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THERMAL CONFORT OF THE ECO-EARTH SANDWICH SYSTEM COMPARED TO MASONRY BLOCK, RAMMED EARTH, AND DRYWALL

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The search for thermal comfort and optimization of materials in construction leads to the development of efficient and alternative construction systems. Understanding the importance of the location, which potential materials are available on the site and locally, encouraging the reuse of material and evaluating which construction system is appropriate for each environment and client capacity. Thermal comfort is important not only because of "comfort" but also because it determines the energy consumption of the building. The Con Lo Que Hay - With what is available 14 workshop (*CLQH 14)*, developed the *eco earth sandwich system* in a small suburban community of the highlands in Quito, Ecuador. In this study the *eco earth sandwich system* will be compared to three other systems: confined masonry, rammed earth, and drywall; to evaluate their thermal inertia and thermal transmittance efficiency. This will be a quantitative approach, based in the evaluation centered on thermodynamics formulas.

Keywords: Thermal comfort, Heat, Efficient, Alternative construction.

1 THERMAL COMFORT IN BUILDINGS

"A good indoor climate is important, not only because it will make its occupants comfortable, but also because it will determine its energy consumption and its sustainability" (Nicol and Humphreys 2002). Most of the actual buildings consider many of these facts to choose better materials that will provide adequate comfort and better energy performance. Most of the times this is limited to the great scale buildings, leaving apart medium and small scale. In addition, most studies are focused on an industrial approach (confined masonry unit, drywall) to this matter, although handcrafted systems (rammed earth, *eco earth sandwich*) can also provide an adequate thermal comfort.

2 METHODOLOGY

This research will compare three different construction systems with our case study: *eco earth sandwich* developed and built in the community of Guapulo by Con lo que hay 14 (CLQH 2019) together with Ensusitio Office (Ensusitio 2020).

This comparison will be based on the thermal conductivity of the four types of constructive systems: the *eco earth sandwich*, confined masonry, the rammed earth, and drywall. Based on secondary research of scientific and academic articles, the thermal inertia and thermal transmittance of each one of the constructive systems will be detailed. Technical specifics of each system will be detailed to clearly develop the comparison.

For a better understanding of the calculations, it is important to understand thermal conductivity, which is related to the calculations on thermal transmittance and thermal inertia.

3 THERMAL CONDUCTIVITY

Thermal conductivity is a property of a material that allows it to transfer more or less heat. "The heat transfer rate through a material is proportional to the negative temperature gradient and to the area through which heat flows" (Berardi *et al.* 2018).

4 THERMAL INERTIA

Thermal inertia can be defined as "the degree of slowness with which the temperature of a body approaches its surroundings" (Ng *et al*. 2011). When the results are higher, it means the material has a better thermal inertia through which heat flows" (Berardi *et al.* 2018).

$$I = \sqrt{\lambda \rho c} \tag{1}$$

where, λ: thermal conductivity expressed in watts-per-meter-square-Kelvin (W/m^{2}K), ρ: density, c: specific heating capacity.

5 THERMAL TRANSMITTANCE

The thermal transmittance is defined as the heat transmission per time unit through a material or construction element induced by the temperature difference between the climate on both sides (indoor, exterior). The units for its measurement are: W/m^{2}K (MIDUVI 2018). The growing attention to energy savings in the building sector has led to more and more performing walls characterized by very low values of thermal transmittance (Asdrubali *et al.* 2014).

$$R = \frac{e}{\lambda} \tag{2}$$

where, R: thermal resistance, e: thickness of the material, λ: thermal conductivity in W/m^{2}K.

$$U = \frac{1}{RT} \tag{3}$$

where, U: thermal transmittance, *1*: constant value, RT: total thermal resistance of the material.

When thermal transmittance is low, it means the material has better insulation capacity.

6 THERMAL INERTIA AND TRANSMITANCE: ECO EARTH SANDWICH SYSTEM

The eco earth sandwich, is an alternative constructive system of reinforced rammed earth wall which has spatial and structural application being safe, acoustic, thermal, and self-bearing. (Figure 1).

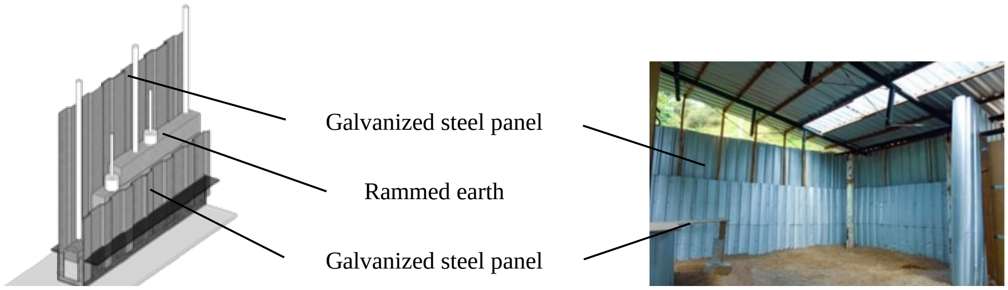

Figure 1. *Eco earth sandwich*.

6.1 Thermal Inertia

As per the Eq. (1): the square root of multiplying: thermal conductivity of the galvanized steel panel is 49.2 W/mK (specific heat of 512), times density of 7800, times volumetric calorific capacity of 3993600 giving a thermal inertia of 19783.14 W/m^{2}K. The square root of multiplying: thermal conductivity of rammed earth is 0.16 W/mK (specific heat of 1841), times density of 1500 times volumetric calorific capacity of 2761500 giving a thermal inertia of 664.71 W/m^{2}K. The total thermal inertia of the eco earth sandwich system by adding the thermal inertia of the galvanized steel panel and the thermal inertia of rammed earth is **20447.85 W/m^{2}K**.

6.2 Thermal Transmittance

To calculate the thermal transmittance, we first need to calculate the thermal resistance, as per the Eq. (2) considering 2 galvanized steel panels, each with a thickness of 0.04m, divided by the thermal conductivity of 49 gives a thermal resistance of 0.0008. For the rammed earth we divide the thickness of 0.2m, by the thermal conductivity of 0.16 W/mK giving a thermal resistance of 1.25. This adds to a total of 1.2516 thermal Resistance.

To calculate the thermal transmittance, as per the Eq. (3) dividing 1 by 1.216 thermal resistance, results in a thermal transmittance of **0.79 W/m^{2}K**.

7 THERMAL INERTIA AND TRANSMITANCE: CONCRETE MASONRY UNIT

The concrete masonry unit (CMU) wall, braced vertically with steel rods, set on a foundation of reinforced concrete, confined by a reinforced concrete crowning beam. See Figure 2.

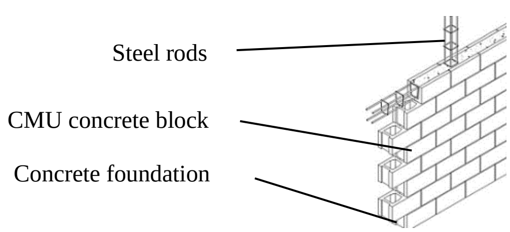

Figure 2. Concrete masonry unit (CMU).

7.1 Thermal Inertia

The thermal Inertia as per the Eq. (1): the square root of multiplying: thermal conductivity of concrete masonry unit (CMU) 0.171 W/mK (specific Heat of 669) times Density of 2300, times volumetric calorific Capacity of 1538700 giving a thermal inertia of **263.17 W/m^{2}K.**

7.2 Thermal Transmittance

To calculate the thermal transmittance we first need to calculate the thermal resistance, as per the Eq. (2) considering the concrete masonry unit wall has a thickness of 0.15m, divided by the thermal conductivity of 0.171 gives a thermal resistance 0.087.

To calculate the thermal transmittance, as per the Eq. (3) dividing 1 by 0.87 thermal resistance, results in a thermal transmittance of **1.14 W/m^{2}K**.

8 THERMAL INERTIA AND TRANSMITANCE: RAMMED EARTH

The confined rammed earth wall rammed with a reusable cast of plywood, set on a stone and cements foundation and confined by cement coronation beam. See Figure 3.

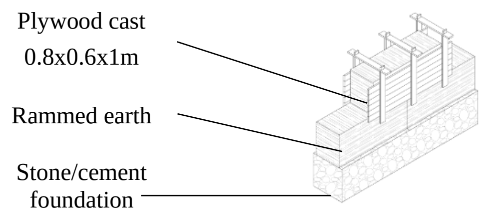

Figure 3. Rammed earth.

The thermal inertia of rammed earth system as per the Eq. (1): the square root of multiplying: thermal conductivity of rammed earth 0.16 W/mK (specific heat of 1841) times density of 1500, times volumetric calorific capacity of 2761500 giving a thermal inertia of **664.71 W/m^{2}K.**

8.1 Thermal Transmittance

To calculate the thermal transmittance, we first need to calculate the thermal resistance, as per the Eq. (2) considering the rammed earth wall has a thickness of 0.4m, divided by the thermal conductivity of 0.16 gives a thermal resistance 2.5.

To calculate the thermal transmittance, as per the Eq. (3) dividing 1 by 2.5 thermal resistance, results in a thermal transmittance of **0.4 W/m^{2}K**.

9 THERMAL INERTIA AND TRANSMITANCE: DRYWALL

The Fiberglass + Plaster + Paperboard wall put on a galvanized steel structure, set on a cement foundation. See Figure 4.

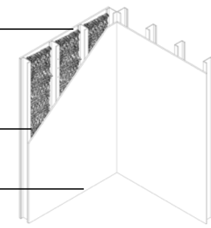

Figure 4. Drywall.

9.1 Thermal Inertia drywall

As per the Eq. (1): the square root of multiplying: thermal conductivity of gypsum panel is 0.3 W/mK (specific heat of 837) times density of 750, times volumetric calorific capacity of 627750 giving a thermal inertia of 433.96 W/m^{2}K. The square root of multiplying: thermal conductivity fiberglass is 0.04 W/mK (specific Heat of 795), times density of 15 times volumetric calorific capacity of 11925 giving a thermal inertia of 11.93 W/m^{2}K.

The total Thermal inertia of the drywall system by adding the thermal inertia of the gypsum panel and the thermal inertia of fiberglass is **445.89 W/m^{2}K.**

9.2 Thermal Transmittance

To calculate the thermal transmittance we first need to calculate the thermal resistance, as per the Eq. (2) considering 2 gypsum panels, each with a thickness of 0.012m, divided by the thermal conductivity of 0.3 gives a thermal resistance of 0.04. For the fiberglass we divide the thickness of 0.2m, by the thermal conductivity of 0.16W/mK giving a thermal resistance of 1.25. This adds to a total of 1.2516 thermal Resistance.

To calculate the thermal transmittance, as per the Eq. (3) dividing 1 by 2.33 thermal resistance, results in a thermal transmittance of **0.42 W/m^{2}K.**

10 RESULTS

10.1 Thermal Inertia

Based on the calculation, we could determine that the eco earth sandwich has the highest thermal inertia (20447.85), the reason is the feature that each element (earth and steel panel) provide, the steel panel with high thermal conductivity, and the earth with a high volumetric calorific capacity, allow to take a high level of heat and store it, providing an appropriate indoor climate and thermal comfort, in the other hand drywall has the lowest thermal inertia(, due to the low capacity of its materials to store heat. It is important to consider some facts such as the place and region where these constructive systems are going to be applied.

10.2 Thermal Transmittance

Based on the calculations, we could determine that rammed earth has the best thermal transmittance, earth due to its width and composition has a high volumetric calorific capacity, this allows to isolate spaces, which means an adequate indoor climate and thermal comfort, CMU has the lowest thermal transmittance due to the low capacity to maintain heat, and eco earth sandwich is the third better construction system due to the earth with a high isolate capacity, but with a counterproductive feature of the steel panel.

11 CONCLUSIONS

In this case of study, the *eco earth sandwich* is the constructive system that has 20447.85 W/m^2K of thermal inertia, this is because of the high thermal conductivity of steel, combined with the high thermal inertia of the earth, resulting in the best thermal inertia of these four constructive methods. And the traditional confined masonry is the one with the lowest thermal inertia with 1818.85 W/m^2K, this is because of the low thermal conductivity and capacity to maintain heat of the concrete masonry unit.

Table 1. Thermal transmittance and inertia.

	Thermal Transmittance		**Thermal Inertia**
Eco earth Sandwich	20447.85	**Rammed Earth**	0.4
Rammed Earth	664.71	**Drywall**	0.42
Drywall	445.89	***Eco earth Sandwich***	0.79
CMU	263.17	**CMU**	1.14

The rammed earth is the best constructive system for transmittance, it means it has the best capacity to isolate any space; the *eco earth sandwich* is the third best, behind the drywall, which due to its materials, especially fiberglass wool, is the second-best.

The results of this research demonstrate that a better development of a building in terms of comfort and indoor climate could be achieved without using expensive materials. Instead, we could use materials available in the same place where a project is going to be developed.

12 RECOMMENDATIONS

In order to complement a complete analysis of this construction system (*eco earth sandwich*) it is also important, study diverse aspects related to economics, ecological footprint, etc.

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