ENERGY COSTS COMPARISON OF MASONRY MADE FROM DIFFERENT MATERIALS

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Abstract: This works aimed to compare the energy spent in four masonry models of fence used in a housing model. The energetic coefficients of conventional building materials such as cement, lime, sand, ceramic brick, ceramic block and concrete block were obtained by consulting the literature. The adobe was produced with clay soil with sand correction in the proportion of two parts of soil to a sand, 2:1 in mass. The energy coefficients for the adobe production, labor, mortar of soil and lime were calculated by the energy spent from obtaining the materials to the execution of the masonry. It was identified that the calculated values for total masonry labor were, respectively, 135.95 MJ, 78.99 MJ, 55.05 MJ and 44.37 MJ for adobe, ceramic brick, ceramic block, and concrete block. The energy coefficient and the energetic index per square meter of adobe construction were 229.22 kJ kg^{-1} and 52,445.54 kJ m^{-2}, respectively. The total energy consumption for the masonry of the construction model with 44.80 m^2 made of adobe was 12,450.81 MJ. The total energy consumption for the concrete block was 16,016.91 MJ. The total energy consumption for the ceramic and ceramic brick were 34,794.04 and 77,589.87 MJ, respectively. It was concluded that the masonry executed with adobe presented the lowest energy consumption, presenting a higher sustainability level. The correction with sand represented an increase of 68.16% of the energy coefficient of the adobe. The model using adobe compared to ceramic brick promoted an energy saving of 83.95%.

Keywords: Adobe, Non-conventional materials, Sustainability, Construction, Embodied energy.

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INTRODUCTION

Sustainable development is defined by the increase in quality of life, economic and environmental social relations for present and future generations (ORTIZ; CASTELLS; SONNEMANN, 2009).

Wood and soil, besides being found in abundance in rural areas, are also considered recyclable, reusable and energy-saving materials when compared to conventional building materials such as cement, gravel and steel. Because they are found at the construction site, the energy and economic cost of logistics is zero or much lower.

The adobe is a material considered recyclable because it is made only of the mixture of soil and water without the burning process. In its process of demolition or decomposition of the material, it returns to the original state of soil without the necessity of spending with energy of reprocessing.

The reused or recycled materials can be used in new buildings generating a built-in energy flow (SCHEUER; KEOLEIAN; REPPE, 2003). About 37 to 42% of the energy incorporated can be recovered using recyclable materials. The energy expended on the materials in the construction of a building with 50 years of half life can be represented in up to 40% (THORMARK, 2002).

According to BRASIL (2008), five of the ten industrial sectors with the highest energy consumption are directly linked to construction sector. In world terms, it is estimated that up to 40% of energy resources will be used in the construction sector (TAVARES; LAMBERTS, 2005),

In Brazil, the generation of construction and demolition wastes (CDW) is approximately 300 kg m^{-2} from new buildings, while developed countries generate 100 kg m^{-2}. In cities with more than 500,000 inhabitants, the CDW share represents half the weight of urban ceramic waste (MONTEIRO et al., 2001).

Embedded energy can be quantified in two ways: Gross Energy Requirement consumed at all stages of the material production chain or Process Energy Requirement representing the 80% in relation to that calculated in the entire production chain of the material LAWSON (1996).

Among the energy phases of the life cycle of the construction of a university with a total area of 7,300 m² since: the acquisition of the materials, construction and renovation of the building in the primary phase, it was identified that the operation phase was the 97.7% of total energy expenditure. The energy required for dismantling, demolition and transport represents only 0.2% SCHEUER, KEOLEIAN and REPPE (2003).

Szokolay (1997) estimates the energy embedded in two levels: the main energy, which includes the energy content of the building materials and components and the operating energy, which is the amount consumed annually for lighting, heating, cooling, ventilation and maintenance in the building. Campos et al. (2003) in their research in the construction of a hay warehouse found that the masonry stage is the stage that consumes the most energy, 50.35%, being the ceramic bricks component is responsible for 93% of this stage.

A model of construction made of adobe by Shukla, Tiwari and Sodha (2009) showed that the material compared to burned brick is much more environmentally friendly, the model made with burnt brick demanded 720 GJ $100m^{-2}$ of construction involving the entire life cycle and the adobe spent 475 GJ $100m^{-2}$ with a 34% reduction in energy consumption.

The adobe is a very old construction technique that uses a lot if nowadays. Because it is a construction technique, where sintering does not occur and its raw material (soil), can be found at the work site, thus reducing energy costs in production processes and transportation. Besides not requiring specialized labor and have a great thermal comfort (CORRÊA et al., 2015).

The energy embedded in an 8-hole 9x19x19 cm ceramic block presents 7,164.92 kJ (TAVARES et al., 2006). The adobe with 35x26x10 cm presents 2,635.00 kJ of embedded energy while the concrete block with 41x21x21 cm has 30,595.00 kJ (SEMINÁRIO IBERO-AMERICANO DE ARQUITETURA E CONSTRUÇÃO COM TERRA - SIACOT, 1976).

The regionalization of the construction is of extreme importance for the calculation of energy, since a large part of the energy expenditure of a material is directly associated to the logistics process.

The objective of the present study was compare the energy cost on masonry stage of a rural house using four different masonry materials: adobe, ceramic block, ceramic brick and concrete block evaluating the energy coefficient of the material, the spent labor in construction and mortar of settlement.

MATERIAL AND METHODS

An estimate was made of the energy involved in the construction of a rural dwelling. The house consists of 2.8 m height and divided into 6 areas: bathroom; kitchen; living room, bedroom, hall and a service area, totaling 50.00 linear meters of masonry. The total area of the house is 44.80 m², Figure 1. Containing 123.89 m² of masonry discounted the areas of doors and windows. The coefficients energy values were calculated of each material with its respective mortar and labor energy for the construction.

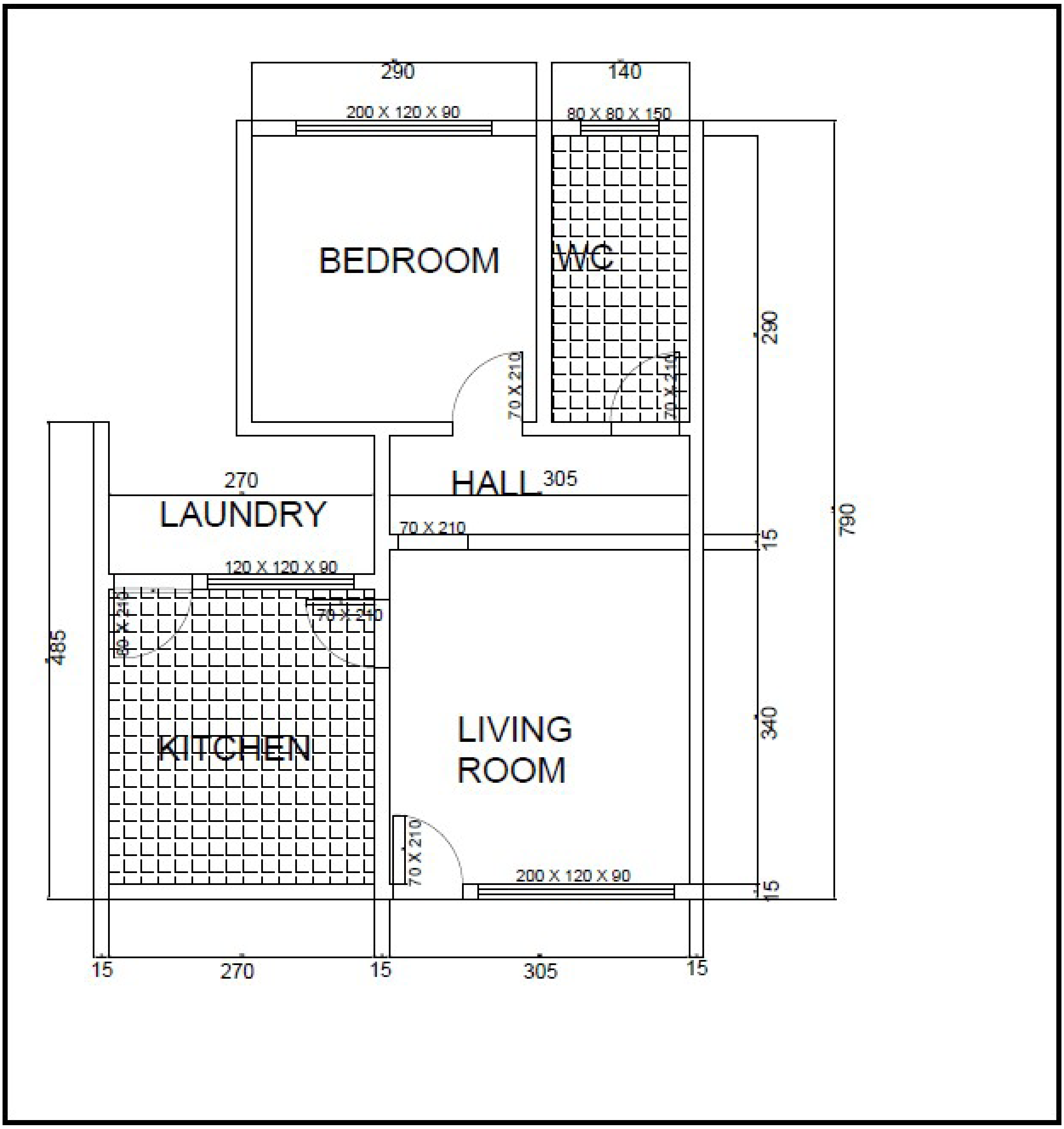

Figure 1. Low floor of the housing model.

Transportation of materials is a major factor in the cost and energy of a building. The energy cost varies a lot from the construction site. Aiming to make a comparison specifically among the materials was considered already being in the place of the work, nullifying the energetic cost of transport.

The adobe was made from a clay soil with the addition of sand for correction in the proportion of 2:1 (two parts of soil to one of sand). The adobe have 30x15x8 (length x width x height) of dimension. The estimate for the embedded energy of the adobe was calculated in the stages from the extraction of the ground, preparation of the earth, fabrication and the drying of the adobe. In the first stage, soil extraction, a soil at 1.2 m depth was used, free of organic matter from an area that would be used for paving. A hydraulic diesel excavator with power of 148 HP was used in this stage for 16 minutes to 4 tons of soil consuming 3.26 liters of diesel. Souza et al., (2009) found an average consumption of 5.5 L h^{-1} using a backhoe of 78 HP. Esturba (2014), analyzing 45 backhoe, got with average consumption of 7.1 L h^{-1} and energy efficiency of 68%. The second step consisted of the preparation of the soil removed; the human labor was used for the sieving in the number 4 sieve (4.75 mm aperture). The third step called for the manufacture was made by manual mixing, using human labor and subsequent mechanical homogenization using a device called "maromba" having a three-phase 3 CV engine with a volume of 200 liters and on its axis a set of 6 propellers with capacity to mix 100 kg of soil at a time and with efficiency of 0.9. After mixing, the fourth stage consisted of drying the adobes in a place protected from the sun so that there were no sudden losses of water and possible cracks occurring for 21 to 28 days, varying with the temperature and humidity of the local environment.

The mortar used for masonry of adobe sealing was soil and lime with the trace 1:3 (1 part of lime and 3 parts of soil). The mortar used for the ceramic brick and the ceramic block was cement and sand with the trace (1:6). For concrete block mortar, cement and sand were used with the trace (1:7). In the masonry model using adobe, the adobe was placed so that the width of the masonry was 14 centimeters and the total masonry mass, adobe and mortar, per square meter was 259.80 kg. In the masonry made of concrete blocks, sealing blocks were used in the dimensions 39x19x19 cm (LxWxH), each block weighing 10.50 kg and the mass per square meter of masonry was 150.95 kg with a width of 19 cm. In the model using the ceramic blocks, the blocks were sealed in the dimensions of 29x19x9 centimeters (LxWxA), with 4.30 kg of mass per block, with the value of the mass per square meter of masonry of 111.66 kg and the width of 9 centimeters. For the model using ceramic bricks with 19x5.3x10 cm (LxWxH) and 2.80 kg per brick, it presented a mass per square meter of masonry of 239.71 kg and width of 10 centimeters. A comparative diagram is represented in Figure 2.

The values of the energetic coefficients of the ceramic block, concrete block and ceramic brick were found in the literature. For quantity human labor, required materials and volumes of mortars for constructions were calculated according to Baêta, Peloso and Homem (1993).

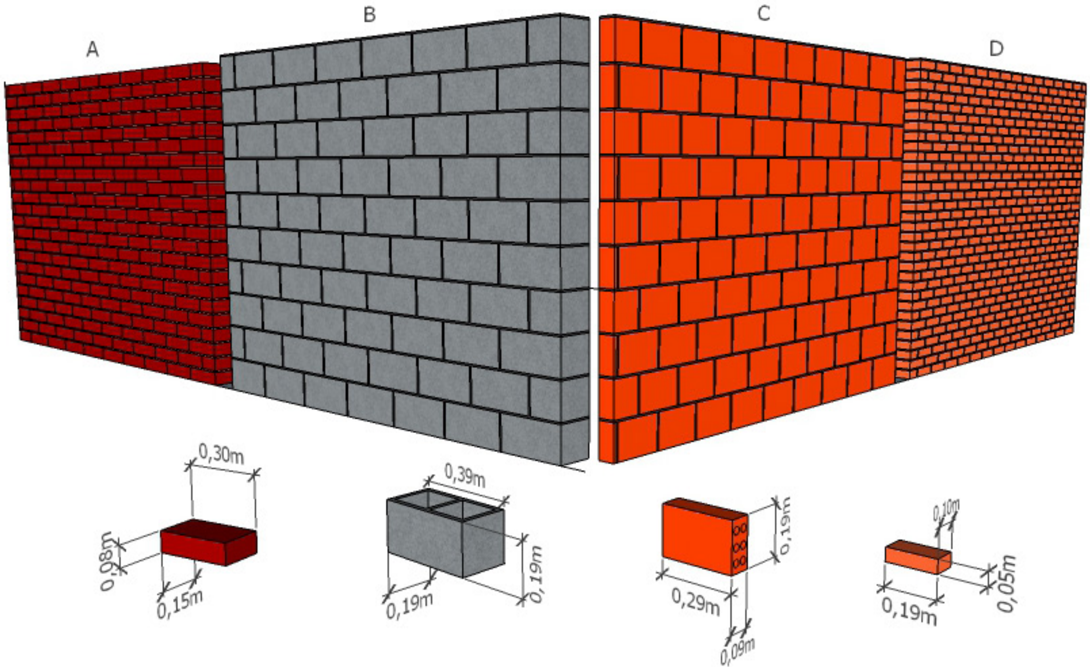

Figure 2. Representative scheme of masonry (dimensions in centimeters). (A) Adobe, (B) concrete block, (C) ceramic block and (D) ceramic brick.

RESULTS AND DISCUSSION

The value of the energy coefficient of the adobe was 229.22 kJ kg^{-2}, the detailed energy values for each stage of the adobe production is detailed in Table 1. The sand to correct the soil to make the adobe was the component that had more energy representation, 68.16% of the total adobe, and due to the high-energy value of its coefficient. In the extraction stage, 3.26 liters of diesel oil were required to extract 4 tons of soil, despite the low volume and low machine operating time. The energy cost represented 16.97% of the energy coefficient of the adobe, showing that diesel oil has a high-energy ratio due to its entire process from oil extraction to refinement. In the soil homogenization stage, using the "maromba" machinery, 13.01% of the energy coefficient of the adobe is observed, due to the consumption of electric energy. Although it took a long time, the energy expenditure of the labor force in the whole process represented the smallest part with only 1.85%. Even representing a small share of total energy expenditure for adobe production, labor can be seen as high employability from the socioeconomic point of view, for most of the process is handmade and manual.

The energy used for the manpower was the least represented in all construction models. Adobe was the highest value found among the models, with 1,097.38 kJ m^{-2}, due to the robustness, the smaller masonry cover area and the need for soil screening to produce the mortar. The workforce of the adobe represented 1.09% of the total consumption in the construction of the masonry. The other models presented 0.10%, 0.16% and 0.28% respectively for ceramic brick, ceramic block and concrete block.

Among the energy costs of laying mortar, ceramic brick presented the highest value 58,087.19 kJ m^{-2}, the high value is due to the high energy contained in the cement and because of the larger volume of mortar due to the smaller area of brick covering. Adobe presented the second value 46,956.00 kJ m^{-2} representing 46.72% of the total energy spent per square meter of masonry. The high cost of the mortar adobe is due to the area of adobe covering 28x14 cm^2 and the use of hydrated lime in the composition of the mortar used 9.03 kg of hydrated lime per m^2 masonry. The energetic expenses of the mortar of the other models per square meter of masonry were less significant, 9.83% and 12.93%, respectively, for ceramic block and concrete block. Although cement and sand are used in mortars, the coating volume is smaller compared to adobe and because they express a much higher total energy value in relation to adobe.

The step that most demanded energy, among the mentioned models was the energy coefficient of building element. In Table 2, it can be seen that of the coefficients of the building elements, the adobe has the lowest energy value, representing only 7.90% of the ceramic block and 7.64% of the ceramic brick. The great difference is the burning process that demands a lot of energy, which can be electricity, firewood or diesel oil that occur in the process of manufacturing ceramic materials.

Table 1. Stages of energy expenditure to obtain the energy coefficient of adobe.

Steps	Component	Energy	Unit	Expenditure	Unit	Soil amount (kg)	Adobe energy (kJ kg^{-1})
Extraction							
Hydraulic excavator	Diesel (1)	47780.00	kJ L^{-1}	3.256	Liters	4000	38.89
Production							
Sand	Sand (2)	312.50	kJ kg^{-1}			2000	156.25
Soil	Soil (3)	0.00	kJ kg^{-1}			4000	0.00
Soil preparation	Labor (4)	386.40	kJ h^{-1}	20	Hours	4000	1.93
Homogenization	Electricity	8053.56	kJ h^{-1}	0.34	Hours	100	29.83
Mixing and molding	Labor (4)	386.40	kJ h^{-1}	24	Hours	4000	2.32
Total							229.22

The numbers in parentheses represent the literatures from which the cited coefficients were obtained, and are listed below: (1) Doering (1980); (2) medium values: Scheuer; Keoleian; Reppe (2003); Shukla; Tiwari; Sodha (2009); Galan-Marin; Rivera-Gomez; Garcia-Martinez (2016); (3) Shukla; Tiwari; Sodha (2009); (4) Pellizzi (1992).

Compared to the concrete block, the adobe represents 26.65% of the spent energy, this lower value is due to the air-drying process differently than it occurs in the ceramic materials. Although cement has a high-energy coefficient, its use in blocks represents 7 to 10% of the mass of the block according to Galan-Marin; Rivera-Gomez and Garcia-Martinez (2016), therefore its energy coefficient is lower than the ceramic materials.

Although the values of the energetic coefficients of the ceramic block and ceramic brick are similar, 2900 and 3000 kJ kg^{-1} respectively, it is observed that when dealing with the value per square meter of masonry the difference between them increases considerably 290,911.24 and 646,724.75 kJ m^{-2} for the ceramic block and ceramic brick, respectively. The major difference is the area of masonry and material density. The ceramic brick had a masonry covering area of 0.0101 m^2 and a density of 2.78 g cm^{-3} while the ceramic block had a masonry covering area of 0.0551 m^2 and a density of 0.87 g cm^{-3}. The energetic coefficient of the concrete block, despite being 3.75 times greater than the adobe in kJ kg^{-1}, approaches when compared to the value per square meter of masonry 100.498,91 and 135.243,11 kJ m^{-2} for the adobe and concrete block, respectively. The similarity occurs by the

Table 2. Energy composition of masonry models by component, by area and total construction.

Masonry model	Energy coefficient	Unit	Energy index (kJ m^{-2})	Total construction (MJ)
ADOBE				
Adobe element	229.22	kJ kg-1	52,445.54	6,497.48
Mortar (1:3)				
Lime	5,200.00 (1)	kJ kg-1	46,956.00	5,817.38
Soil	0.00 (2)	kJ kg-1	0.00	0.00
Labor	386.40 (3)	kJ h-1	1,097.38	135.95
Total			100,498.91	12,450.81
CERAMIC BLOCK				
Ceramic block element	2,900.00 (4)	kJ kg-1	261,870.00	32,443.07
Mortar (1:6)				
Cement	7,500.00 (5)	kJ kg-1	22,875.00	1,587.03
Sand	312.50 (6)	kJ kg-1	5,721.88	708.88
Labor	386.40	kJ h-1	444.36	55.05
Total			290,911.24	36,040.99
CONCRETE BLOCK				
Concrete block element	860.00 (7)	kJ kg-1	117,390.00	14,543.45
Mortar (1:7)				
Cement	7,500.00	kJ kg-1	13.545.00	1,678.09
Sand	312.50	kJ kg-1	3.950.00	489.37
Labor	386.40	kJ h-1	358.11	44.37
Total			135,243.11	16,755.27
CERAMIC BRICK				
Ceramic brick element	3,000.00 (8)	kJ kg-1	588,000.00	72,847.32
Mortar (1:6)				
Cement	7,500.00	kJ kg-1	46.470.00	5,757.17
Sand	312.50	kJ kg-1	11.617.19	1,439.25
Labor	386.40	kJ h-1	637.56	78.99
Total			646,724.75	80,122.73

The numbers in parentheses represent the literatures from which the cited coefficients were obtained, and are listed below: (1) Boustead; Hancock (1979); (2) Shukla; Tiwari; Sodha (2009); (3) Pellizzi (1992); (4) Tavares (2006); (5) Reddy; Jagadish (2002); (6) medium values: Scheuer; Keoleian; Reppe (2003); Shukla; Tiwari; Sodha (2009); Galan-Marin; Rivera-Gomez; Garcia-Martinez (2016); (7) Alcorn (1996); (8) Hammond et al. (2008).

process that does not use the burning in the two components, by the masonry cover area of the concrete block is greater than 8 times that of the adobe and by the density 1.89 g cm^{-3} for the adobe and 0.74 g cm^{-2} for the concrete block.

Comparing the energy consumption of masonry made with stone blocks, ceramic brick, concrete block, soil-cement blocks and steam cured mud blocks concluded the masonry made with soil-cement blocks had the lowest energy demand, representing 33% of the ceramic brick. Second is the concrete block masonry representing 40 to 45% of the ceramic brick masonry, presents 2,141.00 MJ m^{-3} (REDDY; JAGADISH, 2003).

Compared to the total masonry consumption for the house, the adobe presented 12,450.81 MJ equivalent to a saving of 22.26% compared to the concrete block, 64.21% compared to the ceramic block and 83.95% of the ceramic brick (SEMINÁRIO IBERO-AMERICANO DE ARQUITETURA E CONSTRUÇÃO COM TERRA - SIACOT, 1976). Gupta (2000) and Shukla; Tiwari and Sodha (2009) affirm that the adobe represents a smaller energy expenditure compared to materials that undergo the process of burning or those who use cement.

Campos et al. (2003) found the value of 1,132, 692.48 kJ m^{-2} of masonry using the massive brick with the largest dimension turned to the width of the masonry. In the present work the value found was 588.00,00 kJ m^{-2}, representing practically the half for using the massive brick with its largest dimension facing the length of the masonry. proportionally the results are consistent.

CONCLUSIONS

The adobe energy coefficient was 229.22 kJ. kg^{-1}, lower than the energetic coefficients of the other materials. For adobe production, the item that presented the highest energy expenditure was sand for soil correction 68.16%. The energetic index by construction area of masonry for a rural dwelling using adobe was 110,498.91 kJ. m^{-2} lower than all other models of masonry.

The model with the greatest energy demand was that of massive brick with 80,122.73 MJ. The concrete block was the model that most approached the adobe with 16,775.27 MJ. It is concluded that the construction made by adobe requires less energy when compared to conventional models.

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