International Journal of Science Academic Research
Vol. 02, Issue 08, pp.2007-2012, August, 2021
Available online at http://www.scienceijsar.com
ISSN: 2582-6425

Research Article

CONTRIBUTION OF SOME DESIGN FEATURES TO THE INDOOR AIR TEMPERATURE OF NATURALLY VENTILATED CLASSROOMS IN PUBLIC SCHOOLS OF MINNA, NIGERIA

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Received 20th June 2021; **Accepted** 15th July 2021; **Published online** 27th August 2021

Abstract

Thousands of prototypical classrooms have been built as part of the Universal Basic Education programme for public schools in all the 36 states of Nigeria. However there seems to be no study that has examined the contributions of the design features of these classrooms to the indoor air temperature. In view of this, the present study examined the potential contribution of some key design features to the indoor air temperature of naturally ventilated classrooms of 11public schools in Minna. Minna is the capital city of one of the 36 states in Nigeria. The study involved literature review into how design features contributes to the indoor air temperature of naturally ventilated buildings in the tropics .Following the literature review, a series of physical surveys were conducted in which the data concerning some design features were collected. The data collected relates to the followings: orientation, plant, shading devices, colour of walls, depth to height ration, floor to ceiling height, windows, thermal mass and thermal and thermal resistance, thermal load from occupancy and equipment. The physical surveys were carried out between March-April 2017.Analysis of data from the physical surveys suggest that some design features can contribute in promoting high indoor air temperature in the classrooms of public schools in Minna. Lastly, based on the findings from this study, recommendations that aims to reduce high temperature in NV classrooms were suggested for public schools in Nigeria, this because public schools have similar classroom design across the country.

Keywords: Naturally Ventilated (NV) buildings, Naturally Ventilated Classrooms, Indoor air temperature,Public schools, Potential contribution.

INTRODUCTION

Summary of results from previous research shows that some design features (e.g. orientation, plants and thermal properties of building materials) can contribute towards increasing or reducing the indoor air temperature of naturally ventilated buildings in the tropics (Baruch Givoni *et al.,* 2011).Motivated by the summary of results of research mentioned here, this study aims to explore how design features of naturally ventilated classrooms in public schools of Minna contributes to the indoor air temperature. The rationale for the aim of this study is that; thousands of naturally ventilated classrooms have been procured for public schools by the Universal Basic Education programme (UBE) in Nigeria since the establishment of the programme in 2004, however there seems to paucity of published works showing the contributions of the design features to the indoor air temperature of the classrooms built as result of the programme. UBE is an educational programme in Nigeria, part of the programme includes the procurement of similar naturally ventilated classrooms for public schools in the 36 states of Nigeria.

In respect to aim of this study mentioned in the past paragraph, the objectives of this study are as follows:

1. To understand the contributions design features to the indoor air temperature of Naturally ventilated buildings in the tropics
2. To analyse the contributions of some design features to the indoor air temperature of public schools.
3. To make recommendation that may promote relatively low indoor air temperature in naturally ventilated classrooms of public schools in Nigeria.

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Since public schools have similar design features in Nigeria, the contribution and key implication of this study is that; the results from this study may assist in resonating best practices and policies for the design and construction of classrooms that depends on natural, this is with respect of providing suitable indoor air temperature for the thermal comfort and learning of school children. This paper is part of an unpublished PhD study submitted in 2019 to the Newcastle University, UK by the author of this paper. This paper consist seven sections: introduction, literature review, methodology, results, discussion, conclusion and recommendations. The literature review will focus on how design features contributes to the indoor air temperature of naturally ventilated buildings in the tropics.

Literature review: the contributions of some design features to the indoor air temperature of Naturally Ventilated (NV) buildings in the tropics

Orientation

Buildings are often oriented for religious and physical considerations. As regards physical considerations: An NV building that is oriented with its longest side on the East - West axis can contribute to the development of high air temperature indoors. This is in comparison when the same building is oriented with its shortest on the East-West axis.(Baruch Givoni, 1994; Rabah & Mito, 2000; Tantasavasdi, Srebric, & Chen, 2001; Zahiri & Altan, 2016).

Cross and single sided ventilation system

Cross ventilation has the potential to increase the rate of dissipation of hot air indoor depending on the prevailing wind speed, this can contribute to lowering the air temperature in a tropical building. In contrast, single sided ventilation system in a NV building in the tropics could retard the rate by which hot air is dissipated, this can contribute to high air temperature indoors (Awbi, 1994; Garde, Mara, Lauret, Boyer, & Celaire, 2001; Baruch Givoni, 1994; Tantasavasdi *et al.,* 2001).

Shading devices

Shading devices are generally designed to curtail the transmission of direct and reflected rays from the sun in to buildings. When shading devices act by curtailing the penetration of direct and reflected solar radiations into NV buildings in the tropics, they can contribute towards minimising heat gain and lowering the air temperatures indoors. On the other hand, when shading devices are not employed in an NV building in the tropics, this situation can contribute to high air temperature, particularly in cases where the openings are on the East –West axis (Al-Tamimi & Fadzil, 2011; Evola, Gullo, & Marletta, 2017; Kirimtat *et al.,* 2016).

Plants

Trees, tall shrubs, grasses and vines have the potentials to absorb relatively large amount of direct and reflected solar radiation that may be incident onthe interiors of tropical buildings (de Abreu-Harbich, Labaki, & Matzarakis, 2015; Baruch Givoni, 1998; Gomez-Muñoz, Porta-Gándara, & Fernández, 2010; Huang, Akbari, Taha, & Rosenfeld, 1987; Ridha, Ginestet, & Lorente, 2018; Shashua-Bar *et al.,* 2011). This attribute of plants mentioned here can limit the amount of solar heat gain into naturally ventilated school buildings in the tropics, and contribute to low air temperature indoors. Inversely, when plants (e.g. trees, tall shrubs, grasses) are not integrated as design features of NV buildings in very hot areas of the tropics, the fabric of such buildings are likely to be exposed to direct and reflected solar heat gain and high air temperature indoors.

Depth to height ratio

In order to increase air flow and promote low air temperature in an NV building by natural ventilation , the depth (width) between two opposite walls that have windows should not exceed five times the floor to ceiling height of the interior space as given by the for mular d<5xh (DfES, 2006).In short, this means that the ability of transporting heat from indoors to outdoors via the windows may be retarded, in situation where d>5xh, in an NV building, by extension this situation can contribute high indoor air temperature in the NV building.

Thermal mass and thermal resistance

As regards thermal mass, NV building (e.g. classroom) in the tropics that the fabric is made up of materials with high thermal mass can absorb relatively large amount of solar heat gain without transmitting them indoors during the day. By extension, this could limit the occurrences of high air temperature in the NV building during the day. Inversely, NV buildings in the tropics with fabric of low thermal masses can absorb large amount of solar radiation and promote high air temperature indoors the during day (Al-Sanea, Zedan, & Al-Hussain, 2012; Amos-Abanyie, Akuffo, & Kutin-Sanwu, 2013; Cheng, Ng, & Givoni, 2005; Zhou, Zhang, Lin, & Li, 2008). As regards thermal resistance, NV buildings in the tropics with fabrics made from material of low U values have the potential to resist or frustrate the rate of solar heat gain indoors and contribute to low indoor air temperature (Al-Jabri, Hago, Al-Nuaimi, & Al-Saidy, 2005; B Givoni, 1976; Kukreja, 1978; Peng & Wu, 2008). Inversely this suggest that, NV buildings in the tropics with fabrics made from material of high U values can promote solar heat gain that can contribute to high indoor air temperature.

The colour of walls and roofs of buildings

Results of experiments have shown that dark coloured surfaces of walls and roofs have the capacity to absorb solar heat indoors, this is in comparison to lightly coloured surfaces of walls and roofs. The results mentioned here suggest that naturally ventilated school buildings (e.g. classrooms) with dark coloured roofs and walls can promote solar heat gain and elevated air temperature indoors. Inversely this means that naturally ventilated school buildings (e.g. classrooms) in the tropics with lightly coloured roofs and walls can reflect solar heat and promote lower air temperature (Bakhlah & Hassan, 2012; Bansal, Garg, & Kothari, 1992; Cheng *et al.,* 2005; Barukh Givoni & Hoffman, 1968; Shen, Tan, & Tzempelikos, 2011).

Roof vents (openings in the space of pitch roofs)

There are studies with evidences showing the effect of roof vents on the air temperatures of buildings. For example, Givoni (1976) reported the findings of Van Stratten *et al.* (1957).The findings suggests that in hot regions, buildings with roof vents can limit increase in surface temperature of ceilings and indoor air temperature. In sum, the finding of Van Stratten *et al*. (1957) reported here appears to suggest that roof vents could be beneficial to the design of naturally ventilated classrooms in the tropics for the sake of lowering the indoor air temperature. Similar result to the work of the author earlier mentioned here have been obtained from a recent research by Soleimani *et al.* (2017).

2.9Thermal loads from Occupancy and equipment

Heat gain from peoples and equipment in a building can contribute to the thermal loads in the same building (Awbi, 1994).Also, findings from a study by Ding *et al.*(2016) suggests that reasonable amount of heat can be gained indoors of buildings from lighting, occupants and equipment. In sum, the review in this subsection suggest that occupants and heat generating appliances in NV buildings can contribute to the heat gain indoors and elevated air temperatures.

METHODS

The sample of schools and the geographic context of the study

The study was conducted with classrooms of schools that were design and built by the Universal Basic Education (UBE) programme in Nigeria. Schools under the UBE programme consist of mainly public primary and junior secondary schools.UBE programme is a ‘mandatory’ educational programme by the federal government of Nigeria. The programme specifies similar (standardised) curriculum and building design features for educating children in public primary and junior secondary schools in all the 36 states of Nigeria. In view of the background provided above, 11 public schools located in different parts of Minna were utilised as samples for this study, this is following a permission obtained from Ministry of Education in Minna. The sample of schools used for this study was 11.This is because as at the time of this study the author of this work visited about 33 schools within Minna and the outskirts, however only 11 schools voluntarily gave us permission to collect data from their schools. Minna is the capital city of Niger state, and the state is presently one of the 36 states in the federal republic of Nigeria. Minna is located within the tropics on latitudes 8^0 to11^0N, the city is characterised by relatively high outdoor air temperatures most times of the year. Outdoor air temperatures in Minna could read above 40^0C in the month of March (peak period) and above 30^0C most times of the year ^{0}C (Nigerian Metrological Agency, 2016).

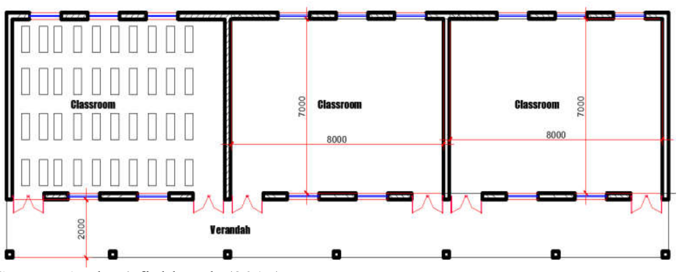
Data collection and data analysis

The study entailed physical surveys of the design features of classrooms and the surroundings of 11 public schools mentioned in 3.1. The physical surveys were mainly carried out via linear measurements, visual observations, and photographs. The design features of the classrooms of the schools that were physically surveyed are related to the following: plan, orientation, heat generating fittings and equipment, windows, plantings (vegetation cover), roof vents, shading devices, floors, and thermal properties of the walls, floors and roofs, depth to height ratio and verandah. These design features were physically surveyed in this study based on the fact that literature review in section 2.0 of this paper shows that they can contribute in increasing or lowering the indoor air temperature of naturally ventilated buildings in the tropics. Following the method used for collecting data described here, descriptive analysis was utilised in analysing and reporting the data collected from the physical surveys.

RESULTS

The plan, size and orientation of the classrooms

The plan of the classrooms in the schools are rectangular in terms of form. Field measurement during the physical surveys shows that the area of each classroom is on the average 56m^2 (i.e.7x 8 Meters). See Figure 1 for the floor plan of a typical block of classroom surveyed in this study. Also, it was observed that most of the block classrooms in the schools surveyed were orientated with their shortest sides on the east-west axis.



Source. Author' fieldwork (2017)

Figure 1. Typical plan of a block of classroom in the schools surveyed in this study

The ventilation system, equipment and fittings

Natural ventilation is the key source of ventilating classrooms. Similarly, findings from the physical surveys shows that, computers, projectors, artificial lightings and heaters are not fittings and equipment that in the classrooms

Plantings (vegetation)

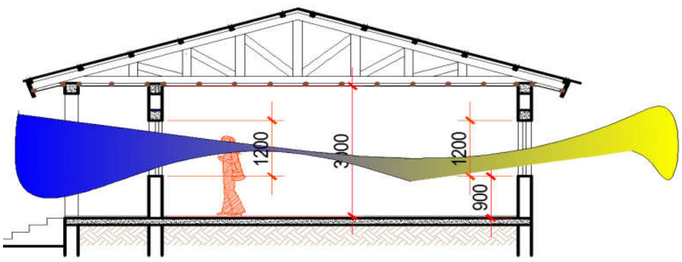
The use of the plants in the surroundings of the schools surveyed is scant, Figure 2 suggests. In short, Figure 2 suggest that the landscape of the sample of schools surveyed in this study is mostly characterised by sandy soil.

Source. Fieldwork by author (2017

Figure 2. The nature of the landscape in the schools surveyed

The windows

The window strategy and vertical positioning of window: It was observed that the windows in each classroom are positioned on two opposite walls, Figure 3. This is probably an attempt to promote the rate of air flow via cross ventilation. Additionally, measurements shows that the windows are positioned within the walls of the classrooms at the height of 0.9 to 2.1m above the floor level. In sum, the result reported here shows that the windows in the classrooms surveyed in this study were positioned within the occupancy heights, (seating and standing heights), Figure 4.



Source: Fieldwork by author (2017)

Figure 3. The positioning of windows on two opposite walls in the classrooms surveyed

Source: Fieldwork by author (2017).

Figure 4. The vertical positioning of windows within the seating heights of the pupils

The window opening area: The percentage of window area to floor area in each classroom was evaluated to be approximately 13%. Also, evaluation from the physical surveys shows that the percentage of window/ wall area ratio is approximately 30%.

Material used for the windows: Result from the physical surveys indicates that the material used for the windows frames and sashes are made from metal sections and sheets respectively, Figure 5. However the thickness of metal used for the window frame and sashes were not measured.

Source. Fieldwork by author (2017).4.7 Shading devices

Figure 5. The metal sashes and frame of windows

Results from this study showed that there are no shading devices on the entire stretch of windows at the back side (rear) of the classrooms, Figure 6.

Source: Fieldwork by author (2017)

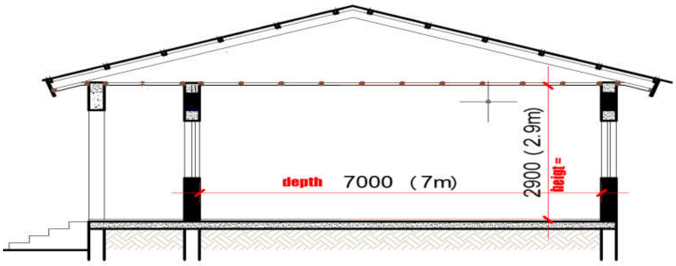
Figure 6. Typical backside of the classrooms surveyed in this study.

The floor to ceiling height

From the physical surveys carried out, it was observed that the average measured floor to ceiling height of the classrooms in the sample of schools is approximately 2.9m (2900mm).

The depth / height ratio

In order for a space to be effectively ventilated, the depth of that space should be less than 5 times the floor to ceiling height, as given by formula d<5xh (DfES, 2006). In view of this, the height and depth ratio of the classrooms in the schools surveyed in this study is on the average 7< 14.5 as computed from the dimensions in Figure 7. This suggests that the depth/height ratio of the classrooms surveyed in this study is within the range of the formula d<5xh earlier mentioned in this section. The depth (d) in this case represents the width between the windows on opposite walls. (h) Represents the floor to ceiling height of the classrooms, Figure 7.



Source: Fieldwork by author (2017).

Figure 7. Section thruogh a typical classroom

The roofing material and the colour: The material used for the roof covering is corrugated aluminium sheets. The thickness of the aluminium roofing sheet mentioned here was identified to be about 0.55mm, this is from the project unit of State Universal Basic Education Board (SUBEB) in Minna. Also, it was visually observed that the colour of the aluminium roofing sheets are usually of two types: dark green or light blue. Furthermore, it was observed that the roofing sheets were often not installed with insulation panels.

Roof vents and the ceiling material: It was observed that there are no vents provided in the roof of the classrooms that may assist in ventilating the space between the roofing sheets and the ceiling. Similarly, it was observed that the ceiling in a typical classroom are hard board sheets.

The walls and the colour: Hollow sandcrete blocks appears to be widely used as walling units in the construction of buildings in Nigeria (Abdullahi, 2005). Interestingly, it was observed from the physical surveys that the walls of the classrooms in the schools surveyed are constructed with the 225mm wide, 225mm high and 450mm long hollow sandcrete blocks. However, the main concern here is that, the sandcrete blocks used for the construction of the walls of the classrooms surveyed in this study can be classified as walling units with relatively high thermal mass (Reardon, McGee, & Milne, 2013). Furthermore, the colour of the walls of the classrooms surveyed are usually painted with a light colour (cream colour).

The floors: Observations from the physical surveys showed that the floor of a typical classroom is150mm thick mass concrete and finished with a 25mm thick terrazzo. The results reported here suggest that the floor of the classrooms consist of materials with high thermal mass. Mass concrete is generally classified as building materials with high thermal mass (Reardon *et al.,* 2013)

DISCUSSION

The current study examined the contributions of some design features to the indoor air temperature of classrooms in public schools of Minna, Nigeria. The discussion of the key results from this study is presented in the subsequent paragraphs of this section. The results from the physical surveys carried out in this study shows that public primary and junior secondary schools in Nigeria are strictly under the UBE programme (Education, 2005) .These schools are usually built with similar (prototypical) design features regardless of the different climatic zones in the country. Probably due to site constraints, it was observed that some of the classroom blocks are orientated with their longest sides on the east-west axis. The findings reported here runs against the principle of orientating naturally ventilated buildings in the tropics. This is because, authors have emphasised the need to orientate NV buildings in the tropics with the longest sides on North-South axis in order to promote lower indoor air temperature (Baruch Givoni, 1994; Rabah & Mito, 2000; Tantasavasdi *et al.,* 2001; Zahiri & Altan, 2016). Furthermore, results, from the physical surveys shows natural ventilation is the key sourceof ventilating classrooms. One implication of the finding reported here is that, during hot seasons the indoor air temperature in the classrooms can also be hot. This is based on the fact that, Baruch Givoni (1998) asserts that buildings that are not mechanically cooled have the tendencies for the indoor air temperature to vary directly with that of the outdoor air temperature. Similarly, finding from the physical surveys showed that the use plantings (e.g. trees, vines, shrubs and lawns) is scant, Figure 2. This finding has the potential of promoting high air temperature in classrooms with the risks of thermal discomforts for the teachers and pupils. Interestingly, results from the physical surveys showed the classrooms are cross ventilated. As well, the windows are positioned within occupancy height Figure 4. This result resonates the strategies put by some authors in promoting low air temperatures in tropical buildings (Awbi, 1994; Garde *et al.,* 2001; Baruch Givoni, 1994; Tantasavasdi *et al.,* 2001). Again, findings from the physical surveys indicates that the percentage of window to floor area ratio in the classrooms of public schools in Minna is approximately 13%. This value (13 %.) is relatively "small" in comparison to the value suggested from previous research. This is because authors have suggested that 20-25% window to floor area ratio is more desirable for enhancing natural ventilation in tropical buildings (Al-Tamimi, Fadzil, & Harun, 2011; Kukreja, 1978; Tantasavasdi *et al.,* 2001). In short, the findings reported here concerning the "small" window to floor area can impede the rate by which hot air dissipates from inside the classrooms to the outside. In turn, this could contribute to the occurrences of high air temperature in classrooms.

Likewise, it has been reported that the windows of the classrooms are metal sections and sheets Figure 4.5. The use of metal sheets as the sashes of windows as reported here can promote solar heat gain into classrooms of public schools in Minna. In turn, this can contribute to the development of high air temperature in the classrooms particularly during hot periods. As well, findings from the physical surveys shows that the entire stretch of windows at the back side (rear side) of the classrooms in the schools surveyed have no shading devices, Figure 4.6.The lack of shading devices at the rear side of the classrooms reported here could encourage the penetration of direct and reflected solar radiations in to the classrooms; this may in turn promote high air temperature particularly in cases when the rear side of a classroom faces the east directly. Also, findings from the physical surveys showed that aluminium sheets were utilised as the roof coverings of the classrooms. Surprisingly, the aluminium used for the roof covering sheets were not insulated. Thus far, the findings reported here has the capability of promoting solar heat gain and high air temperature in the classrooms of public schools in Minna. Lastly, findings from the physical surveys suggest that the roof structure of the classrooms do not have vents. By extension, the finding reported can promote solar heat gain and high air temperature in the classrooms of the schools surveyed in this study.

Conclusion

- Orientation of classrooms with the longest sides on the North-South axis is desirable for promoting lower indoor air temperature in schools that depends on Natural ventilation in the tropics.
- Orienting the longest side of classrooms along the East-West axis can contribute to high indoor air temperature in classrooms of naturally ventilated schools that are located in the tropics.
- Naturally ventilated schools without trees and shrubs as landscape elements can contribute to high indoor air temperature in classrooms, particularly in cases where there is no appropriate orientation and shading devices employed.
- Trees and shrubs and shading devices have the potential of contributing towards reducing the indoor air temperature of naturally ventilated schools in the tropics
- Naturally ventilated schools in the tropics that are built with material of high thermal mass can promote low indoor air temperature during the day. Inversely naturally ventilated schools in the tropics that are constructed with materials of low thermal mass can contribute to high indoor air temperature during the day.
- Naturally ventilated schools in the tropics without roof vents can contribute to high indoor air temperature particularly in cases where no appropriate insulation is applied to the roofing material and ceiling.

Recommendation for the design naturally ventilated classrooms in public schools of Nigeria

Find below recommendations this study that may be utilised in the design and construction naturally ventilated classrooms in public schools of Minna and other places in Nigeria. This is for promoting low in indoor air temperature and thermal comfort of school children in Nigeria.

- The percentage of window to floor area ratio of classrooms that strictly depend on natural ventilation in Nigeria should be in the range 20 -30%.
- Metals should not be used for the sashes of the windows of classrooms in public schools in Nigeria. Windows sashes made of materials such as wood or PVC may be desirable for windows of classrooms in Nigeria. PVC and wood relatively have better insulation values than metals.
- Clay tiles should be utilised as roof covering of naturally ventilated classrooms in Nigeria, this for the sake of reducing solar heat gain and high air temperatures.
- The current study recommends the use of roof vents in the design and construction of naturally ventilated classrooms in public schools of Nigeria, this may curtail solar heat gain via the ceilings into the classrooms.
- This study recommends the planting of evergreen or semi-evergreen trees (e.g. neem tree) around naturally ventilated classrooms of public schools in Nigeria. Trees generally have the potentials to limit solar heat gain and the occurrence of high air temperatures(Shashua□Bar *et al.,* 2011)
- Naturally ventilated classrooms in public schools of Nigeria should as much as possible be orientated with their shortest sides on the east-west axis.

Acknowledgments: I am grateful to Dr John Kamara and Dr Neveen Hamza, both were my supervisors at the Newcastle University during my PhD study. I thank the Ministry of Education Minna for permitting this study to take place using public schools in Minna.

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