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Optimizing thermal comfort for tropical residential designs in Nigeria: How Significant are the walling fabrics?

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Abstract
Harsh tropical climate occasioned by high temperature (through solar gain) with its attendant indoor thermal discomfort, prompted an investigation into a sustainable method of improving indoor thermal comfort through thermal analyses of contributory roles of the walling fabrics. Using 'DesignBuilder' simulation tool, a model of a single-storey building, representative of the predominant residential design typology in the *Ogbomoso* study area of Nigeria was thermally analysed by substituting the prevalent cement plaster on the interior surfaces of the core walling units, hollow sandcrete block-walls, with plywood, timber and rug in succession. Contrary to expectations, no significant improvements on the indoor thermal comfort were observed as the major sources of solar heat gain were noted to be from the roof fabric and the external windows. The study therefore suggests rather, the need for thermal improvement on the components of the identified heat enhancing fabrics for improved indoor thermal comfort in the study area.

Key words: Thermal Comfort, Building Fabrics, Tropical Climate, sandcrete block, Cement Plaster, U-Value

1.0 Introduction
The most obvious requirement of any dwelling is to enable people to rest, eat and sleep comfortably (Angus, 1968; Appah and Koranteng, 2012). A good indoor climate is the one which takes individual needs into account, facilitates personal influence on environmental conditions and particularly considers the needs of sensitive and exposed groups. It also ensures absence of damaging effects on health and ensures that at least, 80% of residents or users of buildings are satisfied (Fergus et al, 2012; Torben and Peter, 2010). This is perhaps the most important aspect of the design since if the occupiers are not satisfied with the comfort conditions within, the building is regarded as a failure.

Tropical region includes all the areas on earth where the sun reaches a point directly overhead at least once during the solar year. It is predominantly characterised with high solar gains with its attendant high temperature, leaving all the twelve months having mean temperatures above 18°C (64°F) (Wikipedia, 2012). As such, tropical cities like Ogbomoso, Western Nigeria within this context, are characterised with high exterior temperature as much as 34°C (93.2°F) in some instances (Ayinla, 2011). This no doubt, would impact on the living conditions of the people particularly the design approach, with a view to shielding the interior spaces from the prevailing harsh outdoor climatic conditions.

Human considers an environment as thermally comfortable if no thermal discomfort is present (i.e. thermal neutrality exists), else he either feels too warm or too cold. His perception of indoor (i.e. interior) thermal comfort is largely influenced by the fabric of the building envelope (particularly the floor, wall, window and roof) as well as his current thermodynamic processes at the time of comfort evaluation (Ward, 2004).

As human thermodynamic processes are affected by a number of factors inclusive of the body metabolic rate, clothing level, air velocity, air temperature, mean radiant temperature, among others, so also the overall indoor energy balance is influenced by the fabric of the building envelope, as determined by its insulation level which either enhances or inhibits transfer of thermal energy across its membrane (Ajibola, 2001; Barrios et al, 2012; Givoni, 1998; Randall, 2007).

To facilitate comfortable interior living conditions in this region on one part, direct application of technological advancement has enhanced integration of active energy source into the building design for attainment of required thermal comfort by the users. However, this is achieved not without the attendant use of non-renewable fossil fuelling source(s) which is usually characterised with its resulting phenomenal global warming, atmospheric pollution, dwindling natural resources, and disruptions in eco-systems, among others. (Koenigsberger et al, 1974; Baofeng, 2004; Michael and Friedrich, 2002; Hyde, 2000).

On the other hand, the current global call for near zero-carbon designs (Mathur and Chand, 2002) has necessitated the imperative need for researches in recent past on the possibility of sustainable buildings with particular interests on passive designs and use of available renewable energy sources inclusive of solar designs (Kefan, 2006; Koenigsberger et al, 1974). Along this direction, use of local materials such as bamboo, mud, brick, adobe, straw-bale among others to complement or as total replacements for the readily available walling unit, ‘sandcrete block’ (finished on both sides, interior and exterior with cement plaster), was introduced. Despite their considerable effectiveness in regulating the interior temperature to an acceptable extent, these materials could not stand the test of time as they are either partly economically unsustainable (i.e. beyond the reach of the generality of the people), structurally deficient, susceptible to exterior climatic elements or availability restricted to particular locality or regions among others (author’s field study, 2011).

As a brief turning from this sustainable approach, this study therefore seeks to evaluate thermal insulation properties of the building fabric with reference to the wall, specifically, the choice of the wall finishes on the interior surface of residential buildings in the tropical city of Ogbomoso, Nigeria. This is with a view to optimising indoor thermal comfort with a selection from numerous identifiable, readily available wall finishes to serve as a partial or complete replacement for the costly, predominant cement plaster, currently in practice.

2.0 The Study Area: Its Climate and the Design Implications

Ogbomoso, a typical city in the South Western Nigeria, lies on latitude 8º08´ North of the equator and longitude 4º15´ East of the Greenwich Meridian within a derived Savannah region. Temperatures throughout Nigeria are generally high as diurnal variations are more pronounced than seasonal ones. Ogbomoso in particular has a climate largely independent of the topographical features but varies by the interactions between two principal wind currents; *The Harmattan* (often appears as a dense fog and covers everything with a layer of fine particles) and *South-West Wind.* While the former is hot and dry and carries a reddish dust from the desert (North-East), causing high temperatures during the day and cools at nights, the latter which is moist, blows off the Atlantic Ocean, thereby facilitating cloudy and rainy weather. The interactions between these two air masses play a distinct role in the country's seasons and temperatures (Nationsencyclopedia, 2012; Traveltips, 2012). As such, two major seasons of Rainy and Dry are experienced on an annual basis.

From a five-year, monthly study (2004-2008) conducted by Ayinla (2011), Ogbomoso has an average air temperature range of between 25.13 and 28.51ºC with highest maximum and least minimum values of 34.73 and 18.9ºC respectively. This is accompanied with high solar radiation (i.e. radiation value of above 10KJ/m^2/day for some months), high humidity (usually above 60%) and low air velocity (usually between 1.5 and 2.0m/s) which usually result in thermal discomfort of the interior spaces in most part of the year. This implies a high propensity of the building occupants in the area to experience thermal discomfort during most part of the year. (Countrystudies, 2012; Nationsencyclopedia, 2012; Traveltips, 2012). Hence, the need for appropriate design interventions, through thermal analyses of the prevalent fabrics of the building envelope in the area without (or with least) recourse to mechanical installations. This is to mitigate the effects of the harsh outdoor climatic elements (particularly high temperature and solar gains) on the interior living conditions of the building occupants.

In doing this, numerical dominance of 'single storey, three-bedroom apartment, single unit' residential building typology (i.e. bungalows) in the study area facilitates its selection for the study with a view to generalising the research output for the area.

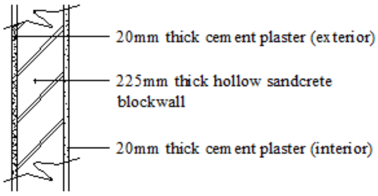
3.0 Computer Modelling and Simulation Strategy

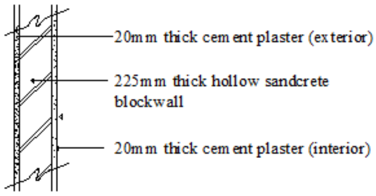
Computer simulation has been proven to be a reliable tool for investigating thermal performance of buildings as it provides dynamic analyses with accurate results (Aditi, 2010). In this wise, DesignBuilder was chosen for the purpose of these analyses in view of its advanced graphical user interface which has been specially developed to run EnergyPlus simulations with virtual building models as it readily provides tools for energy efficiency and sustainability analyses (such as solar and weather tools), which are very important for this study. As such, a virtual model of a three-bedroom apartment, representative of the predominant residential building typology in the study area was generated to test the effects of the changing components of the wall finishes on the indoor thermal comfort conditions

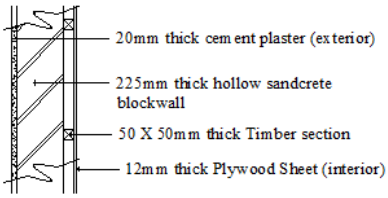
The model was a one storey building covering a land area of 13.5 by 10.5 square metres. It consisted of three Bedrooms, Living Area, Kitchen, Dining, combined Bath/Toilets, Store and Sit-out. The floor to floor height was maintained at 3.0m. The core walling material remained hollow sandcrete block-walls of 225mm and 150mm thicknesses for external walls and partitions respectively. While the external finish on the core walling material remained 20mm thick cement plaster for every case of the simulations, cement plaster, plywood, timber and rug were used in succession on the interior surfaces for the alternative cases of the design propositions. These are as graphically illustrated in Table 1 below. Asbestos roofing sheets and Asbestos ceiling sheets with timber roof carcass formed the roof elements in each case of the simulations.

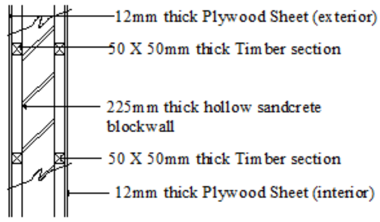
The overall simulation strategy involved modelling and simulation of each of the cases in categories I and II above and comparison of the results in respect of the output variables.

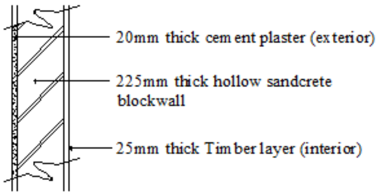
Table 1: Sectional Views of the Wall Finishes (Source: Author's AutoCAD Drafting, 2012)

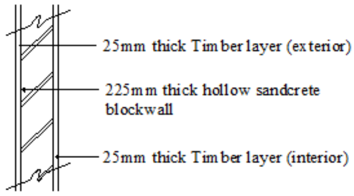
<table>
<tr><th>Category/Finish Material</th><th>Sectional View: External Wall</th><th>Sectional View: Partition</th></tr>
<tr><td>I: PLASTER</td><td>

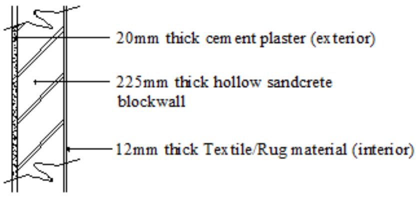
U-value: 1.035W/m^2K</td><td>

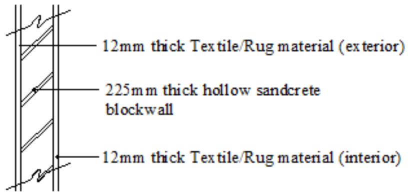
U-value: 1.223W/m K</td></tr>
<tr><td>II: PLYWOOD</td><td>

U-value: 0.799W/m^2K</td><td>

U-value: 0.714W/m^2K</td></tr>
<tr><td>I: TIMBER</td><td>

U-value: 0.947W/m^2K</td><td>

U-value: 0.991W/m K</td></tr>
<tr><td>I: RUG</td><td>

U-value: 0.944W/m^2K</td><td>

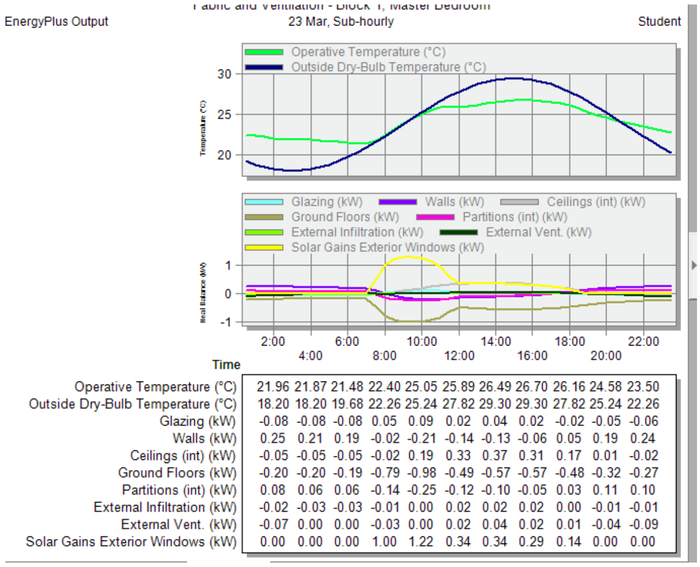
U-value: 0.986W/m K</td></tr>
</table>

The simulation output variables considered relevant in each case include; Passive Solar Gains (due to the Wall Fabrics, Partitions, Glazing, Ceiling, Ground Floor Materials, Exterior Windows, External Infiltration and External Ventilation) obtained through Cooling Design Simulation during the day with highest recorded temperature (in the hottest month) in the study area (i.e. 23rd of March, as revealed in the climatic study of the area). So also are the Comfort Temperature and the Temperature Distribution in each zone, in each case of the simulations. Effects of varying compositions of the wall finishes on the indoor thermal comfort are then established by comparing the values obtained in each case of the simulations for different categories of the virtual models as described earlier. Through these comparisons, significant roles played by each component of the wall fabric on the overall indoor thermal comfort in the residential buildings in the study area are established.

4.0 Simulation Outputs and Discussion of the Results.

From every analysed case of the solar gains through the walls (both at the 'Building' and 'Zone' levels), no significant gains were recorded throughout the simulations despite the alterations in the fabric of the wall finish in each case (i.e. from the base case of plaster to plywood; to timber and; to rug) as the average difference in the solar gains through the walls between the materials remain less than 8%, each recorded hour of the simulations. Similarly, there is no any extreme case of the operative temperature falling outside the acceptable comfort boundaries for all cases of the finishes considered.

However, the investigation reveals significant solar gains into the interior through the Exterior Windows and the Ceiling fabric as illustrated in Figure 1 below. As such, attention needs to be paid to these elements of the building envelope in future thermal analyses as the study indicates their major contributions to the huge heat gains into the interior spaces in the study area.



Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Operative Temperature (°C)	21.96	21.87	21.48	22.40	25.05	25.89	26.49	26.70	26.16	24.58	23.50
Outside Dry-Bulb Temperature (°C)	18.20	18.20	19.68	22.26	25.24	27.82	29.30	29.30	27.82	25.24	22.26
Glazing (kW)	-0.08	-0.08	-0.08	0.05	0.09	0.02	0.04	0.02	-0.02	-0.05	-0.06
Walls (kW)	0.25	0.21	0.19	-0.02	-0.21	-0.14	-0.13	-0.06	0.05	0.19	0.24
Ceilings (int) (kW)	-0.05	-0.05	-0.05	-0.02	0.19	0.33	0.37	0.31	0.17	0.01	-0.02
Ground Floors (kW)	-0.20	-0.20	-0.19	-0.79	-0.98	-0.49	-0.57	-0.57	-0.48	-0.32	-0.27
Partitions (int) (kW)	0.08	0.06	0.06	-0.14	-0.25	-0.12	-0.10	-0.05	0.03	0.11	0.10
External Infiltration (kW)	-0.02	-0.03	-0.03	-0.01	0.00	0.02	0.02	0.02	0.00	-0.01	-0.01
External Vent. (kW)	-0.07	0.00	0.00	-0.03	0.00	0.02	0.04	0.02	0.01	-0.04	-0.09
Solar Gains Exterior Windows (kW)	0.00	0.00	0.00	1.00	1.22	0.34	0.34	0.29	0.14	0.00	0.00

Figure1: Simulation results indicating different heat gain sources at the building level
(source: DesignBuilder Simulation output, 2012)

5.0 Recommendations and Conclusion

This study evaluates thermal insulation properties of the building fabric with reference to the wall, specifically, the choice of the wall finishes on the interior surface of residential buildings in the tropical city of Ogbomoso, Nigeria. This is with a view to optimizing indoor thermal comfort with a selection from numerous identifiable, readily available wall finishes, to serve as a partial or complete replacement for the costly, predominant cement plaster currently in practice. In going about this, comparative thermal effects of the existing building material (i.e. cement plaster) vis-a-viz the potential substitutes (i.e. Plywood, Timber and Rug) on the interior thermal conditions of the predominant residential design typology in the study area, Ogbomoso, Nigeria, was carried out using a computer simulation tool, DesignBuilder (version V3).

Results of the simulations showed no significant improvements on the indoor thermal conditions of the functional spaces despite the alterations in the components of the fabrics of the wall finishes. As such, the choice of the interior surface finish on the core walling material in the study area, hollow sandcrete block-walls, remains a matter of personal preference for the aesthetic quality of the surface finish and has no significant effect on the indoor comfort temperature. The results also revealed the beneficial cooling effects attributable to the ground floor surface as well as the duo of the External Ventilation and the External Infiltration, as natural ventilation was adopted for every case of the simulations.

However, the results indicate significant heat gains through both the ceiling fabric and the exterior glazing. It is thereby recommended that the thermal properties of the materials to serve both purposes be properly evaluated in the future studies. As such, introduction of specific insulating materials coupled with use of low-energy glass material (as against ordinary 6mm thick clear glass adopted for the exterior window glazing in this study) respectively could be introduced.

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