PERFORMANCE EVALUATION OF CLAY-EXPANDED MORTAR (CONCRETE) COMPOUNDED PANELS FOR RATIONAL MASONRY APPLIED TO LOW COST HOUSING. A CASE STUDY FOR BRAZIL

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ABSTRACT

The present work is being developed on the scope of the Department of Civil Engineering, Constructive System Division, at the University of Brasilia. The present housing problem in Brazil is widely known due to the existence of numerous homeless people in rural areas and also in urban centres. The most recent figure indeed points out a shortage of 5.6 million, including metropolitan and rural areas (Planning Ministry – PNUD/SEPURB, 1995). Moreover, quite frequently, the developed product for the proposals (low-cost housing) does not offer its user the expected quality or performance. The objectives of this work are performance evaluation of clay-expanded mortar compounded panels for rational masonry applied to low cost housing in Brazil. Strength and thermal performances, as well as the quality and the rationalization, were analysed, select by the requirements comprised in the guideline ISO – DP 6241. Some tests were performed: safety strength (soft body, hard body, suspended piece and closure doors) and the thermal conductivity index. The thermal performance analysis results of the internal temperature presented were obtained with a study simulation of the constructive system. The results were compared with conventional masonry constituted by ceramic blocks..

Key words: performance evaluation; clay-expanded mortar compounded panels; in-use structural performance; thermal performance; qualitative and rational masonry; construction systems; low-cost housing.

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INTRODUCTION AND OBJECTIVES

Brazil’s housing deficit is of increasing concern, manly at the largest urban centres where a huge part of the population lives in unsecured and inadequate homes and the remaining ones do not even have a place where to live. Therefore, the said deficit refers to both quality and quantity.

Many new materials, components and construction systems have become available in the last decades, and a lot has been researched about their possible contributions for the reduction of the housing deficit. According to the performance of these new construction systems it is of absolute importance to verify whether these materials follow the suggested importance by their manufacturers and also whether they constitute a better alternative to the conventional building systems.

The objectives of the present study are about the performance evaluation of a construction system constituted by clay-expanded mortar compounded panels for rational masonry, named MODULAN system by its manufacturer. The system is made for earthly housing of social character. The results will be compared to conventional masonry, made of ceramic bricks.

The ISO-DP 6241 establishes 14 requirements for the user of home, requirements that vary from the structural safety in use (including the generally applied weights by the dweller) until the thermal levels of comfort and functionality. As for the methodology for the performance evaluation, the IPT (1998) requires that for each of these requirements correspond requisites of qualitative and quantitative criteria.

In this study, the following requisites are considered for the evaluation of the said system: Structural performance in use; thermal performance and performance according to quality and rational.

METHODOLOGY

For the evaluation of the structural performance in use, essays were made to the MODULAN system prototype. Essays to the resistance to the impact of soft and hard bodies, behaviour to the suspended piece and to the sudden door slamming were all completed. The necessary arrangements for the essays were developed based on the ABNT guidelines: MB 3256; MB 3259; NBR 5081 and NBR 8054, and also for what is established by the IPT (1998) document.

The applied methodology to the present study, for the thermal performance evaluation, has, as established basis, the guidelines established by IPT (1998) for the system performance use.

For the analysis of the thermal process, of the existing methods (calculations, in loco measurements our simulation through the use of software), it was observed that the simulation through the use of software is being increasingly utilized, especially due to the speed in obtaining the final results.

For the simulation of the thermal performance, some software may be cited, like: ARCHIPAK (University of Queensland), CASAMO-CLIM (Centre d’Ènergie de l´Ècole de Mines à Paris), EASY (University of Pretoria, South Africa), DOE-2 (Lawrence Berkeley Laboratory, USA), NBSLD (National Bureau of Standards, USA), ARQUITROP (Federal University at São Carlos, Brazil), etc. For this study, ARQUITROP was used, since its database contains the climate patterns for the main Brazilian cities, besides a database of thermal characteristics for the materials and components usually used for civil construction. The thermal performance evaluation was done with the climate data for the city of Goiânia, where the prototype is being manufactured.

Regarding the quality and rational performances, such analysis was done based on the information provided by the manufacturer, material characterization essays and visits made to the prototype.

DESCRIPTION OF THE MODULAN SYSTEM AND THE PANELS UNDER STUDY

The MODULAN construction system is composed of clay-expanded mortar compounded panels, structured in its shape with profiles of galvanized steel. Three types of panels are manufactured: external wall panels, internal wall panels (single or with additions), and floor panels.

The panels used for the external walls are 0,04 m thick, made of concrete; the expanded clay used as gross mortar. The volume used by the manufacturer is of 1:2,0: 2,5 and 198 litres of water. The remaining panels are made of common concrete, but those for the washed areas are 0,06m thick.

The armour for the panels is made of welded steel mesh, welded to the galvanized steel profiles, distributed according to the resistance requirements of the panel.

The moulding for the panels is manufactured in open metal forms. Aspersion and the stocking in pallets make the cure.

The panels receive PVA paste on both faces, internal painting in PVA and external paint based on coloured rubber. They are interlinked with solder, and internally waterproofed with silicone, and externally with plastic paste. Tile covering may be directly applied over the floor panels or walls.

The panels are concreted with inserted squaring and additions, planned before the concreting.

As for the covering, that is made with clay shingles with plastered insides, excepting for the bathrooms, where concrete panels are used. Eaves are laterally applied and balconies on the frontispiece of the prototype.

RESULTS

Structural Performance in Use

Resistance to soft body impacts

This test's goal pertains to the verification of the wall's resistance to soft body impacts. The performance evaluation was done with a prototype, the way it was already explained. Tests were performed over one of the external walls of the prototype.

As a soft body, a cylindrical leather bag was used, with the 0.35m in diameter and 0.90m in length, with a total mass of 40 kg. A pendulum system was mounted, rigged to a truck's crane supported with a steel cable.

A graphic registration device was used for the transversal dislocations, installed facing the opposite body to the one to be tested, at a height of h/2 = 1.40m.

Table 1 – Criteria for soft body impacts on pillars and external walls with a structural function. SOURCE: IPT (1998)

Components	Energy (J)	Max. Dislocation		Requirements and Observations
	Outside/Inside	Dhi	Dhr	
Pillars and Walls with a Structural Function	120	-	-	No damage
	240	L/250	-	No damage
	240	-	-	No damage
	240	-	L/1000	No damage
	360*	-	-	Cracks and other damages
	480*	-	-	Cracks and other damages
	720*	-	-	Cracks and other damages

(*) Safety impacts: no rupture or loss of stability is allowed.

Table 2 – Results obtained after the soft body test

Λh (m)	I E (J)	Dhi (mm)	Dhr (mm)	Observations
0.30	1st 120	-	-	No damage
0.30	1st 240	-	-	No damage
0.60	2nd 240	-	-	No damage
0.60	3rd 240	-	-	No damage
0.90	1st 360	-	-	Dislocation connection between the panels 0.20 m above the floor
1.20	1st 480	-	-	Increase in the dislocation 0.25 m
1.80	1st 720	-	-	Increase in the dislocation 0.25 m

For the impacts, the cylindrical bag was dislocated until its gravity centre attained Λh (height for the soft body fall) from 0.30, 0.60, 0.90, 1.20 and 1.80 m, from the resting position, hitting the material to be tested with impact energies E of 120, 240 (3 impacts), 360, 480, and 720 J, respectively. Dhi (instant transversal dislocation) and Dhr (residual transversal dislocation) for the energy of 240 J, the 1st and 3rd impacts being considered.

No considerable damages were observed in the wall after the application of all impacts, showing the MODULAN system and the tested wall may be considered satisfactory as far as soft body impacts are concerned.

Resistance to hard body impacts

This test was conducted in order to evaluate the wall in relation to hard body impacts. The tests were conducted on one of the external walls of the prototype, with the help of a 5.00 m high portico and 1.00 m width.

For the impact, massive steel spheres, with 0.050 m for a mass of 500 g and approximately 0.067 m for a mass of 1000 g, were used.

The test was conducted throwing spheres suspended by a steel cable and let go in a pendulum movement, from h height, till they hit the wall. The spheres, thrown at different heights supplied the impact energies required for the test.

The accepted criteria for the analysis of an impact with a hard body requires that the wall (or the component to be tested) may not show cracks, splinters, ruptures or dents superior to “2.0 mm” when subjected to an impact at any place. Any occurrence of such failures may be duly registered. For this testing the impact energies concerning the spheres of 500 and 1000 g, were considered, as indicated at Table 3.

Table 3 – Impact energies considered for a hard body test. SOURCE: IPT (1998)

Impact energy (J)	5	25
Mass sphere (g)	500	1000
Fall from height (cm)	100	250

The table 4.1 and table 4.2 show values concerning the depth of the dents left after the different impacts, for the defined heights for the falls.

Table 4.1 – Depth of the dents (mm) left after the hard body impact testing

Impact energy 5J	Nº 1	Nº 2	Nº 3	Nº 4	Nº 5	Nº 6	Nº 7	Nº 8	Nº 9	Nº 10
h = 100 cm, 500 g	0.2	0.1	0.5	0.2	0.3	0.4	0.5	0.2	0.5	0.4

Table 4.2 – Depth of the dents (mm) left after the hard body impact testing

Impact energy 25J	Nº 1	Nº 2	Nº3	Nº4	Nº5	Nº6	Nº7	Nº8	Nº9	Nº10
h = 250 cm, 1000 g	0.6	0.5	0.6	0.4	0.4	0.3	-	0.3	0.3	0.3

The MODULAN construction system has shown a "satisfactory" performance under the action of a hard body impact, with the occurrence of dents inferior to the allowed limit of 2 mm.

Suspended parts behaviour

This test has the objective of the evaluation of a wall at the time of application of a suspended part that may be constituted by chests, cupboards, cisterns, etc. As for the testing, the object was one of the internal faces of the prototype, made of expanded clay concrete panels.

Regarding the behaviour of the suspended part, IPT (1998) establishes as criteria that the internal walls of the house, with or without a structural function, may resist to a vertical eccentric charge of 784 N (80 Kgf) without the following occurrences:

a) *dhi > h / 500*, where *dhi* is the instantaneous dislocation and *h* is the wall height

b) *dhr > h / 2000*, where *dhr* is the residual dislocation and *h* is the wall height

c) tearing off of fixing devices, ruptures, cracking or scaling at the charge transmission areas; small indentations or dents are, however, accepted

d) Any damage outside of the charge transmission area, at any face of the wall.

For the testing, the measuring instruments (deflectometers), were positioned at heights of h/2, 3/4h and 1/4h, where after their calibration the placement of weights (10 Kgf) was done, well as the registration of the dislocation readings, occurred *dhi* and *dhr* (after 15 minutes of charging).

Usually appropriated for the fixation of suspended parts in housing buildings, 8 mm screws and wads were chosen for fixing the suspended parts. Charges were gradually applied to (from 20 to 20 kgf) while the corresponding readings for the dislocations were being done. A total charge of 80 kgf was placed.

The readings taken during the tests were compared within the established limits for dhi and dhr equal to 5.6 and 1.4 mm (for h=2.80 m), respectively.

Table 5 – Values for the total deformation (mm) obtained at the suspended part test

Deflectometers	Dhi and Dhr, in mm, for the 4 charging steps (kgf)							
	20		40		60		80	
	Dhi	Dhr	Dhi	Dhr	Dhi	Dhr	Dhi	Dhr
Def 01 (3h/4)	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03
Def 02 (h/2)	0	0	0.01	0.01	0.01	0.01	0.01	0.01
Def. 03 (h/4)	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03

After the suspended part test, it was concluded that the MODULAN system performs satisfactorily once the observed dislocations are below the established ones in the criteria, for an applied maximal charge of 80 kgf.

<u>Harsh door slamming</u>

This test relates to the wall and door evaluation (as well as its elements) whenever doors are slammed. As a model for this test a metallic door indicated by the company, as well as an external wall of the prototype were chosen.
The equipment used for this test included a tripod, a metallic rod having at one of the extremities a pulley fixed in a block and a support for weights up to 20 kg.

The door was initially positioned at a 60º angle in relation to the wall. The test was performed with a cycle of ten harsh door slamming against its knocker, caused by the free fall of a group of weights totalling 15 kg (147N), which, tied to the door handle, through a steel cable, provided the required movement to the test. After the application of each of the impacts, visual inspections were done, and also checked whether the normal movement of opening and closing of the door were affected.

Table 6 – Observed occurrences at the harsh door-slamming test with the following application charge: 15 kg (147 N)

Impact	Tested face
1	No occurrences
2	No occurrences
3	No occurrences
4	No occurrences
5	No occurrences
6	Denting at the junction between the pole and the door at 0.30 m from the floor
7	Increase of the denting to a height of 0.50 m
8	Increase of the denting to a height of 0.60 m
9	Small indentation at the hinge placed at mid-door
10	Small warping of the door plank

The considered criteria for this test, establishes that under the action of 10 harsh door slamming, the external walls, with a structural function, may not evidence damages like: ruptures, fissions, denting at the contours, as well as in the areas of its fixation, denting at the joints of the panels and damages at the knockers.

The damages observed in the walls, door, knocker and locks were not considered of significance. Therefore, it was concluded that, as far as the harsh door slamming is concerned, the MODULAN system performs satisfactorily.

THERMAL PERFORMANCE

The evaluation of the thermal performance consists in the verification whether the environmental conditions are satisfactory, regarding the thermal level of comfort provided to the users, the global response to be considered, although it will vary according to the climatic region. For the present study, the City of Goiânia - GO was considered since the prototype will be implemented in this region.

For the evaluation of the thermal performance of the system under study, the first procedure concerned the characterization of the expanded clay concrete compounded panels. After that, a simulation was carried out in order to study the system behaviour for

the months of July and September, those with the lower and higher outside air temperatures, respectively. Then, those results were compared to those of conventional masonry.
The used program contains a data bank that simulates the thermal performance and checks for the climatic adequacy of the edifications (buildings), in order to optimize the thermal comfort, thus, saving hydro (electrical) energy.

Thermal conductivity of expanded clay concrete

Tests of thermal conductivity were performed for the expanded clay concrete, the material that the panels under study are made of. The value found for "λ" was 0.83 (W/mk).

Exposure conditions and criteria followed for the evaluation of the thermal performance

For the analysis of the thermal performance requirements, exposure conditions were adopted, concerning the City of Goiânia – GO, such as air temperature, relative humidity, solar radiation, wind speed and direction, etc., obtained from the ARQUITROP 3 database, with climatic data about 200 Brazilian cities, primarily compiled from the National Meteorology Institute of the Ministry of Agriculture and the Directory of Routes from the Aeronautics Ministry, over a period of 30 years.

Regarding the criteria for performance, in the present study were considered those adopted by IPT (1998) with the limits for air temperature satisfying the requirements of guideline ISO 7730 (denominated as comfort zone), within the interval between 18ºC and 29ºC for an air speed higher than 0.5 m/s. For the case of a person sleeping during the night, with heavy blankets, the inferior limit becomes 12ºC.

The performance is considered satisfactory, or not, for the previously established comfort conditions, with three distinct performance zones, indicated by "A", "B" and "C" (good, regular and unsatisfactory), concerning the seasons of Summer and Winter, as indicated below.

For the summer: Level A – An environment which internal conditions be those required as comfort by ISO 7730 at all times of the day, that is, an interior temperature always inferior to 29ºC; Level B – if the maximal daily value of the interior air temperature does not exceed the maximum value of the exterior air temperature, and Level C – when the maximal daily value of the interior air exceeds the maximal value of the exterior air temperature.

For the winter: Level A – The comfort requirements are looked after all day, that is, an interior temperature always higher than 18ºC; Level B – if the minimal daily value of the interior air temperature is, at least for one hour of the day, higher or equal to the value of the minimal temperature of reference, and Level C – if the minimal, daily value of the interior air temperature is lower that the minimal value for the temperature of reference.

Application and obtained results with the ARQUITROP software

For the simulations, a standard room, like a dormitory, was adopted, since it is widely considered as the critical room for the project under study. It had the following characteristics: window area / floor area of 18%; levelled floor of 2.60 m and external walls of a light colour. Simulations were made with the standard room window facing North (the most critical of all), for the seasons of summer and winter.

For the summer period, regarding the standard room with clay expanded concrete panels, the temperature of the interior air showed higher values than the highest exterior temperature of the room, at a level C performance.

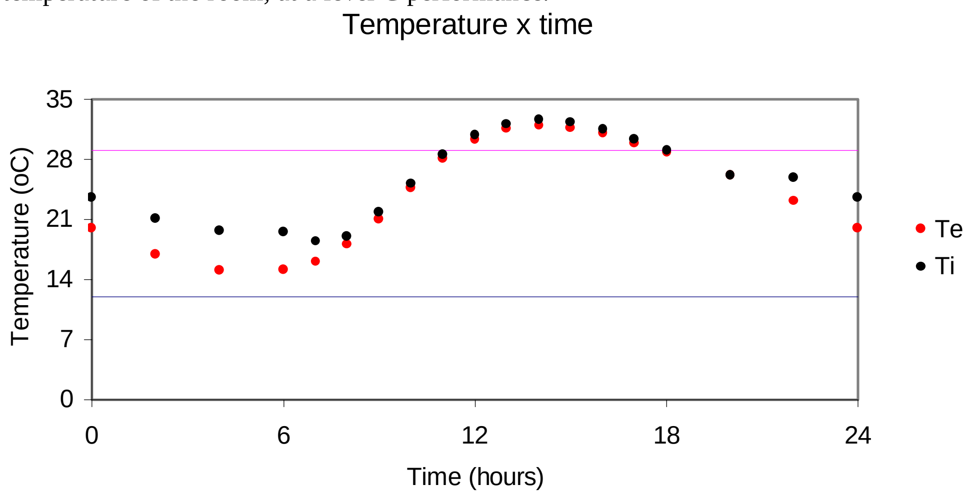

Plate 1 – Ameliorated conditions – clay expanded concrete during summer

Looking at the raising of the levels of comfort, venetian blinds were adopted for the standard room window. The subsequent obtained results are presented at plate 1. The maximal interior temperature is very close to the maximal exterior temperature, at a Level B performance.

Conventional masonry, ameliorated with the use of venetian blinds, in the sleeping room, has shown a similar performance to the one presented on Plate 1.

For the winter period a good behaviour at the level B performance was observed (considering that at this time of the year the minimum limit for the lowest temperature is of 12ºC) and the conventional masonry test also has a similar behaviour to the performance a level B.

QUALITY AND RATIONALIZATION PERFORMANCE

Functionality

For the functionality analysis, Table 7 shows the values regarding minimal measures and areas, according to the Goiânia – GO building code and the observed values. We can conclude the project has satisfied the requirements, presenting the minimal satisfactory measures (Lm) and areas (Sm) allowing its use as economic housing units.

Table 7 – L min. and S min required x L min and S min performance of the project

Environments	L min Req (m)	S min Req. (m2)	Lproj (m)	S proj (m2)
Bedroom 1	2.4	7.5	2.9	8.4
Bedroom 2	2.4	7.5	2.9	8.4
Bedroom 3	2.4	7.5	2.9	8.4
Living room	2.6	9.0	2.9	10.8
Kitchen	1.8	3.75	1.8	5.05
Bathroom	1.1	-	1.1	2.31

Project and Building System Flexibility

The MODULAN system shows possibilities for the housing unit amplification, since there is a compartment modulation, through a 2.90 m module. Amplification is obtained by coupling welded metallic profiles. Besides, we realized the company has other modular projects among which those for the bathroom units can be cited.

Component Conception Rationalization

By analysing projects and observing prototypes at the assembly phase, we concluded there is a rationalization in the conception of the components, in their adequate connections (or joints), with a standardized procedure, made by welded metallic profiles. There is an appropriate profile for each type of connection.

Another observed advantage, comparatively to the conventional system, is that the panels do not require a covering mortar (it is frequently observed, in the case of conventional masonry, high levels of mortar loss derived of problems with materials and masonry use).

Compatibility Among Architectural, Structural and Installation Projects

There is compatibility among the architectural, structural and installation projects, once that: countermarks, the structure and the installations are planned to be inlaid into the panels before their concreting, thus avoiding future breakouts in their insertion or plumbing.

Material Adequacy Regarding Local Availability

It was considered there is a material adequacy regarding the local availability, since welded steel mesh (also used in tiles) and expanded clay come from the State of São Paulo, a production centre of many other materials used in the Midwest region. Other materials like concrete, sand, clay, gravel, etc, can be acquired in the region.

Production and Assembly Process Rationalization

Regarding the production and assembly process rationalization, it was observed the production operations are planned and produced at adequate places, with previously established procedures for: framing assembly; positioning of the framing in the squares constituted by welded profiles; concrete preparation; concreting of the panels with devices for the framing coverage; inlaying of installations and countermarks; transportation of the panels; finishing and final painting of the prototype.

Material Quality Control (at receiving and production)

For the material quality control, some observations will be made regarding framing and the constituting materials for concrete and the concrete.

As far as framing is concerned, in this case the welded steel mesh, there is receiving control, however made in a sporadic way, after results supplied by the manufacturer. A better control at receiving, through more frequent testing is suggested, performed by a recognized lab (but not the manufacturer's).

Regarding the materials, which constitute the concrete, it may be considered satisfactory the control over them, not only where stocking is concerned but also about the results obtained from the company. It is, however recommended, for the possibility of production increase, that a small lab may be installed with conditions to conduct granulation testing and for the impurity degree of the aggregates. For the concrete, observations are the same made for framing, since being a product generated by its own industry, lacks receiving control.

Characteristic resistance of concrete to compression (Fck), specified for the panel projects, is of 20 MPa (Fck > 20 MPa). According to the results obtained through the tests conducted, the resistance shows values above the specified ones.

Visual Evaluation of the Prototype, at the Assembly Phase and after Completion

Two prototypes were visited, one during the assembly phase and another after completion (or ready). None of them presented any problems of breaking or cracking, since all their joints were planned with welding, thus preventing improvised operations at the moment of their assembly. Also, no problems with warping, verticality or deflexions were observed, indicating an existing standard of finishing quality.

CONCLUSIONS

This study consisted in the evaluation of the MODULAN system, an evaluation focusing the extended clay mortar (concrete) compounded panels, since these are the system's technological innovation. The main conclusions are presented below, for each of the analysed requirements, compared to convention masonry composed of ceramic blocks.

Regarding the structural performance, all the values obtained in the tests have abided to the considered criteria, so that we can conclude the system is satisfactory concerning the application of occupation charges, as well as to the resistance to soft and hard body impacts, its behaviour when charges derived of suspended parts were applied and harsh door slamming.

Conventional masonry, made of ceramic blocks (bricks) also presents satisfactory results, as far as the structural performance is concerned, and no problems have been observed through the long period of time while it has been in use, excepting for some cases regarding the behaviour of suspended parts, the fixation of screws, when these are applied to the hollow of the block. In many new systems composed by panels not adequate to the fixation of screws, those are to be applied in mountings appropriate for such purpose. It is of interest to verify that the manufacturer possesses, in this case, a user's manual indicating the correct procedures.

Although this system has presented a good structural performance, we have frequently seen systems that do not abide to these requisites, placing at risk the user's safety.

Regarding the thermal performance, the system has shown a better behaviour for the winter than for the summer, with similar results for winter and summer when compared to 0.14 m thick conventional masonry, constituted of ceramic blocks, both with a performance at the B level. It was observed that the prototype carries 0.50 m eaves at the sides and balcony, bettering the standard conditions for the summer. Besides this, however, we recommend that the placement of venetian blinds in the bedroom windows may be mandatory.

Relating to the quality and rationalization of the system under study, it's performance is considered satisfactory, with some recommendations above described. Unfortunately, the conventional system in Brazil, made of ceramic blocks, has not often performed satisfactorily regarding these requisites. About quality: recent researches held at the University of Brasilia, by the author, have shown that in samples of 14 different suppliers of ceramic blocks, its majority did not provide a good quality of their components, when considering the requisites for resistance to compression, level of absorption and uniformity in their dimensions. Concerning the production process, the methods used in the manufacture of masonry are archaic, generating a low productivity in the process. Although this scenario has been improved in recent years, due to the frequent quest for better quality, the levels of loss, found in the chapter concerning masonry are still high.
Still regarding losses, there are advantages in the use of panels over conventional masonry, since these do not require covering mortar (they just require painting), while masonry requires covering mortar, nowadays considered like real "evils" in terms of the generation of loss at our construction sites.

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