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Building Energy Performance Evaluation for an Office Complex in Nigeria

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Abstract— this study evaluates the building energy performance for an office complex with different building materials: block work material with a concrete slab as roof with a view to establishing energy performance as well as design variables that can be used to facilitate low energy building designs in Nigeria. This was achieved through energy-audit end use analyses from field work (empirical approach) and computer simulation. SAVISCAD software was used to conduct the computer simulation component of the research. The simulation involves evaluation of architectural design variables identified from design guidance for low energy buildings as well as design recommendations for tropical climates influence on building energy performance in Federal University of Technology, Akure. This study focuses on specific design recommendation with the aim of informing further office design regulations in Nigeria. The result indicates that block work material with a concrete slab as roof is not suitable for office designs because it has a high required cooling capacity of 1.61TR which is considered too high compared to other materials to achieve human comfort in an office complex.

.**Index Terms**— Energy performance, Corrugated, Concrete slab, Saviscad, Simulation, Empirical, Tropical, Architectural

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1 Introduction

Latest development in building industry has highlighted the benefit associated with building low cost efficient building[1]. Buildings are designed in different forms to suite a particular interest or purpose. A building is any permanent or temporary structure enclosed within exterior walls and a roof including all attached apparatus, equipment, and fixtures that cannot be removed without cutting into ceiling, floors, or walls. These structures in the past were built by people not schooled in any kind of formal architectural design or with identifiable building techniques rather they depended on the cover the structure of the earth could provide for them purposes of shelter, warmth and security [2]. Energy is the property of matter and radiation that is manifested as a capacity to perform work, especially to provide light and heat, or to work machines. The structure of a building determines the flow of heat coupled with material selection. Some building materials generate excess heat, hence this need to be considered when drafting a building plan. Furthermore, the flow of heat is affected by certain factors such as: the number of windows, the number of doors, the position of the doors and windows, the direction of wind current, the position of the building relative to sun set and sun rise, the choice of roofing style considered, the choice of material used in roofing and design concept etc. All this factors contribute immensely to heat generation and build-up in a building[3].

More so, heat loss occurs by conduction through foundations, floors, walls, ceilings, roofs, windows and doors. Heat flow in and out of a building resulting from conduction can be reduced with a high level of insulation in the attic, sidewalls, basement walls and doors. Also, the windows should have a low 'U' value. Tremendous work has been done by building engineers to ascertain energy building coefficient and ways of reducing cost and energy for comfort by introducing natural light into buildings thereby saving energy as well as creating an attractive environment that improves the well-being of office users. The provision of effective daylight in buildings can be assessed using average daylight factors by ensuring that occupants have a view of the sky. The average daylight factor will be influenced by the size and area of windows in relation to the office, the light transmittance of the glass, how bright internal surfaces and finishes are, the depth of reveals, and presence of overhangs and other external obstructions which may restrict the amount of day lighting entering the room. Window design has a key impact on day lighting. As a rough rule of thumb, a window will introduce effective daylight into a room to a distance twice the head height of the opening. The use of high ceilings and clerestory windows can be effective in providing good daylight. Sun pipes and skylights can also be used to introduce daylight to windowless areas[4].

Temperature controls are essential to avoid space overheating and should be used to ensure minimum comfort conditions for employees. The more active the employees, the lower the temperature value required to provide comfort. Temperature controls can be used to pre-cool small office buildings so that they take less power to cool during peak demand and to reduce heat and cooling temperature during unoccupied periods in offices or when occupants are sleeping—in case of homes and hotels. Selecting office equipment with a reduced heat output can reduce cooling demands by ensuring equipment has effective controls that can automatically switch it off when it is not in use. The use of flat screen monitors can significantly reduce heat gains, while at the same time reduce energy use for the equipment thereby using office space more effectively. These benefits usually compensate for the higher cost of flat screen monitors which makes most businesses rely on a range of office equipment in order to function. From the basic essentials such as computers, monitors, printers, fax machines and photocopiers to projectors, scanners and teleconference facilities, it is widely recognized that these items have become integral to daily activity. Office equipment is the fastest growing energy user in the business world consuming 15% of the total electricity used in offices. This is expected to rise to 30 per cent by 2020[4]. Buildings account for about 40% of global energy consumption [5]; in which office buildings are major contributors. The scope of this study is to investigate an office complex with different building materials such as: block work plywood and glass structures, with a view to establishing energy performances as well as design variables that can be used to facilitate low energy building design in Nigeria. This will be achieved through energy audit end use analyses from field work and computer simulation. The result is expected to show the potentials of energy savings by reducing space cooling load. SAVISCAD software will be used to conduct the computer simulation component of the research. The simulation involves evaluation of architectural design variables identified from design guidance for low energy buildings as well as design recommendations for tropical climates influence on building energy performance in Federal University of Technology, Akure. This research will focus on specific design recommendation with the aim of informing further office design regulations in Nigeria.

2 LITERATURE REVIEW

Building performance evaluation as a defined process originated in the 1960s with work in the US military to assess its facilities. In 1964 the Royal institute of British Architect's (RIBA) plan of work was published, including 'stage M' which enabled architects to formally carry out a post project review[6]. However, this feedback was not focused on occupant's feedback or energy in use consumption hence, it was not widely adopted. In 1968 Strathclyde University established a Building Performance Research Unit, and published a ground-breaking book called "Building Performance" in 1972. A 1972 revision of the RIBA plan of work removed 'stage M' from its publication. In 1975, the term Post Occupancy Evaluation' (POE) was used in the AIA journal, in relation to Hospital investigation. There was a leap forward with the post occupancy Review of Building and their Engineering (PROBE) studies. The studies were carried out between 1995 and 2002 on twenty buildings, including nine office buildings, seven educational buildings, and four other office types[6].

A wide range of techniques have been use to evaluate energy efficiency of a building. The result can be used to make comparisons between the measured heat loss and the predicted steady-state heat loss, but if any discrepancy in performance is identified, it is not possible to be able to identify the reasons why such a discrepancy occurs. A much richer insight and understanding of the principal heat loss mechanisms occurring within a particular dwelling can be obtained. The evaluation of energy performance of buildings (EPB) depends on several factors, which are related with local climate contest.

In northern Europe the climate is cold during the most part of the year and the evaluation of EPB depends on energy heating dispersions. In those countries the project of buildings technical solutions requires to strongly insulate the wrapped and the frames, and to capture the solar energy throughout frames and wall-accumulation. In southern countries, where climate is hot and dry, the buildings' technical solutions requires to subtract overheating by means of wind-passive ventilation, cooling plants an taking advantages of thermal inertia of wall, justify neither of the aforementioned approaches of the buildings technical solutions. In these countries it is necessary to use flexible solutions, which could change depending on climate conditions. As a result, the historical architecture typology and rural buildings in these countries have some flexible architectural elements such as porch, court, patio, frame with shutter, and so on. The building construction technologies developed during twentieth century does not take into account the energy behavior. Only recent standards, (Normative En 832, Thermal Performance of Buildings) which follows an approach developed in northern countries, have introduced the obligation of winter insulation. The same approach has been used in Mediterranean area countries with reduces size of insulation. . The constructive technologies after 1950 have reduced the thermal inertia of the buildings wrapped and structure and reduced the wall thickness. The heating plants supply the heating of buildings and the wall insulation, which are not resolved with insulation materials. After the energy crisis in 1973 and climate change policies during 1980 the European Union have produced a series of standards until the EN 832. In the same period the society had an economy increase.

This economic growth created a modification of the comfort indoor perception and satisfaction. People need comfort indoor during all year: in winter and in summer season. These factors have contributed to diffusion of cooling plants and split systems in residential and other buildings. All this factors cause the increase of energy consumption in buildings sector, especially in the Mediterranean area country where the energy is expended during winter to heating and during summer to cooling. Nevertheless, in the Mediterranean area the climate is not too cold or too hot.

The effect of the absorptance of external surfaces of buildings on heating, cooling and total loads was studied using the TRNSYS simulation program. Two types of construction materials, namely heavy weight concrete block and light weight concrete were used in the simulation. They also calculated the effects of the absorptance on energy loads for insulated buildings. They reported that, for un-insulated buildings, as the absorptance was changed from one to zero, the total energy load decreased by 32%, while for insulated buildings, it decreased by 26% in Amman. Whereas the decrease was about 47% for un-insulated and 32% for insulated buildings in Aqaba[7].

A new approach was proposed based on a stochastic simulation method for uncertainty in peak cooling load calculations. The stochastic solution was compared with the conventional solutions, and a universal sensitivity analysis was assumed to identify the most significant uncertainties[8].

The calculation of optimal thermal loads of intermittently heated building was carried out. An unconstrained optimal control algorithm was proposed which used feed-forward to compensate the weather conditions and model predictive programming (MPP) for set-point tracking. They concluded that the peak load depended on the set-back time of the indoor temperature. The peak load was larger while energy consumption and the set-back time were smaller[9].

The thermal loads of non-residential buildings were evaluated based on simplified weather data, using the Transfer Function Method to run load calculations and the validation was evaluated according to the ASHRAE Standard 140. They also reported that the methodology showed good results for cases with low mass envelope, but revealed limitation to represent thermal inertia influence on the annual cooling and heating loads[10].
A study on optimum insulation thickness in walls and energy savings in Tunisian buildings using analytical method based on Complex Finite Fourier Transform (CFFT) for calculation of cooling and heating transmission loads considering different types of wall colors and wall orientations were carried out. It was assumed that wall orientation had a small effect for optimum insulation thickness, but more topical effect on energy savings which reached a maximum value of 23.78 TND/m2 for east facing wall. Their analysis showed that economic parameters, like insulation cost, inflation and discount rates, energy cost and building life, had a perceptible effect on optimum insulation and energy saving. They also performed a comparison of the present study with the degree-days model[11].

A simplified calculation method was developed for designing cooling loads in underfloor air distribution (UFAD) systems. The results obtained from a UFAD system were comparedwith traditional mixing overhead (OH) systems. The results revealed that, generally, underfloor air distribution (UFAD) system had a peak cooling load 19% higher than an overhead (OH) cooling load[12].

The heat gain and calculated cooling load of a Computer Laboratory and Excellent Centre Rooms in the Faculty of Mechanical Engineering, University Malaysia Pahang were analyzed using cooling load calculation method and cooling load factor method based on ASHRAE 1997 fundamental handbook and then verified by data provided by contractor of building. From this calculation, it was found that the highest heat gain in the Computer Laboratory Room and in Excellent Centre Room is 20458.6 W and 33541.3 W respectively[13].

The effects of different outdoor design conditions on cooling loads and air conditioning systems were investigated. The cooling coil capacities obtained from the different outdoor design conditions considered in this studies were compared with each other. It was reported that a significant part of the cooling load dependent on outdoor weather conditions[14].

3 METHODOLOGY

This research basically focuses on the evaluation of energy performance for an office complex with identified specifications. Thus, the calculation of energy is based on the characteristics of the office building and its installed equipment, heat generated through the walls, roof and fenestration area. Data are gathered through empirical method.
To calculate the overall energy using basic energy equation,
$Q=UA\Delta T$
Where:
Q –total energy
U –overall convective heat transfer co-efficient
A –cross-sectional Area and
ΔT –change in temperature or temperature gradient.
Determination of the overall energy consumed by the building from different sources will now be calculated through (wall, solar, lightening, window, electrical gadget and so on).

A. Heat through the Wall

$Q=U\times A\times CLTD$……………………………………………….1

Where Q is the total energy, U = overall convective heat transfer co-efficient,
CLTD is Cooling Load temperature Difference

B. Heat from Solar

$Q=A\times SC\times SHGF\times CLF$ ……………………..…....………………..2

Where A is cross-sectional Area, SC is shading co-efficient, SHGF = solar heat gain factor, CLF is the cooling load factor

C. Heat through Ceiling

$Q=U\times A\times TD$…………………………………………….…………..3

Where Q is the total energy, A = Cross- Sectional Area, TD is Temperature Difference.

D. Heat through Floor

$Q=U\times A\times TD$………………………………………………….…..4

Where Q = is the total energy, A = Cross- Sectional Area, TD is Temperature Difference

E. Heat through the Roof

$Q=U\times A\times CLTD$……………………….……………………..5

Where Q is the total energy, U is overall convective heat transfer co-efficient,
CLTD is Cooling Load temperature Difference

F. Heat through Internal Light

$Q=INPUT\times CLF$…………………………………………………6
INPUT is rating from electrical Data, CLF is Cooling Load Factor

G. Heat through People

$Q_S=No\times Sen.H.G\times CLF$………………………………………..7

Sen.H.G is Sensible Heat Gain from Occupants, CLF is Cooling Load Factor

Q_L=No×Lat.H.G
Lat. H.G is Latent Heat Gain from occupants

H. Heat through Appliances

Q_S=Heat Gain×CLF…………………………………………..…..8
Q_L = Heat Gain

I. Heat through Power

Q=Heat Gain×CLF……………………………………….………9
CLF = Cooling Load Factor

J. Heat through Fenestration and Infiltration Air

Sensble=No×Sen.H.G.×CLF……………………………..….10

Latent=No×Lat.H.G Latent = No x Lat. H.G

4 HEAT LOAD ANALYSIS

This section gives an empirical analysis of the heat load for the sample office building which is made of a block work material with a concrete slab as roof.

A. Office Data

Length of office = 4.16m; Breadth of office = 2.70 m; Height of office = 3.49 m; Window =1.71m^2

B. Area of Office

A_1 = 14.52m^2; A_2= 14.52m^2; A3= 9.423m^2; A4= 9.423m^2; Window Area = 7.713m^2.

Table 1: Inside and Outside Temperature and humidity for the sample office

Time	*Inside Temperature*	*Inside Humidity*	*Outside Temperature*	*Outside Humidity*
Period 1	24.5	82.3	29.7	80.9
Period 2	25.9	80.2	31.8	78.8
Period 3	29.8	79.9	32.6	75.7
Period 4	30.1	75.6	33.7	70.6

Period 1= 8am-10am, Period 2= 10am-12pm,
Period 3= 12pm-2pm, Period 4= 2pm-4pm.

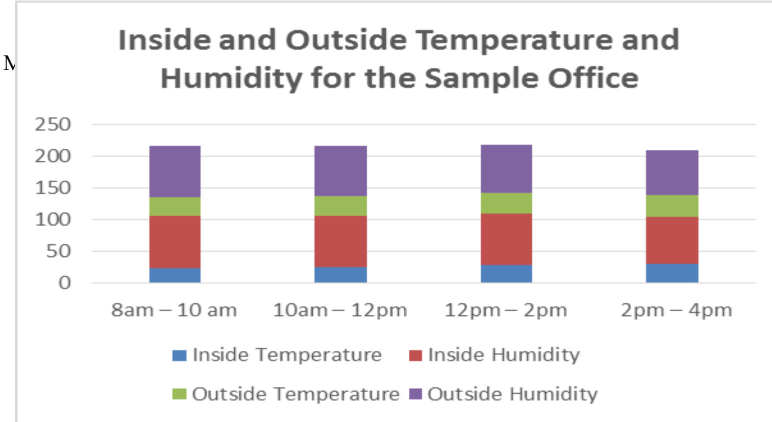

Fig. 1: Inside and Outside Temperature and humidity for the Sample Office

To calculate heat generated through the wall, insulation or air space + 203.2mm common brick is considered with U = 1.379W/mC^0, corresponding CLTD with direction of wall.

Table 2: Heat Gain through the Wall of the Sample Office

U(W/m⁰C)	Area (m^2)	CLTD	Q (W)
1.379	14.52	4.38	87.70
1.379	14.52	4.38	87.70
1.379	9.42	4.38	56.89
1.379	7.71	4.38	46.57
	Total		**278.86**

Heat through the wall Q1 = 278.86W (sensible).

C. Heat through the Roof Q_2

$T_{i,average}$=27.57^{0}C; $T_{o,average}$=31.95^{0}C

$T_{o,average}$-$T_{i,average}$ =4.38^{0}C
Area of roof = 14.52m^2

The U- value for roof is considered at 1500 solar time.

Heat through roof Q_2 = U x A x (To – Ti) = 2288.5W (sensible)

D. Heat through the Floor (Q_3)

Floor area = 14.52m^2
Q_3 = U x A x (To – Ti) = 76.32W (sensible)

E. Heat through the Glass (Q_4)

SC – shading co efficient is neglected since the glass is not shaded

Q_4 = U x A x (To – Ti) + SGHF = 251.98W (sensible)

F. Heat through Infiltration (Q_5)

To calculate this heat there is need to know the mass flow, through ACF, density of air with the room volume
Mass flow rate (in) = (density of air x (ACH x volume of the room) / 3600
Mass (in) = 5.962 x 10^{-3}kg/s

Q_5= M x C x (To – Ti) = 26.68W.

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G. Internal Load Calculation

i. Load due to Occupant

Since the main user main user of the office are female(2), 85% of adult male sensible heat will be used, average number of person that visit the office on daily basis is 30 and spend an average of 15min, most of which are student.

30 x 15min = 450min = 7.5h, it then assume they all spend 8hours.

Qs= number of occupant x SHG = 13.5W (sensible)

Ql = number of occupant x SHG =13.5W (latent)

ii. Load due to Lighting

Qlight = 261.36W (sensible)

iii. Load due to appliance

Printer = (3 x 50) = 150W
Desktop P.C = 70W
Laptop = 50W
Mini-freezer = 150W
T.v = 100W
Micro – wave = 600W
Standing fan = 25W
Total sensible = 995W

iv. Required Cooling Capacity Calculation

It is assumed that all equipment in the sample office work for 8hours

Qs = 995 x 0.78 = 778.1W (sensible)

Total sensible and latent loads are obtained by summing-up all the sensible and latent load components (both external as well as internal) as:

Qsensible= 4599.3 W
Qlatent = 13.5 W
Total load on the office is:
Qtotal = Qsensible + Qlatent = 4612.78 W
Room Sensible Heat Factor (RSHF) is given by:
RSHF = Qsensible/Qtotal = 0.997

To calculate the required cooling capacity, one has to know the losses in return air ducts. Ventilation may be neglected as the infiltration can take care of the small ventilation requirement. Hence using a safety factor of 1.25, the required cooling capacity is:

Required cooling capacity = 4612.78 X 1.25 = 5765.97W = 5765.97 / 3573.4 ≈ 1.614TR

5 SAVISCAD LOAD ESTIMATION FOR THE OFFICE COMPLEX

The software was developed using standard value assumptions by ASHRAE for calculating cooling loads. The software estimates cooling load of buildings in southern and northern regions in Nigeria under the following categories: heavy, medium and light construction work. In this analysis, it is assumed that all buildings are oriented towards the southern region with medium construction categorization.

Table 3: Empirical and Software Result

	SavisCAD Load Estimation (W)	Empirical Calculation (W)
Load	4748	5765.97
TR	1.35	1.61

The software estimates the cooling capacity of two other office buildings together with the empirically estimated cooling capacity in order to provide a point of reference for building energy performance evaluation. Table 4 gives a summary of the estimated results for the required cooling capacity of two other offices constructed using the following materials: plywood work material with concrete slab as roof and a block work material with corrugated roofing sheet.

Table 4: Summary of Required Cooling Capacity for Earlier Known Office Buildings

Offices	TR
Sample Office 1	0.84
Sample Office 2	1.61
Sample Office 3	0.49

From the result above, Sample office 1—with roofing sheet and block material—requires cooling of 0.84TR. This is as a result of its physical characteristics as well as the equipment installed in it, the heat gain from the office user together with the average number of people visiting the office on weekly basis in the month of July. The heat gain through the roof is the second highest with a rating of 1182.4W compared to that of Sample office 2 (with concrete slab as roof) with a value of 2288W. This indicates that concrete roof requires more cooling than aluminum roof. It should however be noted that heat through the roof is a function of area, U-value and differential temperature. Furthermore, sample office 1 has a smaller area compared to sample office 2 by a small value just like the temperature and U-value.

Sample office 2 which has the highest required cooling of (1.61TR) shows that it might not be too conducive if an appropriate cooling device is not installed. From the result above, it can be deduced that the installed equipment in sample office 2 also contributes to generation of heat.

Sample office 3 with a plywood material and concrete slab as roof requires the least cooling of about 0.49TR. This is because of several factors such as: U-value of the building material, differential temperature—as this office lacks direct exposure to sunlight—low surrounding temperature, area, installed equipment, number of users and people that patronized the office.

SAVISCAD result shows that more cooling will be required in Sample office 2 with a required cooling capacity of 1.61TR compared to the other office buildings.

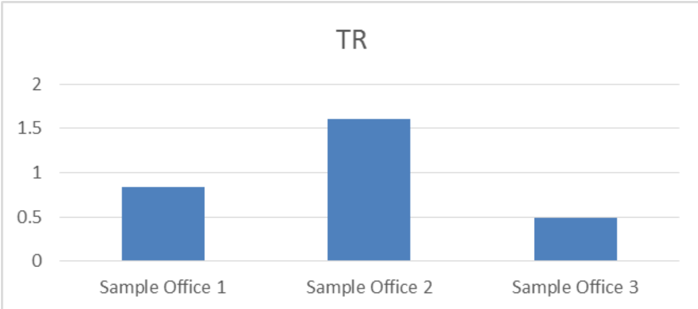

Fig. 2: The graph above shows variation in the required cooling capacity for three sample offices

6 CONCLUSION

The study indicates that an office complex built with a concrete slab as roof in a tropical region like Nigeria is not cost efficient compared to other roofing materials as deduced from the heat load analysis. Hence, architects and building engineers need to put to consideration the nature of material to be used for roofing office complexes in order to save cost and achieve maximum human comfort. Also, they need to provide standard dimensions and shading material for window constructions to plummet the amount of heat generated in office buildings. The result from the load estimation software indicates that using plywood material and concrete slab is more palatable as it does not contribute much to heat generation in the office. This study has succeeded in evaluating the building energy performance for an office complex as well as giving recommendations to ameliorate cooling cost and achieve maximum human comfort in office buildings.

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