COMPRESSED EARTH BLOCKS, THEIR THERMAL DELAY AND ENVIRONMENTAL IMPACT

[1]Roux Gutiérrez Rubén Salvador; [1]Velazquez Lozano Jesús, [1] Rodríguez Deytz Homero
[1]Facultad de Arquitectura Unidad Saltillo, Universidad Autónoma de Coahuila
Blvd. Fundadores Km 13, Ciudad Universitaria UAdeC, Arteaga, Coahuila México. CP 25354
e-mail: rubenrouxgutierrez@uadec.edu.mx, rroux33@hotmail.com; jvelazq@uadec.edu.mx, jvl1059@hotmail.com; homeror2013@gmail.com

ABSTRACT

This communication is the result of research that addresses the issue of blocks of compressed earth (CEB – Compressed Earth Blocks) thermal properties, to corroborate the advantages of this alternative construction material, conventional materials, to check that these materials can meet the needs of the population in their decent housing construction, improving the quality of life of the user and producing less environmental impact. Thermal tests were simulating the effect of the Sun on a wall, registering the temperature during the tests determining the thermal delay on the walls depending on the material. It is as well as with the results of the tests determined which the optimal material for use as housing enclosure is. On the other hand is the study of the CEB, stabilized with hydroxide of lime and cement, seeking to comply with the Mexican standards, in the section relating to materials for use in masonry buildings and thus verify that these materials comply with quality requirements, as well as conventional materials, coupled with the analysis of the life cycle (LCA) in two populations of BCE's stabilized with cementations seeking to determine their environmental impact and finally to be able to compare them with existing databases of conventional materials.

Keywords: CEB, Thermal delay, construction with land, stabilization, environmental impact

1.- Introduction

The commentary on how much the use of alternate and regional materials in construction is practicable, however, when a reference is made to some of these, they are associated with materials used in a satisfactory manner by some civilizations for the edification of their habitat, nevertheless, nowadays, commentary on these traditional materials exists, where they are considered “low quality” or are just reviled regarding their quality as they are used by people with scarce resources for the self-edification of their housing.

Building with earth is a millenary technique in mankind’s history, where man employed it to protect himself from the outdoors. According to Neves (2007) passing the construction with earth by the proper technical and cultural adaptations of each region. Past ages inhabitants knew how to explore the good properties of the earth and use it in beautiful constructions. (Neves, 2007).

However according to McHenry (2004) radical changes produced by the Industrial Revolution, low cost energy, a fast expansion of transport systems, distribution and preference for more “modern” materials such as Portland cement which had an important paper on World War II for the reconstruction of European cities, virtually ended the use of earth as construction material. (McHenry, 2004).

Currently in Mexico, construction with earth is a technique practiced in a handcrafted manner, without official norms to regulate its use, which is why its diffusion on the construction market is minimal.

Neither do studies about the material’s physical aspects exist as is the case of the material’s thermal capacity particularly of the Compressed Earth Blocks (CEB) technique, which allows to make a comparison about conventional materials and to corroborate their energy efficiency and the grade of their sustainability.

The CEB is a construction material manufactured with a mixture of raw earth and a stabilizer, like lime, cement, asphalt or gypsum, which is molded and compressed using a mechanical or manual press. It’s been used as a substitute for the fired clay brick in construction activities; using it in the construction of walls manually piling it on and using a mixture of the same materials as a base mortar.

The manual press of Colombian patent “Cinva–Ram” has been used in its manufactory in the present study, looking to homogenize them and achieve a quality in accordance with the Mexican Norms (NMX-C-404-ONNCCE-2005; NMX-C-036-ONNCCE-2004; NMX-C-037-ONNCCE-2005) described by the Construction Industry, as well as determine and stabilize those CEB’s with CPO-20 cement and for the case of the use of Calcium Hydroxide.

Two objectives are stablished for the present research under these premises:

2.- Objectives

- The analysis of the thermal properties in the compressed earth blocks, to determine the thermal delay they present upon applying a heat source in a controlled environment, in this case the laboratory. This way the thermal transmission through self-elaborated walls with compressed earth blocks (CEB), conventional concrete blocks and fired clay brick is compared.
- Develop, identify and evaluate the environmental impacts and saturated energy associated with the production, management, implementation, use and disposal of CEB, with the purpose of comparing the results obtained of the populations of CEB stabilized with calcium hydroxide.

The tests of thermal conductivity will be limited to applying a constant heat source, to take measurements of the temperature presented by the tested walls, and thus compare their behavior.

In the earth materials' case it's very important since it can be achieved to have a house inside its thermal comfort area, unlike the conventional construction materials, making the use of mechanical air conditioning equipment unnecessary, to achieve this comfort, mostly in zones with rainy tropical climates.
The thermal delay tests will allow to determine the time it takes for the wall's outer side's temperature to pass into the wall's inner side, the thermal inertia or the ability to store a material's heat depends on the specific mass, density and heat, this characteristic is what determines the use of mechanical air conditioning in a building in a major or minor degree.
With that carried away and obtaining the results, a Life Cycle Analysis (LCA) will be realized, in agreement with the norm: NMX-SSA-14040-IMNC-2008, which indicates the particularities about the life cycle analysis, principles and frame of reference. To realize the LCA, the SimaPro 7.3 version software was used, a program that allows to determine the materials' impacts when carrying out the LCA from the cradle to the grave.

3. Methodology

3.1. Thermal delay

Walls were produced using: concrete blocks (15x20x40cm), the fired clay brick (6x12x24cm) and the CEB (10x14x29cm). It has been built: two single CEB walls without plaster, two single CEB walls with lime plaster, a double wall with lime plaster and 4:1 sand, a wall without plaster, a fired clay brick wall and a conventional block wall; for a total of eight walls to test, with approximate measurements of 40x40 cm. The mortar used was of 1:1/2:3 cement, lime and sand.
The test consisted in the analysis of the registered temperatures on both sides of the walls where thermocouples were placed, a constant heat source was created which consisted of a wooded board with 6 Osram brand lightbulbs of 150 W. The walls were placed one by one at a 34.5 cm. stablished distance from the wooden board and the temperatures on both sides of the wall were registered. For the results' recollection the HOBO ware U-12 software was used, which was programed to take the temperature every 15 min interval for each side through eight hours, then the data was charted to appreciate the thermal delay and this way confirm or reject the hypothesis, see pictures 1 and 2.
In chart 1: a synopsis of the maximum temperatures the different materials of the walls reached is shown, in addition showing the delay, that is to say, how much time went by since the moment in which the maximum temperatures on each side of the wall were registered, which is the thermal delay.

Type of wall	Maximum temperature		Thermal delay time	Reduction Factor
	Side of the wall			
	Exposed °C	Rear °C		$\mu = \frac{T_i \max}{T_o \max}$
Single CEB without plaster 1	57.786	33.183	1 h	1.741
Single CEB without plaster 2	54.602	32.407	1 h	1.685
CEB plaster 1	55.832	30.343	1:15 h	1.840
CEB plaster 2	55.021	30.444	1:30 h	1.807
Double CEB with plaster	55.56	25.695	4:15 h	2.162
Double CEB without plaster	60.918	26.671	4:15 h	2.28
Fired clay brick	58.776	37.645	0:30 h	1.561
Block	64.838	34.387	0:30 h	1.886

Chart 1 “Delay time and reduction factor. Source: Self-elaboration. 2014

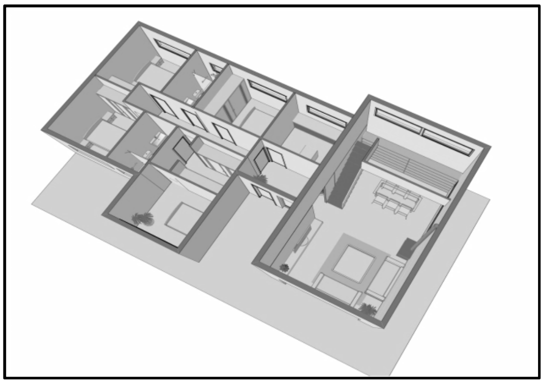

Fig. 1 “Photograph previous to the beginning of the test”. Source: Self-elaboration. 2014

Fig. 2 “Photograph during the test”. Source: Self-elaboration. 2014

After testing the eight walls and analyzing the data, the next charts were developed with which in the thermal delay of each wall is observed graphically.
To be able to calculate the thermal delay the temperatures of each of the walls were registered during eight (8) hours, taking record each 15 minutes and afterwards the wall was left to cool down through eight (8) hours, which were also registered in the charts. This way, the temperature variations and the time it takes to pass the energy from one side to the other are shown.
The charts belong to the eight (8) tested walls and the eight (8) hours of cool down, two curves that represent the side exposed to the heat source are shown, which is the lightbulbs plaque and the opposite side are shown. The point where the maximum temperature is reached on each side of the wall is shown, see picture 3.

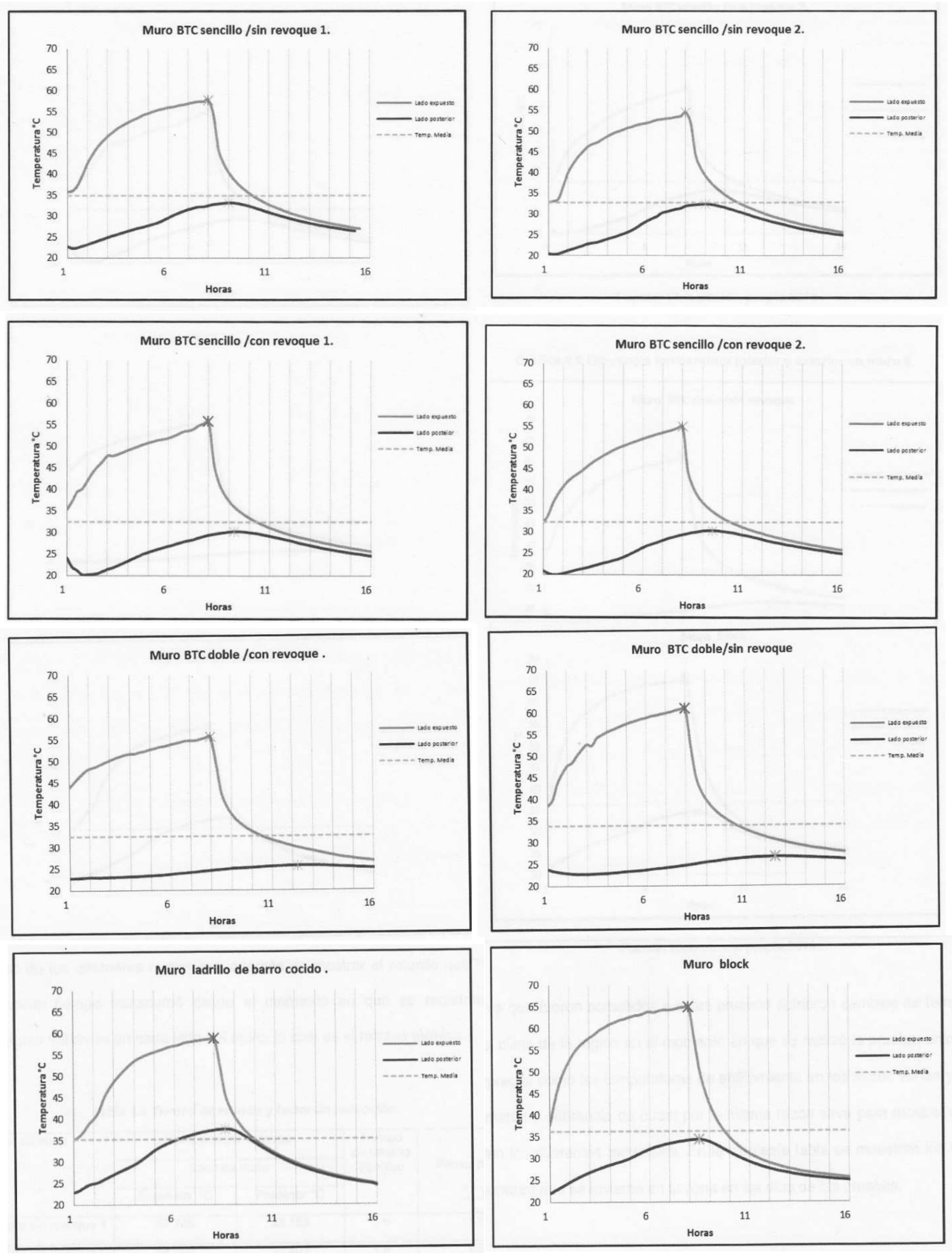

Fig. 3 “Inner and outer temperatures differences on the test walls”. Source: Self-elaboration. 2014

3.2. Environmental impact analysis

The evaluation methodology stablishes the characterization factors through which the environmental impacts will be quantified. For most impacts described on Chart 3, the characterization will be carried by the TRACI 2 (Tool for the Reduction and

Assessment of Chemical and other environmental Impact) V4.00 2012 method developed by the United States' Environmental Protection Agency. Nevertheless, there exist some impacts that the TRACI 2 method doesn't have implemented in its system and that will also be evaluated. This is the case of the soil and the depletion of mineral resources, for which the ReCiPe Midpoint (I) V1.06 / World ReCiPe I method will be used, one of the most updated and harmonized methods to date and that has been developed by Pré Consultants. The energy resources will be evaluated with the CED (Cumulative Energy Demand V1.8) method. The selected impact categories are described on Chart 2.

Impact category	**Description**
Thinning of the ozone layer	The ozone layer is a filter of ultraviolet radiation towards the Earth. The chlorofluorocarbon compounds (CFCs) destroy this layer.
Climate change	An increase on the Earth's temperature as a consequence of gas emission of greenhouse effect such as CO2, CH4, NOx, O3, etc. (fuel burning, industrial emissions, etc.).
Photochemical oxidation (smog)	It's a photochemical oxidant that along the COV and NOx (fuel burning, industrial emissions, etc.) forms the photochemical smog.
Acidification	Decrease on the soil and water's pH as a consequence of the emissions of NOx, SO2, NO2, NH3, HCl, HF, etc.
Eutrophication	Increase of inorganic nutrients SO-4 and NO-3 in the water (feces, fertilizers, etc.).
Carcinogenic compounds	Chemical compounds that generate cancer in the human being.
Non-carcinogenic pollutants	Chemical compounds that generate diseases different to cancer.
Respiratory effects	Pollutants that cause respiratory diseases.
Ecotoxicity	Pollutants that cause toxicity to the ecosystems (plants and animals).
Use of agricultural and urban soil.	The use of the soil generates environmental impacts. Agricultural or urban area of soil used and/or occupied derivative of an industrial activity
Depletion of mineral resources	For example: minerals such as bauxite, limestone, iron, etc.
Depletion of fossil resources	For example: petroleum, natural gas, coal, etc.
Saturated energy	Energy required along the life cycle of a product. Includes energy of non-renewable fossil origin, nuclear, biomass or renewable of solar origin, geothermal, wind, and water.

Chart 2 "Environmental impact description". Source: AIDICO. 2011

In relation to the Life Cycle Analysis' results, the data about the entrances and exits of the CEB fabrication's unitary processes were developed from the production practice realized by Dr. Roux especially on year 2011, enclosed in the region of Tamaulipas, at the northeast of the Mexican Republic. The compilation technique of this data was realized from the academic self-experience.
The same can be said about the type and quantity of raw materials, just like the transport distances from its supply area.

Nevertheless, the raw materials' supply stage qualitative data, which include the materials' extraction and processing, like for example cement, or the kind of transport, have been taken from the US LCI database, which shows average data from the United States through a mixture of technologies. When it has not been possible to gather information, the Ecoinvent database was used.
The life cycle model designed on the SimaPro software has been realized using the processes indicated on Chart 3.

Process	Database process	Database
Portland cement	Portland cement, at plant/US	US LCI
Truck transport	Transport, single unit truck, diesel powered/US	
Demolition machinery	Loader operation, large, INW/RNA	
Gasoline mixer	Gasoline, combusted in equipment/US	
Clay	Clay, at mine/CH U	Ecoinvent
Sand	Sand, at mine/CH U	
Hydraulic lime	Lime, hydraulic, at plant/CH U	
Hydraulic lime packing	Kraft paper, unbleached, at plant/RER U	
Water	Tap water, at user/RER U	
Glue	Vinyl acetate, at plant/RER U	
Table salt	Sodium hydroxide, 50% in H2O, diaphragm cell, at plant/RER U	
CEB dump	Disposal, limestone residue, 5% water, to inert material landfill/CH U	

Chart 3 "Selected processes in the model". Source: AIDICO, 2011.

The LCA results of the wall built with CEB stabilized with calcium hydroxide are shown on Chart 4 and picture 4 by Functional Unit, i.e. 1 m^2 of wall.
As it can be observed, the raw materials and the manufacturing present the largest environmental impact with a value between 22% - 92% of each category's total impact as seen in picture 4.
The wall's construction stage contributes importantly on the categories of *water resources' depletion* and to a lesser degree the ones related to *the thinning of the ozone layer* and the *mineral resources' depletion*.

Impact category	MP and manufacturing	Construction and maintenance	End purpose	TOTAL
Thinning of the ozone layer (kg CFC-11 eq)	1.08E-06	1.04E-07	1.32E-08	**1.20E-06**
Climate change (kg CO_2 eq)	35.74	2.04	3.40	**41.18**
Photochemical oxidants - smog (kg O_3 eq)	6.34	0.07	1.01	**7.42**
Acidification (mol H+ eq)	12.24	0.18	1.86	**14.28**
Eutrophication (kg N eq)	1.50E-02	2.47E-04	1.97E-03	**1.72E-02**
Human health: carcinogens (HTU)	2.88E-07	1.41E-09	4.73E-08	**3.37E-07**
SH: non-carcinogens (HTU)	3.49E-06	7.37E-08	4.56E-07	**4.02E-06**
SH: respiratory effects (kg MP10 eq)	1.83E-02	6.62E-04	2.57E-03	**2.15E-02**
Ecotoxicity (ETU)	50.89	0.04	8.73	**59.66**
Use of agricultural and urban soil (m^2a)	11.21	0.00	0.02	**11.24**
Water resources' depletion (m^3)	0.41	1.43	0.00	**1.84**
Mineral resources' depletion (kg Fe eq)	3.51E-02	3.07E-03	4.70E-06	**3.82E-02**
Fossil resources' depletion (kg Petroleum eq)	8.85	0.23	1.14	**10.22**
Saturated energy (MJ)	451.14	11.85	48.11	**511.10**

HTU: Human Toxicity Unit (Toxicity cases/kg $_{emission}$).
ETU: Ecosystems' Toxicity Unit (PAF m^3 day /kg $_{emitted}$).
PAF: Potentially Affected Fraction of species.

Chart 4 "LCA global results of the CEB wall stabilized with Calcium Hydroxide".
Source: AIDICO, 2011

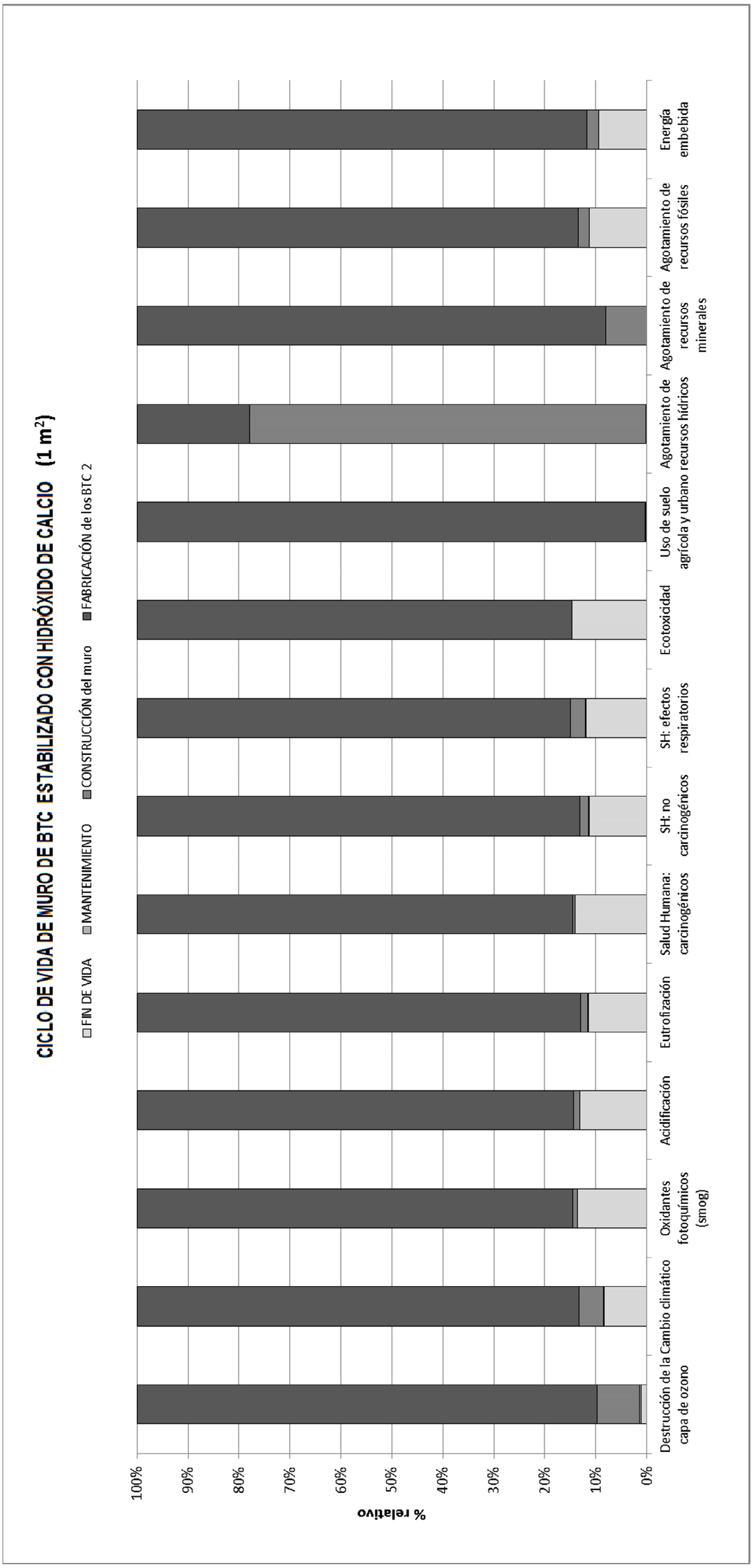

Fig. 4. “Square meter impacts of CEB manufactured walls stabilized with Calcium Hydroxide”. Source: AIDICO, 2011

The end purpose is another stage with relevant impact over most of the categories. Lastly, maintenance does not influence the whole. The mixing process by the mixer is the cause of more than 50% of the impact related the *smog*, *climate change, acidification*, *eutrophication*, *carcinogens*, *nom-carcinogens*, *ecotoxicity*, *fossil resources' depletion* and in the *saturated energy*, due to the manufacturing and combustion of the gasoline it consumes.
Calcium hydroxide is responsible for 1% of the impact on the ecotoxicity category and 80% of the impact on the thinning of the ozone layer category, due to the diesel that the machinery uses for its extraction.
Calcium hydroxide packing presents its largest impact than the *soil's use* since wood plantations are required for paper manufacturing even though it also influences the rest of the categories.
Sand influences with a 50% of the whole impact related to the *water resources' depletion* and with a 20% related to the *mineral resources' depletion*.
The raw materials' transport influences up to a 15% depending on the impact category. In this case it's also the manufacturing and combustion of gasoline in the process with most *saturated energy*, all of which comes from fossil resources. On second place the energy consumption would be the calcium hydroxide's.
To define the environmental impact of CEB stabilized with calcium hydroxide, compared with the conventional materials chart 5 is introduced:

Material	Energy incorporated in Mj/m^2	Emissions of CO_2/m^2
Concrete block	385.12[2]	53.49[2]
Fired clay brick	579.00[1]	80.41[1]
CEB stabilized with Calcium Hydroxide at 7%	511.10[3]	42.18[3]
[1]Vázquez Espío, 2001 [2]Howland Albear & Jiménez de la Fe, 2010 [3]Data obtained from the LCA realized		

Chart 5 "Comparison of the environmental impact degree from the CBE wall stabilized with Calcium Hydroxide with other conventional materials". S*ource: Dr. Roux, 2011*

4.- Conclusion

The use of earth as construction material is a technique that has been taken after decades of neglect, when considered as a handcrafted and traditional construction technique without counting on technical studies back-up on their behavior in comparison with other conventional materials, that's why the importance of the present study of Compressed Earth Blocks (CEB), which granted the calculation of the thermal delay from one wall manufactured with said material and to make the comparison with walls manufactured with conventional materials.
Taking the research hypothesis which tries to verify that a CEB has the capacity to regulate an abode's inner temperature, therefore gives advantages compared with the conventional materials used in construction; according to the results on the thermal delay tests it can be deduced that the CEB improve the thermal comfort sensation inside the housing were obtained, considerably better than the concrete block and the fired clay brick given that it showed a major thermal delay of nearly five and a half hours than these. So it is confirmed that through the day the CEB will present a lower temperature on the wall's outer side, just as in the inner side of the housing when exposed to a great heat source than the other tested materials.

As a final conclusion, it was verified that with CEB walls that can form a housing it will result fresher on summer and hotter on winter, due to this material's thermal mass which is of 1740 kJ/m3, against the brick's 1360 kJ/m3 and the concrete block's 550 kJ/m3 (Pastormerlo & Souza, 2013), as well as consuming less energy resources due to it being a material of natural origin and it does not require an industrialization process, just the addition of a stabilizer on accordance to the needs of the soil employed, which is why when reintegrating it to nature the impact it will have over it is minimal. It also has the savings on the housing conditioning as an economical advantage, in comparison with the other materials due to the faster passage of heat that the brick and concrete block present.

The impact of Calcium Hydroxide packing stands out related to the use of soil due to the trees required for paper manufacturing. On the wall construction stage, it contributes importantly in relation to the depletion of water sources and the depletion of natural resources. The final process influences up to a 15% of the CEB stabilized with Calcium Hydroxide. Maintenance barely influences over the whole.

Even though any industrial process will have a negative effect over its environment that must be evaluated with the purpose to identify its transformation phases in which it results more damaging. In summary, for the present study's case, it's been stablished that the proper stabilizer to manufacture compressed earth blocks (CEB) is Calcium Hydroxide for having less impact than cement on its natural environment and over health.

Lastly when comparing the CEB with conventional materials we can see that the CEB with Calcium Hydroxide is the one that possesses the best behavior, only surpassed by the energy incorporated by the concrete blocks, but with less CO^2 production than these last ones.

REFERENCES

[1] Ecoinvent (2010). Base de datos de ciclo de vida. ETH Zurich. Suiza

[2] EPA (2011). Herramienta para la Reducción y Evaluación de la Química y Otros Impactos Ambientales (TRACI), EPA. USA

[3] Neves, C. (2007), Arquitectura y construcción con tierra: Pasado, hoy y futuro. En: García Izaguirre, V. M., Roux Gutiérrez, R. S; et al.(Edits.). Anuario de investigación de construcción con tierra y del diseño sustentable. Editorial Universidad Autónoma de Tamaulipas. México.

[4] Howland Albear, J. J., & Jiménez de la Fe, S. (2010). Obras, Revista Cubana de la Construcción. Recuperado el 9 de Enero de 2012.

[5] Mc. Henry, Paul Graham (2004). Adobe como construir fácilmente. Trillas. México

[6] Vázquez Espío, M. (2001). Construcción e impacto sobre el ambiente: el caso de la tierra y otros materiales. Informes de la Construcción, 29-43.

[7] Pastormerlo, J., & Souza, E. (30 de agosto de 2013). Instituto del Cemento Portland Argentino. Obtenido de http://www.icpa.org.ar/publico/Plataforma%20Hormigon/masa%20termica.pdf

[8] Secretaría de Economía (2008). NMX-SSA-14040-IMNC-2008 Gestión ambiental análisis de ciclo de vida principios y marco de referencia. SE. México

[9] Secretaría de Economía (2004). NMX-C-036-ONNCCE-2004 Industria de la construcción-mampostería-resistencia a la compresión de bloques, tabiques o ladrillos y tabicones y adoquines-método de ensayo. SE. México

[10] Secretaría de Economía (2005) NMX-C-037-ONNCCE-2005 Industria de la construcción mampostería determinación de la absorción total y la absorción inicial de agua en bloques, tabiques o ladrillos y tabicones método de ensayo. SE. México

[11] Secretaría de Economía (2005) NMX-C-404-ONNCCE-2005 Industria de la construcción-mampostería-bloques, tabiques o ladrillos y tabicones para uso estructural-especificaciones y métodos de ensayo. SE. México.