through the characterization of the resident population).

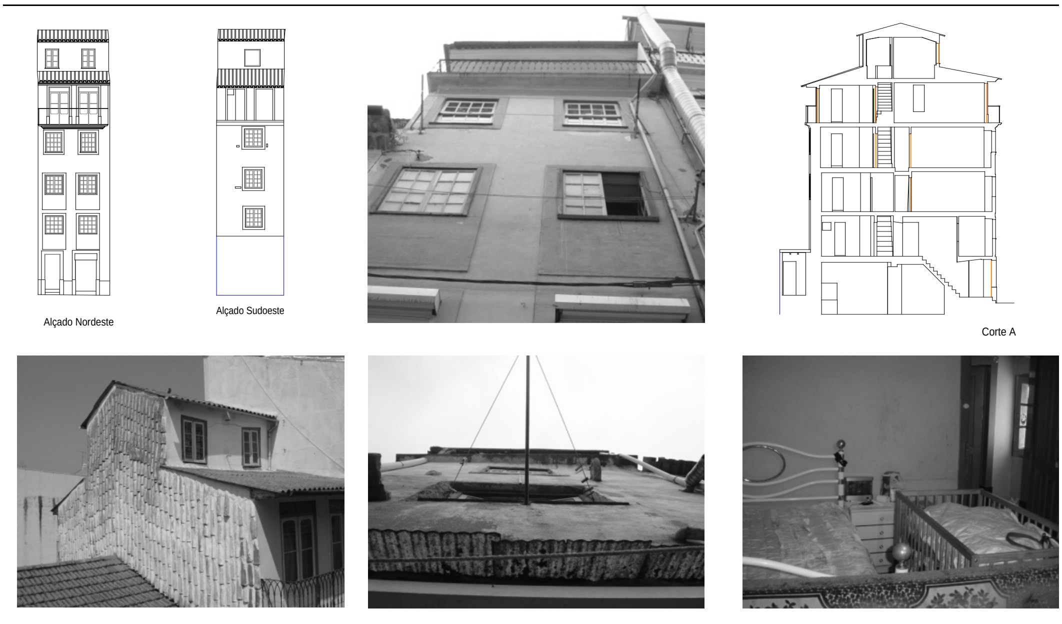


Figure 4. Facades, views and images from downtown's building

Figure 4 shows an example of one of the buildings used in this work, with some drawings and pictures from inside and outside.

3 Behaviour analysis of the building's envelope

3.1 Tools used to analyze thermal behaviour – RCCTE and DesignBuilder

To analyze the thermal behaviour of the building's envelope it was used the Code of the Buildings' Thermal Performance Characteristics (RCCTE) [5], which analyzes the needs for heating and cooling of the building in accordance with the losses and gains related with its geometry, characteristics and climatic conditions of the location.
In a second step it was used a energy simulation program, the DesignBuilder [6], which allows to evaluate the thermal performance of the building according to the parameters established, in this case it was analyzed the gains and losses associated with the model built for this purpose (Figure 5).

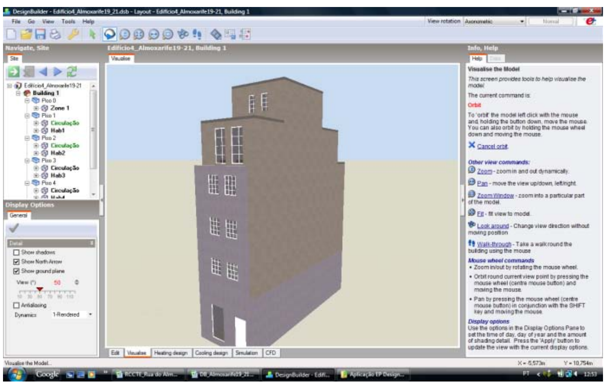


Figure 5. DesignBuilder Interface with the model used

The option for an intervention strategy aimed to improve the thermal performance of construction took into account: i) the maintenance of existing materials whenever possible to preserve them without compromising the interior conditions, ii) the maintenance of exterior features in order to keep unaffected the image of the urban area which is intended to preserve and iii) improving the thermal performance in order to grant the conditions to other issues, such as the indoor air quality, the hygiene and health features.
The intervention was performed in order to strengthen the building's thermal envelope considering:

- The insulation, in the interior surface of the wall (air layer (2cm) + EPS (2cm) + plasterboard (6cm)) ;
- Reinforcement of the openings through the application of an additional frame and the recovery of the existing elements.

3.2 Thermal performance by using traditional materials and techniques

Considering the conditions of the existing building, the U values needed to apply the tools of analysis was calculated. The results are presented in Table 2, which shows also the maximum and the reference U values in accordance with the RCCTE.
Table 3 shows the U values after considering the changes arising from the proposed intervention.

Table 2. U values of the building envelope

Building element	**Characterization**	$U_{existent}$	$U_{reference}$ [1]	$U_{maximum}$ [2]
Exterior walls	Stone ("rachão") (0,6m) covering with plaster of lime and sand	1,92	0,70	1,80
Interior walls	"Tabique fasquiado" with different covers	2,16	1,40	2,00
Wall between **different** buildings	"Frontal"	2,19	1,40	2,00
Floor	Wood	1,40	1,00	1,65
Ceiling	Wood / Plasterboard (Floor 0)		1,00	1,65
Openings*	Structure with wood / aluminium and simple colourless glass (3mm)	3,90/4,60	4,30**	
Roof	View structure	3,80 (asc)	0,50	1,25

* Value of maximum solar factor = 0,20.
** Medium value (day and night). The existent night protection should be included.

Table 3. U values after the intervention proposed

Building element	$U_{existent}$	$U_{intervention}$	$U_{reference}$	$U_{maximum}$
Exterior walls	1,92	0,55	0,70	1,80
Interior walls	2,16	2,16	1,40	2,00
Walls between buildings	2,19	0,81	1,40	2,00
Floor	1,40	1,40	1,00	1,65
Ceiling			1,00	1,65
Openings	3,90/4,60	2,20	4,30	
Roof	3,80 (↑)		0,50	1,25

The application of RCCTE turned possible to define the needs of heating and cooling according to the losses and gains envisaged. Table 4 presents the results of this application, which is held in each household (there are two in this building)

[1]The reference and maximum U values are established in the Code of the Buildings' Thermal Performance Characteristics [RCCTE, 2006]

Table 4. Results from RCCTE application in one household (Floor 1)

Needs		Existent	Walls insulation	Walls and openings insulation	Unity
Heating needs	Maximum (Ni)	69,19	69,19	69,19	KWh/m2.Ano
	Household (Nic)	100,75	65,15	57,38	KWh/m2.Ano
Cooling needs	Maximum (Nv)	18,00	18,00	18,00	KWh/m2.Ano
	Household (Nvc)	1,71	2,44	3,09	KWh/m2.Ano
Global needs of primary energy (Ntc)		5,95	4,93	4,71	Kgep/m2.Ano

Table 5 presents the results of implementing RCCTE to the second household, located on the upper floor.

Table 5. Results from RCCTE application in the second household (Floors 4 e 5)

Needs		Existent	Walls insulation	Walls and openings insulation	Unity
Heating needs	Maximum (Ni)	95,61	95,61	95,61	KWh/m2.Ano
	Household (Nic)	233,10	131,78	119,73	KWh/m2.Ano
Cooling needs	Maximum (Nv)	18,00	18,00	18,00	KWh/m2.Ano
	Household (Nvc)	17,17	23,29	26,47	KWh/m2.Ano
Global needs of primary energy (Ntc)			9,27	8,95	Kgep/m2.Ano

As part of the analysis conducted by RCCTE and according to the strategies adopted, there was a significant reduction in losses from the envelope and opaque glazing. This cutback was reflected in the results by reducing the nominal heating needs between 25% and 40%; in contrast, an increase in nominal cooling needs is possible to be noted, from 39% to 80% due to reduced losses. Through the global needs of primary energy (Ntc), reflecting the energy consumption, it's possible to observe that there was a reduction in the first floor of 21% and in the floor 4 and 5 the value of Ntc is lower by about 37%.

From the application of the DesignBuilder software it was possible to reach the results shown in Table 6, in the same households mentioned before.

The results allow analyzing the changes in the heat balance of each dwelling in accordance with the changes arbitrated. Regarding this, it was analyzed the change in overall heat balance according to the simulations. In the habitation located on the 1st floor there was a reduction of 43% and 56% in heating requirements considering, respectively i) application of the counter-façade and ii) application of both the counter-façade and double frame. In the habitations located on the 4th and 5th floors, considering the same alternatives, there was a reduction of 56% and 57%, respectively.

Table 6. Results of DesignBuilder software application

Situation	Description	Openings (KWh)	Walls (KWh)	Roof (KWh)	Floor (KWh)	Infiltration (KWh)	Needs (KWh)		Solar gains (KWh)
							Heating	Lighting	
Household - Floor 1									
A	Existent building	-461,29	-352,04	0,05	-288,27	-586,34	263,93	204,58	1000,28
Refurbishment									
A-PI	Walls isolated	-452,49	-121,26	0,08	-274,22	-572,71	149,77	206,03	843,06
A-PI CD	Walls and openings isolated	-273,86	-127,08	0,24	-299,7	-584,49	115,67	208,07	736,85
Household - Floor 4 and 5									
Situation	Description	Openings (KWh)	Walls (KWh)	Roof (KWh)	Floor (KWh)	Infiltration (KWh)	Needs (KWh) Heating	Needs (KWh) Lighting	Solar gains (KWh)
A	Existent building	-1595,99	-3933,37	-198,56	0,28	-827,76	2575,15	313,28	3017,13
Refurbishment									
A-PI	Walls isolated	-2068,54	-1713,02	-208,39	-0,11	-1004,38	1115,34	311,02	3017,13
A-PI CD	Walls and openings isolated	-1013,26	-2255,76	-246,90	-0,16	-1005,62	1101,53	312,94	2564,57

4 Conclusion

The old districts of Portuguese cities are inserted in consolidated urban structures, enclosed by the city's growth and conditioned by the constraints of urban gothic plot. The suiting between the patterns of urbanization and housing of the 10^{th} century, even with the changes made over the years, and the current conditions is a challenge that interventions carried out in these areas have to deal with. The actions of intervention must consider several parameters beyond the technical issues, namely i) the improvement of housing conditions, ii) the respect for urban infrastructure, iii) the support for social relations, iv) the fostering of local economic activity, v) the maintenance of urban memory, vi) the cultural and heritage value.

Given the need to reduce energy consumption as a way to decrease the impact of human activity on the environment, the analysis of this part of the built environment is fundamental when considering the needs arising from the quality of these buildings.

This work shows that these buildings, which show adverse construction characteristics in face of the techniques and materials available today in the construction industry, have a poor indoor environment quality. This study does not consider the significant degradation of the buildings which affect negatively the initial results (considering the existing building).

This study shows also that small interventions can have significant results at the level of the indoor environmental conditions and of the energy consumption in these buildings to achieve minimum levels of comfort. The thermal enhancement of the vertical opaque surrounding, in particular by thermal walls and glazing strengthening, can contribute to about 50% reduction in losses of the building.

The improvement of these buildings is a key strategy for recovering degraded urban areas and to control the spreading out of the city. The paradigm of sustainable development has imposed a fundamental condition for human existence: the control over the occupation and the impact on the environment. This occupation has been characterized by the destruction and excessive consumption of resources. The contribution of these urban areas could be significant if the society assume its recovery as an alternative to new construction.

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