Paving Materials for Urban Heat Island Mitigation in Tropics; A Comparative Study on Mud Concrete Paving

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Abstract— **Developments in urban sector require to follow proper planning in every aspect to rescue causing severe environmental issues such as urban heat island thus global warming, losing the native appearance etc. Both Surface and Atmospheric urban heat island make high impacts on thermal comfort in tropical hot climates. Therefore, the selection of materials, especially focusing on outdoor paving plays a vital role with respect to the urban heat island mitigation and achieving human thermal comfort thus sustainability. Popular materials found for outdoor paving are asphalts, concrete, burnt clay bricks etc. However, there are many drawbacks of using paving blocks in outdoors as a whole, with respect to the user's thermal comfort as well as sustainability. Thereby, there is a gap of knowledge in identifying and developing thermal properties of materials used for outdoors. Accordingly, this research suggests evaluating and comparing the thermal performance of newly invented soil based material that is mud concrete paving block with selected popular paving materials used for outdoor development in Sri Lanka. Cement concrete, burnt brick, Asphalt and Mud concrete paving blocks are selected as sample materials and equal areas of each specimen were paved in an unshaded open space where direct solar radiation reaches. Secondly, the same colour was applied on the surfaces of the specimens to avoid the albedo effect. The results obtained were analyzed in terms of thermal performance. The results indicated that the material properties and their surface colour have an influence on its thermal performance. Further, results have proven that the mud concrete paving block has high potential on its thermal performance as a sustainable solution to be used in outdoor development.**

Index Terms— **albedo effect, outdoor thermal comfort, paving materials, urban heat island effect**

I. Introduction

Many developments worldwide have made the human lifestyle more comfortable but more complicated. However, these developments seem to be concerned only about the technical and economic viability rather than the environment and human health. Hence, these developments are causing severe environmental issues such as global warming, urban heat island (UHI) effects, losing the natural appearance etc.

Although many kinds of research and experimental data are available relating to the indoor conditions of buildings, very limited information is available relating to outdoor conditions including selecting construction materials used in open urban areas. This is mainly due to the difficulty in describing the outdoor spaces due to their conditions which often undergo rapid changes. Outdoor development includes many elements such as sidewalks, street corners, tree and landscape strips, street furnishing, benches, signage, trash receptacles, lighting, bus shelters, medians, curbs, bicycle facilities, crossings, public art, and cafe spaces. Therefore, numerous design criteria have to be considered in the design of outdoor environments.[1] stated that modern and contemporary public and semi-public urban spaces (eg: squares, courts, streets, commercial and transit centers) seem to have very poor thermal comfort performances when compared to that of traditional urban spaces. Therefore, urban developments should be designed to meet the technical, economic and social requirements of not only the developers but also the users[1]. Further, the designs also should identify suitable construction solutions and urban planning methods which minimize environmental impacts and harmful impacts on human health. [2] highlighted that promoting the use of suitable materials can minimize the negative effects produced by artificial outdoor surfaces[2].

The UHI effect is an incident in which surface and air temperatures are elevated due to the retention and emittance of solar heat from hardscapes such as roads, pavements, buildings and other structures. The growth and modify the cities by replacing the natural land cover with manmade pavements, buildings and other infrastructure, are cause to the UHI [3]. This is one of the reasons that contribute to the temperature increase in urban areas a considerable amount. As a result, it creates outdoor thermal discomfort conditions as artificial surfaces warm the surrounding air to undesirable levels, especially in tropical climatic conditions. Pavements (including roads, pedestrian walkways etc.) are one of the main hardscapes contributing to the UHI effect and to the energy balance of the urban surface [3]. Therefore, paving material is one of the main contributors to the phenomenon of the UHI effect[2]. At present, such growth of heat islands is increasingly becoming an additional and highly-complex environmental issue. It

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was also recently recognized that heat has a divesting impact on human health. Therefore, heat is negatively influencing the living standard and the health of city dwellers [4]. Therefore, it is essential to understand the mechanism of UHI which influences the near surface air temperature with the increase of temperature in urban areas. As a result of urbanization and by the use of pavement structures with poor thermal properties which prevent natural processes, the temperature in urban areas is increased. The typical natural ground heats up during the day, but it releases heat during the night. This natural process and its balance are disturbed once the natural ground is built up with high heat storage absorbing materials such as asphalt and concrete[2].

The temperature in urban areas can be significantly reduced by replacing dark coloured pavements and roofing with light and heat-reflective concrete based materials, along with careful planting of trees [5]. Therefore, the albedo value of construction material is one of the most important factors to be considered when selecting a material for outdoor development, especially in countries with hot climatic conditions.

According to various previous studies, cool materials can significantly contribute to the reduction of surface temperatures up to several degrees. The use of cool pavements (pavement made out of materials with high albedo) and the use of reflective materials for the roof are some efficient mitigation strategy for reducing the intensity of heat island in urban areas[5-10].

The unpaved surface creates problems throughout the year, in both the rainy and dry seasons. During the rainy season, the roads become waterlogged because there exists little or no provision for adequate surface or subsurface drainage of the roads, and during the dry season dust is raised. It is a major environmental and health hazard[11]. The use of paving blocks would reduce these problems on such roads. Burnt clay brick pavers could be manufactured locally, without complicated technology

Many other materials such as granite, asphalt, concrete etc. exist in modern outdoor development and cement block paving are available in numerous shapes and colours. During the past few years the number of types of blocks, especially those with decorative characteristics, has greatly increased.

Asphalt concrete and cement concrete are commonly used for the construction of all outdoor development such as road parking lots, walkways etc.[12]. Concrete block pavements have become an attractive engineering and economical material in the construction of walkways worldwide in recent times This is because concrete blocks are more economical and durable. Though concrete paving blocks are more common, there are several drawbacks relating to our climatic condition. Urban heat island effect which is one of these drawbacks, it can create major adverse conditions against the environment and human health. Hence, it is highly critical to investigate these impacts with existing material [13-15].

According to[8], the albedo value of cement concrete pavement surfaces is higher than that of asphalt and granite. The concrete base reaches a temperature lower than 5 ℃ of the temperature of asphalt and less hot than asphalt, both in maximum and continuously high (summer) temperatures. This makes it more comfortable for use in cities due to its warming properties[8].

The concrete sidewalk is the most environmentally friendly solution to reduce long–term impacts because it shows a lower Global Warming Potential (GWP) and lower Primary Energy Demand (PED) than asphalt and granite. However, the disadvantage of concrete sidewalks is it account for Green House Gas (GHG) emissions that are higher than those of asphalt sidewalks. The impact of concrete slabs is mainly associated with the cement content which is the largest impact contributor for all cement based materials used in sidewalks [15].

However large energy consumption, CO2 emission and dust emission are the biggest environmental concerns with regard to cement and concrete products are some disadvantages. In order to minimize these environmental impacts, it is better to reduce the use of concrete in construction. Granite is the natural stone which is most commonly used for exterior paving due to its hardness, durability and aesthetics. Though this material is aesthetically more pleasing than concrete or asphalt sidewalks, their construction cost is normally higher.

Construction with the earth is one ancient technology which still remains alive. Though, the composition of the earth varies drastically around the world because of climatic conditions. There are some undesirable properties of soil as a construction material [16]. Historically, mud is a material that was extensively used in construction even before the advent of cement and concrete. The earth as a construction material has advantages as well as disadvantages depending on the requirements, applications. Some of the main advantages of the earth are availability in large quantities, low price, etc.

The shortcomings are principally low mechanical characteristics, unsatisfactory resistance to weathering and liability to volume changes, especially in the case of clayey soils. But, these can be modified by soil stabilization [17].

Brick is one of the most popular construction materials in many countries due to its properties such as durability, relatively low cost, availability, sound and heat insulation and acceptable fire resistance, attractive appearance. Bricks can be either conventional type or alternative types. The conventional bricks can be identified as burnt clay bricks and ti is the major type used for construction worldwide [18]. Burnt Brick: The brick industry is very old and goes back to about 5000 years. However, mud concrete paving block is newly invented to address the above mention the adverse effect of existing materials which are used to outdoor development such as concrete, asphalt and granite [19].

Though there have been several types of research towards the improvement of engineering properties of existing paving materials, less attention has been paid towards user comfort and environment impacts that can be created due to the use of artificial material in outdoor development. Therefore, this research is to identify the thermal properties of materials which are used in outdoor development and compare with mud concrete paving's

II. Materials and Method

One possible approach towards more sustainable construction is to promote the use of alternative, low-energy and renewable material such as earth. Therefore, the main goal of this research is to evaluate the thermal performance of newly invented soil based material that is mud concrete paving block and compare with existing materials.

The experiment of the research was conducted in an open area where the paving materials are exposed to direct solar radiation.

The research was conducted in University of Moratuwa premises, one of the main university in Sri Lanka.

The mud concrete paving block is a combination of soil and Portland cement mixed together with the addition of water. Mud concrete paving blocks were cast using soil with a clay content of 5%, a sand content of 60%, gravel content 35% and 22% cement content[19]. Required numbers of paving blocks were cast in actual size inside the laboratory for the evaluation of thermal performance.

Comparative thermal performance of mud concrete paving block was examined by paving a 2.0 m x 2.0 m area with mud concrete paving blocks, and with different other paving materials that are available in the present industry while keeping the same sub base and are kept under same normal exposure conditions. The selected paving materials were burnt bricks, cement concrete blocks, and asphalt. Temperatures were measured on the surface of the areas paved with the above mentioned materials. Bare ground surface temperature and ambient temperature were also measured as controls. Additionally, temperature measurements were taken at a height 1ft above each paving area to identify the reflectivity of the materials. For all observation areas, the temperature was taken simultaneously at 10 min interval using a data logger. The temperature measurements were performed for a four-day period and 24hrs for each day.

Temperature measurements were taken as two sets of observations. The materials were tested with their native colour and then it was tested after painting them with the same colour to avoid the Albedo effect. Fig. 1 shows the four observation areas with four different paving materials. The colour applied was beige to match the colour of Mud Concrete Paving Block. Fig. 2 shows the change in colour on the paving areas while Fig. 3 shows the painted measurements were analyzed for comparison.

Figure 1. Four observation areas with four different paving materials and data logger

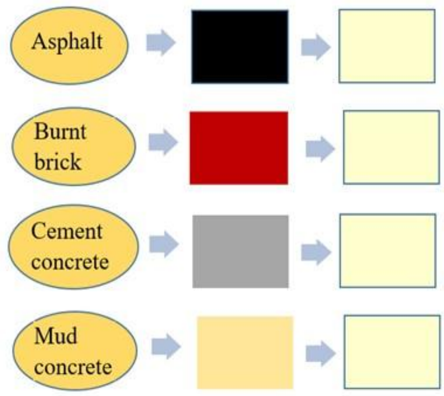

Figure 2. change in colour on the paving areas

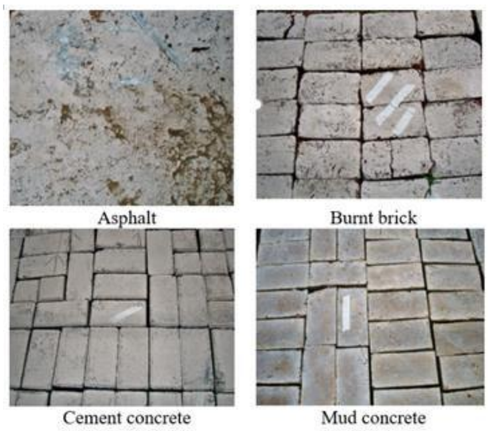

Figure 3. Painted paving areas

III. Results and Discussion

Surface temperature readings and air temperature readings for each sample were taken. The surface temperature (T_{sur}) and temperature of bare ground (T_{bg}) Vs air temperature above1ft from the paving surface (T_{1ft}), the ambient air temperature (T_{amb}) were measured to identify the thermal behaviour of the surfaces and in the immediate surroundings which is affecting for urban heat island effect.

The climate of the selected area is hot and dry during the measurement period similar to the most part of the year as well as most urban areas found in Sri Lanka. The meteorological data of the area shows, February to late March are the hot months of the year, with the daily average temperature ranging from 28-30 ^{0}C and the daily maximum temperature ranging from 31 ^{0}C to 35 ^{0}C. The daily average relative humidity is around 70-80%, and the average wind speed is 5-6 km/hr during the period of measurement.

The temperature variations on the paved areas with their native colour were analyzed first. The 24hrs of the day dividend into two as daytime from 7.00am to 7.000 pm and as night time from 7.00 pm to 7. 00 am during the thermal investigation. The maximum average ambient air temperature during these days was 31.38^{0}C at 2.00pm and throughout the day time all the surfaces heated up rapidly compared to the bare ground.

During the night time, all the paving and bare ground surfaces show nearly the same temperature with variation less than 0.8^{0}C. The temperature variation of all the paving materials selected is shown in Fig. 4.

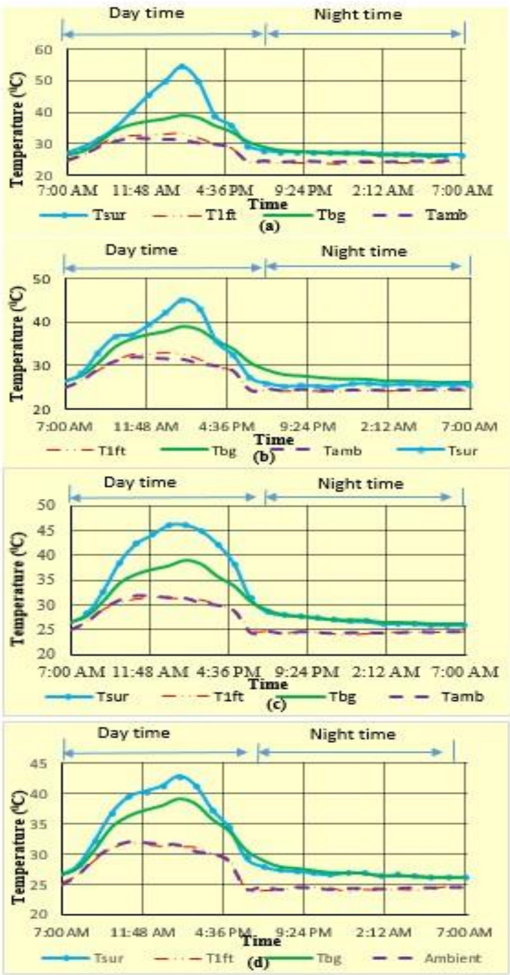

Figure 4. Temperature variation of selected paving materials material (a) Asphalt,(b) Burnt brick, (c) Cement concrete, (d) Mud concrete

The maximum temperature of the asphalt surface during day time was 54.43 ^{0}C, which is 17.63 ^{0}C higher than the bare ground temperature due to the high thermal capacity of the asphalt paving than bare ground. The maximum temperature at a height of 1ft above the asphalt surface reached 33.22 ^{0}C, showing a difference between the ambient temperature and the temperature at a height of 1ft above of 1.84 ^{0}C due to the high albedo of the asphalt.

In the case of burnt brick paving, the maximum temperature of the burnt brick surface was 45.00 ^{0}C, which is 8.2 0C higher than the bare ground temperature due to the high thermal capacity of the burnt brick paving than bare ground. However, this temperature difference was less than 9.43^{0}C the temperature difference between bare ground and asphalt surface. Therefore, it can be concluded that the thermal capacity of the burnt brick is less than the asphalt. Further, this is much better than dark asphalt as paving material when considering the user comfortability, because the burnt brick surface temperature is less in the considerable amount than that of the dark asphalt surface.

The maximum temperature at a height of 1ft above the surface reached 32.88 ^{0}C, showing a difference between the ambient temperature and the temperature at a height of 1ft above 1^{0}C due to the high albedo of the burnt brick.

In the case of cement concrete paving the maximum temperature of the surface was 46.30 ^{0}C, which is 7.38 ^{0}C higher than the natural ground temperature due to the high thermal capacity of the cement concrete paving than the natural ground. However, this temperature difference was less than that of the temperature difference between the natural ground and asphalt and the temperature difference between the natural ground and burnt brick as well. Therefore, it can be concluded that the thermal capacity of the cement concrete is less than the asphalt and burnt brick.

The maximum temperature at a height of 1ft above the surface reached 32.88 0C, showing a minor difference (about 1) between the ambient temperature. This shows that the lighter colour with a high albedo, cement concrete paving is less reflective material.

In the case of mud concrete paving the maximum temperature of the surface was 42.80 ^{0}C, which is 3.8 ^{0}C higher than the bare ground temperature due to the thermal capacity of the mud concrete paving than bare ground. However, this temperature difference was significantly less than temperature different between bare ground and asphalt, burnt brick as well as cement concrete. Therefore, it can be concluded that the thermal capacity of the mud concrete is less than the that of all the other paving materials and it is the best innovation when addressing the user uncomfortably due to high surface temperature.

The maximum temperature at a height of 1ft above the surface reached 31.82 ^{0}C, showing a minor difference between the ambient temperature. This shows that the mud concrete paving also less reflective material. The comparison of the surface temperature variation of each paving area is shown in Fig. 5 and Fig. 6 shows the comparison of temperature variation of 1ft above the surface.

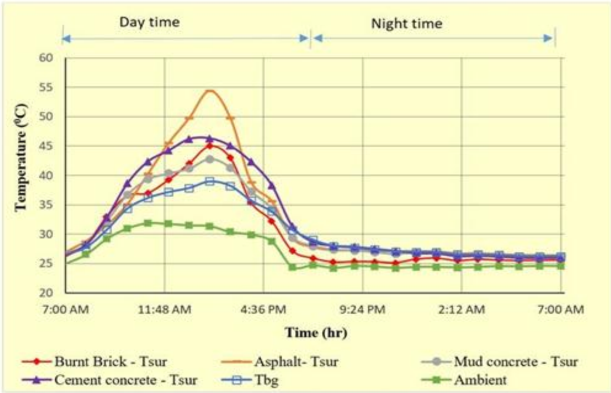

Figure 5. The comparison of the surface temperature variation of each paving area

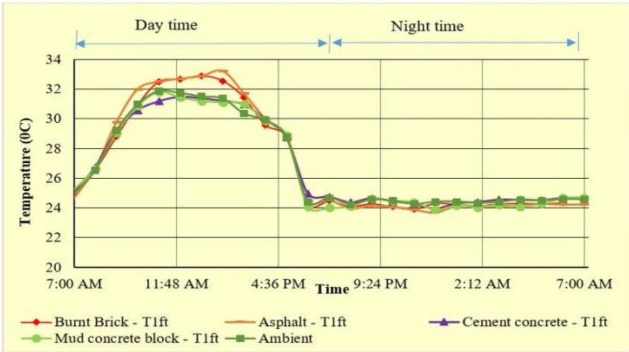

Figure 6. The comparison of the temperature variation of 1ft above the surface

Then the same testing method was repeated and results were analyzed for the painted paved areas to avoid the effect of colour to the surface temperature and surrounding air temperature. The results showed that all the surfaces heated up rapidly compared to the bare ground throughout the day time. During the night time, all the surfaces show nearly similar temperatures within a miner range of variation. Comparison of temperature variations after applying the surface colour for all the paving materials, with temperatures of the surfaces before applying the paint is shown in Fig. 7.

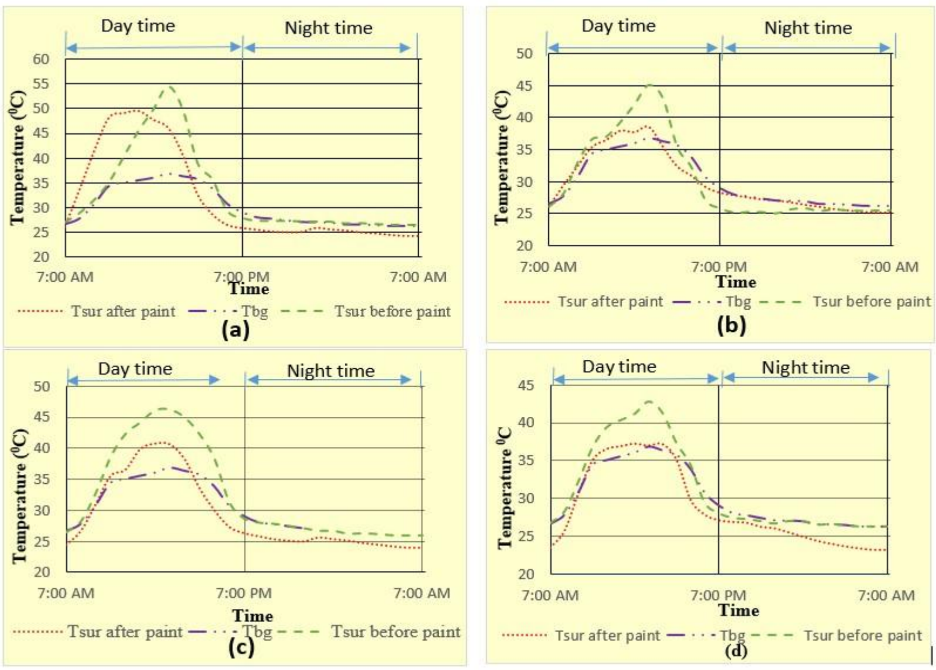

Figure 7. Comparison of temperature variations after applying the surface colour for all the paving materials, with temperatures of the surfaces before applying the paint (a) Asphalt,(b) Burnt brick, (c) Cement concrete, (d) Mud concrete

The maximum temperature of the painted asphalt surface during day time was 49.43^{0}C, which is 12.63 ^{0}C higher than the bare ground temperature, and which is less than 5 .00 ^{0}C with compared to the surface temperature before painting. The result indicates that, by reducing the surface colour, the surface temperature can be reduced.

The maximum temperature of the painted burnt brick surface showed a value of 38.59 ^{0}C which was less 6.41^{0}C than the unpainted surface of it, but which was extra than 1.79 ^{0}C the bear ground temperature. Even though the surface temperature value of painted burnt brick was higher than the surface temperature value of bare ground, it could decrease the surface temp. of burnt brick by a considerable amount due to the application of lighter colour paint.

The maximum temperature of the painted cement concrete surface showed a value of 40.67 ^{0}C, which was less 5.63 ^{0}C than the unpainted surface of it.

In the case of mud concrete paving, the maximum temperature value of the painted surface was 37.25^{0}C, which is 5.5 ^{0}C less than the unpainted mud concrete surface.

All the above results proved the capability of light coloured surfaces to reduce the thermal capacity of a material by increasing its albedo value.

The maximum T_{1ft} of painted asphalt surface reached a value of 37.06 ^{0}C, which is 3.84 ^{0}C greater than T_{1ft} of unpainted asphalt, and 4.9 ^{0}C higher than the ambient temperature.

This shows that it has caused to increase the air temperature of immediate surroundings, by increasing the urban heat island effect than the unpaved area.

The maximum T1ft of burnt brick surface reached 41.69 0C which is 8.81 0C higher than the unpainted case and 9.8 0C higher than the ambient temperature.

This shows that it has caused to increase the air temperature of immediate surroundings, by increasing the urban heat island effect than the unpaved area and this effect is higher than the result acquired for asphalt. Therefore, it can be concluded that by reducing the surface temperature by applying the lighter colour to the surface, and by improving the albedo value of the materials can course unexpected adverse side effects too. Nevertheless, it is clear that the surface colour or albedo value is not the only factor which influences on the thermal behavior of the material, but the properties of the material also can be affected together.

In the case of cement concrete and mud concrete, the maximum temperature at a height of 1ft above the surface reached the same temperature in their unpainted case as well.

When discussing the overall results, the surface temperature values obtained for light colour applied asphalt surface can be identified greater than the surface temperature values obtained for other materials even in their native colour, (refer Fig. 8) which depicts that using asphalt as an outdoor paving material shows unproductive in terms of thermal comfort point of view.

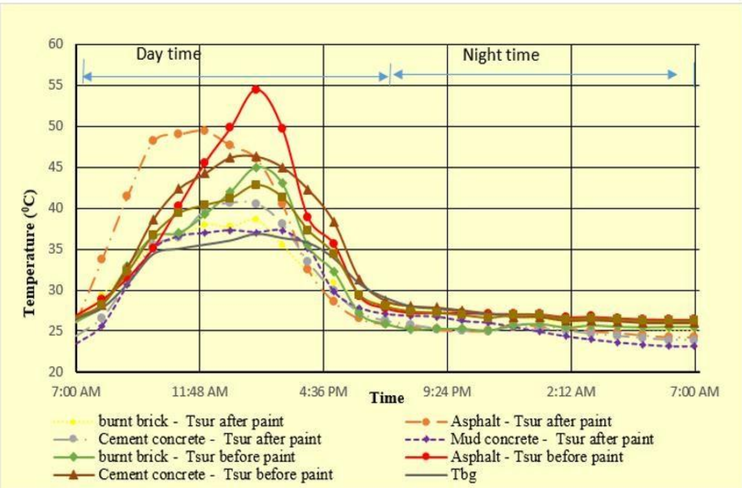

Figure 8. Comparison of surface temperature variations after applying the surface colour for all the paving materials, with temperatures of the surfaces before applying the paint

Out of all the selected materials, two of earth related materials (burnt brick, mud conc.) shows less surface temperature results after the application of light colour on it; mud concrete paving showed lesser results.

In terms of air temperature values obtained, the light colour applied burnt brick paving showed the highest reflectivity value (highest air temperature value in the immediate surrounding). Therefore, it can be considered as the highest contributor to urban heat island effect, out of all the selected paving materials. (refer Fig. 9)

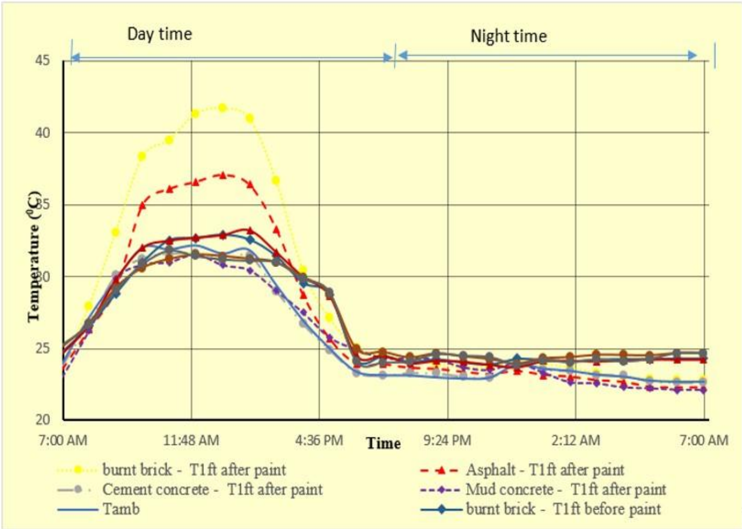

Figure 9. Comparison of T $_{1ft}$ temperature variations after applying the surface colour for all the paving materials, with temperatures of the surfaces before applying the paint

In the case of mud concrete paving, the results showed a lesser temperature increase in both surface and air temperature in the immediate surrounding. (refer Fig. 8 & 9), which depicts the absorptivity and reflectivity properties of mud concrete is neutral compared to the other materials. This finding opens further research directions to explore the energy's behavior with mud concrete properties.

IV. Conclusion and Recommendations

The knowledge of thermal behaviour of various urban surfaces and landscaping is an important tool for planners and designers. Use of outdoor paving blocks provides an attractive solution, preventing from the unpleasant muddy situation in rainy seasons even though, its proved that the manmade hard surfaces (selected paving materials) contribute in heating up the outdoor environment than natural bare ground. Since such impervious artificial surfaces work as "heat sources "to the urban environment, the research recommends the usage of impervious pavements to be reduced in terms of reducing urban heat island effect, thus global warming. Identification and utilization of environment-friendly, eco-materials in infrastructure developments can lead to climatic restoration in urban areas in the future, as well as to gain outdoor human thermal comfort.The newly invented mud concrete paving block is proved to be a fascinating innovation to address the current trending thermal issues, such as urban heat island effect. Therefore, the research recommends using mud concrete paving blocks as the most successful paving solution for tropical outdoors, moreover, it is further recommended to use manmade pavings together with turfing, which avoids albedo effect as well as encouraging photosynthesis.

V. Limitations and Further Directions

The mud concrete paving block which was developed up to this level has strength limitations to be used in vehicular parking areas. Thus further research can be conducted to develop such restrictions of mud concrete.

Only one colour variation was used in this research due to time limitations, but this research can be further developed with more colour variations/range applied on the material surfaces.

Identified potential paving block materials can be further developed with the application of continues wet surfaces and increasing the porosity properties of the materials etc.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All three authors contributed to Conceptualization and methodology. Authors G.H.Galabada and Malthi Rajapakse contributed for Experimental work, data collection, data analysis and manuscript writing. Author Prof. Rangika Halwatura supervised the research work, reviewed and edited the final manuscript. Finally, all authors had approved the final version of this manuscript.

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- F.R. Arooz, , R.U. Halwatura, Mud-concrete block (MCB): mix design & durability characteristics, Case Studies in Construction Materials,
  Volume 8, June 2018, Pages 39–50
- R.U. Galagoda , G.Y. Jayasinghea, R.U. Halwatura , H.T. Rupasinghe, The impact of urban green infrastructure as a sustainable approach towards tropical micro-climatic changes and human thermal comfort, Urban Forestry & Urban Greening, 2018

- S Pathirana, · A Rodrigo, · R U Halwatura,Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate, International Journal of Energy and Environmental Engineering, 2018.

Prof. Halwatura is guiding about 7 fellows for the Ph.D program while working as a Professor in Department of Civil Engineering, University of Moratuwa, Sri Lanka. He has visited many foreign countries for presenting research papers in international conferences. He has also delivered many invited talks and also chaired and co-chaired national and international conferences and also a reviewer of several international journals. He was awarded in several times for his contribution to the development of science and technology; the most reason few awards are listed below, TWAS (The World Academy of Science) Young scientist award – 2017

- Award for Outstanding Research award with distinction, University of Moratuwa. 2017
- Presidential Awards for Academic Publications, 2018