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Structural and Thermal Performance of low-cost house buildings in Maceió, Northeastern Brazil: Analysis of construction walls made of blocks using recycled aggregates

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Abstract

An important issue in Brazil nowadays is the lack of appropriate low-cost housing however, construction and demolition residues present appropriated physical and chemical properties in case of employment as construction material. With regard to the quality and performance of dwellings, this paper shows the results of structural and thermal performance evaluation of a building prototype of approximately $40m^2$ made of concrete blocks which were produced with recycled construction and demolition aggregates, according to government exigencies in Maceió, a tropical humid city in Northeastern Brazil. The blocks were developed in the Federal University of Alagoas Technological Research Center and made in a precast concrete factory called INDARC and their strucktural performance was analyzed after experimental tests. The bedding mortar was produced with recycled aggregates and its influence in the masonry was analyzed. The thermal performance monitoring period was summer time in Maceió. Outdoor and indoor measurements were carried out with HOBO data-loggers and superficial temperatures with infrared thermometers. Final results were compared to outdoor conditions, with regard to daily temperature swings and comfort levels. Some improvements were suggested regarding the thermal performance. Experiments indicate the application viability of that construction system in order to obtain improvement of low-cost housing politics, emphasizing the importance of aspects to be considered in building design, such as user's well fare and comfort and energy savings. This research can also empower the production, in large scale, of low-cost and sustainable building components.

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1. Introduction

One of the most relevant challenges for public administrations nowadays, is the urban residues destination. The transformation of construction and demolition solid residues into construction material, to be used in concrete blocks and mortars becomes relevant since it can point to an alternative for low cost housing and contributes to the environment preservation.

The viability of use of recycled construction and demolition aggregates to concrete and mortar composites has been studied in Brazil by Pinto [1], Hanasaki et al. [2], Levy & Helene [3], and other researchers, who recommend a more detailed study about the material structural performance. The results found evidence, however, on pertinence and potentiality of investigations on the theme.

However, despite the confirmation of the importance of residues recycling use for civil construction, there is still a lack of normative references, based on theoretical-experimental studies that particularly evaluate the performance of recycling constructive systems prototypes. The decisions on new materials, components and constructive systems use should be supported by scientific evidence that shows appropriate applications. In that way, it is imposed to researchers and professionals of the area, implementation of research to evaluate new components destined to civil construction in order to archive similar results to already known components.

A building construction should guarantee to its users good habitability levels. That means structural safety, sanitation, durability, functionality and comfort, for demand human activities development. However, it is known that low cost house projects usually demand unnecessarily active energy systems because of precarious conditions of comfort and salubrity.

Thus, this present work aims to evaluate structural and thermal performance of a popular house prototype, built up using concrete blocks made of recycled construction and demolition aggregates, submitted to hot and humid climate standard conditions of Maceió, a city located in the Northeast region of Brazil, a South America developing country. The social aspect of this work is emphasized by the importance of performance evaluation in low-cost houses for the poorest population of Alagoas, the state of which Maceió is the capital, that depends basically on climatic adapted constructions, its comfort and salubrity with the use of low cost and energy materials and constructive techniques.

The results of this project can motivate governmental programs housing, based on the production of sustainable housing and its components.

2. Characterization of the studied area

Maceió is a 512km^2 city located on the Northeastern coast of Brazil, washed by Atlantic Ocean, between the latitude 9º39'57" and longitude 35º44'07". It is inhabited by approximately 800.000 people.

Its climate is characterized as hot-humid due to its low latitude, intense solar radiation and low daily, seasonal and annual thermal variations of air temperature, with annual average temperature of 25.5°C and annual variation of 3.4°C among the monthly medium values of medium temperatures. From November to February there are typically hot conditions; and between June and August typically high pluviosity (dry season). The most frequent winds come from the Southeast quadrant; the annual relative humidity is 78%. The annual average of precipitation is 1654mm, and rainy months are from April to July.

3. Execution proceeding of the prototype

The residue used for the construction of the prototype was gotten from a residence demolition. The improvement of the residue was carried out in NPT, a technological research center of the Federal University of Alagoas (UFAL). The residue was mostly constituted of ceramic material.

A prototype of the block was developed considering modulation aspects to prevent breakings, improvisations and consequently wastefulness. The block modulate dimension (Figure 1) was 1/8 of the meter, which facilitates the adaptation of walls modulation (Figure 2).

After experiments to produce a block in laboratory, the blocks were finally produced in a local precast concrete factory. In the house construction the bedding mortar between the blocks was produced using recycled construction and demolition aggregates mixed *in loco*.

In all the prototype execution term, technological control of the materials, that is blocks and bedding mortar was carried out. The prototype house was built in the Federal University of Alagoas neighborhoods (UFAL). The structural system adopted was structural masonry, which requires a carefully execution due to walls supports structure.

The finished prototype (Figure 3) constitutes a typology model of a popular habitation that abides to Brazil's governmental habitation program standards.

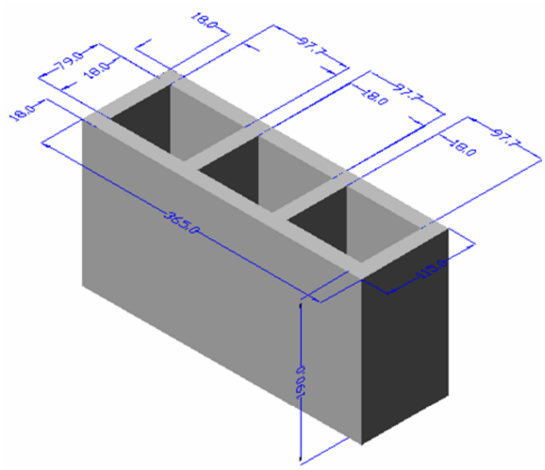

Figure 1: Model of the block used in the prototype

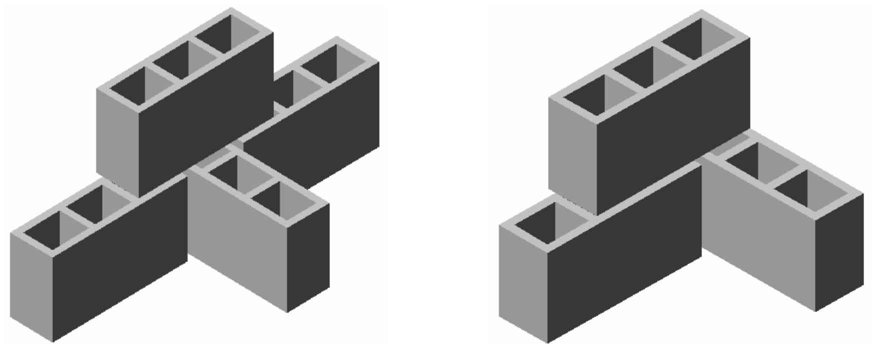

Figure 2: Walls modulation examples

Figure 3: Finished prototype.

4. Structural and Thermal Performance

4.1 Structural performance of prototype

For structure evaluation, structural loads included wind action. The cover own weight was 0.78 kN/m^2 and to the accidental load it was adopted 0.3 kN/m^2 as well, which caused 57.3 kN to the total load from cover in all structure. Adding the own weight of the blocks, the load wall resulted 4.1 kN/m. The horizontal loads proceeding from no linearity in vertical direction of the wall and from wind, resulted in a total load of 5 kN in the vertical direction and 5.45 kN in the horizontal direction at the walls. Table 1 shows compression stress for all the loads admitted in the walls (Figure 4) of the prototype.

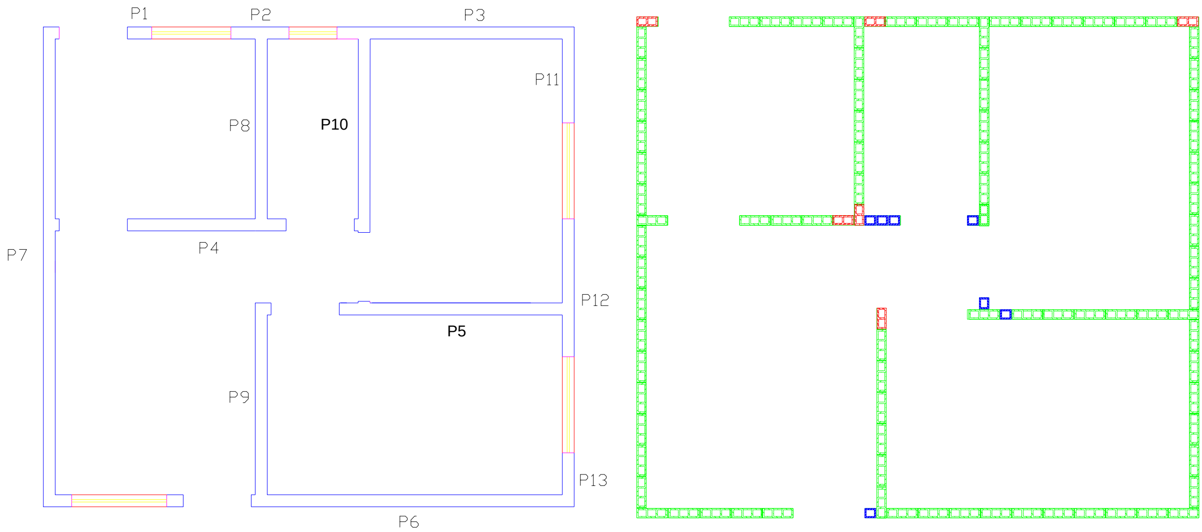

Figure 4: Walls modulations at the prototype

Table 1: Stress compression at the walls

-	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Stress (MPa)	0.052	0.054	0.06	0.06	0.06	0.062	0.073	0.06	0.056	0.058	0.054	0.072	0.051

4.2 Thermal evaluation of the prototype

First, to thermal evaluation on the prototype, tests measurements of air temperature and relative air humidity of two consecutive days of clear sky were made. Those field observations were made during the summer, when the largest thermal field discomfort caused by high temperature levels, is noticed. Afterwards, in order to compare the field data and the climatic adaptation, computational simulations took place with the software ARQUITROP [4], objectifying thermal performance evaluation of several simulations such as orientation, openings dimension etc. In a third experiment, a computational simulation took place with the program ANALYSIS 1.5 [5], to predict users' thermal conditions, by the calculation of PMV (Predicted Mean Vote) and PPD (Percentage of Unsatisfied People)values, in agreement with methodology developed in Fanger [6].

4.2.1 The climatic observations

The measurements were realized with datallogers (spelling), in two rooms of the prototype, at the height of 1.50m of the floor. To the sensor located in the living-room another sensor was coupled to register immediate outside temperatures.

During the measurement period the windows and internal doors were kept open in the schedules between 8:00h and 17:00h. The instruments registered air temperature and relative humidity in two consecutive days.

In agreement with the data obtained in the observation, the maximum registered absolute temperature was 31.5ºC at 13:00h o'clock, in the bedroom. The same value was registered at 14:00h o'clock, while outside data shows 32.7ºC (reduction of 1.2ºC). The low absolute temperature was registered at 05:00 and 06:00h (24.8ºC). The lowest temperature registered in the immediate exterior was 23.6ºC.

The largest thermal reduction obtained during observations was 1.4ºC, and the smallest was 0.4ºC. Illustration 5 displays results of air temperature in the studied room.

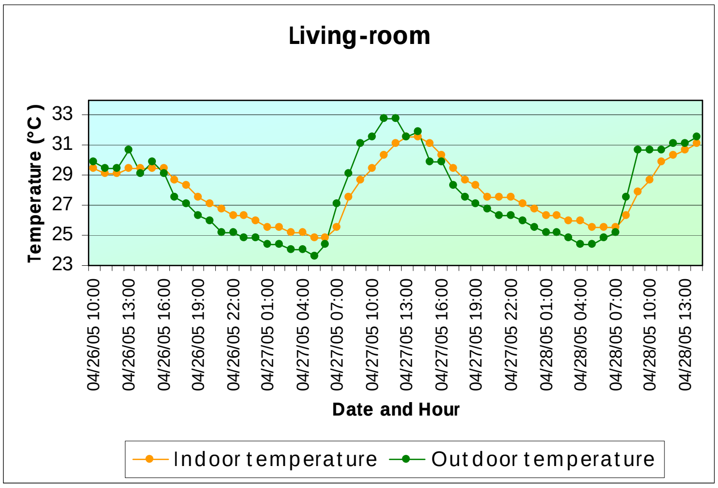

Figure 5: Inside and outside temperatures in living-room, during the measurement period.

In the living-room, the relative air humidity oscillated between 61.7% and 81.9%. The highest values were usually reached between 05:00 and 07:00h in the morning. The lowest relative humidity value coincided with the highest value of air temperature at 14:00h. This room has one of its walls west oriented and it receives, therefore, a larger amount of direct solar radiation. In the bedroom relative air humidity values were much higher, oscillating between 83.5% and 100%.

For the region where the prototype is located, the need not to be painted, in this sense (RORIZ et al) [7], and the prototype assists that recommendation. The openings should correspond to 40% of the floor area to promote ventilation. However, none of the rooms obey this recommendation, being bedroom 1 the most critical case, wich has only 8.4% of the floor area corresponding to the useful area of ventilation.

The thermal transmittance (U) of the wall, should be lower than or equal to 3.60 W/m^2. However, as it comes to research on new material, there is still lock of normalized data on the concrete block obtained from construction and demolition residues recycling. In any way, the equivalent thermal transmittance to a block of common concrete is inadequate (3.8 W / m2. K) for a 15 cm thick wall.

4.2.2 The thermal performance simulations

The first thermal simulation was realized in order to obtain first considerations regarding thermal performance of the constructive system. The software ARQUITROP [4] was used for thermal evaluation of several simulations – changing of construction situation, such as orientation, dimension of openings and systems of walls and coverings. The software outputs results of indoor and outdoor air temperatures, relative humidity, won thermal of heat, wind speed, etc., being, therefore, of great usefulness for the object of the research. The simulations were made considering thermal characteristics of a constructive system composed of concrete blocks, covered with cement mortar and white color paint.

The computational program used requests data that concern to the operation of the room (number of users, schedule of permanence, heat produced inside of the room by electric apparels, etc.). To this simulation, occupation of two people, in the schedule between 13:00 and 20:00h and the use of a 60 W lamp starting at 17:00 and with duration of 6 hours was considered.

The living-room was chosen considering the possibility of four orientations of the room in relation to true North. The resulting variations air temperature of those simulations were then analyzed and the living-room's occupation pattern was established: between 13:00 h and 20:00h. Orientation 2 (270° north) presented the highest values of inside temperature (maximum of 32°C at 18:00 o'clock), while orientation 4 proved to be the most favorable situation. The largest differences in temperature were recorded between 17:00 and 22:00.

The highest values of temperature were imputed to the software ANALYSIS [5] for users' comfort conditions under such temperatures evaluation. The program calculates the thermal comfort sensation according to the method of Fanger [6]. For the present work, it was adopted that the possible user of the house would be using 0.4clo, seating relaxed (58W/m2). The considered relative humidity was 75% and the air speed 0.1 m/s. In the graphic below, the hours in red were considered "hot"; the hours in orange, "slightly hot" and the ones in blue, "comfortable".

Table 2: Hourly temperatures in agreement with the different simulated orientations.

	Hour / Temperature °C								
	13:00	14:00	15:00	16:00	17:00	18:00	20:00	22:00	24:00
ORIENTATION1	**31,1**	**31,1**	**30,9**	**30,4**	**29,9**	**30,8**	**29,6**	**27,5**	**26,5**
ORIENTATION2	**31,1**	**31,2**	**30,9**	**30,6**	**30,3**	**32,1**	**30,8**	**27,6**	**26,6**
ORIENTATION3	**31,2**	**31,3**	**31**	**30,6**	**30,1**	**31,4**	**30,1**	**27,6**	**26,6**
ORIENTATION4	**31,4**	**31,3**	**30,9**	**30,5**	**30**	**30,8**	**29,6**	**27,5**	**26,6**

Even though simulated increasing of the openings in $2.4m^2$ had been taken into test, the resultant air temperature has not decreased, because the software considers an opening as an enlargement of solar radiation entrance area, and then, and thus, excessive heat gain, what actually happens. However, it despises the higher volume of air entrance with the increase of an opening, which can, cause a reduction in the apparent temperature of up to 2.5°C.

5. CONCLUSIONS

The possibility of use of construction and demolition residue to produce concrete blocks revealed that the concrete blocks and cement mortar produced with recycled construction and demolition aggregates presents good mechanic characterization with simple productive techniques which reveals an excellent alternative for social dwellings, because of the environmental aspects of recycling to be tested in small communities by associative groups. Therefore, habitation costs need to be studied.

The structural evaluation of the prototype has been proved to be satisfactory, which confirmed that the material is adequate for use. However, complementary studies are needed to quantify additional structural performance and durability aspects for the system.

Final results suggest the importance of the orientation and the correct construction materials use to ensure thermal comfort for the users. This research confirms the need of the bioclimatic strategies application mainly at low cost homes, where the use of artificial acclimatization is economically unviable. It will be necessary to accommodate a longer period of measurements in two different seasons that characterize the climate of the city, besides the measurements of the walls superficial temperatures. The present research constitutes an important investigation, for obtaining quite significant preliminary data. It is recommended initially, to improve conditions in houses for allow income population that the following aspects must be considered.

- an appropriate orientation,
- larger windows protections,
- lining increment and
- increase of ventilation areas that doesn't receive solar radiation in a direct way.

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