ENERGY-EFFICIENT RETROFINTTING: MOURARIA AS CASE-STUDY

ANALYSIS OF FOUR CONSTRUCTION TYPES

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INTRODUCTION

Energy-Efficient retrofitting aims at the conjunction of two emergent topics: Rehabilitation of the Portuguese houses, mainly their historical centers, and the quest for sustainability in the construction sector, which is essential in the fight against global warming.

For this purpose, the implementation of Passive Solar Building Design strategies in the historical neighbourhood Mouraria, in Lisbon, were evaluated. Building-wise, an analysis and comparison was made, that focused on the thermal construction layouts of different epochs, to define rehabilitation recommendations that improve the building's thermal conditions and minimize their energy consumption. Since this is one of the most degraded neighbourhoods in Lisbon, the impact of such recommendations, must be thoroughly analysed in the neighbourhood scale.

1. SUSTAINABILITY AND REHABILITATION

1.1. SUSTAINABILITY: DEVELOPMENT STEPS

The Industrial revolution that started at the end of the XIII century, was define by a set of profound technological transformations that influenced great part of our economical and social global system. The discovery of coal, followed by the discovery of oil, resulted in an increase of pollution and overwhelming energy consumption. Awareness of the character of non-renewable fossil resources and the importance of alternative energy sources, took place with the historical oil crisis of 1973, alerting the developed countries to its inevitability and consequences of its end.

At the same time, a new way to conceive buildings rose along with technological developments that neither adapted nor took advantage of its surroundings. This type of Architecture: Bioclimatic or Passive Design is developed through these forgotten principles, with the goal to bring interior comfort to its residents/inhabitants along with the reduction of energy consumption rate for climate control and illumination.

Meanwhile the Kyoto Convention, carried out at the end of the year 1997, triggered for the development of a global policy to invert the process of global warming. The need for the introduction of such measures, necessary to comply with the established goals, had repercussions in the Portuguese governmental policies, and legislation. Specifically related to construction, the revision of *Regulamento das Características Comportamento Térmico dos Edifícios (RCCTE)*, and the drafting of the *Sistema Nacional de Certificação Energética (SCE)*, mandatorily applied since the beginning of 2009.

1.2. THE IMPORTANCE OF BUILDING REHABILITATION OF THE PORTUGUESE HOUSING

Portugal has recent houses, with 75% of the housing built in the last forty years (Paiva, 2006). On the other hand, the government has concentrated its financial support to home owners by subsidies in their own houses or newly built houses in the city suburbs, instead of investing in the retrofitting of their city centers.

Accordingly to the European Union studies, Portugal was in the top positions of the wrecked homes' ranking in the 23 countries of E.U., with 10,6% of its homes in such conditions, that is considerable distant from the values of the United Kingdom and Netherlands. Most of the European countries have increasingly invested in the sustainable development of their cities, that has to forcibly focus on the retrofitting of older and degraded parts of their cities, with social, economical, and environmental repercussions. Despite this panorama, in 2002, the rehabilitation of buildings in Portugal gained a greater importance in the construction industry (about 7%) well below the average of EU (about 35%) (Pinho, 2005). However, there has been a rising awareness concerning this question, taking into account the Portuguese housing situation, and the urgency to rethink the different ways of building with more balanced impacts environmentally and economically.

1.3. ENERGY-EFFICIENT RETROFITTING

The greatest environmental impact of the buildings occurs during its exploration period, mainly in terms of energy consumption, and this is often aggravated by origin deficiencies and obsolescence. According to *Agenda 21*, buildings are responsible for 40% of energy consumption and 30% of CO_2 emissions.

From time to time, some good construction principles have been left out, derived mainly from economical and aesthetic reasons, leading to a greater discomfort, but supported on technological evolution, aimed at the application of artificial systems. It's necessary to implement Passive Design strategies that guarantee the thermic comfort, to combine the building's healthy functioning with a significant energy consumption decrease. In Portugal, several policies have been established for the development of energy efficiency in existing constructions, however, it is necessary to understand the different constructive typologies needs to sketch different rehabilitation solutions and strategies.

We're walking towards the transformation of existing threats into development opportunities that ally the housing reality of our country with the expansion of a type of construction adapted to the planet's needs.

2. MOURARIA

2.1. HISTORICAL SKETCH

Nowadays, Mouraria's neighborhood is a significant part of Northwestern descent of the *Castelo de S. Jorge* hill, composed of the parishes of *Socorro, S. Cristóvão/S. Lourenço* and part of *Anjos, Graça, Santa Justa* and *S. Tiago.*

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Picture 1 – Localization of Mouraria's neighborhood in Lisbon (fonte: AA.VV, 1996)

It's occupation goes back to the Christian reconquest epoch of 1170, based on the charter that *D. Afonso Henriques* gave to the Moors, to expel them from the city and force their setting in the northern border of the castle. The inside of the neighborhood wasn't a linear space, as it was composed by several dead-end streets, characteristic of Arab urban morphology. In 1497, *D. Manuel* sentences the expulsion of two ethic religious minorities in Portugal, forcing its inhabitants to convert to Christianity or to leave the country.

With the 1755 earthquake, Lisbon was severely devastated. Mouraria was spared, and given a few exceptions, the urban mesh was kept, and many buildings were rebuilt with wreckage from the earthquake or raised from new constructions methods (Vieira, 1994). The existing buildings had, for the most part, low quality with serious insalubrious situations.

In the beginning of the 20th century, the ideal of civilizing urbanism for typical neighborhoods gains several followers. In downtown Mouraria, a destroyed area at that time, the construction of a great plaza – *Martim Moniz,* was planned, having been carried out only in 1997. The systematic demolitions gravely affected the core activities that characterized and gave life to the area (AA.VV., 1989). “Gradually, a new urban ideology is installed in the autarchy (..)” that originated, in 1985, the *Gabinete Local da Mouraria (Menezes: 2004: 60).* In 1996, the *Plano de Urbanização do Núcleo Histórico da Mouraria* was introduced, were several types of interventions were defined, that were later carried out.

In 2003, political changes were registered in the executive body of *Lisboa's* City Hall and the *Gabinetes Técnicos Locais* lost their action counterparts in the neighborhoods. Today they execute part of the licensing processes and finalize the unfinished constructions initiated around 2003.

2.2. PASSIVE DESIGN PRINCIPLES

The strategies described below are associated with building's rehabilitation, however some important passive design aspects exclusively related to new constructions, are not mentioned.

Area and Windows types

Windows oriented to the north must be reduced due to its diminished solar gains and heat loss in winter. A southern orientation is translated into direct solar gains in the winter and the possibility of excessive gains in the summer, reason for these to be carefully dimensioned and shaded. When oriented east and west, the windows have a solar incidence difficult to be shaded, requiring greater attention during its dimensioning. With the technological development, several types of glass have been enhanced that reduce solar gains during summer and heat loss in winter, such as the double glass, colored glass, reflective glass and low emission glass.

A synthesis of the evolution on windows' dimensions, related to the studied construction typologies, is made on Table 1:

Table 1 - Characterization of the windows in the different constructive typologies

CONSTRUCTION TYPE	 *PRÉ-POMBALINO*	 *POMBALINO*	 *"GAIOLEIRO"*	 CONCRETE CONSTRUCTION
WINDOWS TYPE	▪ Few and small windows, between 0,40 and 0,80m wide	▪ Windows between 0,9 and 1,20 wide	▪ Streching of window proportions; ▪ Multiplication of windows; ▪ Windows widening through twin windows	▪ New structural conception that makes window's stretching possible (in Mouraria windows are not mostly stretched due to integration concerns)

Shading

The windows can be protected by a variety of shading elements applied either on the outside or the inside, being the former more efficient since it easily prevent heat entrance into the glass surface. From a local analysis, it was found that the predominant shading devices are interior wood shutters and exterior blinds, usually complemented with light colored curtains. In recent construction it is seldom found exterior shutters and improvised shading systems, such as awnings.

Thermal inertia

The thermal inertia of an element can be defined as its heat storing capacity, absorbing the daily temperature fluctuation. The exterior surroundings store the daily energy from the exterior and interior, releasing it during the night (Goulding, 1993; Tirone, 2007). During the summer, natural ventilation plays an important role, allowing the dissipation of heat existing on the inside during the night. Table 2 presents a brief analysis of the type of thermal inertia in the different building typologies:

Table 2 - Characterization of inertia types on different building typologies

CONSTRUTION TYPE	THERMAL INTERIA TYPE
PRÉ-POMBALINO	Stone or mixed construction masonry walls, about 1m thick on the ground floor. The remaining floors were made of the frontal walls or brick masonry, approximately 0.20m thick.
POMBALINO	Stone or mixed masonry walls of about 0.90m thick
"GAIOLEIRO"	Façade walls of ordinary stone masonry in gables and *saguão* in solid brick. Walls with about 0.90m thick on the ground floor, reaching up to 0.30m thick on the top floor.
CONCRETE CONSTRUCTION	Brick walls of about 0.30m thick. Aplication of thermal insulation.

Thermal insulation

The insulation[1] is mainly intended to increase the thermal resistance[2] of the building envelope to reduce heat exchange with the outside. Separating the different elements can be done by the interior, in the air-space, or externally, having the latter several advantages. In the context of rehabilitation, the introduction of thermal insulation can be an issue that requires greater sensitivity, since there is an increase of technical, functional and aesthetic conditions.

Natural ventilation

Natural ventilation is a process arising from the existence of a difference in pressure or temperature between two different points, being a common phenomenon between two opposing fronts. Ventilation can be simple, transverse or crossed, depending on the windows' spatial positioning. The first, done by a single facade and it is less effective than the second, which as the name suggests, is carried across the building through opposite exterior walls.

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[1] "'Thermal insulation' is the material with thermal conductivity below 0.065 W / m ° C, or whose thermal resistance is superior to 0.30 m2. ° C / W "(DL 80/2006)

[2] "'Thermal resistance of a construction element' is the inverse of the amount of heat per time unit and per area unit flowing through the element of construction per temperature difference unit between its two sides." (DL 80/2006)

3. CASE-STUDY

3.1. GOALS

The purpose of this dissertation is to evaluate the importance of implementing strategies for passive design at the building and neighborhood level, in the Mouraria area. At the building level, it's intended to analyze and compare the thermal performance of buildings from different periods, in order to establish recommendations for rehabilitation to help improve the thermal comfort with lower energy consumption of these buildings. At the neighborhood level, it's intended to assess the impact that the implementation of these recommendations may have on the energy consumption.

3.2. METHODOLOGY

Having opted to undertake the neighborhood level evaluation based on the different constructive periods, it became necessary to analyze, on a building level, the energy behavior of the various construction types existent in Mouraria: *Pre-Pombalino*, *Pombalino*, "Gaioleiro" and Concrete Construction. So, a representative building of constructive period was chosen and evaluated, based on the available information and field visits made to the sites.

Picture 2 - *Largo da Achada, 2* after rehabilitation

Picture 3 - *Rua das Farinha 1-3* nowadays (fonte: autor, 2009)

Picture 4 - *Rua da Mouraria 8-16* after rehabilitation

Picture 5 - *Rua João do Outeiro 6-14*

The analyses were performed using the *Ecotect* software. This analysis required that three-dimensional models of the buildings and their surroundings to be made within this software. The evaluation was made based on the energy consumption analysis, expressed in kWh/m2, which calculates the amount of energy needed to keep a given space with its temperatures within the comfort range of the considered reference, assuming the presence of an HVAC system on the heated spaces and the absence of natural ventilation..

3.3. BUILDING CHARACTERIZATION

Pré-Pombalina construction, Largo da Achada 2

The *Largo da Achada nº2* building is one built before the 1755 earthquake that, damaged by the earthquake, was rebuilt using materials of its own downfall. Constructively, the exterior walls of Level 0 are composed of plastered stone masonry, and the upper floors were made of plastered brick masonry. The floor and cover consisted of wooden beams, and the windows were made of wooden frames with glass shutters and simple interior, also made of wood. The rehabilitation was carried out by EPUL in 2007, and the type adjusts to current needs, maintaining and rehabilitating its main building blocks.

Pombalina construction, Rua das Farinhas 1-3

The *Rua das Farinhas 1-3* building is a Pombalina construction, probably built using debris resulting from the earthquake of 1755. Constructively, the exterior walls and some interior ground floor walls were made of towed stone masonry. In the upper floors, the interior walls were composed of *frontal* and *tabique* walls. The floor and cover were made of wooden beams and windows composed by wood frames with simple glass and interior shutters, also made of wood. The rehabilitation, carried out between 1999 and 2000 by *Gabinete Técnico da Mouraria*, is made respecting the structure and spatial organization, making better use of the building and improving health solutions.

"Gaioleiro", Rua da Mouraria 8-16 | Escadinhas da Saúde 10

Erected between 1906 and 1908, the building of *Rua da Mouraria 8-16* is part of the first "gaioleiros" to be built, still with a quality construction. Constructively, all exterior walls were made of plastered stone masonry with the exception of the attic, covered with sheet metal on the outside. The interior walls were composed of *frontal* and *tabique* walls and the windows protected and shaded by wooden frames with simple glass and wood shutters also by the interior. The structure and coverage of the floor consisted of wooden beams. Between 2000 and 2001 it is rehabilitated by *the Gabinete Técnico da Mouraria*, with respect to its structure, facade and spatial organization. During the construction, part of the southern facade collapsed, forcing the modification of the existing structure.

Construção em Betão, Rua João do Outeiro 6-14

The origin of this building probably dates back to the sixteenth century, having a considerable architectural value (Marques et al., 1989). Its irreversible state of ruin made it impossible to recover, being then demolished and reconstructed in 1990. This project was designed in full respect to the facades' design, and creating an interior courtyard to improve its living conditions.

Structurally the building is concrete based, and its exterior elements consist of double-walled, simple and sloped roof with a concrete slab. The double walls are made of concrete on its exterior surface, brick on its interior and inner insulation through extruded polystyrene and the simple walls are composed of concrete. The windows are protected with frames of wood and simple glass and wooden shutters through the interior.

3.4. RESULTS ANALYSIS

The evaluation was performed by simulating the energy consumption of each building in its original state and then rehabilitated, to make proposals for improvement. For each case two floors were simulated, the intermediate and higher, in order to analyze the thermal performance of building a type floor and in the worst possible case.

Pre-Pombalina construction, Largo da Achada 2

In this building the simulations compare two floors, the ground floor and a top (2nd floor), the latter not being coverage.

Characterized by high thermal inertia of the outer walls (0.60 m of stone masonry) and the small number of windows, Level 0 has low total energy consumption, with only 13.5 kWh/m^2 year. By contrast, Level 2, with exterior walls in brickwork of 0.25m and a higher percentage of glass, has a significant energy consumption of 33.9 kWh/m^2 year, 151% higher than Level 0.

In the building's refurbishment the introduction of double glazing and aluminum window frames with thermal cut is reflected in improvements of 15 and 12% in energy consumption for heating floors 0 and 2 respectively. It was also placed, extruded polystyrene 0.06m, thermal insulation in the coverage. It happens, as mentioned above, that the adjacent space to the cover consists of an unheated compartment and, being also an uninhabited area, there will be exchange of heat between this floor and the one bellow. It should have been chosen to apply the insulation on the slab track, secured with weaker concrete. This concludes that In this case, the application of thermal insulation is not advantageous. Final figures are 11.5 and 29.0 kWh/m^2 a year on floors 0 and 2 respectively, with a reduction of about 15% compared to baseline.

Pombalina Construction, Rua das Farinhas 1-3

The total energy consumption of the middle floor is of 24.2 is kWh/m^2 year, 57% of which are for heating, and the rest for cooling. The upper floor, of which the external envelope is mostly defined by the coverage, both superiorly and laterally, has a power consumption of 26.4 kWh/m^2, with 81% being for heating. Although in this case there is an easy transfer of heat during a summer day because of the low thermal resistance, there is also has aneasy heat dissipation during the night, which is essential to the floor's cooling. In its rehabilitation, with the application of thermal insulation on the cover, heat dissipation is made more difficult, leading to its concentration within the compartments, with an increase of 147% in energy consumption for cooling. This happens because Ecotect don't account with nocturne ventilation in summer.

It is proposed to remove the existing insulation on the cover and replacement of windows by wooden frames with double glazing, resulting in improvements of 10% on both floors for a total final energy consumption of 22.0 kWh/m^2 on the middle floor and 23.7 kWh/m^2 in the upper floor.

"Gaioleiro", Rua da Mouraria 8-16 | Escadinhas da Saúde 10

It is observed that the high area of glass, common in "*Gaioleiro*" buildings is one of the factors contributing to the high energy consumption of the building. Thus, the intakes are recorded 31.8 and 34.3 kWh/m^2 year in the Intermediate and Superior floors respectively, due not only to heat transfer from the coverage, but also the highest percentage of existing glazed.

With the rehabilitation of the building some of its elements are replaced and others are introduced. We highlight the following changes. The traditional wooden floors were replaced with concrete slabs with thickness of 0.20m, leading to a decrease in energy consumption for cooling. This difference is most noticeable in the middle floor, with a 4% reduction in consumption, probably due to the existence of two adjacent slabs, the lower and the higher. The replacement of frontal walls and *tabique* by walls of concrete and brick brings some changes as well. The unheated areas are now mostly made of concrete walls, increasing the energy consumption of the adjacent compartments. It is seen the increase of about 5% of energy consumption when compared with the values of consumption recorded by the introduction of concrete slab.

The proposal goes for the introduction of windows with wooden frames with wooden frames and applying thermal insulation in the walls between heated and unheated spaces. The first step brings significant changes in the energy consumption of the simulated floors, different depending on the window's area. The introduction of insulation brings also important reductions, with a decrease of 11 and 14% in total energy consumption of floors 4 and 7 respectively, when compared with the values recorded with the introduction of double glazing. Comparing the initial values with the final proposed there is a reduction of 25 and 34% at floors 4 and 7, with final observed values of 24.0 kWh/m^2 and 22.6 kWh/m^2 year.

Concrete Construction*, Rua João do Outeiro 6-14*

The simulations have recorded initial high energy consumption values, with cooling needs much inferior to those of heating. In the middle floor, level 1, it has a total consumption of 30.6 kWh/m^2, of which 22% are for cooling. The upper floor has a 74% higher consumption, with 53.3 kWh/m2 year. Such high consumption is justified due to several factors: lack of insulation in the interior courtyard walls, in the walls separating heated and unheated spaces, and, for the upper floor, also due to the lack of insulation in the building's blind wall.

The proposal is made based on these problems, isolating the referred walls and also applying double glazed with wooden frames. This leads to a 26% reduction in energy consumption on Level 1 and 60% in the upper floor. Simulations introducing double glazing did not record conclusive results.

3.5. Summary Results

The summary of the results was performed using two separate processes: accounting for the number of buildings of every constructive era and their respective area, specifying the one relative to the bottom floor and the cover; and the simulation, for each building, of the energy consumption in the original state and with the proposals previously submitted[3]. From the areas calculated and simulated values it can be seen that with the introduction of the proposed measures, there is a reduction of about 17% in energy consumption in *Mouraria*'s critical area, saving a total of between 1.7 and 2.2 MWh.

[3] The simulation of the proposal for the *Largo da Achada 2* does not include the application of external thermal insulation.

4. PROJECT RECOMMENDATIONS

Following the previous chapters, and based on the analysis presented, it is intended to list here, in summary, some passive design measures that can be applied for the rehabilitation of buildings:

1. On the interior spatial organization, spaces of residence must be located with the best possible solar orientation, corresponding the remaining to areas of service;

2. Although exterior shading is more effective, due to issues related to maintaining the integrity and authenticity of old buildings, interior wood shutters, where existing, should be maintained and can be complemented by systems of adjustable interior shade;

3. It is recommended to repair the components of the glazing (such as aged joints) to reduce uncontrolled air leaks. One can also recur to replacing single-pane glass with double-windows, with preferential application of wooden frames in historical areas;

5. On the outer walls made of stone masonry, brick or concrete with high thermal transfer coefficient, its mass must be increased or, preferably, added insulation. The constructive solutions with best results are as follow: To amend the outer walls to doubled walls with air-space and inner insulation, when the exterior wall exists, and the application of thermal insulation by the exterior, far more effective than others; The application of thermal insulation by the interior, although easy to apply, is not recommended since interior thermal inertia ceases to exist;

6. Placing insulation in the walls that divide heated and unheated spaces, preferably by the exterior and especially when they are composed of pieces of concrete;

7. Buildings in which the cover's floor is not inhabitable, predominantly existent in the pre-*Pombalina* constructions, the insulation should be applied in the slab, to reduce heat exchange between inhabited and uninhabited areas.

CONCLUSION

Defining rehabilitation as an operation which aims to give the buildings a better quality regarding to its current state and the date of its construction, a method was drawn from which it is possible to increase the thermal comfort, health conditions and, simultaneously, reduce their energy consumption, taking into account the authenticity and historical value of most of these buildings.

The analysis that was made focused on, the influence of windows on the thermal status of the building, the importance of the application of thermal isolation, and the thermal inertia role on thermal regulation of the building's interiors. The definition of such recommendations, adequate to each type of construction in Mouraria, provides a comprehensive view on the importance of their application, concluding that a significant reduction in yearly energy consumption could be achieved (between 1.7 and 2.2 millions of kWh), in reference to heating and cooling. These values result emphasizing the importance and urgency of this type of rehabilitation.

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