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PASSIVE ARCHITECTURAL DESIGN STRATEGIES FOR REDUCING COOLING LOAD WITHIN ICT FACILITIES IN TROPICAL HOT AND DRY CLIMATE

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Abstract

Designing with climate has always been a necessity and must always be given a major consideration. This study is aimed at exploring the potential of using passive architectural design strategies to reduce the cooling load in ICT buildings within the tropical hot and dry climate of Nigeria. The research adopted mixed method; case study and quasi-experimental research design, through the use of dynamic simulation as the main investigatory tool. One case building was selected for analysis and five passive design strategies were applied. The performance of the case building was accessed using a scientifically validated energy simulation software Eco-tech for the parametric analysis of simulated results. Results showed that a significant reduction of cooling load was achieved due to the application of the following passive design strategies: Double skinned façade (47.2%), shading devices (26.5%), light colour coating (11.5%) and double glazing (15%) respectively. Findings from the study shows that reduction in cooling demand are achieved due to the minimising of external heat gain because of the integration of the passive design strategies. Finally, the study recommends that materials for wall and roofs within the tropical hot and dry should have low solar absorption rate.

Keywords: Designing with climate, cooling load, external heat gain, ICT buildings, passive architectural design strategies,

INTRODUCTION

Background

Designing with climate has always been a necessity and must always be given a major consideration. According to Steven, Lowell, Steve and Tom (2012), Change in weather pattern usually affect energy demand, especially with increased peak electricity use of air conditioning and energy supply, with reduced reliability and efficiency. Energy consumption in buildings has become a central issue in global dialog towards sustainable development (Mu'azu, 2012). The quest for reduction in energy consumption actually began after the oil crisis of 1973, after which countries aimed to reduce global energy consumption by mainly reducing the energy use in buildings for heating, cooling and ventilation (Antony & Ruba, 2013). Studies over the years have shown that the built environment consume more energy than other sectors in many parts of the world. According to Levine et al.(2014), buildings consume about 40% of the world energy production and contribute as much as one-third the total global greenhouse gas emission. Of the 40% energy consumed by buildings as stated above, 2% of it is consumed by ICT related buildings as a result of IT equipment, cooling, air movement and lighting and as such ICT requires process cooling system to remove excess heat (Peter & Ross, 2017).

Most buildings in Nigeria ICT building inclusive, hardly consider energy efficiency due to ignorance, lack of awareness and/or improper policy on building regulations by Government (Nwofe, 2014). Thus attention of researchers and professionals is directed towards designing buildings which are able to reduce the energy consumption of mechanical air conditioning systems by sustaining free-running conditions for a long period (Givoni, 1994).

Problem Statement

ICT buildings consume about 2% energy out of the 40% total energy consumed by buildings, which is as a result of internally generated heat and heat gain by building(Peter & Ross, 2017).

In developing countries like Nigeria, with poor energy infrastructure leading to epileptic power supply, high electricity tariff and harsh climatic condition (notably excessive heat from solar radiation mostly in the tropical hot and dry region) designing a building to house ICT facilities will require special design considerations, being that the building will be generating heat internally as well as gaining heat externally too.

This research therefore seek to explore the possibilities of reducing energy consumption by exploring passive architectural strategies to reduce the cooling load of building housing ICT facilities within the tropical hot and dry climate of Nigeria.

Aim and objectives

The aim of this paper is to explore the potential of selected passive architectural design strategies in reducing cooling demand energy consumption in ICT buildings.

The aim of this research therefore, will be achieved through the following objectives:

i. To evaluate selected passive design strategies in reducing cooling load.
ii. To evaluate the reduction in energy consumption by using the selected passive design strategies

LITERATURE REVIEW

Passive Design strategies for Energy reduction

Four passive strategies were applied to the base line model to serve as the independent variables as discussed below

Double Façade

Terri- Meyer (2003), described double skin façade as a pair of glass skin seperated by an air corridor which also incoporate the passive design strategies of natural ventilation, day lightening and solar heat gain. Double façade was designed and introduced on the east-west orientation of the base line model as shown in the Figure 1, when simulated it was able to reduce 53% in the first case and 48.9% in the second case.

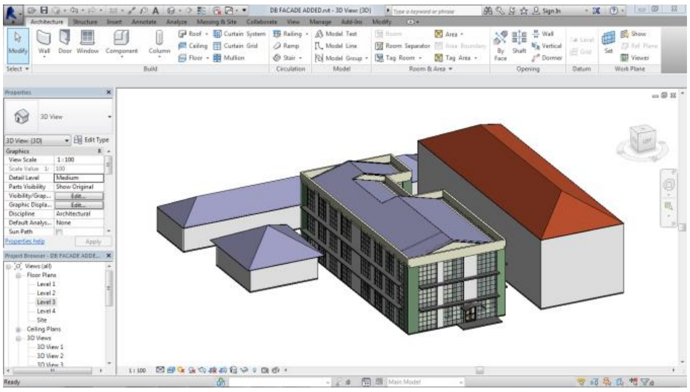

Figure 1: Double skinned facade introduced on base line model (Source: Authors, 2017)

There are various classifications of double skinned façade. Terri- Meyer (2003),described three basic system types: Buffer System, Extract Air System and Twin Face System. The twin face system was adopted for this study due to its flexibility in allowing for natural ventilation and its ability to moderate temperature dissipations within the façade.

Building Orientation

Orientation refers to the placing of a building relative to seasonal variations in the sun's path as well as predominant wind patterns. A good orientation can enhance energy efficiency of a building, by making it comfortable for the occupants while running at a cheaper cost in term of energy consumption. The orientation of the building for energy efficiency depend to a large extent on predominant climatic condition of the location. For example in the tropics, the weather condition is very hot with very high solar intensity, which makes the orientation of buildings most suitable in directions where the larger part of the building faces the Northsouth orientation. This is to prevent or reduce the rate of building absorbing sun rays, which help reduce the cooling load of the building (Chris, Max&Dick, 2013). This study however laid more emphasis on the east-west orientation as shown in the Figure 2. In order to reduce the effect of solar radiation on this axis the use of horizontal and vertical shading with double skinned façade were introduced on the base line model which yeilded effective result, reducing 53.8% of cooling load.

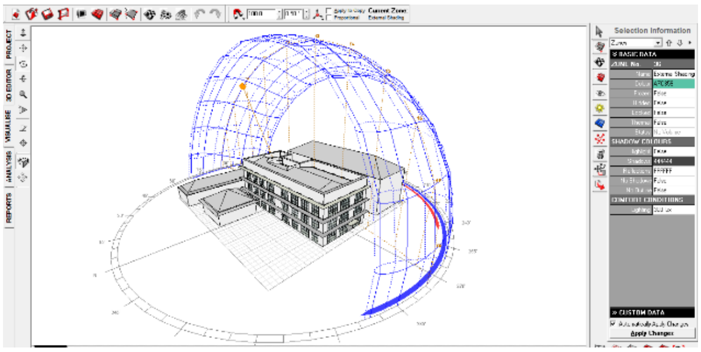

Figure2: Base line model placed in the east-west orientation(Source: Authors, 2017)

Shading Strategies

Shading is an important strategy for reducing solar heat gain especially through external openings on the building envelope. It is a known fact that most of the solar heat gain comes from the radiation through external openings on the building envelope. Hence, shading of the building envelope and the openings on it from solar radiation using well designed shading strategies and devices be of paramount importance in the tropical climate. According to Singhal et al.(2013), when designing shading devices for windows, the required horizontal shadow angles (HSA) and vertical shadow angles (VSA) need to be established. These angles are important to determine the depth of a shading device over a window and are dependant on both the oreintation of the window plane and the sun path as shown in Figure 3.

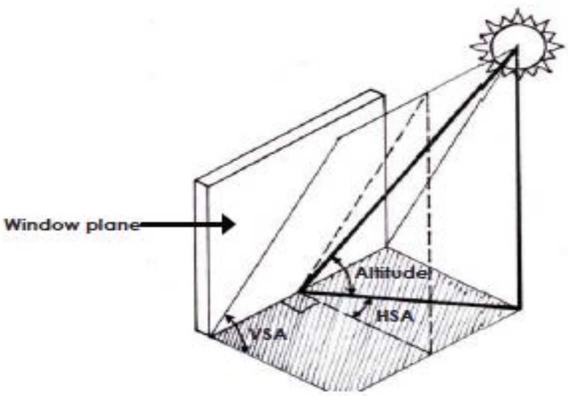

Figure 0: HSA and VSA in relation to window plane.
(Source: (Singhal, Mukund, Rajiv, Biswajit, & Ujjainia, 2013)

Horizontal and vertical shading devices were designed with depth of 0.9m and 1.2m respectively, and introduced on the base case model; a significant reduction of energy about 26.5% was recorded.

Light colour coating

Studies have shown that excessive amount of heat can be transmitted from the exterior walls to the interior due to the exposure of the exterior wall to excessive solar radiation (Hui, Hongwei, & Athanasios, 2010). This however, leads to increase cooling load. This study employed the use of cooler (light)colors with low Solar absorption rate on the external wall of the base case model, the result show a reduction in energy.

Double glazing

Glass is known to transmit some amount of heat when exposed to solar radiation. When solar radiation strikes the glass surface, some amount of heat is absorbed, some is reflected. The portion absorbed by the glass is reliant on the depth and the absorption coefficient of the glass. The radiation absorbed is converted to heat on the interior thereby increasing the temperature of the glass. However, when glass panel is double it further reduces the absorption of the solar radiation on the inside. The glass used to double glaze the windows and double skinned façade has a solar heat transmission of 0.75% with a Solar Heat Gain Coefficient of 0.75 (SHGC=0.75), which is interpreted as good and effective in reducing the amounth of heat gain.

A review of similar study

Hanan (2013), conducted a study 'Using Passive Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E. buildings. The aim of the study was to test the usefulness of applying selected passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in hot arid climate. The study adopted simulation as the main investigatory method, the simulation software IES (Integral Environmental Solution) was used to assess the performance of the buildings. The result of the study showed that energy reduction was achieved due to both harnessing of natural ventilation and minimizing of heat gain in line with applying good shadingdevices alongside the use of double glazing.

Batagarawa (2013), carried out a study ' Assessing the Thermal Performance of Phase Change Materials in Composite hot humid/hot dry Climate', the aim of the study was to investigate the possibility of using phase change materials (PCM) in improving indoor thermal comfort while conserving electricity in office buildings. The study adopted a mixed method case study and quasi-experimental, using scientifically validated software Design Builder and EnergyPlus for parametric analysis of simulated result. The result showed that cooling, lighting and appliance load account for approximately 40%, 12% and 48% respectively. Simulation results indicated that the magnitude of energy saving can be achieved by optimizing the passive and climate sensitive design aspects of the building and an electricity saving of 26%. A review of the literature indicated that a limited number of studies have examined passive strategies in reducing energy consumption in ICT facilities in the tropical savanah climate of Nigeria.

Research Methodology

Climate of Study Area

The Koppen climate classification, classified Nigeria into four broad climatic zones namely; the tropical monsoon climate, the tropical savanna climate or tropical wet and dry, the Sahel climate or tropical dry climate and Alpine climate or highland climate. In this classification, Kaduna, the study area falls within the tropical wet and dry climatic region, it experiences three weather conditions annually and they include a warm, humid rainy season and an extremely hot dry season, with temperature climbing as high as 40^0c (104.0^0F) (Weatherbase, 2017).

The selected case study

To carry out the analysis, a case building was selected within the study climate, which was the Hephzibah building located in Kaduna along Abuja Street. The building has an east-west orientation, making it suitable for the passive strategies to be tested. The energy consumption of the case building is as shown in Table 1.

Table 1: Electricity Consumption Rate of the Case Study

	Load(kw/h)	**cost per one kw/h(₦ 28)**	**%**
IT equipment	366724.23	10269745.337	59.7
Appliances	48328	1353377.312	7.9
Cooling load	169009.516	4732942.4861	27.5
Lighting load	30,694	859554.776	5.0
Total	**614755.23**	**17215605.461**	

Source: *Authors' Fieldwork (2017)*

This research adopted quasi-experimental research design, through the use of dynamic simulation as the main investigatory tool. The quasi-experimental design was employed due to its ability to examine causality which is the aim of this research. By identifying key variables, computer simulations were used to examine the effect of the variables on reducing cooling load. Energy simulation software Ecotec was used to examine the performance of the building selected as a base line model.Five passive strategies were considered in order to evaluate the collective effect of applying all these strategies on reducing cooling load in ICT facilities; they include: Double skinned façade, shading, Double glazing, Materia and Micro climate. The sequence shown in Figure 4was followed to achieve the desired result.

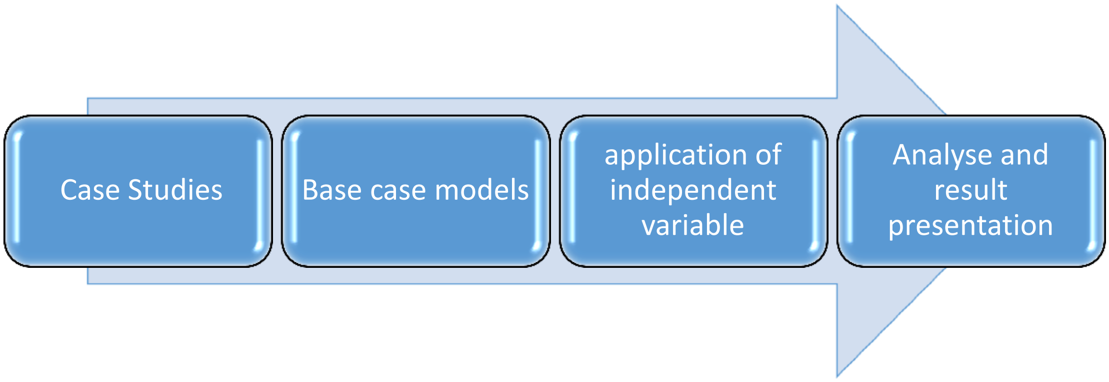

Figure 4: Sequence for data collection, analysis and result presentation

The data collected from the field survey such as occupancy schedule of the case building, material schedule and energy consumption. The software Eco-tech requires climatic data to run a valid simulation in given location, these climatic data were added as separate weather files input in the software before running the simulation (Stage one of sequence). The data were input in the simulation software for the base case model and simulated, the result of cooling load was compared with the one measured on site. (Stage two of sequence). The stage (three) saw the application of independent variables (Orientation, material, shading, double glazing and double façade) on the base case model and simulation carried out to determine the monthly cooling load and the possible energy reduction. The final stage of the sequence was analysis and result presentation in tables and graphs. It is worthy to note that the case building was simulated in three (3) scenario. 1) The case building in its present state, 2) with the combination of shading devices, double glazing of windows and light coated materials .3) double skinned façade.

Results and Discussion

This section consists of simulated results in line with the objective of the study, which is to evaluate selected passive design strategies in reducing cooling load.

The first scenario simulation was carried out in order to compare the measured in Table.1 and simulated results in Table.2. The difference between the results was found to be less than 5%, which according to Rahman et al (2008), a difference less than 5% makes the modelling procedure.

Monthly Heating/Cooling Loads of the Case Building in its Present State. (Scenario 1)

Max Heating: 0.0 C - No Heating.

Max Cooling: 147.175 kW at 15:00 on 5th May

MONTH	HEATING (kWh)	COOLING (kWh)	TOTAL (kWh)
Jan	0	7911.256	7911.256
Feb	0	11753.733	11753.733
Mar	0	19780.482	19780.482
Apr	0	21314.768	21314.768
May	0	22476.992	22476.992
Jun	0	16245.322	16245.322
Jul	0	11768.221	11768.221
Aug	0	10550.033	10550.033
Sep	0	11958.641	11958.641
Oct	0	17089.055	17089.055
Nov	0	12556.526	12556.526
Dec	0	7104.497	7104.497
TOTAL	**0**	**170509.516**	**170509.516**
PER M²	**0**	**239.782**	**239.782**

Table 2: Cooling Result of Existing Building

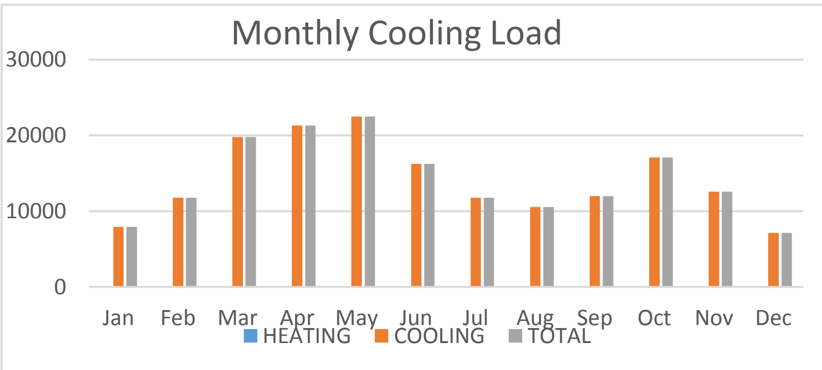

Figure 5: Monthly Cooling Load for Existing Case Building.

Simulation of the case study with consideration of some variables (Double glazing, materials, and Shading devices)

Max Heating: 0.0 C - No Heating
Max Cooling: 75.664 kW at 12:00pm on 11th May
Table 3: Cooling Result on Base-Case Model

	HEATING	COOLING	TOTAL
MONTH	**(kWh)**	**(kWh)**	**(kWh)**
Jan	1.67	3869.714	3871.384
Feb	0	6017.76	6017.76
Mar	0	10628.243	10628.243
Apr	0	11754.305	11754.305
May	0	12586.073	12586.073
Jun	0	8615.369	8615.369
Jul	0	6258.722	6258.722
Aug	0	5430.299	5430.299
Sep	0	6230.766	6230.766
Oct	0	9274.935	9274.935
Nov	0	6374.783	6374.783
Dec	0	3524.649	3524.649
TOTAL	**1.67**	**90565.617**	**90567.289**

Source: Authors' Analysis (2017)

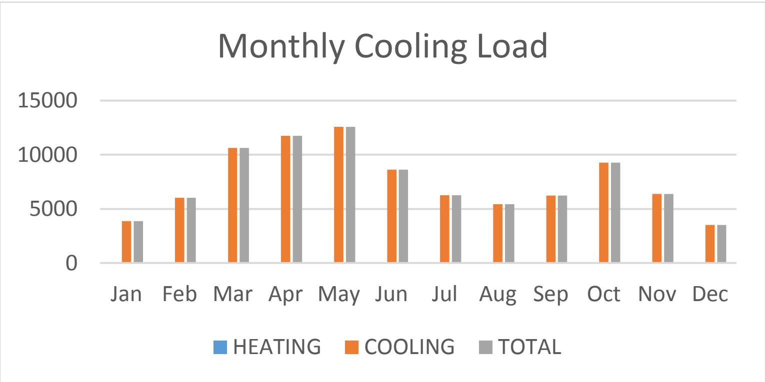

Figure 6: Monthly Cooling Loads of base-line model

Max Heating: 0.0 C - No Heating
Max Cooling: 80.797 kW at 12:00 on 11th May

Table 4: Cooling Result on Base-Line Model with Double Facade.

	HEATING	COOLING	TOTAL
MONTH	**(kWh)**	**(kWh)**	**(kWh)**
Jan	0	4151.354	4151.354
Feb	0	5590.281	5590.281
Mar	0	8864.329	8864.329
Apr	0	9236.464	9236.464
May	0	10365.71	10365.71
Jun	0	7570.45	7570.45
Jul	0	5702.387	5702.387
Aug	0	4880.492	4880.492
Sep	0	5394.458	5394.458
Oct	0	8326.75	8326.75
Nov	0	6556.929	6556.929
Dec	0	3883.93	3883.93
TOTAL	**0**	**80523.531**	**80523.531**

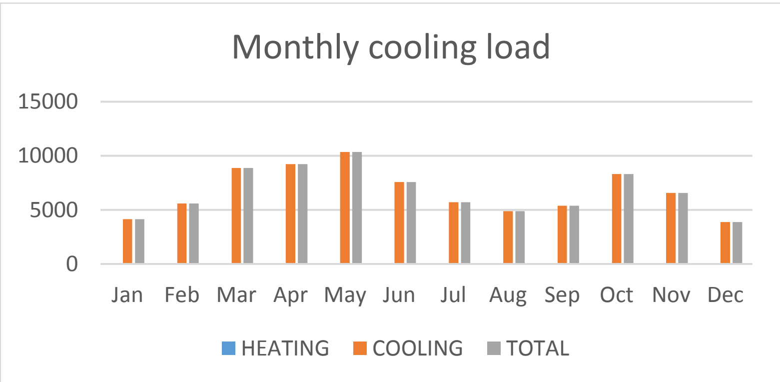

Figure 7 Monthly Cooling Loads of base-line model with double facade.

Discussion

Given that the monthly cooling load of the existing case building as represented in Table 2, and Figure 5, with the month of May experiencing the highest cooling demand while the month of January experiencing the lowest cooling demand, the total annual cooling demand amount to 170509.516 kw/h. It was observed that after the application of the passive strategies, there was a significant reduction in annual cooling demand as follows: double glazing 15% amounting to 144933.0886 kw/h, light color coating with high reflectance 11.5% amounting to 150,900.92166 kw/h, shading devices 26.5% amounting to 125324.49426kw/h and double skinned façade 47% amounting to 80523.531 kw/h. The combination of double glazing, light color coating with high reflectance and shading devices saw the reduction in the annual cooling load by 53% from 170509.516 kw/h to 90565.617 kw/h as shown in Table

3 and Figure 6, while double skinned façade reduced by 47% from 170509.516 kw/h to 80523.531kw/h as shown in Table 4 and Figure 7. The result showed that the selected passive strategies were able to reduce the cooling load, however, double skinned façade was more effective, reducing about 47% as shown in Figure 8. These findings corroborate Hannan's (2013),which showed a significant reduction in energy in residential building by using passive design strategies.

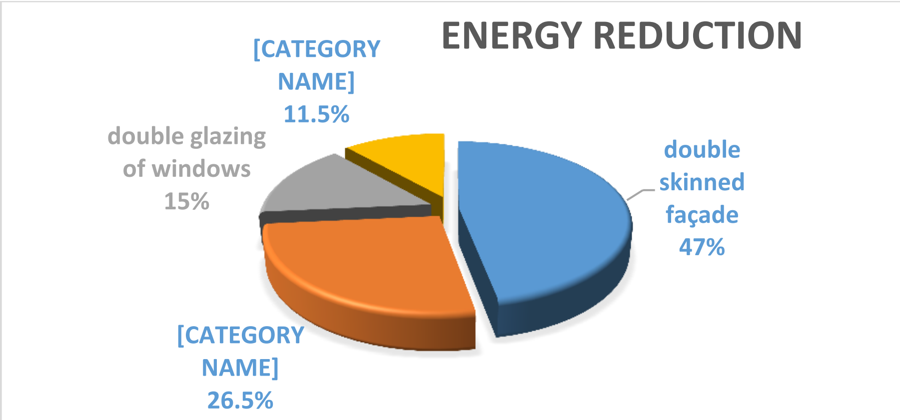

Figure 8: Reduction of Annual Cooling Load

Conclusions

The energy consumption of a building depends largely on the climatic condition of the location of a building as shown in Figure 5.There is variation in the monthly cooling load of the building as a result of the monthly climatic conditions, however with passive design strategies this study has shown that energy can be reduced. Hence, the study recommends that architects should integrate passive design strategies as an integral part of design and architectural expression in reducing the cooling load in hot and dry tropical climate.

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