

# Dynamic, Clay Secondary Walling for Heat Reduction, in Tropical Indoors

Malathi Rajapaksha, P.D. Dharmaratne and R.U. Halwatura

**Abstract:** Warming ambient climates in hot - warm climates causes a boost of internal air temperature during the daytime, creating uncomfortable thermal circumstances which affect human physical and mental wellbeing. Modifying indoor thermal discomfort into a comfortable condition is promising with thoughtful material usage, architectural and engineering interventions that involve 'passive mode'. The use of layered facade interventions is such a popular passive cooling approach which is proven successful but leftover a few drawbacks in its practical usage. The research involved developing a clay panel to be applied as a secondary skin, which is thin, lightweight, easily removable, and maintainable, evading the hitches and accelerating indoor heat absorption, further becoming an ultimate eco-friendly low cost, low embedded energy solution. The research methodology involved identifying the material's best mix proportion for optimum air permeability, the simplest practical casting method of the panel, identifying optimum configurations on panel's self-cooling, the best firing temperature, and the firing time, etc. Analysis of the results proves the invention's capability in heat absorption, thus reducing the indoor air temperature. With the uncomplicated technologies in the invention, it provides opportunity even for layman in production. Further, the invention has possibilities in playing a vital role in socio-cultural aspects in the field of construction as well.

**Keywords:** Cooling, Clay, Dynamic, Secondary wall, Porous, Air permeable

## 1. Introduction


In hot humid climates, the late hours of the nights and the early mornings can be experienced as comfortable, both outdoors and indoors, or even as chilly, apparently reflecting their acclimatization to the local climate [1][17]. But in the daytime, it has become a level that exceeds the human threshold of indoor thermal comfort [28]. In this situation, nowadays, active cooling systems which consume energy have found common practice for climate modification (Heating Ventilation and Air Conditioning) in most parts of the world [24]. Energy represents a considerably higher percentage of the running cost of a building and affects the optical and thermal comfort of the occupants, resulting in critical global environmental issues at the same time [2][3].

There is a raised need in applying various sustainable design concepts to modify the indoor overheating condition into a favourable thermal environment, alongside reducing energy consumption in buildings. Passive and Bio Climatic Architecture, which aims at reducing heat gains through the intervention of building designs, carries significant importance and demand in this regard [4]. In the context of


sustainability, this approach promotes less environmental impacts and meets social needs in a cost-effective manner, helping to preserve resources and biodiversity. Involvement of building design between climate and occupants is two-ways. They are:

- 1) Response to impact from outside the building (environmental loads) for maintaining thermally favourable and visually comfortable indoors.
- 2) Response to impact from components and systems inside a building (internal loads) for the benefit of occupant's comfort. Passive cooling strategies, that are tested and proven successful in terms of their energy efficiency and minimal environmental impact.

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The use of these cost-effective interventions in buildings is rarely seen and less popular compared to high energy-consuming, active cooling systems. However, many of known passive cooling strategies consist of drawbacks, either when they are applied in the tropical climatic conditions or when used individually, which becomes the main motivation of this research.

For instance, evaporative cooling causes long-term health issues due to high humidity levels in the air and dampness. Also, direct evaporative cooling (cooled and humidified air is directly brought into the building) can have low efficiency in the case of a humid climate, where air can be close to its saturation point. It is evident that daytime direct natural ventilation in the tropics is less effective in cooling as it carries outdoor heated air indoors and it can carry dust and odour [5]. Moreover, the use of natural ventilation as a mode of indoor cooling is experienced to be less effective as the velocity is uncertain throughout.

Therefore, a knowledge gap is identified in finding innovative energy-efficient, healthy, and effective indoor cooling systems. This research intends in addressing this gap with a holistic approach, collaborating on the known principles of thermal comfort/building physics such as thermal mass effect, structural cooling, nocturnal cooling, stack effect, etc. This research presents a hybrid cooling system for indoors which combine clay double walling with low energy consuming mechanical ventilation supply for better thermal performance.

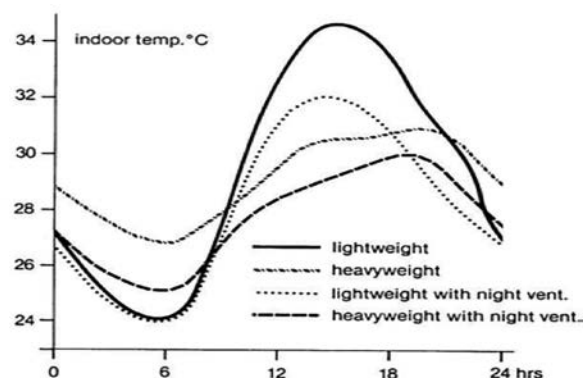
In terms of climate, the building envelope always performs as a climate modifier. For example, in cold climates, the building envelope is used to prevent outdoor coolness gaining into the building by sealing the indoors, and in warm countries, the same building envelope is used to avoid outdoor heat transmitting into the building [6] [19]. In both situations, there are common factors included in envelope performance as the following solar heat gain factors (SHF) of the building are:

- 1) The absorptivity of the envelope
- 2) The insulation value of the envelope
- 3) Mass of the envelope

To increase the thermal performance of the envelope, most important task is to identify thermal characteristics and, out of the above,

'thermal mass' is the capacity of a material to absorb radiation or heat. The thermal capacity is a factor to be considered in moderate climates also. Low thermal capacity or 'quick response' structures warm up quickly but also cool rapidly. Large thermal capacity structures will have a long 'heat-up time' but will conserve heat after switching off the heating. This method is one of the main contributors to modifying indoor climate in terms of heat [25]. Therefore, thermal mass is made use of both in cold and warm climates as a climate modifier.

High thermal mass materials such as mud, adobe, and stone are used in these regions for the construction of the building envelope, deliberating their high thermal capacity and absorption. In hot climates, walls are constructed thicker, as they can absorb and store the outside direct solar heat and diffuse solar heat. When the wall is thick and its material has a high thermal capacity, the heat transfer from the outside to the inside becomes delayed [27] (Figure 1 - from Baker N.V, as referred to by Szokolay, 1996).



**Figure 1 - Thermal Mass Effect of Heavy and Lightweight Walls**

Within this context, the invention involves developing a cooling system for indoor heat reduction and gain of cool. The system comprises 'Fired clay panels' working together with a continuous negative ventilation supply. Fired clay panel is to be used as a second skin, which is not a heavy wall but an easily fixable, removable, and maintainable, environmentally friendly solution.

Clay is chosen to be the main material for the product as it is the foremost proven sustainable construction material for indoor cooling as well as one of the cost feasible, mostly, and freely available material, in tropics including Sri Lanka. The panel made of clay mix composition is fired for better formation of internal pores for

cross ventilation. A collective set of these fired panels is fixed to the inside of the primary wall with an air gap in-between. Concurrently, a low energy-consuming mechanism is used to suck the heated indoor air through the 'dynamic clay secondary wall panel' and released to the outside.

## 2. Aim and Objectives

The focus of this paper is to present the characteristics and effectiveness of the proposed dynamic clay secondary wall panels.

## 3. Materials, Methods, and Results

### 3.1 Improving the Internal Porosity of Clay with Organic Waste Compounds

It is known that clay can create internal pores once it is fired into a high temperature and these internal pores can retain air within. This can cause reducing the amount of heat entering the building interior from the outdoors, clay being a heat barrier. Even if the "clay" is decided as the base material for the secondary wall panel, a suitable type of clay is needed to be selected [7][23]. The following characteristics of earthenware, porcelain and stoneware clay were evaluated in this case.

**a**

	EARTHENWARE CLAY	PORCELAIN CLAY	STONEWARE CLAY
FIRING TEMPERATURE	Cone 06 (997 °C)	Cone 09 (1260°C)	Cone 06 (997°C) Cone 09 (1260°C)
POROSITY	Porous	Non -porous	Slightly porous
ABSORPTION	12% -14%	0.5-2%	1.5-3%

**b**

EARTHENWARE CLAY	PORCELAIN CLAY	STONEWARE CLAY
Colour range from white to brick red	Colour range from white to brown	Colour range from gray to dark brown
Various texture	Various texture	Various texture
Porous surface	Non-Porous	Slightly porous
Relatively fragile	Relatively less fragile	Relatively strong

**Figure 2 - Characteristics of Different Clay Types**





- Colour range, texture, porosity, fragility
- Firing temp., porosity, absorption

Based on above literature [7], the following types of commonly available earthenware clay from different areas of the island were selected to be tested (Table 1). Furthermore, few organic wastes which are available in Sri Lanka, such as pineapple leaves, palm oil waste, straw etc., were studied to be mixed with clay. Based on literature [8][9][10][18][19][20][22] and expert knowledge, and considering the general availability, the following five types of organic wastes were selected for the experiment. Refer (Table 2).

**Table 1 - Commonly Available Clay Types Used for the Experiment**

1. Pure Red Clay (Meetiya goda)	
2. Pure White Clay (Dediya wala)	
3. Brick Clay (Ungrounded, directly from sediments)	
4. Red Pottery Clay (Ground Clay)	
5. Pure Chinese Clay	

**Table 2 - Commonly Available Organic Waste Types used for the Experiment**

1. Saw Dust (4cm particles)	
2. Coconut Fiber (4 cm parts)	
3. Rice Husk (normal particles)	
4. Straws (4 cm parts)	
5. Rubber Powder	

### 3.2 Casting the Clay Panel

The selected five organic waste samples are oven-dried to 100°C degrees for 24 hours which removes the moisture uniformly. Since the intention of mixing compounds with clay is to create optimum continuous internal porosity upon the firing of compound particles, the particles size was kept large. Thereby, the particles such as sawdust, straw and coconut fiber were kept as 4 cm long, white rice husk and rubber dust were kept to their original size.

Each compound type was mixed with each of the five clay types into 50:50 (clay: compound) volumetric proportion. The samples were cast manually into 3 inches x 6 inches size using formwork. The moisture content of each clay type was maintained approximately similar according to the following formula during this test.

$$MC = \frac{w - d}{w} \times 100$$

w = wet weight

d = weight after oven drying

### 3.3 Air Drying

The specimens that were cast were air-dried at room temperature for 24 hours. In wet clay, when the water starts to evaporate, the clay starts to dry, and the particles of clay are drawn closer together, resulting in shrinkage. Many problems with clay arise due to uneven rates of drying, which create stresses in the clay. Sometimes, these stresses show-up right away as cracks or warpages, other times not until during or even after firing. So, it is important to ensure that drying is even. If oven drying is not done, the process of air drying is taken place by ensuring uniform thicknesses throughout the piece, letting slow drying, and even slowing down the drying of certain parts. Clays that have very fine particle sizes will shrink more than clays with larger particle sizes [11].

### 3.4 Oven Drying

Literature depicts that complete drying does not take place until the piece is in the oven, and it happens after the boiling point of water has been reached (100 °C, or 212 degrees F). Therefore, the samples were oven-dried at 100±5°C for another 24 hours to remove water and then the specimens were cooled down to room temperature. It was done slowly, as the formation of steam within the body of the clay may cause it to burst [11] [49].

### 3.5 Firing the Samples

Oven-dried samples, which consist of 0% moisture content, are then subjected to firing into higher temperatures. The compounds mixed into the clay are assumed to be burned to ash during the firing, creating microscale inner pores where they were located inside the clay panel, and once they were fired to ash, the air can be optimally gathered and act as a barrier from heat transfer, as well as making the panel light in weight [12].

In these experiments, Nabertherm GmbH N100 electric furnace was used for the firing. Four firing temperatures, 400 °C, 600 °C, 800 °C, and 1000°C, were identified for the test, based on literature [13] [14]. All samples were fired to above four different temperatures, but for a similar duration, which is 60 minutes. Altogether 100 samples were subjected to this experiment, counted as 5 (clay types) X 5 (Compounds) X 4 (Firing temperatures).

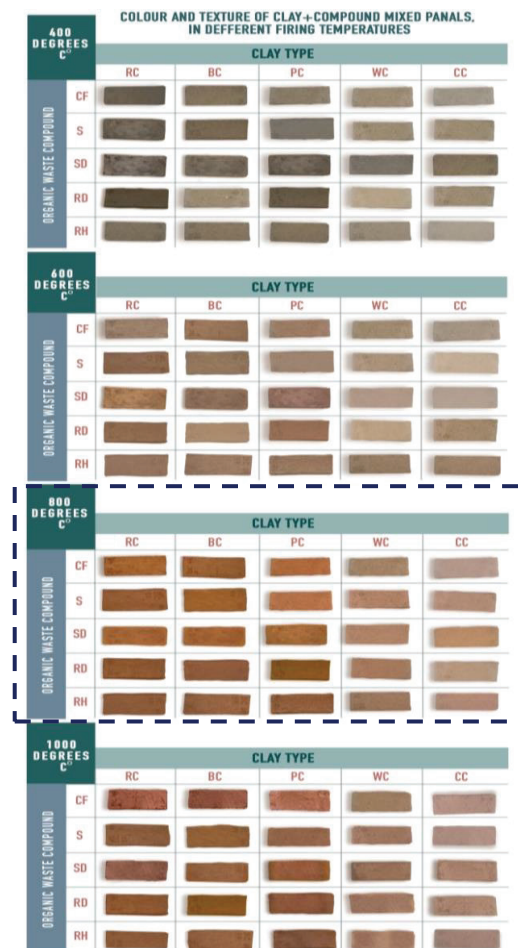


Figure 3 - 100 Samples Categorized According to the Firing Temperatures

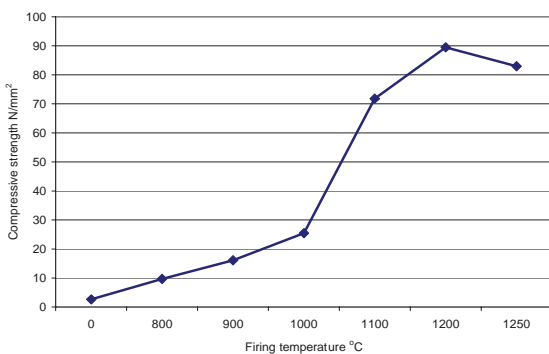
The fired samples were categorized based on the method of the firing temperature to identify its effect on the appearance (colour and texture)

of the panels (Figure 3), in terms of aesthetics. Through this categorization, it was easy to identify that in the lower temperatures, the colour of the clay panels remains grey / light orange, but when the temperature increases to 800 °C -1000 °C range, the colour of the clay panels become more reddish in colour. Also, it was visible that, when the temperature increases, the samples tend to crack and become less fine in texture (Figure 3).

On other hand, the samples which were fired to 800°C degrees were well toned with brick red-orange colour, stable, and had a smooth texture with no cracks. More than 30% of the samples which were fired to 400°C, 600°C, spotted or cracked and didn't get the proper brick red colour.

Further, it was identified that all the samples which were fired to 1000°C have remained in well-toned brick red colour, but most of their texture was spotted, cracked, or scratched.

Referring to the literature on the porosity behaviour of red clay with different temperatures, when the temperature increases, an increase in the size of pores in the microstructure can be identified [6] [15]. The increase of the size of pores in the microstructure can be caused by the reduction of structural strength in the clay panels and that could be the reason why the panels fired to 1000°C tended to crack.

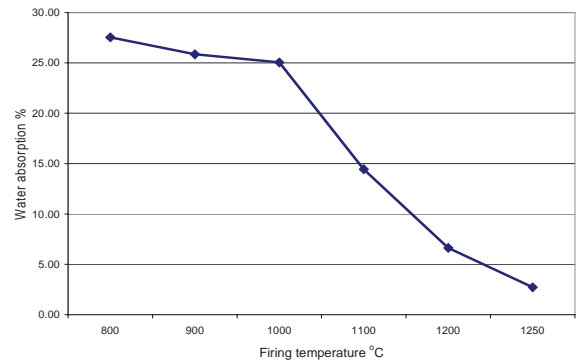


**Figure 4 – Compressive Strength of Fired Clay Bricks with Different Firing Temperatures**

In that sense, further considering effect of the firing temperature for the compressive strength of the sample (Figure 4), lower and higher temperatures have proven less effective, thus firing the clay secondary wall panels to 800°C for 60 minutes is recommended in terms of the appearance (colour tone, texture), general handleability and strength.

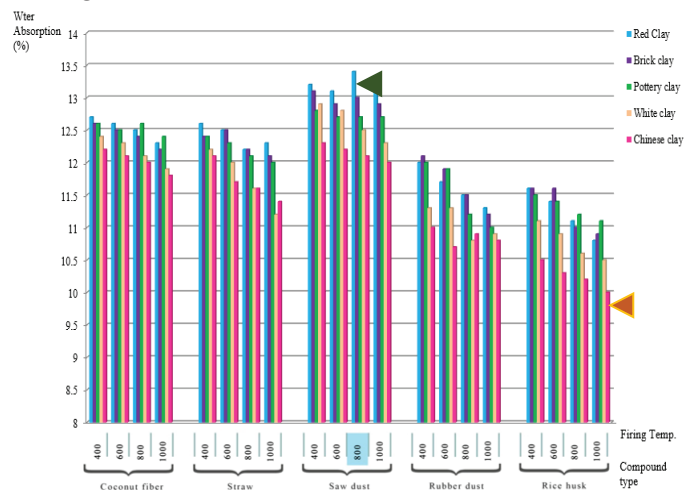
### 3.6 Water Absorption Test for Apparent Porosity

In the next stage, the fired samples were subjected to the water absorption test within a unit time, to identify the optimum performance in apparent porosity (Standard ASTM D570) [2]. Literature provides a basis for this, which is, “a high-water absorption capacity is found in certain samples; the sample contains high number of internal pores in its microstructure” [26]. Further the correlation of water absorption Vs firing temperature of clay is as shown in Figure 5 [14][18].



**Figure 5 – Water Absorption (%) of Fired Clay Bricks with Different Firing Temperatures**

According to the graph in Figure 5, the amount of water absorbed has decreased with an increase of firing temperature. Considering the compressive strength of the clay specimens, the behaviour is the other way around, which is, when the firing temperature increases, the compressive strength is also increased [14] (Figure 4).



**Figure 6 – Water Absorption (mm) of Fired Clay Bricks with Different Organic Waste Compounds**

When there is a high capacity for water absorption in certain samples, it depicts that the sample contains high number of internal pores



in its microstructure [14]. Based on that argument, the fired clay panels made with different compounds were soaked separately in the same amount of water [22].

The test outcome shows that, out of five types of commonly available clay used with commonly available organic compounds, fired samples of red pottery clay (Kaduwela-Grounded) mixed with Sawdust (4 cm particles) showed the best performance in the water absorption test, the results aligning with the findings shown in (Figure 6) [4][2] According to the results, Chinese clay samples with rice husk show the least water absorption within the given test time (Figure 6), which substantiate that fired red clay with sawdust creates optimum internal porosity while the Chinese clay samples with Rice Husk creates the least.

### 3.7 Linear Shrinkage

The linear shrinkage of the samples upon drying and firing was tested to identify its behaviour for the purpose of sizing the clay panel. For this, red clay was mixed with five selected types of natural compounds, and five sample panels were made. A 5 cm line was marked in each panel before they were sent for drying and firing.

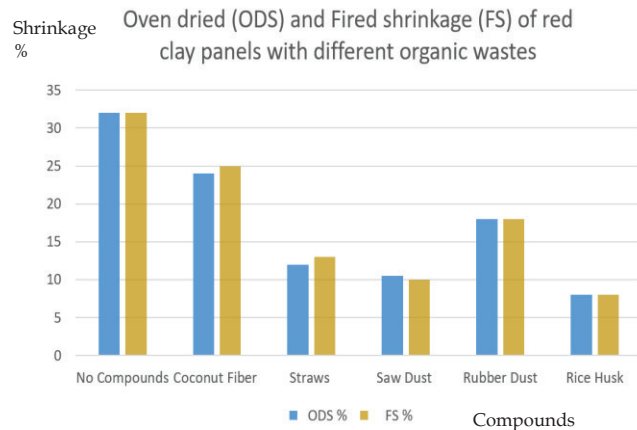


**Figure 7 - Red Clay Panels Mixed with Different Compounds - (A) Before Firing and (B) After**

The oven dried linear shrinkage and the fired linear shrinkage of the clay sample panels with different compound types are presented in Figure 8.

According to the results, a highlighting difference between the results of oven dried shrinkage and fired shrinkage of the samples could not be identified. Also, it shows that pure red clay with no compounds shrink more than when it is mixed with compounds. This also

can be interpreted as the compounds have reduced the shrinkage quality of red clay.



**Figure 8 - Results of the Shrinkage Test; Oven Dried and Fired Shrinkage of the Sample**

In addition, rice husk shows the least shrinkage with red clay, while red clay mixed with rubber powder indicating the second highest firing shrinkage value, while saw dust being the third highest. Coconut fibre and straw showed the same shrinkage values. Not only saw dust succeeded in the water absorption test, but it also remained impressive at the shrinkage test, which concludes the overall best performer with red clay.

At the end of the day, the above series of tests confirms the best material mix proportion, best firing temperature and best firing time duration, of the secondary clay panels, in terms of best internal porosity in the clay panel for indoor temperature flux. All the experiments were planned based on a comprehensive literature survey, and most of the test results agreed with the literature.

### 3.8 Improving Air Permeability Characteristics of the Clay Panel

Possibilities in improving the air permeability characteristics of the clay panel was tested in this experiment. In addition to the micro-scale pores in the clay body as developed with the previous tests, it was tried in improving the cooling capacity of the clay panel by improving structural cooling effect plus ventilative cooling. This test was carried out with 1x1 ft x 1 inch clay sample panels, considering the ease of testing for the application.

The above sized clay panels were cast using the confirmed mix material and then pounced with mm scale holes. The intention of this process

was to improve the area of clay surface which can touch the air, while the cross ventilation occurs through the clay panel, to increase the structural cooling effect of proposed clay panel with cross air movements.

Four main parameters were concerned during this experiment. They are as follows:

- 1) Diameter of the holes (2 mm, 5 mm)
- 2) Hole distribution (distance between each-holes) -(1x1 inch, 2x2 inch)
- 3) Hole Angle (Buoyancy)- (90,45,30 degrees)
- 4) Thickness of the panel (1 cm, 2 cm, 3 cm, 4 cm)

### 3.9 Identifying the Suitable Fabrication Method of the Clay Panels

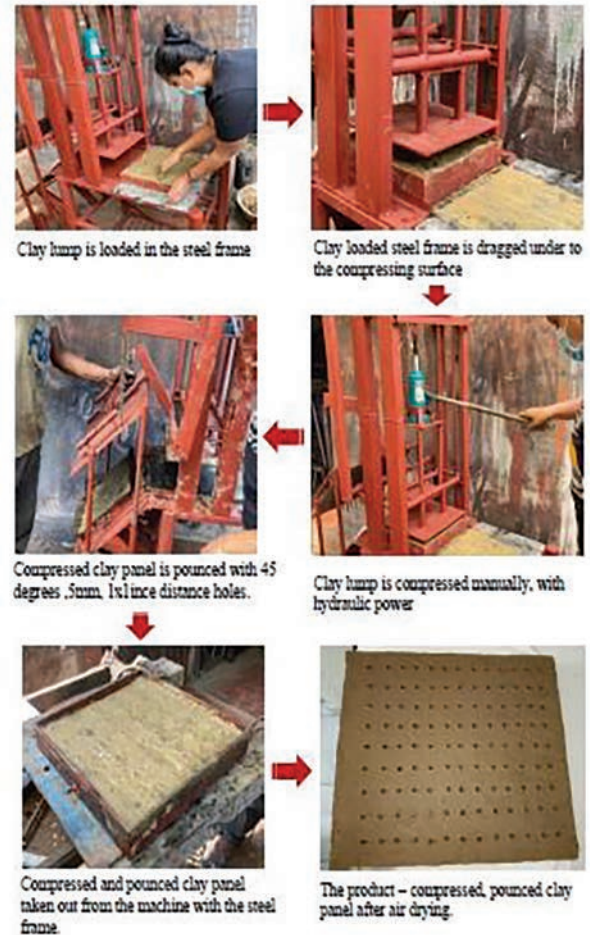
The focus of this experiment was to create a low cost, simple and practical, manually operable method of producing the clay panel with its best quality in terms of architectural appearance. Since the clay panel (component 01) is proposed to be applied as a secondary wall panel, which is non-load bearing, the strength of the product (clay panel) was not highly taken into consideration [21].

The clay panels were initially cast using a timber frame. The clay lumps were compressed by hand until becoming well compressed and stable. The required size for the formwork of the wall panel was confirmed by a series of pilot castings, taking into account the above tested dry shrinkage and firing shrinkage of the clay-compound mixed panel. Initially, the pouncing was done manually with a nail and later with a nailed timber plate. This method is not easy if the exact proportion of wetness within the clay-compound mix and the drying duration of the clay type are not pre-identified. Also, considering the mass production context, it was decided to test an appropriate technique of casting the clay panel.

Literature also confirms that handmade bricks have a lower porosity than normal machine-made bricks as the compression deployed differs [16] [21]. As maintaining higher internal porosity characteristics is required, it was decided to develop a manually operating machine with simple technology to cast the proposed panel.

In support of the fabrication of the proposed clay secondary wall panel, a simple, manually operable machine with hydraulic power which compresses the clay lumps into the required flatness and then pounce it with required hole

size and distance itself. If the clay is high in water content, clay lumps can stick to the formwork while compressing. If so, it becomes difficult to remove the clay lumps out of the formwork with the good shape, as well it does not stay stable due to wetness. To avoid this, a light oil layer on the steel surfaces can be applied before putting the clay lumps in, which is proven successful [20].



**Figure 9 - The Process of Fabricating the Clay Panel with the Machine, Designed by the Author**

With this method, all the panels can be produced with a uniform compression (which helps to maintain a uniform internal porosity level) and even the pouncing characteristics too. Also, it makes the casting of the clay panels quick and easy. Due to the simple technology of the machine, the required labor is less as well; there is no requirement for well-trained /experienced labor for the casting process. The process of compressing and pouncing the clay with the machine until the final product is shown by the series of images in Figure 10.

Clay panels cast with the machine were fired to 800°C degrees for 60 minutes. The final



appearance of the fired clay secondary clay panel is as shown in Figure 10.

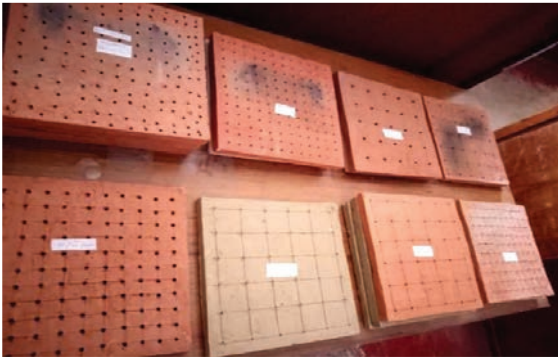


Figure 10 - Final Appearance of the Clay Secondary Wall Panel after Firing

### 3.10 Thermal Performance Investigation

A 3 ft long x1 ft wide x1 ft high perspex chamber was built for this test as per the sketch in Figure 10. The chamber was insulated with 1-inch-thick polystyrene to avoid the transfer of outside heat to the inside. In one narrow façade, a low energy consuming DC fan was fixed to maintain a continuous air suction through the clay panels. Each fired clay panel was inserted to the chamber (Figure 11), and Graphtec GL840M midi logger was used to record the required temperature data. Surface temperature and air temperature were recorded for each panel for 24 h.

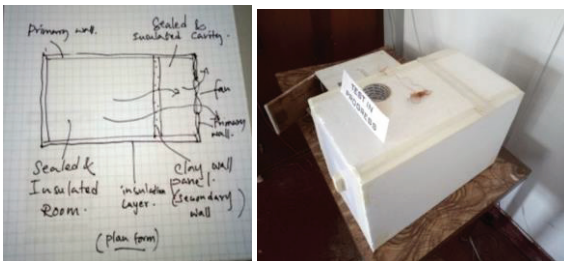


Figure 11 - Thermal Performance Investigation with the Chamber

The investigation results confirmed that the best hole angle as 45 degrees, best hole diameter as 2mm and the best hole distribution as 1-inch x 1-inch hole spacing.

Out of the four thicknesses adopted to confirm the effect of the panel's thickness (1 cm, 2 cm, 3 cm, 4 cm), the best air temperature was recorded with the 4cm thick panel; It depicts that thicker the panel more air temperature reduction gains, which can be a result of the thermal mass effect. The behavior of air temperature of the best case (base case) is presented in Figure 12.

The results show a considerable reduction in air temperature compared to the ambient temperatures of the tested dates. Altogether, a reduction of more than 1.5 °C to 2 °C of indoor air temperature can be observed because of the application of the clay secondary wall panels; This can be identified as a positive heat reduction in indoors in a tropical climate. Good plummet in air temperature was recorded after 24 h from the starting air temperature (Figure 12). An impressive time-lag (approx. 2.5 h) can be observed by comparing the ambient peak temperature and indoor peak temperature time.

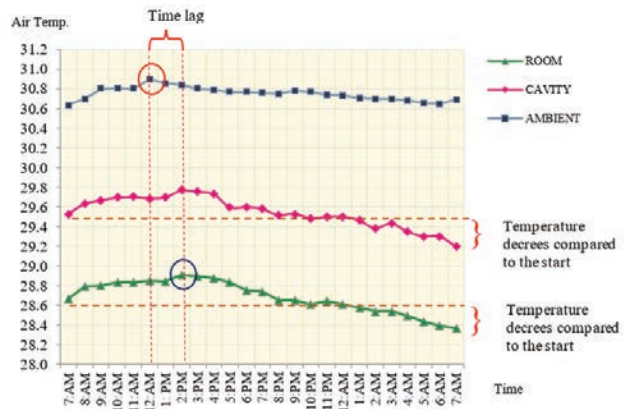


Figure 12 - Thermal Performance Results of the Best Case (Panel with 2mm / 1x1 Hole Distance / 45-hole Angle)

To confirm the above cooling performance, research further expects to apply the clay secondary wall panels with the confirmed configurations with low energy consuming exhaust mechanism, in an actual scale model building in the tropical climate.

## 4. Conclusions

The research presented in this paper investigated the possibility of developing a system amalgamating the known principles of thermal comfort within a practical context to obtain better indoor heat reduction for warm/hot climates. Possibility of Indoor heat discharge and gaining cool concurrently via two correlated components was experimented and identified.

The research concludes that this invention, clay secondary wall panel cooling system, is promising to be the best indoor cooling with the fired clay panels, which is applied as a secondary wall to be made of red clay combined with sawdust in 50: 50 volumetric proportion and pounced with 2 mm

perforations (smaller holes), 1inch x 1inch spacing hole distribution and holes pounced to a 45 degree angle (more buoyance perforations) fired to 800 °C for 60 minutes which is ideal for the clay secondary wall panels of this cooling system.

The clay secondary wall panel needs functioning together with low energy consuming constant negative ventilation mechanism for its best performance. The invention provides sustainable, energy-efficient, low cost and low maintenance, lightweight wall panels for indoor heat reduction in tropics, making use of commonly available clay with natural waste sawdust, combined to an innovative application of a simple technology, which even can be adopted by a layman.

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