FARU FACULTY OF ARCHITECTURE RESEARCH UNIT
UNIVERSITY OF MORATUWA, SRI LANKA

FARU Journal
www.faru.uom.lk

Independence and Interdependence of Sustainable Spaces

THERMAL PERFORMANCE AND USER PERCEPTION ON MUD CONCRETE FLOOR COMPARED TO THE OTHER FLOORS

GALABADA. G.H.[1*], DHARMARATNE P. D.[2], GALKANDA. H.[3] & HALWATURA. R.U.[4]
[1,2,3,4]University of Moratuwa, Moratuwa, Sri Lanka
[1]hyasasiri@yahoo.com, [2]makway.cons@gmail.com , [3]himahansi.galkanda@gmail.com, [4]rangikauh@gmail.com

Abstrac:. New building materials and technologies that provide thermal comfort are expected to gain popularity in the recent past. Hence, efforts to incorporate new building materials are needed to protect populations from the threats of thermal stress that cause an increase in temperatures due to climate change. The earth is identified as the most effective building material to improve the thermal comfortability inside the building. Among several building construction materials, the flooring material provides a more effective role with respect to thermal comfort in a building. This paper presents the evaluation and comparison work carried out to investigate the thermal performance and user perception of newly invented soil based flooring material with other common floorings in Sri Lanka. Temperature measurements were taken on the top surface of flooring materials and were compared the surface temperature of each other and indoor air temperature. User perception was taken through a questionnaire survey by involving hundred and twenty numbers of responses. The results reveal that the soil floor shows a lesser surface temperature at a significant level than the other floorings. Hence, it can be proved that the building construction materials play an important role and earth is one of the most sustainable materials with respect to the indoor thermal comfortability thus, end-user.

Keywords: *Flooring materials, thermal comfortability, tropical climate, sustainable material*

1. Introduction

Primary energy demand in the world has increased drastically in recent decades. Therefore, to the directive for energy efficiency in the built environment, the building sector must decrease its use of energy. In order to meet these targets, many different activities must strive towards the same goal. Buildings are major energy consumers, particularly in counties with extreme climatic conditions consuming a significant amount of energy to heat and cool. For recent decades requirement of air conditioning units have increased, to offset the demands and offer a comfortable interior thermal environment (Latha et al., 2015). Although there are many ways to minimise the heat and air conditioning load in buildings, one of the most critical is to carefully plan and choose the building envelope and its components.

Thermal discomfort can be caused by buildings on their own. If this is not addressed during the design phase, the problem of thermal comfort may become expensive to address afterward. A positive approach to energy efficiency and thermal comfort, which can be observed in the materials chosen to build the structures, is still controversial and not generally adopted. During the development phase, the use of environmentally friendly and low thermally conductive building materials for living spaces/workplaces will give a long-term solution to the issue of heat stress caused by environmental change. However, for a variety of reasons, many workplaces have been unable to embrace such methods as a solution to the problem of thermal comfort (Djongyang et al., 2010).

The thought of green buildings has arisen in recent years, with the primary goal of using environmentally sustainable materials and reducing resource consumption, reducing electricity demand, and is gaining traction in the western world. Traditional expertise in the use of environmentally friendly and thermally tolerant construction materials have been passed down through generations in developed countries and tropical regions (Kumar and Singh, 2013).

*Corresponding author: Tel: +94 718500320 Email Address: hyasasiri@yahoo.com
FARU Journal: Volume 09 Issue 1 DOI: http://doi.org/10.4038/faruj.v9i1.115

The use of construction materials as a passive mechanism for enhancing thermal comfort within the buildings in hot and humid climates is vital, with an emphasis on the factors that make these building materials more suitable to delivering thermal comfort to the indoor environment. However, in low-income environments, the use of locally abundant materials, with due regard for reliability, ease of maintenance, and expense, will be the most required consideration other than the properties of building materials.

New building material technologies that provide energy efficiency and thermal comfort are expected to gain popularity, and efforts to incorporate new building material solutions are needed to shield potential populations from the threats of thermal stress presented by the projected increase in temperatures due to climate change. Among many sustainable materials used to improve the thermal comfortability inside the building, the earth is identified as the most effective material (Bruno *et al.*, 2017; Zami and Lee, 2010). Therefore, a considerable amount of research has been carried out to improve the earth as a construction material, which has been utilised from the ancient stage (Niroumand *et al.*, 2013; McHenry, 1989; Revuelta-Acosta *et al.*, 2010; Minke, 2013). Among them, the flooring material developed using soil is one of the most relevant findings to the current building construction. Proposed flooring was constructed with soil as the main raw material and in several steps. The extracted soil comprises different compositions (gravel, sand, fine particles) in different percentages. However, to produce soil floor, the extracted soil needs to be developed into required composition percentages. Then this developed soil is to be mixed with the required amount of cement and water to produce the soil concrete. Soil concrete laid on the floor and its top surface is smoothed and waxed for proper appearance (Galabada and Halwatura, 2019; Galabada et al., 2020c). The main aim of this study is to compare the user perception and thermal performance of newly invented soil floor with the available conventional floors. This paper presents the experimental work carried out to evaluate the thermal performance and user perception of newly invented soil based flooring material.

2. Literature Review

Many factors such as air temperature, radiant temperature, humidity, air circulation, metabolic rate or human activity, clothes, etc. affect thermal comfort (Epstein and Moran, 2006). In addition, human health may also be influenced by the hot indoor thermal environment at residences or workplaces (Park and Nagy, 2018). Heat stress is a greater challenge in tropical and warmer climates in terms of thermal comfort and heat-related deaths and illnesses. Therefore, the effects of hot working conditions on the working community have been recorded in various research around the world (Latha et al., 2015). The ability of occupants to adjust to thermal equilibrium, physical, mental, and behavioural patterns are referred to as their well-being in a certain environment for a certain climate (Nasrollahi et al., 2008).

However, many workplaces have mounted mechanical equipment such as air conditioners, fans, and different types of cooling devices to counterbalance the hot working atmosphere and give thermal relief to staff. These devices are energy-consuming, expensive to repair, and operate solely on electricity (Nasrollahi et al., 2008).

Minimising the cooling demand of the living spaces is one way to gain thermal comfort while reducing energy consumption. The use of construction materials as a passive strategy in tropical countries with limited resources and energy supply would be inexpensive while increasing thermal comfort. To achieve thermal comfort, several materials with passive cooling properties may be used. This may be an adaptation technique that provides a long-term approach to the problem of rising temperatures and their effect on the living spaces' thermal comfort. Natural materials with inherent thermal insulation capabilities from the outside environment, modern materials with high insulation capabilities, reflective paints, and green roofs are all examples of building envelope materials that are used to provide thermal comfort. Researchers investigated specific factors that could provide thermal comfort to residents, including materials that have been in use for decades, eco-friendly materials, and modern emerging technology materials, with the belief that adequate insulation is required to reduce the thermal impact of radiation from the sun (Feriadi and Wong, 2004; Karmann et al., 2017).

Various researchers have suggested that the thermal output of advanced materials plays a key role in energy conservation and thermal comfort (Latha et al., 2015). Therefore, to achieve the required thermal comfort without losing structural stability, a mixture of natural and synthetic construction materials is frequently used. However, when changing the composition and using a combination of natural and synthetic materials, keep in mind that the features of the materials used must be based on the building's intended application as well as the weather conditions in order to ensure optimum thermal comfort (Shooshtarian et al., 2020). The interior temperature, and hence the thermal comfort of the building's occupants, is also affected by mutual radiation between the wall and the ceiling (Latha, Darshana and Venugopal, 2015). Natural construction materials have been used since the dawn of time, and building materials manufactured with natural ingredients have their range of benefits and drawbacks in today's built world, including problems with load-bearing capability and longevity. In fact, the thermal conductivities of a wide variety of traditional and natural materials are ideal for use in buildings to provide optimum thermal comfort (Kumar and Singh, 2013).

The thermophysical properties of construction materials, building alignment, airflow, building room use, and the combination of modern and passive energy conservation technology all affect a building's thermal comfort (Alfano et al., 2014; Feriadi and Wong, 2004). The building shell acts as a barrier not only to the outside but also to climatic elements that specifically influence the system. Internal thermal comfort is determined by the characteristics of the construction materials used, which are influenced by temperature and humidity outside (Lucas et al., 2002).

Traditional materials have greater thermal conductivities and diffusivities than modern materials, resulting in inefficient and unpleasant heat transport (Kumar and Singh, 2013). Bamboo, timber, grass, linoleum, crushed earth block, rammed earth, cement, vermiculite, flax linen, sisal, seagrass, cork, extended clay grains, coconut, wood fibre plates, and other eco-friendly construction materials are all renewable materials and reduce energy consumption inside buildings (De Luca et al., 2017; Farhat et al., 2014). Marble, concrete, and asphalt are excellent heat conductors that can be avoided in exterior buildings, while materials that carry the least amount of heat from outside to inside, such as some types of glass, and wood, should be used for walls, floors, and windows to provide a comfortable interior (Denisselle and Doubrovsky, 1992). Wood and timber are considered to be strong thermal insulators and are ideal for a number of applications such as windows, doors, roofing, and flooring. Wood's thermal properties are a result of moisture content and wood type since it is a hygroscopic fibre. The way wood is handled and how it is used is primarily determined by its intended use in construction and the environment of the region. Wood products such as fibreboard and hardboard panels built from fibres have lower thermal conductivity values than real hardwood due to a large number of air gaps in the fibre-based panel (Latha et al., 2015).

Straw has been used as a building material for many years because it is biodegradable and has no environmental impact. The use of straw has been a common technology in Mexico, France, Finland, and Australia. A well-constructed straw-bale building has excellent thermal efficiency. In fact, straw is a thermally tolerant fibre with a thermal resistance rating of 6.51 to 7.82 W/m2 K for a 55 cm thick straw-bale which can be the most effective insulator (Garas and Allam, 2011). Interestingly, plastered straw-bale construction is used in load-bearing and in-fill straw-bale construction to produce long lasting, super insulated buildings that have thermal comfort. In tropical climates, straw-bale buildings perform better thermally than other materials used for walls, but they have inherent drawbacks such as less bulk to retain heat in the building fabric and poor load-bearing properties, rendering them unsuitable for taller structures(Park and Nagy, 2018).

Bricks are one of the most significant heat-resistant construction components (Gualtieri et al., 2010). Despite exterior diurnal changes, inside temperatures in red brick structures remained relatively stable, making it an excellent alternative for building material, especially in hot areas. According to studies (Binici et al., 2007) mudbrick reinforced with fibre (FRB), retains the indoor temperature lower throughout the summer. Buildings constructed with FRB work better thermally and have a cooler indoor atmosphere than those constructed with clay bricks (Makaka andMeyer, 2006). In a simulation conducted by Alahabad et al., it was discovered that native materials have greater thermal properties than typical building materials(Alhaddad and Jun, 2013). Mud concrete (Udawattha et al., 2017; Galabada, 2016; Galabada et al., 2020a) and mud concrete reinforced with coir (Galabada et al., 2020b) also have been identified as thermally comfortable construction material in outdoor construction and indoor construction as well.

3. Research Methodology

The flooring material which is newly innovated made out of soil was the main material in this study. To compare the thermal performance and user perception with the soil floor, two other conventional flooring materials were selected. The flooring materials usually used in Sri Lanka are ceramic tile, cement rendered floor, timber, and terrazzo. The flooring materials which were used for the measurements in this study are the ceramic tile and cement rendered floor in addition to mud concrete floor. Because these materials are widely used in Sri Lanka as flooring material. Generally, the typical floor of a house consists of three layers: the finishing layer, the plastering layer (cement mortar) and the structure layer (concrete floor base) in conventional flooring. Ceramic tile and cement rendered floor was constructed accordingly. However, the soil flooring construction is differing from conventional flooring. Therefore, this was performed according to the technique described in related published data (Galabada and Halwatura, 2019; Galabada*et al.*, 2020c).

6ft x 6ft floor area was laid with selected floorings for each other at the place where indoor environment conditions are the same. All three floors were constructed in the same colour to avoid the colour effect on the surface temperature.

3.1. MATERIAL SELECTIONS

<u>CERAMIC TILE FLOOR</u>
Ceramic tiles in size 2ft x 2ft were purchased from the market. The colour of the tile was selected to match the colour of soil floor. The tiles were laid on the levelled concrete floor by applying the cement mortar bedding.

CEMENT RENDERING FLOOR

First, the concrete floor was laid, and then cement mortar bedding was made. The cement was mixed with colour pigment to match the colour of the final finish with the soil flooring colour. Then mixed with water to make a cement slurry. The cement slurry was applied on the top of the mortar bed to have a cement rendered floor.

MUD CONCRETE FLOOR

The soil floor was constructed in a 75mm thick soil cement mix. Since, this soil floor is a new technique, the method of construction and material used to this floor was carried out according to the construction technique described in related published data (Galabada and Halwatura, 2019;Galabada *et al.*, 2020c). Figure 1 shows a few steps of soil floor construction.

Figure1: Steps of soil floor construction

3.2 SURFACE TEMPERATURE VARIATION MEASUREMENT

All the floor samples were left for a week to become uniform condition by removing construction moisture etc., before fixing the data logger for temperature measurements. Then the temperature variation was measured on the floor surface continuously for two weeks period. A data logger as shown in Figure 2 was used to measure the temperature. The temperature on the floor surface and indoor temperature were measured. Then the temperature variation on the surface was compared.

(a) Data logger (b) Soil floor (c) Ceramic tile (d) Cement rendered

Figure 2: Temperature measurements on floor surfaces

3.3 USER PECEPTION

Next, the personal opinion on the mud concrete floor was evaluated. For this, it was planned to give appropriate numbers of questions to a selected group of peoples and collect their opinion on the new product. sufficient numbers were involved in the survey. One hundred and twenty (120) questionnaire were distributed and out of which thirty six (36) numbers from different categories were responded. They were given the questionnaire to obtain their opinion as visual inspection and physical inspection. This questionnaire was done in the site having floor sample areas with three different selected flooring materials. The target group is the general audience, architects, interior designers, engineers, mason, and contractors. For the physical opinion, they were asked to walk through and answer the given questions. The survey was done in two steps, first to evaluate the user perception of Mud concrete and the second step to compare the mud concrete floor with the other conventional floorings.

4. Results and Discussion

4.1 SURFACE TEMPERATURE VARIATION

The temperature variation was measured throughout a week. Out of all observations, three days' observations have to be discarded due to inconveniences. The other four days were taken for the evaluation process. This selected four days' temperature measurements were averaged and set of temperatures of for 24 hrs were averaged, to plot against time. The average 24 hrs temperature variation is shown in Figure 3 below. First, compared the temperature variation pattern for conventional floor surface and indoor air temperature. According to the resultant temperature measurements, the ceramic tile floor and cement rendered floor showed the same variation pattern throughout the day. When comparing the indoor air temperature, during the morning hours (1.00 am-11.00 am) the indoor air temperature kept higher than the floor surface. During midday time till 3.00 pm the floor surface and indoor air temperature became same. Hereafter, during night time ceramic tile floor surface and indoor air temperature kept as same while the cement rendered floor surface became lesser than these two. Though the surface temperature shows differences, these differences are less than 1^0C.

Then temperature variation on soil floor was compared with the other floors. It shows that this variation is lesser than the other floor surfaces and also indoor air at a significant level. The maximum indoor air temperature was observed at 15-16 hr and it was 28^0C and at that time the temperatures were 27^0C, 27.8^0C, 27.8^0C on soil floor, cement rendered floor, and ceramic tile floor respectively. The results showed that the temperature on the soil floor was 1^0C lesser than that of other floor surfaces as well as indoor air temperature. Further, it could be seen that throughout the day the soil floor surface temperature showed a lower value than other surface and indoor air temperatures as well in a significant amount.

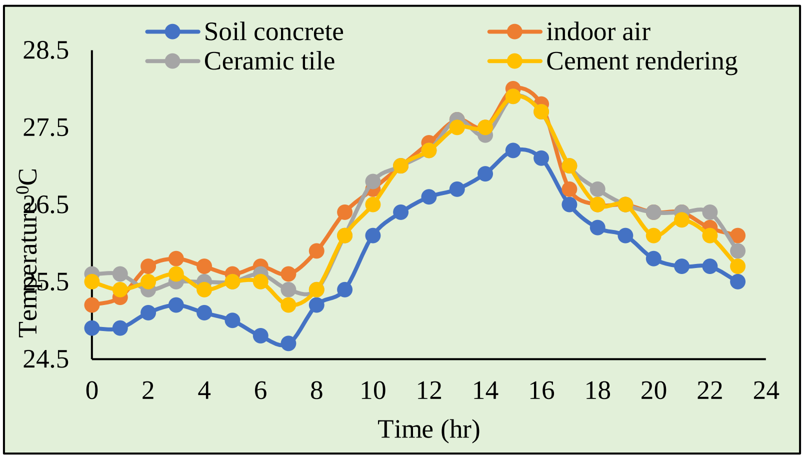

Figure 3: Temperature variation pattern on floor surfaces

4.2 USER PERCEPTION

An important aspect of this survey is to obtain responses to understand the preferences for Mud concrete floor which is innovated in this research. Therefore, first the participants were asked to rank their first impression on newly invented mud concrete floor. According to their answers it was noted that 64% of them felt good first impression on the floor. Figure 4 shows the participant responses.

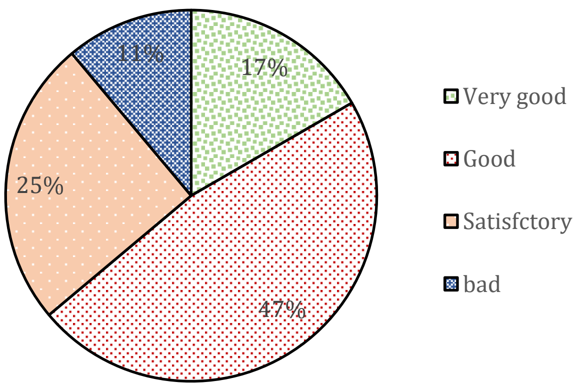

Figure 4: Participants' first impression on the mud concrete

The mental satisfaction related to material comfortability was analysed on physical feeling and visual observation. According to the answers given by the contributors, 80% said the mud concrete was more comfortable while 2% saying discomfort. Rest 3% were dispassionate in feeling on their visual observation. Based on the response after walking on the floor, it was happy to be noticed that 100% of respondents felt comfortable and among them 58% felt more comfortable touch as illustrated in Figure 5.

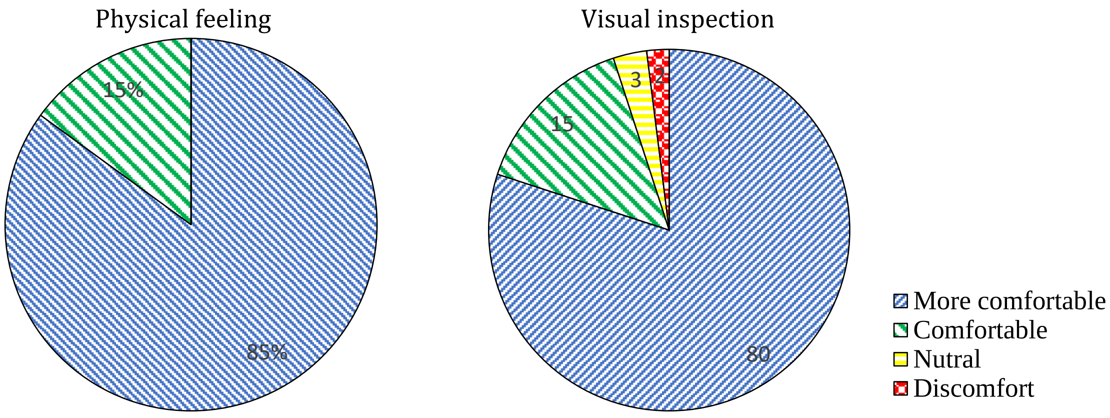

Figure 5: Comfort level by visual inspection and after walking through the floor

Next, the participants were asked to rate their likeliness on the visual appearance of the aggregate placement pattern as most like, like, no idea, dislike, most disliked. The results were graphically presented in Figure 6, where 6. 84 % were interested in the aggregate placement pattern while 9% rejected the aggregate placement patten.

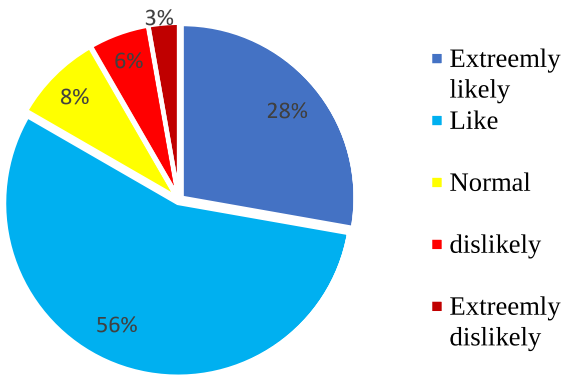

Figure 6: Likeliness on aggregate placement pattern of the mud concrete floor

In the second step, the participants were ranked their opinion on the selected three types of floorings and results were analysed. 83% of the observer's first preference goes to mud concrete floor among selected three flooring types in visual observation and once they touch the floor according to their physical observation 92% of them selected mud concrete floor as their first preference. Figure 7 illustrated their visual and physical preference ranked results separately. All the respondents strongly agreed that the coolest feeling material is mud concrete floor.

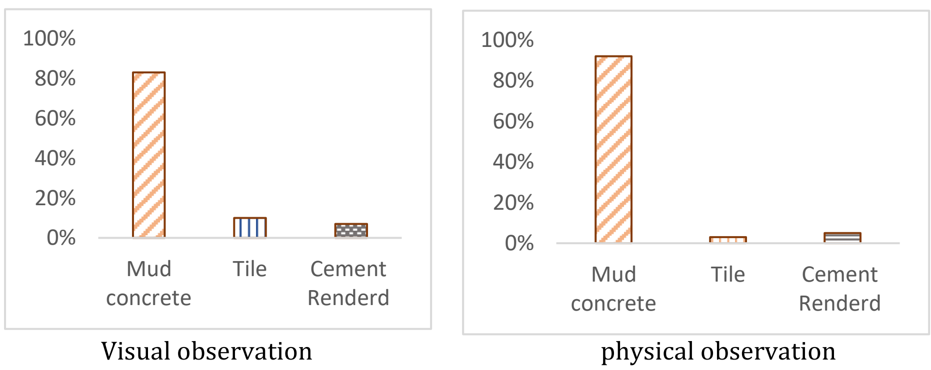

Figure 7: Comparison of preference on flooring material

5. Conclusions

In this study, the thermal performance and the user perception of the newly invented soil floor was compared with the other two flooring materials which are commonly used in Sri Lanka. Thermal performance comparison results show that the temperature of the soil floor was lesser than the temperature of other floor surfaces which were selected and the temperature of the indoor air in a considerable amount. User perception results reveal that the mud concrete floor feels much cool touch and hence their mental satisfaction is high. All the participants strongly agreed to have mud concrete floor rather than conventional floors. Therefore, it can be concluded that soil flooring is one of the good innovations for the building construction industry, especially in countries with a tropical climates. Further, with these results, it is proved that the building construction materials play an important role in indoor thermal comfortability. Therefore, it is obvious that newly innovated soil floor can be used to keep indoor thermal comfortability and save energy use for air condition too.

6. Acknowledgements

The authors would like specially acknowledged to support given by Mr. H.T.R.M. Thanthirige, (Technical officer of Building Materials Laboratory), Mr. D.M.N.L Dissanayaka, (Technical officer of Structural Testing Laboratory), Mrs.W.B.U. Rukma, (Technical Officer of Construction management division) and other supporting staff in these laboratories, Department of Civil Engineering, University of Moratuwa, Sri Lanka.

7. References

Alfano, F.R.D.A, Olesen, B.W., Palella, B.I. and Riccio, G.,2014. Thermal comfort: Design and assessment for energy saving. *Energy and Buildings*, 81, pp. 326–336. doi:10.1016/j.enbuild.2014.06.033.

Alhaddad, M.A. and Jun, Z.T., 2013. A comparative study of the thermal comfort of different building materials in SANA'A. *American Journal of engineering and applied sciences*, 6(1), pp. 20–24.

Binici, H. *et al.,* 2007. Thermal isolation and mechanical properties of fibre reinforced mud bricks as wall materials. *Construction and Building Materials*, 21(4), pp. 901–906. doi:10.1016/j.conbuildmat.2005.11.004.

Bruno, A.W., Gallipoli, D., Perlot, C. and Mendes, J., 2017. Mechanical behaviour of hypercompacted earth for building construction. *Materials and Structures*, 50(2), pp. 1–15.

De Luca, P., Carbone, I. and Nagy, J., 2017. Green building materials: A review of state of the art studies of innovative materials. *Journal of Green Building*, 12, pp. 141–161. doi:10.3992/1943-4618.12.4.141.

Denisselle, A. and Doubrovsky, G., 1992. Material in the form of a plate capable of forming a heat-insulating barrier, fire-protection wall including this material, and casing including such a wall. *FR2672961, Institut National de la Propriete Industrielle, Paris* [Preprint].

Djongyang, N., Tchinda, R. and Njomo, D., 2010. Thermal comfort: A review paper. *Renewable and Sustainable Energy Reviews*, 14(9), pp. 2626–2640. doi:10.1016/j.rser.2010.07.040.

Epstein, Y. and Moran, D.S., 2006. Thermal comfort and the heat stress indices. *Industrial health*, 44(3), pp. 388–398.

Farhat, R., Ghaddar, N.K. and Ghali, K., 2014. Investing in PV systems utilizing savings from building envelop replacement by sustainable local material: a case study in lebanese inland region. *International Journal of Energy Economics and Policy*, 4(4), p. 554.

Feriadi, H. and Wong, N.H., 2004. Thermal comfort for naturally ventilated houses in Indonesia. *Energy and Buildings*, 36(7), pp. 614–626. doi:10.1016/j.enbuild.2004.01.011.

Galabada, G.H., 2016. Mud concrete paving block for pedestrian pavements in tropical climatic conditions. Available at: http://dl.lib.mrt.ac.lk/handle/123/12524.

Galabada, G.H., Rajapaksha, M. and Halwatura, R.U., 2020a. Paving Materials for Urban Heat Island Mitigation in Tropics; A Comparative Study on Mud Concrete Paving', 9(3), p. 9.

Galabada, H., Galkanda, H. ., Dharmaratne, P.D, and Halwatura, R.U.2020b. Investigation of Mechanical Properties of Mud Concrete with Coconut Fiber Reinforcement, in *2020 Moratuwa Engineering Research Conference (MERCon)*. *2020 Moratuwa Engineering Research Conference (MERCon)*, pp. 102–106. doi:10.1109/MERCon50084.2020.9185220.

Galabada, H., Dharmaratne, P.D., , Galkanda, H., Mendis, M, Nilmini, R., 2020c. Soil as an innovative sustainable flooring material, in *2020 From Innovation to Impact (FITI)*. *2020 From Innovation to Impact (FITI)*, pp. 1–6. doi:10.1109/FITI52050.2020.9424881.

Galabada, H. and Halwatura, R.U., 2019. A preliminary study on the use of soil as a floor finishing material, in *2019 From Innovation to Impact (FITI)*. *2019 From Innovation to Impact (FITI)*, pp. 1–4. doi:10.1109/FITI49428.2019.9037635.

Garas, G. and Allam, M., 2011. Thermal performance of plastered rice straw bales and walls: a case study. *International Journal of Sustainable Development and Planning*, 6(2), pp. 226–237. doi:10.2495/SDP-V6-N2-226-237.

Makaka, G and Meyer, E., 2006. Temperature Stability of Traditional and Low-cost Modern Housing in the Eastern Cape, South Africa. *Journal of Building Physics*, 30(1), pp. 71–86.

Gualtieri, M.L. *et al.,* 2010. Thermal conductivity of fired clays: Effects of mineralogical and physical properties of the raw materials. *Applied Clay Science*, 49(3), pp. 269–275. doi:10.1016/j.clay.2010.06.002.

Karmann, C., Schiavon, S. and Bauman, F., 2017. Thermal comfort in buildings using radiant vs. all-air systems: A critical literature review. *Building and Environment*, 111, pp. 123–131. doi:10.1016/j.buildenv.2016.10.020.

Kumar, A. and P Singh, O., 2013. Advances in the building materials for thermal comfort and energy saving. *Recent Patents on Engineering*, 7(3), pp. 220–232.

Latha, P.K., Darshana, Y. and Venugopal, V., 2015. Role of building material in thermal comfort in tropical climates – A review. *Journal of Building Engineering*, 3, pp. 104–113. doi:10.1016/j.jobe.2015.06.003.

Lucas, F., Adelard, L., Garde, F. and Boyer, H., 2002. Study of moisture in buildings for hot humid climates. *Energy and Buildings*, 34(4), pp. 345–355. doi:10.1016/S0378-7788(01)00115-3.
McHenry, P.G., 1989. *Adobe and Rammed Earth Buildings: Design and Construction*. University of Arizona Press.
Minke, G., 2013. *Building with Earth: Design and Technology of a Sustainable Architecture*, *Building with Earth*. Birkhäuser. doi:10.1515/9783034612623.
Nasrollahi, N., Knight, I. and Jones, P., 2008. Workplace satisfaction and thermal comfort in air conditioned office buildings: Findings from a summer survey and field experiments in Iran. *Indoor and Built Environment*, 17(1), pp. 69–79.
Niroumand, H., Zain, M.F.M., Jamil, M. and Niroumand, S., 2013. Earth Architecture from Ancient until Today. *Procedia - Social and Behavioral Sciences*, 89, pp. 222–225. doi:10.1016/j.sbspro.2013.08.838.
Park, J.Y. and Nagy, Z., 2018. Comprehensive analysis of the relationship between thermal comfort and building control research - A data-driven literature review. *Renewable and Sustainable Energy Reviews*, 82, pp. 2664–2679. doi:10.1016/j.rser.2017.09.102.
Revuelta- Acosta J.D., Garcia- Diaz,A., Soto- Zarazua, G.M. and Rico- Garcia, E., 2010. *Adobe as a Sustainable Material: A Thermal Performance*. doi:10.3923/jas.2010.2211.2216.
Shooshtarian, S., Caldera, S., Maqsood, T. and Ryley, T., 2020. Using Recycled Construction and Demolition Waste Products: A Review of Stakeholders' Perceptions, Decisions, and Motivations. *Recycling*, 5(4), p. 31. doi:10.3390/recycling5040031.
Udawattha, C., Galabada, H. and Halwatura, R., 2017. Mud concrete paving block for pedestrian pavements. *Case Studies in Construction Materials*, 7, pp. 249–262. doi:10.1016/j.cscm.2017.08.005.
Zami, M.S. and Lee, A., 2010. Economic benefits of contemporary earth construction in low-cost urban housing – State-of-the-art review. *Journal of Building Appraisal*, 5(3), pp. 259–271. doi:10.1057/jba.2009.32.