Non-Structural Adobe Walls in Housing Buildings - Environmental Performance

Paulo Mendonça

Architecture Department, University of Minho, 4800-058 Guimarães, Portugal
lmendonca@arquitectura.uminho.pt

Abstract

This paper shows a non structural adobe solution in the north of Portugal, using a steel reinforced concrete structure in order to permit adobe walls to be used in higher buildings and be accepted in contemporary demands. A thermal zoning strategy with two distinct inertia areas is proposed. An indirect heat gain heavyweight compartment - made with adobe walls and steel reinforced concrete structure and slabs - was positioned on the south zone and conceived to lodge the resting zones of a house: bedrooms, bathroom and living room. The north compartment, made with lightweight materials - plaster board and fibre-cement panel walls and timber structure - was destined for the working areas: studying, cooking and eating. This zoning strategy allowed a good compromise between construction energy costs and thermal comfort operative costs comparing to a conventional monozone layout solution using the Portuguese conventional hollow brick and steel reinforced concrete constructive system. Both solutions were tested on real scale test cells, and the results are presented here. It was verified that it is possible to implement a solution with adobe walls in order to achieve a thermal performance similar to the conventional hollow brick solution, in a temperate climate, but with a significantly lower environmental cost related with the construction.

Keywords: *Non-structural adobe, Hygrothermal Performance, Sustainability.*

1. Introduction

Improved buildings environmental profile can be made by using lightweight construction materials and systems. But a lightweight building can have problems in terms of thermal comfort in a temperate climate, because of the reduced thermal inertia. The introduction of some thermal mass is essential to achieve comfort with minimum use of mechanical heating and/or cooling systems. Structural earth is not a common solution in north of Portugal, even in past traditional constructions. But non structural use of earth was common, using adobe to fulfil timber grid structures, as it is shown on Figure 1. A mixed-weight system with non structural adobe walls, in order to achieve an ideal compromise between hygrothermal performance and environmental impact of construction in housing buildings is proposed.

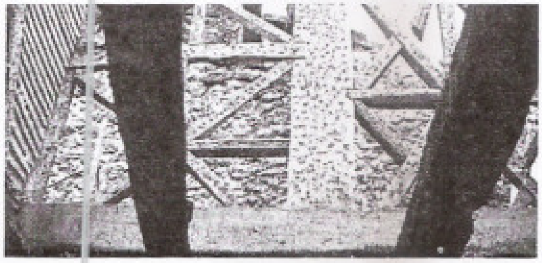


Figure 1 Adobe with timber structure – traditional construction in north of Portugal

2. Proposed Design Strategy

The energetic optimization strategy applied in the proposed solution can be called a thermal zoning system and was developed essentially based on two distinct approaches: façade design optimization – indirect gains and thermal storage optimization – mixed-weight strategy.

The main question was to decide between direct gain and indirect gain strategies:

Direct Gain - the project values for thermal gains are usually higher in a direct gain strategy, but the great asymmetry in the radiant temperature of the building envelope, can cause discomfort. These facts can lead the building occupants to constantly operate the existent shading devices and, consequently, block the thermal gains and change project values;

Indirect Gain - in spite of its lower thermal gains, an indirect gain solution can more effectively guarantee that the project values are closer to reality, because it does not rely on the occupants. The strategy chosen for the proposed design was this.

The south façade can be used to implement combined solutions of ventilation / heat storage, namely the trombe or dynamic walls, which can be explored both for natural heating during the cold season, as for natural cooling during the hot season. The positioning of the heat storage, trombe or dynamic walls on south facing walls, forces the building to open more on other solar orientations. This situation needs to be pondered, as these openings can lead to pernicious heat gains that can compromise the thermal performance of the building, even in winter, and especially on spring and autumn. To avoid overheating in summer it must be avoid openings to East and West.

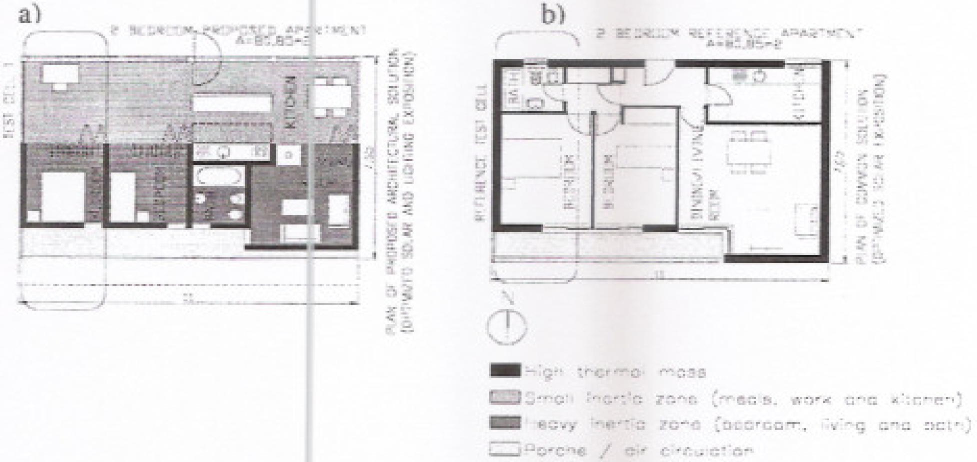


Figure 2 Plans of proposed and conventional housing units (Mendonça 2005)

An example of the proposed thermal zoning architectural solution and of the conventional architectural solution can be observed in Figure 2 a) and b), respectively. The solutions shown in Figure 2 were transposed for two test cells, which were called building test cells - BTC. BTC 1 is the proposed solution, presented in plan on Figure 3 and in section on the right side of Figure 5. and BTC 2 is the conventional solution, presented in Plan on Figure 3 and in section on the left side of Figure 5.

3. Characterization of the Test Cells

Both BTCs have a rectangular shape (approximately 6,5x3,1m), are south/north oriented and have a telescopically moveable window on the south façade in order to allow this space to work as a sunspace or a dynamic/trombe wall.

BTC 1 is divided in two parts separated by a timber moving partition: 1 – an heavyweight south oriented zone (sleeping area) with a concrete structure, pavement and ceiling slabs, adobe walls; 2 – a lightweight north oriented zone with timber structure and sandwich pavement, ceiling and walls. In the heavyweight area there are two types of walls whose positions are indicated on Figure 3: wall 1 is an adobe wall without insulation and a black exterior finishing, suitable for thermal gains; wall 2 (Figure 7a)) is a double leaf wall with a 15cm adobe leaf on the interior, a fiber-wood cement board exterior leaf and a ventilated 15cm air gap with 5cm expanded cork insulation. The north oriented zone (working area) has sandwich panels lightweight pavement and ceiling made with fiber-wood/cement board and expanded cork insulation and triple leaf walls with an exterior ventilated 15cm air gap and an interior superinsulated layer with 8cm of expanded cork and 2cm of coconut fiber (Figure 7b)).

BTC 2 is shown on the right side of Figure 3, has the same dimensional characteristics of BTC 1, but is made with a conventional construction solution. This test cell corresponds to the most common construction system in the contemporary Portuguese buildings –based on a steel reinforced concrete structure, with pavement and ceiling on beam and pot slabs – with pre-stressed concrete "T" beams. The exterior walls are double leaf (15+11cm) hollow brick with 4 cm of extruded polystyrene insulation (XPS) placed in the air gap and finished with plaster on both sides. Figure7c) show the vertical scheme of this wall.

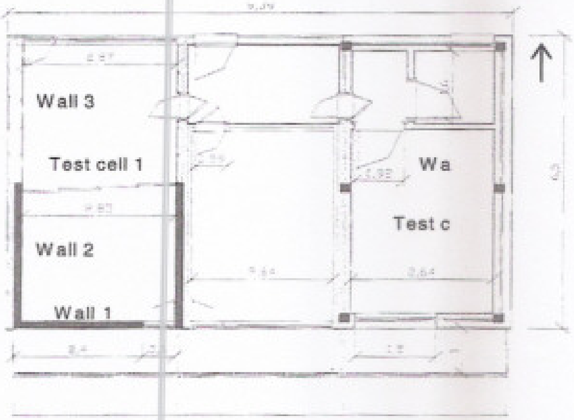


Figure 3 Test cells plan.

Figure 4 Test cells vertical scheme of the north and south façades

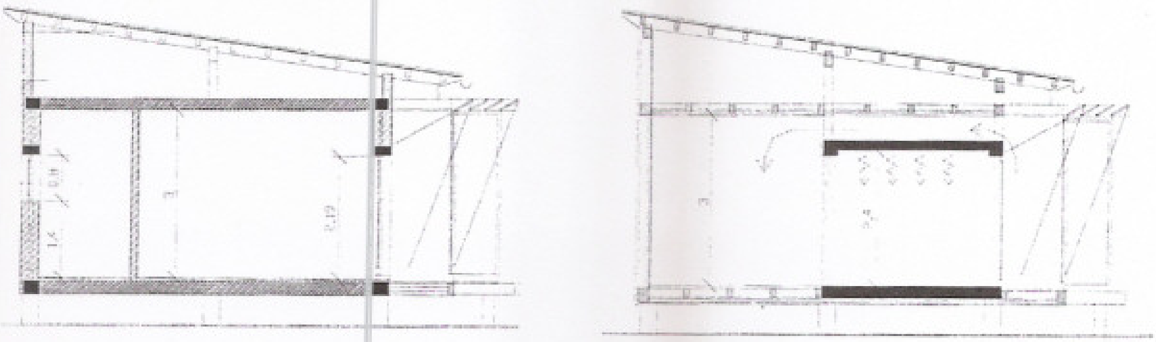


Figure 5 Vertical sections of test cells 1 and 2 – sunspace configuration (distances in m).

Figure 6 shows a group of exterior photographs from building test cells in several construction ph
These test cells were monitored in order to carry out several tests. It was performed an evaluation c
hygrothermal performance in both test cells. The results are presented in the following paragraphs.

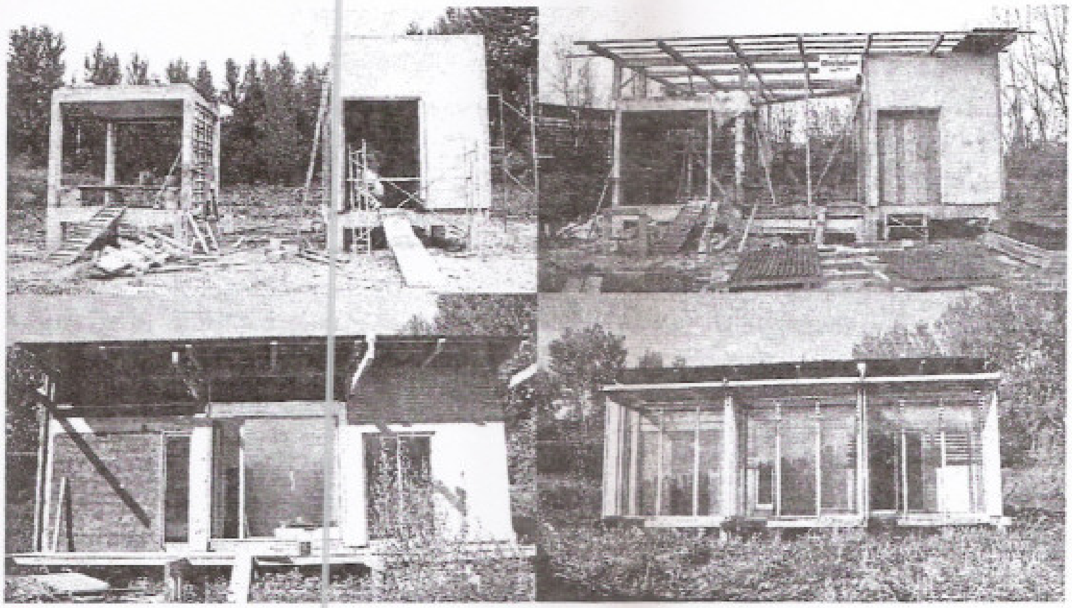


Figure 6 Exterior views of the building test cells construction works

4. Performance Evaluation

The performance evaluation can be divided in two parts: 1 – the predictions before the tes
construction; 2 – the "*in-situ*" evaluation. The first part of the evaluation was carried out to help ch
the best design (both in thermal comfort operation cost and in embodied energy construction cost
second part of the evaluation intended to verify the hygrothermal comfort performance and viabi
the proposed construction.

4.1. Comfort Operation Cost and Environmental Construction Cost

The methods used to predict the hygrothermal performance, before the test cells construction, w
Portuguese thermal regulation in its previous version – RCCTE (RCCTE 1990) and the CSTB esti
method (CSTB 1988).

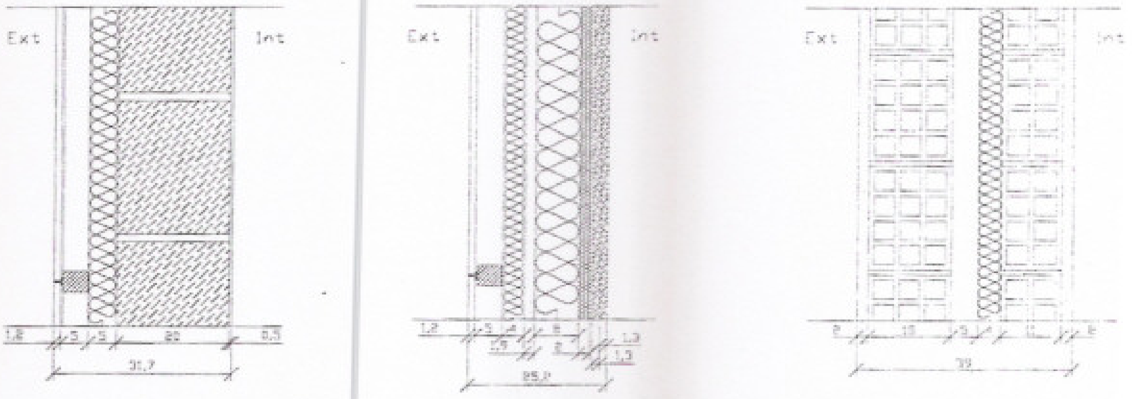


Figure 7 (a) Mixed-weight double leaf wall PMD2.1/15 – wood/cement board, air gap, cork insulation, a
(b) Triple lightweight wall PT(L)3.1 – wood/cement board, air gap, cork insulation, sandwich panel;
(c) Heavyweight double leaf wall PD1.2/15 – Hollow brick and XPS Insulation on the air-gap

Both BTC solutions were previously evaluated under the thermal performance point of view, using the RCCTE (Portuguese thermal regulation) (RCCTE 2006) and the CSTB estimation methods (CSTB 1988), for three possible configurations of south facade, which results are presented on Table 1.

The preference was for a good thermal performance in winter rather than in summer, that is why the solution of attached sunspace was the adopted (Mendonça 2005). Beyond the favourable values foreseen for the heating needs, the sunspace allows a useful area advantage that can be used as circulation in the proposed architectonic solution, although it does not represent a significant increase of cost in relation to a mass or a trombe wall system. From the analysis of the estimated values, it can be concluded that the ideal solution would be to count on the performance of a Dynamic Wall with green-house effect in the summer and an attached sunspace in the winter. As this is not viable in a real situation, considering a sunspace with possibility of opening in the Summer would lead to similar values for the heating necessities closer to case 1 (without complementary glass in the south façade).

Table 1 Heating, cooling and global energetic needs [kWh/year]

	BTC 1 (proposed)		BTC 2 (conventional)	
South facade configuration	Cooling	Heating	Cooling	Heating
1: Without ext. window on south facade	276	1.362	263	1.657
2: Dynamic wall with green-house effect	266	768	244	1.481
3: Attached sunspace	389	759	356	1.252
	Global		Global	
1: Without ext. glass on south facade	1.638		1.920	
2: Dynamic wall with green-house effect	1.034		1.725	
3: Attached sunspace	1.148		1.608	
4: Without complementary window (or opened complementary window) on Summer and Attached Sunspace on Winter (closed complementary window)	1.034		1.496	

A comparative study on the embodied energy of the construction materials and transport consumption of BTC was also done, and it was concluded that BTC 1 presented an energetic global cost of 1.066kWh/m^2 of pavement area (p.a.). BTC 2 presents an energetic global cost of 2.993kWh/m^2 of p.a., as it can be seen on Table 2.

The global Production Energy Consumption (PEC) of the materials was estimated from values in kWh/kg of material and converted in kWh/m^2 of p.a.. This evaluation parameter brought a significant advantage for BTC 1 with 945kWh/m^2 of p.a., while BTC 2 presented an estimated value of 2.751kWh/m^2 of p.a.. This advantageous difference for the proposed solution could also be higher, if in the end of the life span (50 years), the reuse, recycling or the combustion value of the timber used in the structure on the lightweight area of BTC 1 was considered. BTC 2 materials are not reusable, recycling is not economically viable and have no combustion value. (except for the covering structure, which has the same timber structure of BTC 1).

The estimated heating energy consumption, for a 50 year period, was of 2.164kWh/m^2 of p.a. on BTC 1 and of 4.088kWh/m^2 of p.a. on BTC 2, what is equivalent to almost half of the global energy consumption in an overall life cycle analysis.

Table 2 PEC, materials' transport energy and embodied energy with heating needs in a 50-year period by square meter of p.a. on both BTC with attached sunspace

	Embodied energy PEC [kWh/m^2]	Materials transport energy [kWh/m^2]	PEC + transport energy [kWh/m^2]	Energy consumption with heating needs in lifetime [kWh/m^2]	Global energy consumption in lifetime [kWh/m^2]
BTC 1	945	121	1.066	2.164	**3.230**
BTC 2	2.751	242	2.993	4.088	**7.081**

Table 3 PEC and gross weight of the materials on both BTC, by elements' positioning

BTC 1 (Proposed) Cost by elements' positioning	Weight (kg)	PEC (kWh)
1 – Foundation	7.211	2.758
2 – Pavement	7.010	3.800
3 – Walls, doors and windows	**9.678**	**4.645**
4 – Ceiling	5.474	2.604
5 – Covering	1.200	2.255
Total	**30.574**	**16.062**
Pavement area 17m^2		
Total / m^2 (with timber frame on complementary window of sunspace)	**1.798**	**945**

BTC 2 (Conventional) Cost by elements' positioning	Weight (kg)	PEC (kWh)
1 – Foundation	7.211	2.758
2 – Pavement	10.194	4.661
3 – Walls, doors and windows	**17.702**	**27.917**
4 – Ceiling	8.890	3.669
5 – Covering	1.200	2.255
Total	**45.198**	**41.260**
Pavement area 15m^2		
Total / m^2	**3.013**	**2.751**

Based on this study it can be stated that the greatest energetic consumption of a current housing bui in Portugal, even optimized under the hygrothermal point of view is due to the construction phase and most especially to façade elements – walls and windows, as it can be seen on Table 3.

Both BTC in their final configuration were also compared from the economical/energetic aspects:

- BTC 1 presents an economical cost slightly advantageous compared to BTC 2. The econo construction cost (including materials and handwork) of BTC 1 was of 18.889€, while on BTC of 19.002€. This advantage became more significant when the specific cost per square met pavement area was considered. As BTC 1 walls are thinner then those of BTC 2, the pavement of BTC 1 is of 17m^2, while the pavement area of BTC 2 is of 15m^2. The economical constru cost per square mater of pavement area is of 1.111€/m^2 to BTC 1 and of 1.267€/m^2 to BTC 2, can be seen on Table 5;
- Operating energy, in terms of heating needs, and considering a lifetime of 50 years, was convert economical cost. This study was only for the heating needs, as it was considered that Cooling on littoral coastal areas of the north of Portugal, where this study was undertaken, generally d produce energetic consumptions, as natural ventilation during the night hours is usually enou fulfil the Cooling Needs on Summer. BTC 1, with the attached sunspace, presented an estimate for the Cooling Needs of 214€/m^2 of p.a., while BTC 2 presented a cost of 404€/m^2 of p.a., as shown on Table 4.

Table 4 Construction and operating economical costs in a lifetime of 50 years per square meter of pavement area on both BTC with attached sunspaces (Mendonça 2005)

	Economical cost of construction [€/m^2]	Economical cost with heating needs (50 years) [€/m^2]	Total economical cost (50 years) [€/m^2]
BTC 1	1.111	214	**1.325**
BTC 2	1.267	404	**1.671**

: estimated total economical cost is of 1.325€ for BTC 1 and of 1.671€ for BTC 2. The parcel responding to the energy cost to fulfil the heating needs is reduced, even if considered a year period.

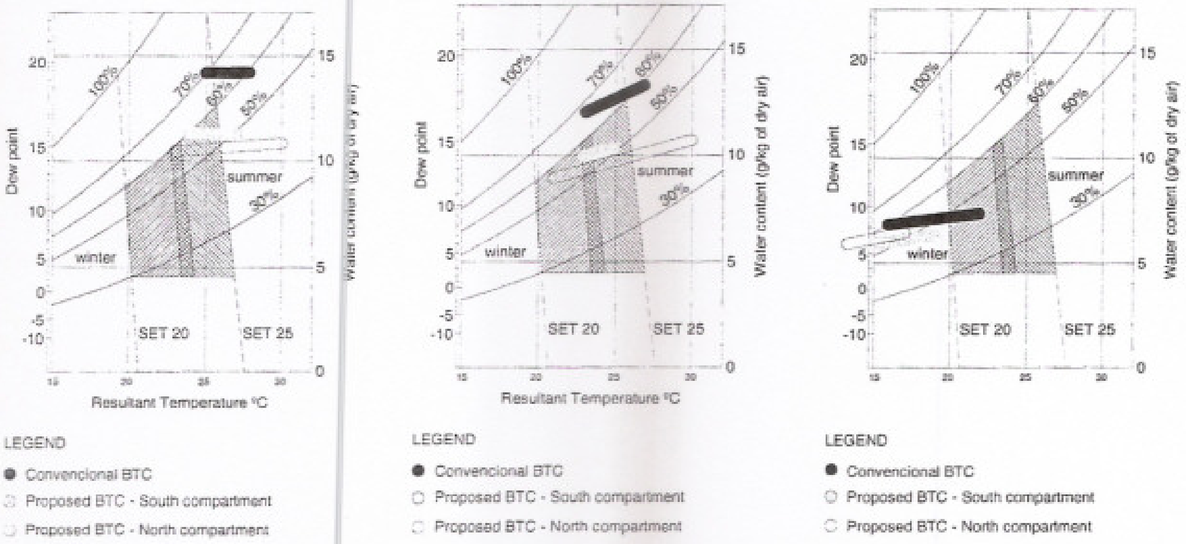
. Experimental Study

: movable partition on BTC 1 allowed the evaluation of two distinct compartment layouts, both by ;rothermal measurements. A significant thermal lag difference due to compartment layouts can be ified by the analysis of the resultant temperature charts.

th the partition opened on summer, only BTC 1 presented values partially inside the comfort zone of ASHRAE comfort chart, being the south compartment of this Cell almost always inside the comfort 1e, as it can be seen on Figure 8a).

th the partition closed and high exterior ambient temperature, only BTC 1 presented values totally ide the comfort zone on south compartment and partially inside this zone on north compartment, even he thermal lag was significant – approximately 7°C. BTC 2 was always outside the comfort zone even t was by a small difference, essentially due to relative humidity, as it can be seen on Figure 8b).

th the partition on BTC closed during the measurements period with low temperatures, only BTC 2 :sented values partially inside the comfort zone. BTC 1 presented a minor difference for the comfort 1e on the south compartment, yet with relative humidity values slightly lower then the rest of the ıdied compartments, as it is shown on Figure 8c).



'igure 8 (a) Comfort evaluation on ASHRAE's comfort chart in the end of summer (15 till 21st September 2003 – opened partition on BTC 1; (b) Comfort evaluation on ASHRAE's comfort chart in the end of spring with high temperatures (14 till 20th May 2004 – closed partition on BTC 1; (c) Comfort evaluation on ASHRAE's comfort chart in the autumn, with low temperatures (12 till 16th November 2004 – closed partition on BTC 1)

. Conclusions

he example presented shows how the global embodied energy of the mixed-weight solution on the roposed BTC, allows to reach a minimum of 40% reduction (even using aluminium frames on the ınspace complementary window) when compared with the BTC 2 (conventional) and even to reach a)% reduction (using timber frames on the Proposed Solution and keeping the aluminium frames on the onventional reference solution). It can also be concluded that the economical cost of the proposed olution was essentially due to intensive hand labour and other non energetic costs and less to the ıaterials' PEC, what is a positive aspect from the environmental point of view.

The Proposed BTC presented also more favourable experimental hygrothermal results during the cooling season but slightly more unfavourable on the heating season. In terms of relative humidity BTC 1 was always more favourable, because measured values were under 60% in most of the cases, while BTC 2 reached values over 70%, specially during Summer, what is going to limit the comfort as well as durability and indoor air quality. This was caused by the inferior hygroscopic inertia of the hollow brick in comparison with the adobe.

Acknowledgements

The author wish to thank FCT (Fundação para a Ciência e Tecnologia – Portugal) for supporting the test cells for non Buildings Project and Pedro Silva for some of the hygrothermal performance measurements.

References

1. Mendonça, P. 2005. "Living under a second skin – strategies for the environmental impact reduction of Solar Passive Constructions in temperate climates" Doctorate Thesis in Civil Engineering; *University of Minho, Civil Engineering Department*, Guimarães, Portugal.
2. RCCTE 1990; "Regulamento das Características do Comportamento Térmico dos Edifícios – Portuguese Building Performance Thermal Regulation"; Decreto-Lei nº 40/90, de 6 de Fevereiro.
3. CSTB 1988. "Régles Th-BV, régles de calcul du coefficient de besoins de chauffage des logements - annexes"; cahiers du *Centre Scientifique et Technique du Bâtiment*, livraison 292, cahier 2274; Paris, Septembre.
4. ASHRAE 1997. "Handbook of Fundamentals"; American society of heating, refrigeration and air-conditioning engineers, Inc., Atlanta.

In our current pursuit of Sustainable Development, Earthen Structures are *true* green buildings that hold enormous relevance and potential in providing solutions for environment friendly buildings that are energy-efficient, comfortable, cost-effective and recyclable. Besides being more responsive to local environmental conditions, they offer sustainable alternatives to modern building materials that are highly energy intensive and contribute heavily to green house gases.

The proceedings comprise peer-reviewed collection of 52 papers on earthen structures and related topics. It comprises contributions from practicing engineers, architects and researchers from across the world. As more sustainable and healthier buildings are sought, this book would serve as a timely asset for readers interested in traditional and modern methods of earth construction. Useful information is available on the adoption of earth based materials such as stabilised soil blocks, rammed earth, fibre reinforced adobe masonry, earthen mortars, etc. Overall, the proceedings would serve as a ready reference to researchers, practicing engineers and architects interested in *Earthen Structures*.

Dr. B V Venkatarama Reddy is a civil engineer with Ph. D. in Structural Engineering from Indian Institute of Science, Bangalore, India. He is currently working as Associate Professor at the Department of Civil Engineering, Indian Institute of Science. He has a number of peer reviewed journal publications in the areas of structural masonry, energy efficient alternative building materials and technologies, and building materials from solid wastes. Prof. Reddy has guided doctoral research programmes and consultant to several projects on alternative building technologies.

Dr. Monto Mani is Assistant Professor at the Centre for Sustainable Technologies, Indian Institute of Science. He holds a Bachelor's degree in Architecture, a Masters' degree in Civil Engineering and a Doctoral specialization in Sustainable Human Settlements. Dr. Monto's research interests include sustainable architecture and human settlements, with particular focus on Climate-responsive buildings, BIPV and Green buildings, Building-comfort studies in tropical regions and Integrated Water and Sanitation in Habitats.

Building on the cover page

Load bearing residential building in Bangalore City, India. The exposed exterior walls are stabilised mud block masonry and the interior walls are stabilised rammed earth. Other features include rammed earth columns for the portico and stabilised mud block filler slab floor slabs.

Interline Publishing

Price Rs. 1500/- **ISBN - 81 - 7296 - 051 - 4**