Energy optimization through thermal zoning—the outer skin

P. Mendonça*, L. Bragança

Civil Engineering Department, University of Minho, Campus de Azurém, 4800 Guimarães, Portugal

ABSTRACT

This paper presents a research work whose objective is to develop architectural project criteria that allow the reduction to the minimum of buildings mass in order to decrease its environmental impact. This should happen without reducing the comfort requirements of occupants, so a research on mixed weight buildings is being made, focusing on two main points: reducing the weight of the outer skin to a minimum and positioning heavyweight elements exclusively in the interior and in night occupied areas—through a material and a thermal inertia zoning strategy. To illustrate this, an experimental research on a test cell prototype, simulating a housing unit applying to this concept is being made and will be compared with a conventional one. The architectural typology of housing in Portugal is presented from an historical, a state of art and from future developments suggested by this study. A research on the properties of the materials proposed will also be presented.

INDEX TERMS

Energy efficiency; Materials; Climate specific design

INTRODUCTION

In the past centuries and at least until 50 years ago, housing buildings in Portugal were made from a combination of extremely heavy envelope walls made of stone, massive brick or compacted earth (often arriving to more then 1000 kg/m^2), lightweight timber pavements and timber/clay and gypsum interior dividing walls (approximately 50 kg/m^2) and timber covering structures with ceramic tiles (approximately 150 kg/m^2). In an example of a house made in Northern Portugal from the eighteenth century, shown in Figure 1, heavy granite stone walls can been seen.

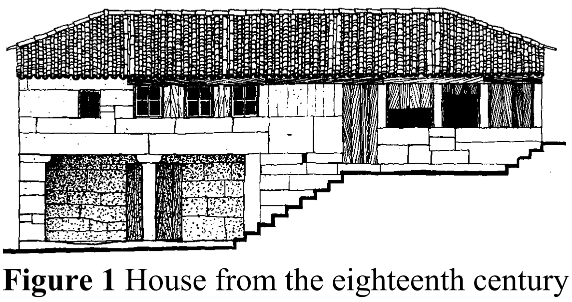


Figure 1 House from the eighteenth century located in the North of Portugal (AAP, 1988).

The gradual loss of proper local identities, consequence of globalization, and the increasing labour costs on construction industry had led to a certain depreciation of local natural materials. Construction has adopted industrialized materials, many of them imported from far distances, with much higher embodied energy and transport costs, such as steel reinforced concrete and industrialized hollow bricks. Most of the modern housing buildings are made with beam and pot slabs (approximately 350 kg/m^2 in 0.30 m thickness) and double pane hollow brick walls (with similar proper weight for a 0.40 m thickness). The average global

* Corresponding author. E-mail: mendonca.u@mail.telepac.pt

weight of a conventional housing building nowadays is very similar to 50 years ago, but the embodied energy per square metre increased and the possibility of recycling the components even decreased. In a study made by the authors, a few changes on materials and technologies can easily permit a reduction of approximately 75% of the global embodied energy of a common Portuguese three-storey housing building and a 77% reduction on overall weight (Mendonça and Bragança, 2001) without significant increase in overall cost. Reduction of proper weight can be achieved by the use of existing prefabricated lightweight modular systems that have smaller energy costs associated with production and transport. A problem related with lightweight buildings is that these are usually characterized by a small thermal inertia, which results in an excessive daily thermal temperature oscillation, and thus they are not considered in housing in spite of the existence of some examples in vernacular architecture in Central littoral areas of Portugal, due to the availability of wood in this area and to the specifically temperate climate conditions near to the sea and great river basin areas. In Figure 2, an example of a house in the littoral centre of Portugal near River Tagus can be seen.

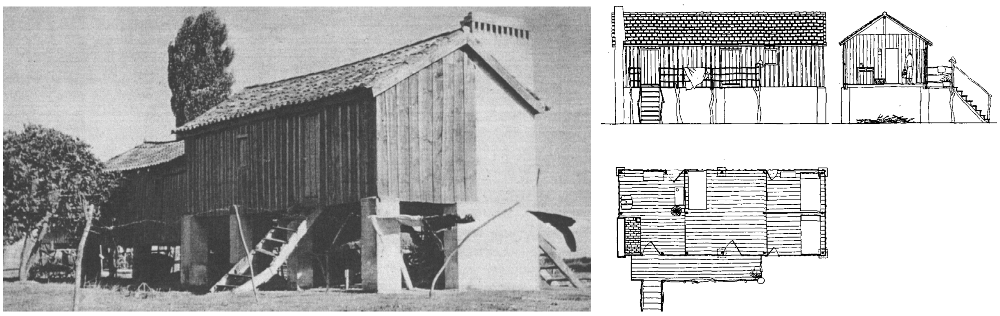


Figure 2 House near River Tagus in littoral centre of Portugal.

STRATEGIES

The strategy of this research focus on two distinct aspects: one is based on thermal inertia zoning, using both lightweight and heavyweight constructive systems that can lead to an overall weight reduction on construction without losing interior comfort standards; the other one is a research on the materials used in the facades of this mixed weight systems relying on a combination of lightweight materials (translucent and transparent) and natural heavyweight local materials that can be used in thermal storage walls and systems.

Materials

Reducing the use of materials implies smaller environmental damages due to the extraction of prime materials, to their transformation processes and to the work yards, with reduction of the noise, dust, wastes and the consumption of energy during the construction and a proportional reduction on energy costs with transport and loss factor (loss factor describes how much a particular material is lost during storage, transport and installation of the final product) (Berge, 1999). The use of local and less-transformed raw materials, or recycled materials, is important. But also the minimum use of those that cannot be locally available, such as reinforcing steel for concrete or transparent materials, that are difficult to be produced locally.

Reduction becomes possible by the introduction of technologies that might optimize the heat gains and losses through the external envelope. Solar heat gains are almost dependent from the use of translucent and transparent materials. These are some of the components in a building that are not usually locally available, and thus the reduction of their weight implies a significant reduction on environmental and economical costs. The introduction of more weight efficient transparent materials can allow the reduction of primary energy production cost per m^2 of facade. A comparative study was made between thermal storage walls (indirect gain) and conventional walls. To evaluate the potential of using a plastic film (in this case a PVC translucent membrane chosen for being a cheep material—used on green stoves) instead of glass on the thermal storage wall, this solution was also included. The use of internal insulation was not considered in this study for being ineffective from the thermal inertia point of view. The parameters in study were the embodied energy, the heat transfer coefficient, the thermal mass and the economical cost.

The four types of wall sections evaluated in this study were (Figures 3 and 4):

1. Double pane wall (0.11 + 0.15. m hollow brick) with air gap and XPS insulation (typical non-structural external wall of nowadays conventional Portuguese housing buildings).
2. Homogeneous wall (0.40 m granite stone wall—typical structural external wall of buildings till 50 years ago).
3. Externally insulated simple pane wall (0.20 m hollow brick with external EPS insulation).
4. Thermal storage wall (0.15 m granite stone wall with glass, 4A, and polymeric film on external face, 4B).

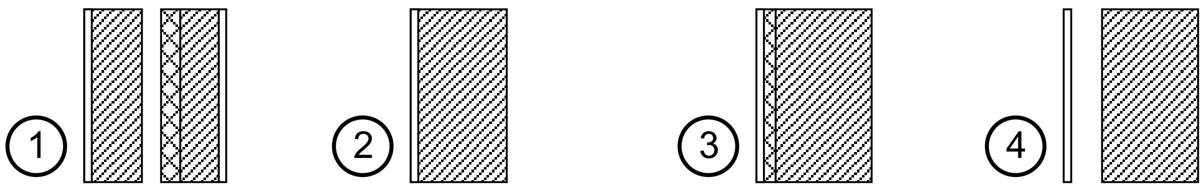
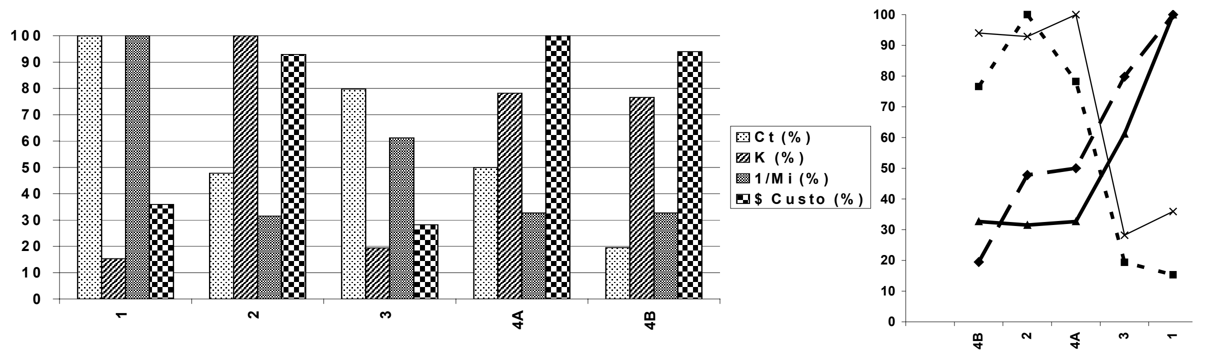


Figure 3 Schematic sections of studied wall types.



With: k: [W/m^2.°C]; Mi: Termal mass [kg/m2]; $: Economical cost of construction (€/m^2);Ct: Embodied Energy (kJ/ m^2)

Figure 4 Comparative analysis of studied wall types (resume chart and growing energy cost).

Thermal Zoning

Long term energy savings implies more than the correct dimensioning of shading, transparency and insulation of facades. In countries with an annual and daily thermal amplitude oscillating below and above the temperature of ideal interior comfort, such as Portugal, where this study is being made (between a minimum of –2.5°C and a maximum of 35°C) and a daily thermal amplitude of 10°C (Mendes *et al.*, 1989), thermal inertia is more important than insulation capacity, as its absence can result in a night rapid descent of temperature and a resulting excessive daily thermal oscillation in the interior. In housing, if in a theoretical analysis the thermal gains could be higher in a direct gain strategy, with the concrete pavement slab taking the role of thermal storage, the temperature and glare due to excessive solar radiation penetrating the interior occupied areas are a cause of discomfort. Apart from the degradation of the furniture and other equipment, a direct gain strategy is not a good solution from a practical point of view, also due to the necessity of daily operating night mobile insulation systems. An indirect gain solution could be more effective in order to keep interior comfort in an easier way.

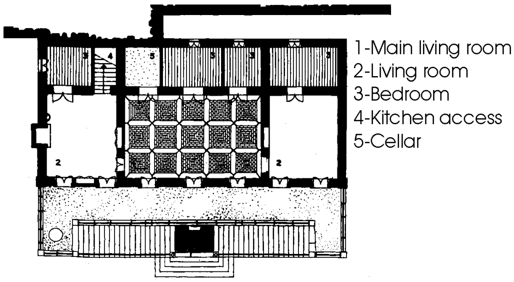


Figure 5 House from the sixteenth century showing a thermal zoning strategy.

A zoning approach was characteristic of some examples of Portuguese ancient houses. In the example shown in Figure 5, a house from the sixteenth century, it can be seen that bedrooms were compartments of small dimensions and small windows aligned on the back facade and all the living spaces of great dimensions were oriented to the main facade and have larger windows. The proposed zoning solution in this study makes use of locally available heavyweight materials, granite stone (or another dense material, such as other kind of stone or compacted earth, depending from local availability) to walls and concrete for the main structure on a central zone and wood for the secondary structure. That is, north facing working zone and south facing veranda. Both façades are lightweight panels and windows, but the south façade was defined as simple pane 6 mm glass with practicable siding timber frames, and north facade as Polyester/PVC membrane (with small practicable timber windows).

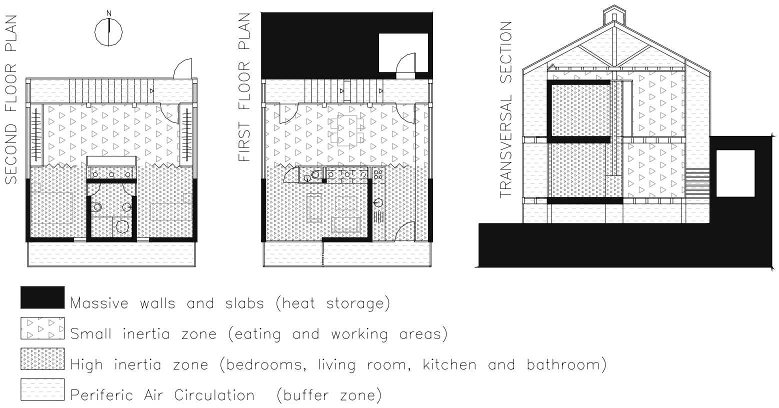
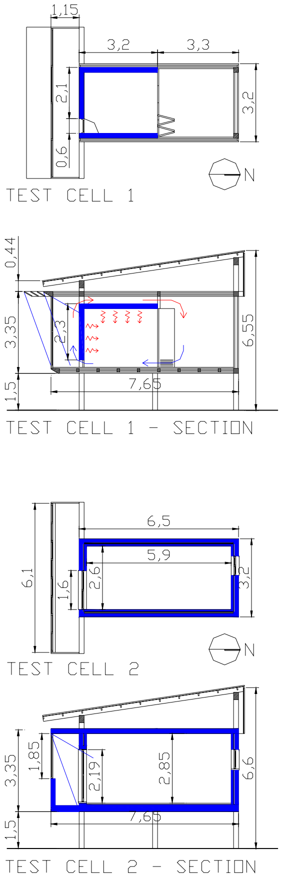


Figure 6 Proposed house with thermal zoning.

Since the South facing wall can take the main role of thermal storage, the bet can be to optimize their performance, and so to use it mainly for indirect gain. The use of combined solutions of ventilation/heat storage, namely by the use of Trombe walls, is an effective method of natural heating during the cold season, when there is enough solar radiation. One problem is that the construction of these interior walls between the window and the occupied zones decrease interior illumination, for they are opaque. The need of a great window surface oriented to South and with its major area closed by thermal storage walls forces the building to open more to other solar orientations. In the proposed solution a working area for studying, cooking and eating receives light throw a double translucent membrane oriented to North (see Figure 6).

TEST CELL STUDY

In order to evaluate the zoning strategy, two Test Cells are being constructed to make experimental rehearsals of the conventional and non-conventional construction systems from the higrothermal and acoustic performance point of view. The configuration of the Test Cells is shown next:



Test Cell 1 will be configured for studying the proposed mixed weight system, and the use of translucent and transparent lightweight materials in facades. The classification of the materials and systems used will not be done just by their thermal, thermal-hygrometric and acoustic performance, but also by the relationship between weight, economical cost and energetic cost per square metre. It is also intended to evaluate the viability and the performance of different interior zones with different thermal characteristics: zones of small thermal oscillation, i.e. heavy inertia (sleeping and living areas—mostly night use), and zones of smaller inertia in the remaining compartments (diurnal use).

Test Cell 2 will be a reference cell, simulating a conventional housing construction (made with a pillar/beam concrete system, beam and pot floor and ceiling slabs and external double wall in hollow clay brick). To compare the zoning architectural conception proposed with the 'conventional' there will be no zoning on this test cell.

Figure 7 Test Cells in construction.

Some simulations over the thermal performance of the Test Cells were already made and are shown in Figure 7, where can be seen the evident reduction of the daily mean superficial temperature swing wave on the heavy inertia zone on the mixed weight building compartment referring to Test Cell 1, zone 1 in comparison with the Test Cell 2 conventional building. To obtain the thermal inertia (only counting conduction) for the envelope, the thermal wave lag (Φ) was calculated in hours, and the thermal wave reduction (μ) in %. The thermal inertia was determined by the following expressions (Mitjà, 1986):

$$\Phi = \frac{x}{2}\cdot\sqrt{\frac{\mathrm{T}}{\sum_n \alpha_\iota \cdot \pi}} \quad \text{and} \quad \mu = e^{-x\cdot\sqrt{\frac{\pi}{T\cdot\sum_n \alpha_1}}}$$

where x is the thickness of the wall (m), T the time period (h), n the number of layers and a the thermal diffusivity (m^2/h).

To determine the global thermal inertia resultant from all the envelope walls' superficial temperatures, the mean value was than calculated (Figure 8).

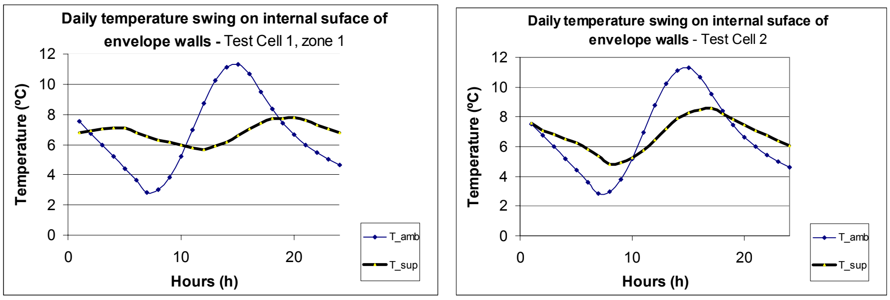


Figure 8 Daily mean superficial temperature swing calculated for the Test Cells.

CONCLUSIONS

The use of lightweight constructive systems can drive to a significant reduction of the environmental impact from extraction, transport and construction, especially when using materials of low energy cost. But, in order to make this reduction viable in a temperate climate, comfort aspects should also be guarded, especially the thermal-hygrometric and acoustic performance. This paper briefly intends to show the potentialities associated with the use of lightweight materials combined with locally available natural heavy thermal mass materials, in order to achieve an optimal thermal inertia through a thermal zoning strategy. To accomplish this, the experimental evaluation of the proposed solutions becomes necessary; that is why two test cells are being constructed.

ACKNOWLEDGEMENTS

This work is an FCT (Fundação para a Ciência e Tecnologia - Portugal) and FSE (Social European Fund) funded project.

REFERENCES

AAP (1988). *Arquitectura Popular em Portugal*. Lisboa.

Berge, B. (1999). *The Ecology of Building Materials*. Bath: Architectural Press.

Mendes, J. *et al.* (1989). Temperaturas exteriores de projecto e números de graus-dias. Lisboa: Instituto Nacional de Meteorologia e Geofísica/LNEC.

Mendonça, P. and Bragança, L. (2001). The minimal environmental impact of buildings. *Proceedings of the 4th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings—IAQVEC 2001*, Changsha, Hunan Province, China.

Mitjá, A., Esteve, J. and Escobar, J.J. (1986). Estalvi d'energia en el disseny d'edificis. Barcelona: Generalitat de Catalunya/Departament d'Indústria i Energia.