THERMAL CHARACTERIZATION OF URBAN HOUSING ENVELOPES AND ITS IMPLICATIONS ON RESIDENTIAL HEAT FLUX IN NIGERIA

JOSIAH NWABUEZE OBIEFUNA[1], EBIN OKAH INAH[1], GIFT DOMINIC EFFIONG[1]*

ABSTRACT. Thermal Characterization of Urban Housing Envelopes and its Implications on Residential Heat Flux in Nigeria Presently, immense attention is on sustainable developments because of the energy crisis, which has inundated the world at an alarming level. As a result, sustainability has become a major consideration that must be given priority while planning and developing modern urban areas. This study examined thermal signatures from selected colours of housing envelopes (roofing materials) used for construction in most rural and urban areas in Nigeria. Data for the study comprised thermal readings from 5 different colours of these materials collected over morning, afternoon and evening periods. Analysis of Variance, ANOVA, was used to test whether the variation across various colours and temporal periods was significant. Findings show that green roofing material has an average reading of 39.8^0C, while black roofing material has an average of 55.6^0C. Besides, orange-coloured material has an average of 34.1^0C, while beige colour has an average of 34.7^0C. Silver colour has an average of 32.1^0C. From the result of the analysis, it was discovered that there exists a significant variation in the thermal absorptive characteristics of the roofing materials considered. Temporally, high temperature $>40^0$C was observed to have been emitted from black and green colours all through afternoon and evening periods suggesting that these colours have high thermal absorptivity. It was therefore recommended that urban development authorities, architects and homeowners should always adopt the right and efficient colours of roofing materials to reduce high incidences of heat absorption and transfer from these materials and also conserve energy that would have been used for cooling or warming. Colours with high reflectivity should be used if a maximum cooling effect is desired. Black and green colours should be avoided in tropical regions due to low solar reflectivity, high thermal absorptivity and heat flux. Building owners should avoid substandard and untreated building materials (non-cool roofs) during roofing construction for good ambience.

[1] *Department of Geography and Environmental Science, Faculty of Environmental Sciences, University of Calabar, P.M.B. 1115, Calabar-Nigeria. https://orcid.org/0000-0003-2426-082X Email: Joeobiefuna@Gmail.com, JoeObiefuna@Unical.edu.ng.*
**Corresponding author*

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1. INTRODUCTION

The answer to the question of whether development in most developing countries is sustainable would be negatively skewed. It is appalling because of the unsustainable manner in which the environment is exploited, through high demand for unmatched aesthetics and personal aggrandizement. There seems to be serious search for glory and vanity at the expense of healthy conditions. This has been the experience in the choice of type and colour of residential apartments.

Colour is defined as the sensation experienced or caused by light reflected from or transmitted through objects (Randall, *ND)*. Colour is an important component of building and roofing design. Housing envelopes also called roofing materials have been described by Wikipedia Online Encyclopaedia, (2015) as the outermost layer on the roof of a building, sometimes self-supporting but generally supported by an underlying structure. However, it has been theorized that dark colours absorb and easily re-emit heat or thermal radiation to their surrounding through radiation and other heat transfer mechanisms (Whyte, 2015). Most dark roof materials reflect 5 to 20 percent of incoming sunlight, while light-colored roof materials typically reflect 55 to 90 percent (Urban & Kurt, 2010). Solar reflectance has lots of effects on keeping housing roofs cool in the sun. So, light colours and smooth surfaces are milder interns of heat generation (Bansal, Garg & Kothari, 1992). Besides, light surfaces also back-scatter or reflect solar energy (Canada Centre for Remote Sensing, CCRS, 2002). Therefore, dark-coloured roofing materials would tend to absorb the sun's energy, causing it to be hotter as the day progresses, making life uncomfortable. Due to exposure to direct sunlight, the roof becomes the hottest element of any building. Suehrcke, Peterson and Selby (2008) reported that about 20 to 95 percent of solar radiation falling on a roof surface during clear sky conditions is absorbed. The absorbed part of solar radiation effects the surface temperature and indoor temperature of the building (Givoni, 1998). However, the effect of colour of the building envelope/roof on its indoor temperature is to an extent dependent on parameters such as building location, quality, orientation, the composition of the walls, windows and air ventilation system (Cheng & Givoni, 2005).

A reconnaissance survey of Calabar revealed hundreds of housing facilities with varying shades of colours of roofing materials ranging from black, orrange, green, blue, brown, grey, bare etc. The choice of most of these colours was made based on either colour preference, the anticipated colour of walls and windows to match, or as suggested by friends, spouse or children. Public and private housing developers randomly choose colours based on taste and fashion rather than function, safety, housing comfort and convenience. High temperature-emitting material used in the construction of any housing unit would tend to increase electricity consumption. It would also reduce the life span of certain materials used in erecting the structures.

In advanced countries, some level of work has been done on this theme but it is evident that due to climate considerations, the nature of roofing materials used in advanced countries are climate-friendly and quite different from what is obtainable in most developing nations, particularly Nigeria, where high conductive metallic roofing materials such as long span, Nigerian corrugated iron sheets popularly known as zinc and Cameroon zinc are prevalently used by the wealthy without considering the likely implications. Nutech (2011) states that as the roof space becomes superheated up to 90°C on a 35°C day, the temperature of rooms below could get unbearable even with insulation, air conditioning becomes overworked and temperature extremes detrimentally affect the durability and longevity of the whole roof structure.
Sadly, most architects do not emphasize the effect of the roof colour and its importance in reducing the indoor air temperature in the building design (Mohammed & Ahmad, 2012). Cool roofs have several benefits (Urban & Kurt, 2010). One of the most obvious advantages of a cool roof is lower energy use and reduced utility bills, increased comfort for building occupants. Bunker et al. (2024) recommends implementing sunlight-reflective roof coatings known as "cool roofs," as a climate change adaptation intervention for passive indoor home cooling. In addition, Singh and Sunayana (2017) stated that the direct and indirect benefits and energy savings potential of cool roofs include reduction of urban heat island, global warming, local air temperature and creation of a more comfortable and healthier environment. Ashtari et al. (2021); Rabah, (2005) believes that it helps to directly sustain thermally favorable conditions in the built-up environment while mitigating energy consumption. Besides, Azari, (2014); Yeganeh, (2015); Yeganeh et al. (2018); Motevallian and Yeganeh, (2020) assert that it helps to reduce the need for heating, cooling, and electrical lighting, meaning that energy efficiency of buildings strongly depends on the thermal performance of their envelopes.

Against these facts, public and private developers randomly choose colours on the basis of taste and fashion, ignoring safety and comfort. This is the mystery that this research tends to unravel by generating accurate data and information on the actual thermal behaviour of these colours, with a view to proper re-orientation. In Calabar, it is certainly a case of ``my people perish because of lack of knowledge`, no known attention has been paid to this nature of research in the study area. This paper assessed the thermal characterization of roofing materials and their implication on housing thermal behaviour in Calabar Municipality, Cross River State, Nigeria. Specifically, the objectives of the study are to:

1. Assess the temperature variability across various colours of roofing materials in the study area.
2. Assess temperature variability over the periods being considered in the study area.
3. To give expert recommendations to planners and developers on planning implications of the use of the best, heat absorbing, heat resistant and sun reflective colours in attaining a better housing experience and energy savings especially, in areas of extreme temperatures

The following specific hypotheses were formulated and tested, and the first states that there is no significant variation in thermal signatures/heat flux across various shades of roofing materials in the study area, while the second states that there is no significant variation in the temporal characteristics of the thermal signatures of various shades of roofing materials in the study area

2. MATERIALS METHOD

This study adopted an experimental route to explanation. In an experiment, a treatment, procedure, or program is intentionally introduced and a result or outcome is observed. Data for this study included spectral characteristics (colour) and thermal readings from various prevalently used colour shades of roofing materials such as green, black, orange, brown and grey. Thermal data were acquired in the form of temperature readings. All thermal or temperature values are continuous, and were expressed in the Celsius (^{0}C) scale.

Data of primary origin were sourced from the roofing samples mounted at the synoptic weather station of the University of Calabar (experimental location) and used to accomplish this research. Data were acquired using required data logger named digital non-contact infrared thermometer.

Various roofing materials of varying shades of colours were acquired from the authorized dealers. Each was of a specified dimension of about 60 centimetres by 60 centimetres and with the same thickness. They were exposed to direct solar radiation, with data logger thermometers (non-contact infrared thermometers) installed for thermal data acquisition from the surface of the samples. Before data reading, the digital apparatus was allowed to self-calibrate for 2 minutes. Due to the availability and variation in the design of the internal ceiling materials such as asbestos, concrete/cement, plastics, Plaster of Paris (PoP), etc., which can influence the amount of heat being transmitted to the housing interior, data acquisition was restricted to the surface of the roofing materials. Data was taken repeatedly to ensure that readings are valid before being recorded. With regards to time, data were acquired from the installations in the afternoon (2 pm), and evening (6 pm) for one month.

Sourced data were analyzed using descriptive statistics. The output was in percentages, averages, tables, charts and graphs, and pictures. Besides, inferential statistics was used to test the hypotheses.

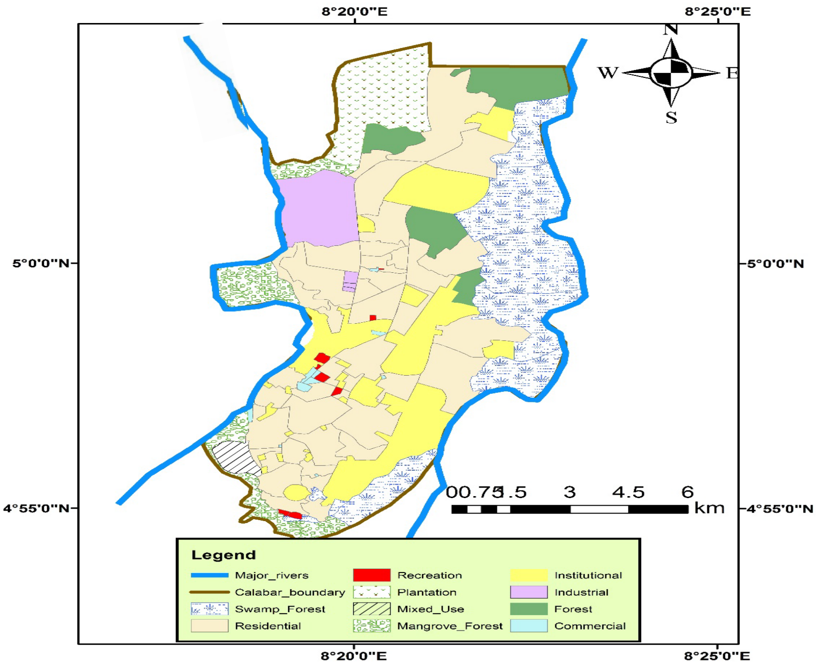

Figure 1: Built-Up Areas and Other Land Uses in Calabar

Source: Source: Obiefuna, et al. (2021)

3. RESULTS

Hypothesis 1

H_0: There is no significant temperature variation in the thermal absorption characteristics across the periods in the study area

In this study, the hypothesis is presented in a null form. The data for the variables were analyzed using One Way Analysis of Variance (ANOVA) and the hypothesis was tested at 0.05 level of significance, the result of the data analysis is presented in Tables 1 and 2.

The results revealed that the calculated F-ratio of 9.47 is greater than the critical F-ratio of 3.06 with 5:2 degrees of freedom at 0.05 level of significance. The analysis further indicates that $p<0.05$. Based on this result, the null hypothesis is rejected while the alternative hypothesis is accepted. This means that there is a significant temperature variation in the thermal absorption characteristics over the periods in the study area. It is also shown in the analysis that though all the categories were significant, the week 2 category shades of roofing materials has the highest score of 40.5, hence contributing more to the significance of the result.

Table 1 Summary of one-way ANOVA of temperature variation in the thermal absorption characteristics across the periods in the study area

Level of influence	N	Mean(X)	Standard Deviation (S.D)	sig
1-7days	5	37.9	2.21	.000
8-14 days	5	40.6	3.05	.000
15-21 days	5	36.5	2.05	.000
22-28 days	5	38.5	3.01	.000
Total 28 days	**20**	**153.5**	**10.36**	**.000**

* p<0.05 df= 5:2 critical F= 3.06

Table 2. One-way ANOVA analysis of temperature variation in the thermal absorption characteristics across the periods in the study area

Source of variation	SS	Df	MS	F-ratio	Sig.
Within group	153.5	5	767.5		
				9.47*	.000
Between group	40.5	2	81.0		
Total	194.0	7			

* p<0.05 df= 5:2 critical F= 3.06

Hypothesis 2

$H_{0:}$ There is no significant temperature variation in the thermal absorption characteristics of various shades of roofing materials in the study area

The data for the variables were analyzed using One Way Analysis of Variance (ANOVA) and the hypothesis was tested at 0.05 level of significance, the result of the data analysis is presented in Tables 3, and 4.

Table 3. Summary of one-way ANOVA of temperature variation in the thermal absorption characteristics of various shades of roofing materials in the study area

Level of influence	N	Mean (X)	Standard Deviation (S.D)	sig
Green colour	4	39.2	2.05	.000
Black colour	4	54.0	3.08	.000
Orange colour	4	33.1	2.02	.000
Biege colour	4	34.3	2.04	.000
Grey colour	4	31.1	2.01	.000
Total 28 days	**20**	**192.0**	**11.2**	**.000**

* p<0.05 df= 5:2 critical F= 3.06

Table 4. One-way ANOVA analysis of temperature variation in the thermal absorption characteristics of various shades of roofs in the study area

Source of variation	**SS**	**Df**	**MS**	**F-ratio**	**Sig.**
Within group	192.0	4	768.0	7.11*	.000
Between group	54.0	2	108.0		
Total	246.0	6			

* p<0.05 df= 5:2 critical F= 3.06

The results revealed that the calculated F-ratio of 7.11 is greater than the critical F-ratio of 3.06 with 4:2 degrees of freedom at 0.05 level of significance. The analysis further indicates that p<0.05. Based on this result, the null hypothesis is rejected while the alternative hypothesis is accepted. This means that there is a significant temperature variation in the thermal absorption characteristics of various shades of roofing material in the study area. It is also shown in the analysis that though all the categories show significance, the Black roofs colour in the 2nd category of all the roof colours has the highest score of 54.0, hence contributed more to the significance of the result.

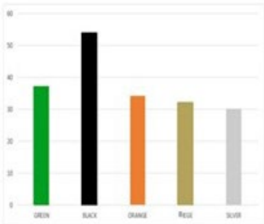

Figure 2: Week one average mean of the five roofing materials

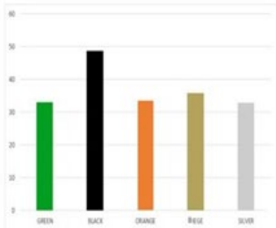

Figure 4: Week three average mean of the five roofing materials

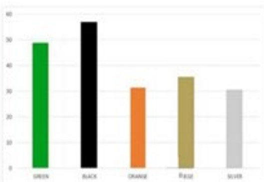

Figure 3: Week two average mean temperature (⁰C) of the five roofing materials

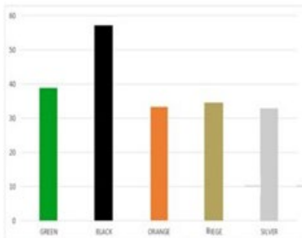

Figure 5: Week four average mean of the five roofing materials

Source: Authors field work

Figures 2,3,4,5 depict the weekly average mean temperature variation on green roofs, black roofs, orange roofs, beige roofs and grey roofs in the study area. From Figure 2, green roofs absorb average mean of 37.1ºc, black roof absorb 53.9ºc, orange roofs absorb 34.3ºc, beige roofs absorb 32.2ºc and grey roofs absorb 30.1ºc. From the result, among the five colours of roofing materials used in the three periods, black roofs had the lowest and the least reflectivity while silver roofs absorbs less and reflect more radiation to the atmosphere, as the most temperature is absorbed mostly in the afternoon.

4. DISCUSSIONS

The findings of the study in relation to the temperature variation in the thermal absorption characteristics across the periods in the study area revealed that week 1 has a total average temperature mean of 7.5, week 2 has a total average temperature mean of 40.5, week3 has a total average temperature mean of 36.6, while week 4 has a total average temperature mean of 38.9. Hence, it was concluded that week 2 has the highest total average temperature mean than any other week. This finding is in line with the findings of Karl et al. (1997, p. 81), that the day-to-day temperature changes are less certain than those of the mean, but observations have suggested that this temperature variability of various shades of roofing materials depending on the colours of the roofs as the climate has become warmer.

In addition, findings with regards to temperature variability of various shades of roofing material revealed that green roofs absorb an average temperature of 39.1, black roofs absorb an average temperature of 54.0, orange roofs absorb an average temperature of 33.1, Beige roofs absorb an average temperature 34.3 and grey roofs absorb an average temperature of 31.4.

Hence, it was concluded that black roofs absorb more temperature than any roof. This finding is in line with the findings of (Sailor, 1995), that darker surfaces absorb more solar radiation while lighter surfaces reflect more light and black colour absorbs a high temperature.

Furthermore, findings with regards to temperature variability over the periods and locations being considered in the study area, show that areas within Ward 6 to Ward 10, with locations such as Federal Housing Ekorinim and satellite town, with high-class residents, have roofs that absorb lesser heat while areas within Ward 1 to Ward 5 with locations such as Big Qua and has working-class residents have roofs with high heat absorption capability. This finding agrees with the findings (Keneth, 2013) that the spatial variation of temperature variability of various roof shades depends on the nature of buildings in the location.

5. CONCLUSION AND RECOMMENDATION

Based on the findings of the study, it is concluded that there is a significant temperature variation in the thermal absorption characteristics of various shades of roofing material in Calabar Metropolis. The variation was observed at different temporal periods with these, this research has been able to expose the need for a better choice of colour of roofing materials in the housing sector.

In accordance with the findings of the study it was thus recommended that;

1. Building owners should adopt state-of-the-art roofing technologies and color shades that allow greater reflection of heat energy. This includes roofing materials with white or lighter color shades and avoiding black materials.
2. Building owners should ensure to avoid fake roofing materials during roofing construction for durability and heat ambiance
3. Temperate/tropical regions should adopt the right color of roofing material for energy efficient temperature regulation.
4. More research covering all colours of roofing materials and all types of ceiling materials is recommended in order to identify the perfect combination for housing heat reduction and energy saving.

REFERENCES

1. Ashtari B, Yeganeh M, Bemanian M and Vojdani Fakhr B (2021). A Conceptual Review of the Potential of Cool Roofs as an Effective Passive Solar Technique: Elaboration of Benefits and Drawbacks. Front. Energy Res. 9:738182. https://doi.org/10.3389/fenrg.2021.738182
2. Azari, R. (2014). Integrated Energy and Environmental Life Cycle Assessment of Office Building Envelopes. Energy and Buildings, 82: 156–162. https://doi.org/10.1016/j.enbuild.2014.06.041
3. Bansal, N. K., Garg, S. N. & Kothari, S. (1992. Effect of exterior surface colour on the thermal performance of buildings Building and Environment 27, 31-37
4. Bunker A , Compoaré G, Sewe M. O, Laurent J.G, Zabré P, Boudo V, Ouédraogo W. A, Ouermi L, Jackson S. T., Arisco N, Vijayakumar G, Yildirim F. B, Barteit S, Maggioni M. A, Woodward A, Buonocore J. J, Regassa M. D, Brück T. Sié A and Bärnighausen T (2024). The effects of cool roofs on health, environmental, and economic outcomes in rural Africa: study protocol for a community-based cluster randomized controlled trial. Trials, 24 (59), 1-18. https://doi.org/10.1186/s13063-023-07804-0
5. Canada Centre for Remote Sensing (CCRS, 2002). Fundamentals of Remote Sensing, Canada. Assessed online from https://natural-resources.canada.ca/sites/nrcan/files/earthsciences/pdf/resource/tutor/fundam/pdf/fundamentals_e.pdf, March, 2024.

6. Cheng, V., Ng, E. &Givoni, B. (2005). Effect of envelope colour and thermal mass on indoor temperatures in hot humid climate. Solar Energy, 78, 528-534.
7. Givoni, B. (1998). Climate considerations in building and urban design, New York, John Wiley and Sons.
8. Mohammed S. B. & Ahmad S. H (2012). The Effect of Roof Colour on Indoor House Temperature In Case of Hadhramout. American Transactions on Engineering & Applied Sciences, 1(4), 365-478. Available at http://TuEngr.com/ATEAS/V01/365-378.pdf
9. Motevalian, N., and Yeganeh, M. (2020). Visually Meaningful Sustainability in National Monuments as an International Heritage. Sustain. Cities Soc. 60,102207. https://doi.org/10.1016/j.scs.2020.102207
10. Nutech Paint (2011). Heat Reflective Roof Coating with Thermal Protection Technology Enhanced with Surface Cleaning Nano Technology. Assessed online on 15th June, 2025, at https://www.yumpu.com/en/document/view/8966661/heat-reflective-roof-coating-with-thermal-nutech-paints
11. Obiefuna, J. N., Inah, E. O., Atsa J. W. U. and Etim. E. A. (2021). Geospatial Assessment of Ambient Air Quality Footprints in Relation to Urban Land uses in Nigeria. *Environment and Ecology Research,* 9(6), 426-446. http://doi.org/10.13189/eer.2021.090609
12. Rabah, K. (2005). Development of Energy-Efficient Passive Solar Building Design in Nicosia Cyprus. Renew. Energ. 30 (6), 937–956. doi:10.1016/j.renene.2004.09.003
13. Randall, D (ND) Instruments for the Measurement of Color, Datacolor International, Charlotte, NC. Assessed online on 15th June 2025, at https://www.scribd.com/document/364731580/Instruments-for-Color-Measurement-pdf
14. Sailor, D. J. (1995).Simulated urban climate response to modifications in surface albedo and vegetative cover. Journal of Applied Meteorology, 34(7), 1694-1704.
15. Whyte, D. B (2015). Absorption of radiant energy by different colours. Science Buddies. Retrieved on 15th June, 2025 at https://www.sciencebuddies.org/science-fair-projects/project-ideas/Phys_p073/physics/radiant-energy-absorption-colors
16. Singh S. P. & Sunayana M (2017) Cool Roof Technology. IJSRD - International Journal for Scientific Research & Development| 4, (11), 97-101
17. Suehrcke, H., Peterson, E. L. & Selby, N. (2008). Effect of roof solar reflectance on the building heat gain in a hot climate. energy and Building, 40: 2224-2235.
18. Urban, B & Kurt R. (2010). Guidelines for Selecting Cool Roofs. Energy Efficiency and Renewable Energy, Assessed online at chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www1.eere.energy.gov/buildings/publications/pdfs/corporate/coolroofguide.pdf
19. Wikipedia online Encyclopedia, (2015). experimental Studies. Assessed on June 15th, 2025 from en.wikipedia.org/wiki/hypothesis

20. Yeganeh, M. (2015). Educating Designing an Architectural Model Based on Natural Principles and Criteria. International Conference New Perspectives in Science Education Florence, Italy.
21. Yeganeh, M., and Kamalizadeh, M. (2018). Territorial Behaviors and Integration Between Buildings and City in Urban Public Spaces of Iran′s Metropolises. Front. Archit. Res. 7 (4), 588–599. https://doi.org/10.1016/j.foar.2018.06.004