IMPACT OF MATERIALS USED IN CONSTRUCTION OF SHADING DEVICES ON QUANTITY OF INDOOR HEAT GAIN IN RESIDENTIAL BUILDINGS IN OWERRI, NIGERIA

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Abstract

The control of indoor temperature of buildings, amongst other tools, has emerged as an important strategy for indoor air climate management. This strategy has become particularly important for stakeholders in the built environment in their efforts towards environmental sustainability. The study sought to investigate the relationship between the material used in constructing shading devices and the quantity of indoor heat gain in residential buildings with a view to developing design strategies for reducing heat gain in residential buildings in Owerri. The research was designed as a field survey. Out of the 13 housing layouts in Owerri, 5 homogenous layouts were chosen by random sampling. Out of a total population size of 1570 housing units, a 5% rule of thumb was applied to select a sample of 79 for the survey. Data was collected using observation schedule and data loggers. The variables in focus were interval variables, hence, Pearson's Product Moment Correlation Analysis tool was used to examine the significance of the relationship at 95% compliance. It was found that there was no significant relationship between the 'Thickness of reinforced concrete overhang' and 'Average heat gain in residential buildings' in Owerri, Nigeria. It was recommended that stakeholders in the built environment be sensitized about the necessity for tackling the problem of heat gain in buildings and the imperative of adopting sun shading devices as a viable tool for achieving this goal. It was equally recommended that further research be conducted on viable, alternative suitable materials that could be used for the construction of shading devices in the study area.

Key words: Environmental sustainability, Indoor heat gain, Residential buildings, Shading devices

INTRODUCTION

The space that is habitable and thus available for erecting buildings on the earth is limited. The same can be said about the building materials and components with which buildings are constructed, as well as the energy required for operating most of the services within them (Sassi, 2006). It has therefore become important for stakeholders in the built environment to make conscious efforts towards environmental sustainability. In doing this, the control of indoor temperature of buildings, amongst other tools, has emerged as an important strategy. The application of this strategy is a part of indoor air climate management (Olotuah, 2015). A cursory observation of parts of Owerri (the study area) indicates that, in many residential buildings, very little effort has been made to apply sun shading devices as a means of reducing the direct entrance of the sun's rays into the houses. In some instances, extensively glazed panels, which extend from the wall plate down to the ground floor slab, serve as windows without recesses or window-hoods protecting them (see plate 1).

Plate 1: Showing extensive glazing of front façade in residential building in Owerri

Source: Fieldwork, 2015

In other instances, designers appear not to make effort to protect the window openings. Rather, thin, decorative concrete mouldings/architraves are placed along the perimeter of the openings. These mouldings hardly exceed 75mm in thickness, thus making no contribution to the shading of the openings (see Plate 2).

Plate 2: Example of concrete moulding/architrave in residential buildings

Source: Fieldwork, 2015

Plate 3: Example of concrete moulding/architrave in residential buildings

Source: Fieldwork, 2015

And in yet other instances, a number of building owners appear to have considered sun shading devices unnecessary and therefore omitted them from the designs. Occupants, however, are forced to resort to housing transformation to manage the resulting discomfort. Additional makeshift/installations using such materials as corrugated-iron-roofing sheets are made over the openings to ward off direct sunrays, as well as wind-driven rain (see Plate 4).

Plate 4: Makeshift shading devices against sun and rain

Source: Fieldwork, 2015

As a consequence of the observed state of affairs, there is the likelihood of high heat gain within the indoor spaces. Accordingly, the occupants would likely expend a large proportion of their finances in cooling the indoors to maintain a comfortable environment. There is therefore the need to investigate the use of shading devices and its effect on indoor heat gain in the area.

The study area

Owerri is located within latitudes 5°16′N and 5°33′N, and longitudes 6°50′E and 7°10′E, and is 159 meters above sea level (maps-streetview.com, 2011). It is the capital of Imo State, Nigeria, (see Figure 1) and occupies a land mass of about 11,420 square kilometres. Imo State shares boundaries with Anambra State to the north, Rivers State to the South and Abia State to the east. Imo State has a high population density, with a population of over 11 million people (National Population Commission, 2006; onlinenigeria.com, 2003). The rivers, which crisscross the State are Imo River and its tributaries. Imo River discharges into River Niger, which joins the Atlantic Ocean via the Niger delta. The area has an abundance of clay minerals, gravel, sand, shale and lignite (Nwachukwu, Feng, & Alinnor, 2011).

Figure 1: Map of Nigeria Showing Imo State (hatched)

Source: Department of Surveying and Geo-informatics, Nnamdi Azikiwe University, Awka, Anambra State, 2016

Geographically, Owerri is situated in the warm-humid zone of the tropical rain forest belt of Nigeria. In this zone, savannah grassland interspersed with oil palm trees has replaced the greater part of the natural vegetation. The area is characterised by two climatic seasons: the rainy season which occurs from April to October; and the dry season, which occurs from November to March. According to Ezeigbo (1990), the area experiences double maximum rainfall peaks in July and in September and a mean annual rainfall of 2152 mm characterizes the wet season. There is an 'August break' during this season, generally observed as a dry period in the last two weeks of August. This sometimes occurs in early September due to the fluctuations in weather patterns. During the dry season, northeast wind blowing from the Mediterranean Sea crosses the Sahara Desert, bringing with it, harsh winds to the southern part of Nigeria (Amadi, et al., 2012). During this period, humidity is usually low and clouds are absent. The monthly temperatures are generally high throughout the year. An average annual temperature of 29.5ºC is typical of Owerri (Climate-data.org, 2023). Imo State is made up of 21 local government (administrative) areas. Three of these, namely Owerri Municipal, Owerri North and Owerri West, are located within Owerri metropolis (see Figure 2).

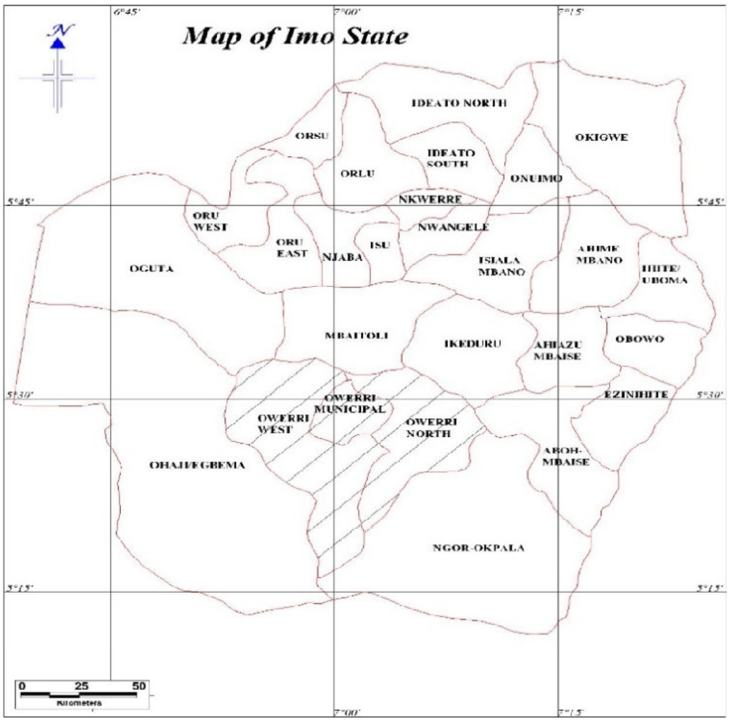

Figure 2: Administrative Map of Imo State, Showing Local Government Areas

Source: Department of Surveying and Geo-informatics, Nnamdi Azikiwe University, Awka, Anambra State, 2016

This study is part of a wider research on the effect of shading devices on indoor heat gain in residential buildings in Owerri, Nigeria. It is aimed at investigating the effect of shading devices on indoor heat gain in residential buildings in Owerri, with a view to developing design strategies to reduce heat gain in residential buildings. As its objective, it specifically sought to investigate the relationship between the material used in constructing shading devices and the quantity of indoor heat gain in the residential buildings in the study area. The null hypothesis proposed to guide the study was 'Thickness of reinforced concrete overhang has no significant effect on quantity of indoor heat gain in residential buildings in Owerri, Nigeria'.

LITERATURE REVIEW

Outdoor temperature levels influence indoor heat gain in residential buildings (Kenny, Flouris, Yagouti, & Notley, 2019). These buildings also gain heat from what is exuded by the people in it, from the lights, computers, copiers, dishwashers, ovens and other appliances. Exposure to sunlight and solar radiation is, however, the main source of heat gain (Warmair.com, 2016). The sun's rays pour through the openings, while transferring other invisible radiation through the walls and the roof. This phenomenon leads to heat accumulation and hence heat gain in the affected building.

This is corroborated by Energy Solutions Center (2008) which posited that the largest source of heat gain in a building is contingent on the nature of building, mainly how much and what type of glass it has and how the glass may or may not be shaded, as well as the type of roof. It also affirmed that the sources of heat gain included solar gain due to direct sunlight through windows as well as through sunlight striking directly on building surfaces and conducted through walls/ceilings into the space. Other sources included warm outdoor air infiltrating the space and brought in via power ventilation, lighting and equipment running in the space and producing waste heat. Additional indoor source of heat included people loads (Energy Solutions Center, 2008).

The potential of materials used in a building to influence heat gain has been established in literature (Penny, 2019; Los Alamos National Laboratory, 2013; DeKorne, 2020). A lot of high-density materials like concrete or bricks have high thermal mass (the ability of a material to absorb and store heat energy). Having these properties means that they store a lot of heat during the day and slowly release it overnight, thus contributing to higher temperatures in a building. This makes them major contributors to heat gain in buildings (Penny, 2019). Whereas several factors contribute to heat gain in the building, it is the relevance of the material used in constructing the shading devices that constitutes the focus of this paper.

Computation of Heat Gain

To calculate heat gain in the buildings, the Stefan-Boltzmann Equation (Bright Hub PM., 2009) was applied. This follows Bozman's law which stated that the total radiant heat energy emitted from a surface is proportional to the fourth power of its absolute temperature (Encyclopædia Britannica, 2009). This heat energy is given by the following Stefan-Boltzmann Equation: $P = e\sigma AT^4$, where: P = Power radiated (Watts); *e* = emissivity (no units); σ = Stefan Boltzmann constant ($5.67\text{x}10^{-8}Wm^{-2}K^{-4}$); A = Surface area ($m^2$); T = Temperature (Kelvin).

This formula gives the relationship between heat gain and the independent variables: emissivity, surface area, and temperature. Emissivity is a measure of how well a surface emits thermal energy. It has no units. It is also described as the fraction of energy being emitted relative to that emitted by a thermally black surface (a black body). A black body with an emissivity value of 1 is regarded as a perfect emitter of heat energy. A material would be considered a perfect thermal mirror if it has an emissivity value of 0; it does not absorb any heat energy and so cannot emit any (ThermoWorks, 2016). The surface area, A in square metres ($m^{2)}$, represents the total area of the surface materials enclosing the indoor space being investigated. The temperature, T in Kelvin (K), represents the air temperature of the indoor space of the residential building being studied. Examples of some common surface materials with their emissivity values are given in Table 1. Concrete was the material seen during the fieldwork.

Table 1: Common Substances Emissivity Table

S/NO.	SURFACE MATERIAL	EMISSIVITY COEFFICIENT (Ɛ)
1.	Aluminium, Painted	0.27-0.67
2.	Asbestos, Board	0.96
3.	Asbestos, Paper	0.93-0.945
4.	Asphalt	0.93
5.	Iron	0.95
6.	Black Enamel Paint	0.80
7.	Brass, Rolled Plate	0.06
8.	Brick, Red Rough	0.93
9.	Brick, Fireclay	0.75
10.	Concrete, Tiles	0.63
11.	Cotton, Cloth	0.77
12.	Copper, Electroplated	0.03
13.	Copper, Polished	0.023-0.052
14.	Copper Nickel Alloy, Polished	0.059
15.	Glass, Smooth	0.92-0.94
16.	Granite	0.45
17.	Limestone	0.90-0.93
18.	Sand	0.76
19.	Sandstone	0.59
20.	Tile	0.97
21.	Wood Oak, Planed	0.885
22.	Wrought Iron	0.94

Source: Thermo Works (2016).

METHODOLOGY

The research design was survey design. A multi-stage random sampling method was applied in the selection of the sample. The universe for the study consisted of the 13 housing layouts within the study area (See Table 2). The buildings to be sampled were shaded buildings, i.e., buildings with some form of shading device designed or installed.

Table 2: List of Housing Layouts in Owerri

SN	LIST OF HOUSING LAYOUTS IN OWERRI
1.	Akwakuma Layout
2.	Aladinma Housing Estate Layout
3.	Aladinma Northern Extension Layout
4.	Amakohia Layout
5.	Emmanuel College Layout
6.	Government Station Layout
7.	Ikenegbu Layout
8.	Ikenegbu Extension Layout
9.	Irete Layout

10.	New Market Layout
11.	Orji Layout
12.	Orlu Road Secretariat Layout
13.	Works Layout

Source: Fieldwork, 2018

At the first stage of the sampling, five layouts were chosen by balloting. These were Akwakuma layout, Aladinma Housing layout, Amakohia layout, Ikenegbu layout and Works layout. The study population consisted of all shaded residential buildings within these randomly selected housing layouts in Owerri. The total number of housing units within these five layouts was 1570 (See Table 3).

Table 3: Distribution of buildings among the Layouts

S/N	LAYOUT	NUMBER OF BUILDINGS IN LAYOUTS	PERCENTAGE OF TOTAL
1	Akwakuma	211	13%
2.	Aladinma	344	22%
3.	Amakohia	230	15%
4.	Ikenegbu	435	28%
5.	Works	350	22%
	TOTAL	**1570**	**100%**

Source: Fieldwork, 2018

Using the rule-of-thumb method suggested by Gay (1987), as cited in Yount (2006), 5% of 1570 = 78.5 (approximately 79) was obtained as sample size. Random sampling was again applied in the selection of which housing units that would be surveyed. In each street, after the first house, every fourth house would be surveyed. Also, these study buildings were chosen from the layouts bearing in mind the factors of willingness by the occupants to be surveyed and cost. The distribution across the layouts, based on their percentage contribution to the total population is shown in Table 4.

Table 4: Population Distribution of Sample Size among the Layouts

NAME OF SAMPLED LAYOUT	NUMBER OF HOUSING UNITS IN EACH SAMPLED LAYOUT	PERCENTAGE OF TOTAL
Akwakuma	11	13%
Aladinma	17	22%
Amakohia	12	15%
Ikenegbu	22	28%
Works	17	22%
TOTAL	**79**	**100%**

Source: Fieldwork, 2018

The main research instruments were observation schedule which was used to collate data on the variables being studied, and data loggers used to gather temperature values and other data during the survey. The temperature data obtained were then used to compute heat gain values, the vital dependent variables in the study.

RESULTS AND DISCUSSION

Analysis of materials used in construction of shading devices

The result of analysis of the data showed that majority of the sampled buildings had shading devices that were made of reinforced concrete. A little less than one third had recessed windows, while a small proportion were made of corrugated iron sheet. This is shown in Figure 4.

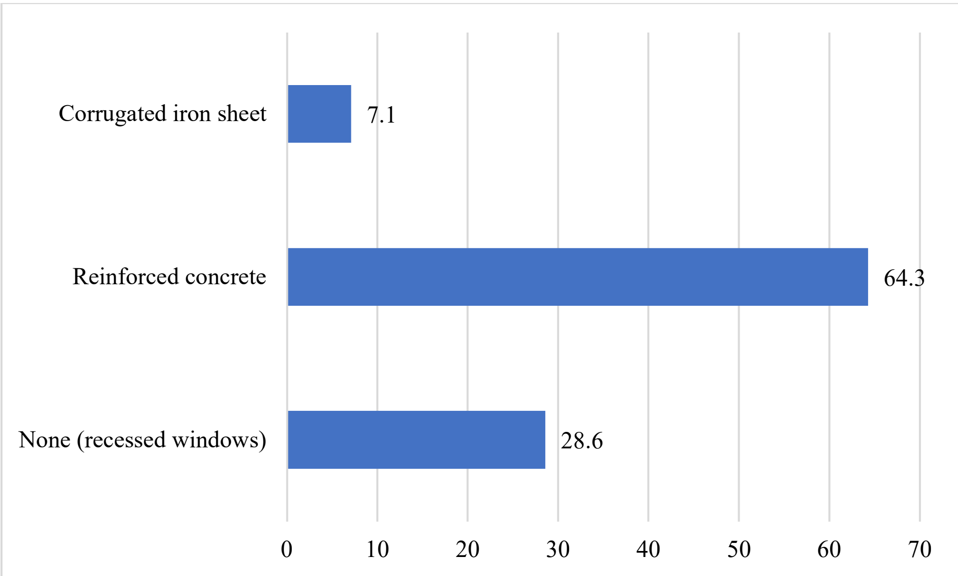

Figure 4: Materials used in construction of shading devices

Source: Fieldwork, 2018

Analysis of thickness of reinforced concrete overhang

Bearing in mind the results shown in Figure 4, an examination of the results of data analysis of thickness of concrete, showed that the housing units which used reinforced concrete shading devices, were equally distributed in two categories: less than 5cm thickness and 5-10 cm thickness. As shown in Figure 4, about one quarter of the houses did not use reinforced concrete devices, while none of the devices used was above 10 cm in thickness. This is shown in Table 5.

Table 51: Data on thickness of reinforced concrete overhang

Value label	Valid Percent	Cumulative Percent
None (recessed windows)	28.6	28.6
Less than 5 cm	35.7	64.3
5 – 10 cm	35.7	100.0
Above 10 cm	0.0	100.0
Total	**100.0**	

Source: Fieldwork, 2018

Heat Gain in sampled buildings

Using data loggers, daily temperature readings were obtained in the residential buildings in the sample. Heat gain values (for the study period: one year) were calculated using the Bozeman's formula described previously. There were similarities in results for the sampled buildings. This is shown in Table 6.

Table 6: Heat Gain values in ascending order of magnitude for the sampled buildings

S/No	No. of Units with similar results	Heat Gain (watts)
1	6	0.000018732
2	6	0.000026129
3	6	0.000068445
4	6	0.000150254
5	6	0.000176659
6	6	0.000239636
7	6	0.000246741
8	6	0.000425754
9	6	0.000515072
10	5	0.000523343
11	5	0.000686456
12	5	0.000897548
13	5	0.001000245
14	5	0.001673204

Source: Fieldwork (2019)

Test of Hypothesis

The relationship between thickness of reinforced concrete overhang and average heat gain in Owerri

The specific objective was to investigate the relationship between the material used in constructing shading devices and the quantity of indoor heat gain in the residential buildings in the study area. The variables in focus were interval variables. Therefore, Pearson's Product Moment Correlation Analysis tool was used to test the significance of the relationship. The result of the analysis showed a Pearson's Product Moment correlation coefficient value of 0.280 and a significance value point of 0.333, which was greater than $\rho = 0.05$ At 95% compliance, it means, therefore, that the relationship is weak, and it is not significant. The null hypothesis was therefore accepted which is that '*there was no significant relationship between the Thickness of reinforced concrete overhang and Average heat gain in residential buildings in Owerri, Nigeria'.* The result is shown in Table 7.

Table 7: Pearson's product moment correlation analysis result of relationship between the thickness of reinforced concrete overhang and average heat gain in residential buildings in Owerri, Nigeria

		Average heat gain
Thickness of reinforced concrete overhang	Pearson's Correlation	0.280
	Sig. (2-tailed)	0.333
	N	14

Source: Fieldwork, 2018

It is evident from the analysed data that reinforced concrete was the most prevalent material used in the construction of sun shading devices (Figure 4). As stated earlier, literature (Penny, 2019; Los Alamos National Laboratory, 2013) affirms a correlation between the thermal properties of a material and its contribution to heat gain in a building. Following from this therefore, it should be expected that in a sample of buildings in the tropical rainforest region, with its prevalent high humidity and average temperature levels, materials with higher thermal density (like concrete) will attract higher heat gains. While noting that concrete was the prevalent material used (almost two thirds of the sample), and that the two thickness categories shared this contribution equally, its varied use appeared not to make any difference. The test of relationship between thickness of concrete used in the shading devices and heat gained in the buildings yielded no significant relationship.

CONCLUSION AND RECOMMENDATION

As stated, the challenge of tackling excessive heat gain in buildings is a major focus for researchers, especially in the design of residential buildings. The reduction of heat gain within indoor spaces of such residential buildings in warm humid climatic areas like Owerri, Nigeria, therefore becomes a mark of successful design. Whereas the results of the study showed no significant relationship between the thickness of reinforced concrete overhang and average heat gain in residential buildings in Owerri, the relationship between material and heat transfer has been established in the literature. Since shading devices are an important strategy for mitigating heat gain, the lack of their use, or their improper use, implies that the problems that arise from this phenomenon will continue unabated. In addition, even if differing thicknesses did not affect heat gain, builders may be better served (economically) by the use of smaller thicknesses in their constructions. It would most likely require more experimentation to confirm which thickness would be optimum.

Following from this, therefore, it is recommended that stakeholders in the built environment in the study area be sensitized through education, and creation of awareness, about the necessity to tackle the problem of heat gain in buildings. Similarly, there is the need to impress upon this group the imperative of adopting sun shading devices as a viable tool for achieving this goal. It is equally recommended that further research be conducted on suitable alternatives to concrete, that could be used for the construction of shading devices. It is expected that with the use of such alternative materials, with better thermal properties, the goal of reducing heat gain in residential buildings could be significantly advanced.

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