THERMAL PERFORMANCE AND ENVIRONMENTAL IMPACT OF CONTEMPORARY EARTH ARCHITECTURE IN PORTUGAL

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Abstract
Guaranteeing protection against the climatic elements no longer represents the single purpose of a building. Thermal comfort and well-being of its occupants has become increasingly important as living standards of modern societies have risen considerably, mostly made possible by a constant and inexpensive supply of energy from fossil fuels. This energy used to heat and cool our buildings, is now recognised as a major contributing factor for climate change, caused by greenhouse gas emissions in the environment. There is hence, an urgent need to move towards environmentally sustainable buildings which maintain comfort while reducing their dependence on fossil fuels, to minimise and counter this threat posed by climate change.

Earth, represents a low environmental impact building material and has been used for centuries, in traditional and vernacular architecture to provide comfort by responding to local climatic conditions. Revisiting those techniques and applying current knowledge and skills to earth architecture, has the potential to contribute towards reducing the environmental impact of present day buildings while still maintaining comfortable conditions for the occupants. Previous research has mostly studied the technical aspects of earth construction, with limited focus on thermal performance of earth buildings and especially, its relation to the thermal comfort of the occupants. Within this context, this study tests the viability of employing earth construction in low rise dwellings with a particular emphasis on its thermal performance.
This paper reflects the study carried out within the framework of an MSc thesis, on the analyses of the thermal performance of contemporary earth houses, focusing on three case studies located in the southern area of *Alentejo* in Portugal.

The methodology used combines thermal modelling of the houses with real data collection of internal temperatures during both the summer and the winter periods. It is accompanied with occupant surveys to assess the users' perception of internal conditions within the house. The study hence focuses on both the 'hard' quantifiable data and the less identifiable but equally important 'soft' qualitative information from the surveys, to holistically evaluate the role of earth construction in achieving thermal comfort in contemporary dwellings in Portugal as well as its possible contribution towards a more sustainable future.

The findings from this research work led to the conclusion that rammed earth, when used with no insulation, although it shows a very effective thermal behaviour during the summer fails to provide comfortable thermal conditions during the coldest periods of the year. However, this problem can be overcome when insulation is used, thus providing thermal comfort both during the winter and during the summer.

1 . INTRODUCTION

According to scientists and researchers, the human impact on global warming is now a given fact. The burning of fossil fuels and consequent greenhouse emissions are deeply affecting the planet at a global scale (Smith, 2007). The building sector alone accounts for more than half of the primary energy consumption globally and consequently for the same portion of greenhouse gas emissions (Roaf et al., 2007). There is hence an urgent need to tackle this serious problem, turning the building sector into part of the solution, and contribute towards a more sustainable world.

The belief that earth as a building material can play a key role in a new more environmentally conscious building paradigm is currently being supported by numerous experts who point out its environmental, cultural and economical advantages when compared to other, more commonly used building materials.

Furthermore, due to its qualities, earth has a lower impact when compared to more conventional building materials. The raw-material to be used in the construction is usually dug from the site, and even if some mechanised system is required to dig, mix or place the earth, the construction process still has a lower embodied energy than a similar construction in brick, concrete or steel (Kimmis et al., 1997). Berge (2000) reinforces this idea and remarks that, in the context of the locally built houses, there is no other construction technique that can compete with the earthen ones in terms of its low environmental impact.

According to a life cycle analysis, carried out by Roaf et al. (2007), which included embodied energy and emissions, it was determined that a house built from rammed earth and local timber has "a lifetime energy impact in the region of 20% less than a house built using medium-density concrete blocks" (Roaf et al., 2007, p.63). The same authors suggest a mix of high thermal mass and timber-framed construction as an interesting and effective strategy for housing, both in terms of low impact and comfort.

Portugal is one of the European countries where earthen architecture is present and evenly spread across the territory since a very early period. The development of earth construction in Portugal reflects the history of the country itself, where several occupations took place and thus a diversity of cultures and traditions were assimilated. Furthermore, due to the country's strategic geographic location by the Mediterranean Sea, which acted as a link to Europe, great civilizations from the East exported their knowledge, inevitably influencing the local customs (Pinheiro, 1991).

Recently there has been a revival of earthen construction techniques in Portugal. Many clients are taking the challenge and choosing earth as building material for the walls of their houses. According to some architects involved in such projects, most of these clients are originally from the country's largest cities, such as Lisbon. Amongst the reasons for their choice is the awareness of the delicate environmental situation, the search for a healthier house away from the stress of an urban life (Correia, 2007), and also some kind of willingness to preserve the local traditions, although a few also choose to have an earthen house with a modern design.

Although the thermal properties and low environmental impact of this millenary building material apparently make it a suitable choice for today's demanding building industry, where the need for sustainable buildings is growing, there are still various obstacles to overcome in order to make the material competitive with other current solutions.

2. SCOPE AND METHODOLOGY

This study, developed as part of an MSc thesis, looks at evaluating the thermal performance of contemporary rammed earth houses in a particular area of Portugal, as well as the environmental impact of this building material. In order to so the following methodology was used:

- Literature review - The literature review focused on both sustainable architecture and earth architecture as concepts, specifically in what concerns the environmental impact of materials and embodied energy;
- Analysis of three case studies, which were selected according to: (a) The material and technique used to build the walls – Rammed Earth; (b) The location – All three buildings should be located within close distance of each

other so that the external conditions could be similar; (c) The acceptance and collaboration of the occupants towards the study;

- Real monitored performance data within the case studies was collected during January/February and July/August. In order to conduct the analysis of the case study's internal thermal conditions two different methods were used: Data loggers were used to record the internal air temperature and occupancy surveys undertaken to determine the occupants' perception of the space in terms of thermal comfort;
- Additional data was collected during 3 field study visits - December, June and August;
- This information is further supported with IES modelling of different construction types.

3 . FINDINGS
3.1 Case Studies

Figs 1, 2, 3 – Case Studies 1, 2, 3 (photos by author, 2008)

The analysis conducted to the case studies revealed that, in terms of thermal performance, the building material earth appears to be more effective during the warmest periods of the year. Although the daily temperatures maintain a relatively constant trend, should a total passive solution be adopted during the winter, i.e. no use of auxiliary heating system, the rammed earth walls alone do not seem to be sufficient to guarantee a comfortable internal temperature.

According to the occupancy questionnaires the heating is mostly used during the evening periods, which increases the internal gains and helps to keep the temperature at a comfortable level during the rest of the day.

Contradicting the poor winter performance, rammed earth houses, are able to provide quite comfortable conditions when the external temperatures are higher. The buildings' occupants have revealed though that the night-cooling ventilation is essential in order to control the internal environment during the summer. In addition, the heat storage capacity of this material is more obvious during the summer as the thermal delay keeps the internal temperature down when the external is higher. Afterwards the heat transfers to the inside progressively.

The information collected during this study also confirms that all the buildings' elements will have some role of influence in the overall thermal performance of the building. For instance, in case study 2, a poor insulated roof reveals a weak point, which explains the lower temperatures in the winter and the heat peaks in the summer. Supporting this theory is also the example of case study 3, where infiltration from a window frame is compromising the heat storage of the thermal mass.

The outcomes appear to indicate that a more airtight and insulated earthen building would successfully provide comfort throughout the year, regardless of the external conditions.

Following these findings an investigation was conducted on how different construction solutions can influence the internal thermal environment of a building

3.2 Thermal Simulation

Following the thermal performance analysis, the thermal simulation aimed not only to assess the thermal performance of an earthen building, but also to compare it with a building constructed with commonly used materials. Moreover it also intended to investigate how to enhance the performance of a rammed earth building by experimenting with different construction options. The computer model is identical in terms of its materiality and proportions as Case Study 3, whether in terms of its physical conditions - shape and materials – or the external environment. The latter, however, was not entirely possible to achieve, as there was no available weather data integrated in the IES-VE software for the exact location of the case studies, therefore the closest weather station in the software database was selected.

3.2.1 Simulation Conditions

Construction Options:

1) Conventional construction:

External wall – plaster (15mm), perforated brick (200mm), polyurethane board (40mm), cavity, perforated brick (70mm), plaster (15mm) – U-value: 0.5W/m^{2}K
Internal wall - plasterboard, brick, plasterboard
Glazing: Double glazing, timber frame

2) Timber frame:

External – brick outer leaf (100mm), cavity (75mm), polyurethane board (25mm), cavity (110mm), gypsum plasterboard (13mm) – U-value: 0.58 W/m^{2}K
Internal walls - plasterboard, brick, plasterboard
Windows: double glazing, timber frame

3) Lightweight construction:

External - weatherboard (20mm), cavity (50mm), plywood (18mm), insulation board(150mm), plywood (18mm), cavity (25mm), plasterboard (15mm) - U-value: 0.22 W/m^{2}K
Internal walls - plasterboard, brick, plasterboard
Windows: double glazing, timber frame

4) Simple rammed earth wall:

External wall - rammed earth – U-value: 1.96W/m^{2}K
Winter garden wall - Slate stone (500mm)
Internal walls - Earthen walls (200mm)
Windows – Double glazing, timber frame

5) Insulated rammed earth wall (40mm insulation):

External –plaster (15mm), cork insulation (40mm), rammed earth wall (500mm), plaster(15mm) – U-value:0.65W/m^{2}K
Winter garden wall - Slate stone (500mm)
Internal walls - Earthen walls (200mm)
Windows: double glazing, timber frame

6) Insulated rammed earth wall (60mm insulation):

External –plaster (15mm), cork insulation (60mm), rammed earth wall (500mm), plaster(15mm) – U-value:0.49W/m^{2}K
Winter garden wall - Slate stone (500mm)
Internal walls - Earthen walls (200mm)
Windows: double glazing, timber frame

Internal Gains:

The building model intents to reproduce the occupancy of a real house, hence some internal gains were considered as well as their respective schedule of occurrence. They are as follows:
- Two people; Lighting; Appliances; Cooking; Computer; TV; Various gains (small appliances distributed through the house); Passive Solar gain.

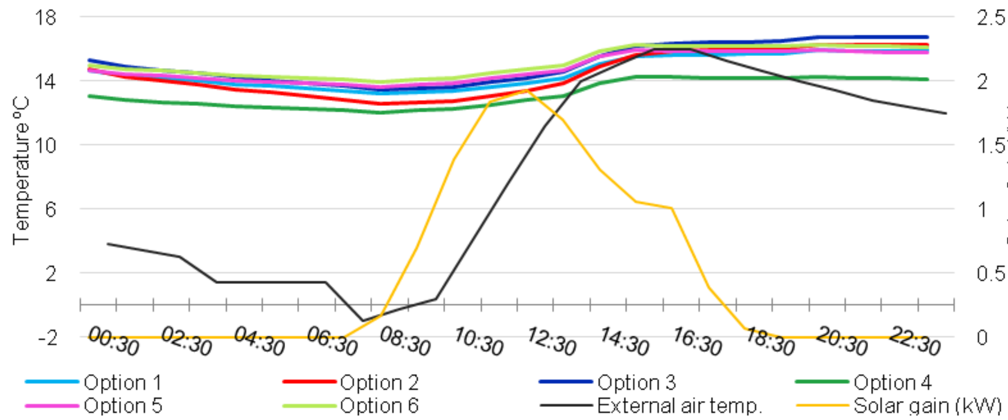
Climatic Conditions:

Although the initial intention was to simulate the model with the same weather conditions as the Case study building, due to lack of weather files on the software that was not possible. The solution was therefore to apply the data from the nearest weather station, which in this case was Sevilla, in Spain.

Nevertheless, this fact did not affect the final outcomes, as the simulation was treated as an independent investigation and provided its own conclusions, which can be complemented with the results from the actual field measurements.

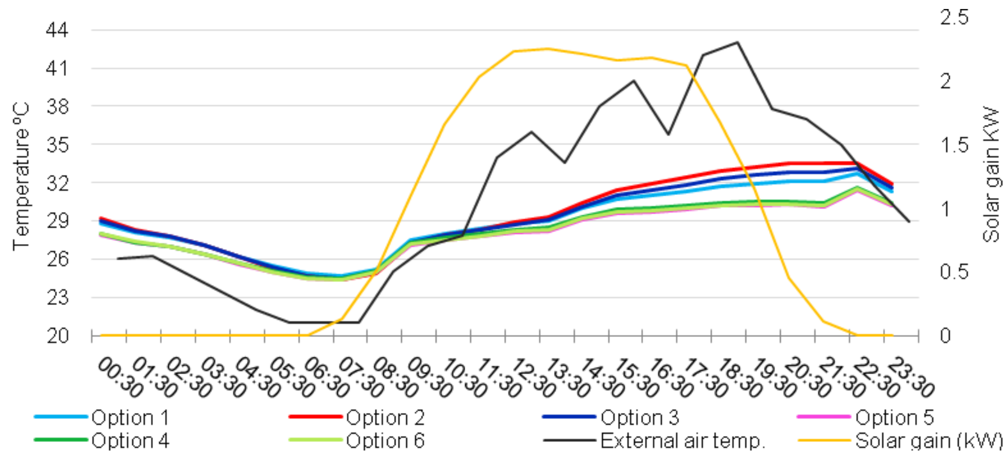
3.3 Thermal Performance – Comparison between construction types

16th January



Graph 1 – Graph illustrating the thermal performance of the different construction options modelled during a winter day.

11th July



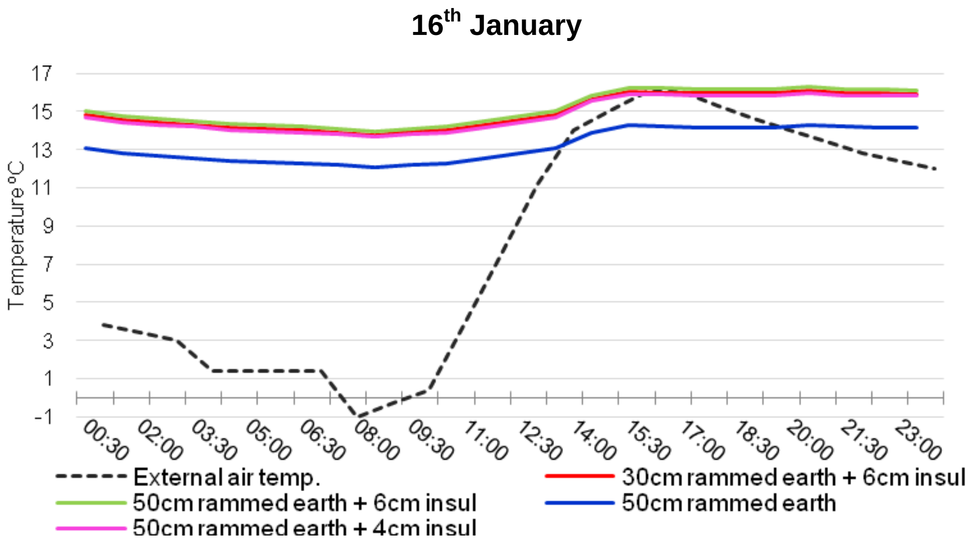
Graph 2 – Graph illustrating the thermal performance of the different construction options modelled during a summer day.

3.4 Thermal Performance – Comparison between rammed earth options

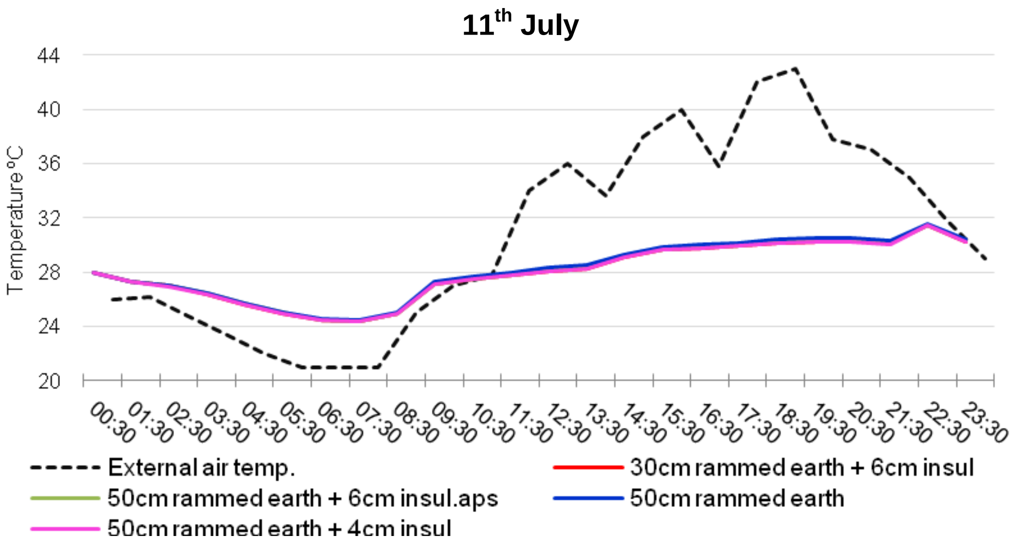
According to the outcomes from the thermal simulation, it was possible to ascertain that a dwelling built mainly with earth can have advantages in terms of thermal comfort.
Although the rammed earth walls give the impression of failing during the coldest period, when compared to the other options, if insulation is added to the external side of the wall, this problem is overcome.

The Option 3 - lightweight - model is able to provide higher temperatures in the winter, but its performance decreases during the hottest period of the year, whereas an insulated earth wall will maintain a cooler internal environment.
In addition, this simulation indicates that the non-insulated earthen buildings would be more appropriate to hot climates, while lightweight construction would have a better performance in cold climates. Moreover, the addition of insulation can now solve the

apparent non suitability of earth in cold climates, making earthen walled buildings effective in terms of thermal performance, both in cold and hot climates.



Graph 3 – Graph illustrating the thermal performance of the different rammed earth options modelled during a winter day.



Graph 4 – Graph illustrating the thermal performance of the different rammed earth options modelled during a summer day

4 . CONCLUSIONS

Temperature measurements taken for the winter and summer periods provided the basis for a general analysis of the buildings' thermal performance. Summing up, all the case studies revealed low temperatures (below comfort levels) during the winter period, whereby occupants occasionally demonstrated dissatisfaction. During the summer the thermal mass of the walls, combined with a night cooling ventilation strategy, contributed for a comfortable internal environment.

The thermal simulation conducted on IES-VE, compared the thermal performance of different materials used for the walls (Graph1 and 2), amongst which were several types of earth-based walls, in a virtual building that mimicked the real conditions as close as possible the real case study 3.

This had the intention of determining which of the construction options would effectively provide comfortable internal conditions, without having to revert to any auxiliary heating or cooling systems.

With regard to winter conditions, the single rammed earth wall is definitely the worst option, whereas the lightweight construction, along with the rammed earth wall with the thicker insulation, represents the best options.
The summer simulation, on the other hand, shows that all the earth-based walls are equally the most effective, and this time, the lightweight construction, which had the best performance during the winter, is amongst the worst performers.

Furthermore, a separate simulation (Graph 3 and 4) focusing only on determining the influence of the walls' thickness on the overall thermal performance revealed that, when insulation is used, there is no significant difference between a 300mm and 500mm earthen wall, during the winter.

Based on the outcomes from both the case study analysis and the thermal simulations, it is possible to conclude that earthen walls can be highly effective during the warmer periods of the year; however the same does not occur during the colder periods. Nevertheless, according to the thermal simulation results, this problem can be easily overcome by adding insulation to the external face of the rammed earth walls. Moreover, the simulation also revealed that this solution (rammed earth plus insulation on the outside) is indeed the best option compared to all the others, since it is able to maintain higher temperatures during the winter and lower temperatures during the summer. This option is also supported by Simões (2006), which claims that although the insulation can indeed be placed on the internal face of the walls, the building will perform better when the insulation is placed on the outside, as the thermal mass is in direct contact with the interior.

Taking into account all the information gathered and accessed for this paper, it can be stated that earth as a building material, when integrated in a carefully designed project has the potential to provide comfortable internal conditions throughout the year passively, thereby avoiding the use of any heating or cooling systems. In theory, this would mean that during the occupancy period of such buildings no energy would be required to maintain comfortable internal temperatures. Adding to all the above mentioned facts the low embodied energy required for the construction of earthen walls as well as their recyclability as two other sustainable bonuses of the product, it seems fair to consider this building material as a worthy choice able to contribute to a more sustainable built environment.

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Curriculum

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