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Optimizing Building Form to Enhance Heat Modulation in Five-Star Hotel Buildings in the Composite Hot Humid/Hot Dry Climate

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Abstract
The increase cost of cooling to provide comfort for hotel occupants have been a major challenge for entrepreneurs in the hotel industry. In view of this, the comfort of every space user starts from the design stage which has made researchers to look deep into design ways to create comfort and energy efficient buildings for users. As a result of this, this research was aimed at optimizing building form in order to enhance heat modulation to reduce cooling load of five-star hotels in the composite hot humid/hot dry climate. An experimental design of the research was carried out using the computer simulation program Ecotect. Five geometric forms (cuboid, cube, cylinder, cone and pyramid) were simulated. The results indicated that a cylindrical building form had the least energy consumption rate resulting to an energy saving of 7.6%, 7.7%, 18.3% and 40.4% over a cube, cuboid, cone and pyramid respectively. Using the cube form as a base case, materials property of each building component was varied and simulated. The results indicated that brick wall provides best comfort for occupants in comparison to concrete and sandcrete wall with an energy saving of 28.43%. Also, marble floor finish best provides comfort over carpet, tiles and concrete floor finish with energy saving of 0.39%, Plaster of Paris (POP) ceiling serves best over PVC and gypsum board ceiling with energy saving of 5.63%. The double glazing with low E aluminum frame provides an energy saving of about 40% when used over double glazing and single glazing with aluminum frames. Thus, applying the principles of heat modulation in a building can considerable reduce the energy consumption of that building by 37.42% annually.

Keywords: Building form, heat modulation, thermal mass, cooling load, comfortable indoor environment.

1.0 Introduction

The modulation of heat as a passive design deals with the thermal storage capacity of the building structure which brings about a reduction in cooling load and moderation of internal temperature with heat discharge at a later time (Santamouris, 2005). In Nigeria over the last two decades, the energy sector has been struggling to supply electricity to meet the demand of the growing population, as a result of this; to generate, transmit, and distribute electricity has fallen short of the required standard (Alawiye, 2011). Due to the growing population and increasing standards of living, the energy demand to meet the global trend increases simultaneously. Buildings in comparison to other economic sector have a very high energy consumption rate which varies from country to country taking up approximately 30–45% of the global energy demand (Santamouris & Kolokotsa, 2013)mainly dominated by the use of air conditioning systems to provide space cooling for the building's occupants (Katili, Boukhanouf, & Wilson, 2015). Among the building industry, hotels are

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found to be one of the most energy intensive sub-sector of the tourism industry in many countries (Priyadarsinia, Xuchaob, & Eang, 2009) with about 50% of the total energy consumption used for space conditioning (Bohdanowicz, Martinac, & Ivo, 2011). The operational cost of running hotels is excessively high because of its 24 hours operation period of which energy is required for the comfort of occupants. Hotels in the hot dry climates have the largest energy consumption in cooling and the energy demand for cooling falls within the range of 35% - 50% of total consumption (International Institute for Energy Conservation, 2015).One good strategy for reducing energy consumption in building is by creating and designing buildings using the optimum form (Rashdi, Suraya, & Embi, 2016).

The use of conventional form in the design of hotels has its effects on the comfort of occupants if proper considerations are given to the location and form of the design. Due to the large variation of the temperature in the tropics, there is a need for designs that would maintain a comfortable indoor temperature with little or no use of modern heating, cooling and ventilation systems leading to a reduction in cooling load and consequent reduction in energy consumption. An obvious gap is seen in the lack of studies addressing some specific cooling strategies, such as the use of thermal mass (heat modulation) in comparison with other passive technique (Prietoa, Knaacka, Kleina, & Auerb, 2017). Hence this research will bridge a gap in knowledge in this area.

The aim of this research is to optimize building form to enhance heat modulation in order to reduce cooling load of hotels.

Heat Modulation is concerned with the thermal storage capacity of the building structure (Santamouris & Kolokotsa, 2013)which controls solar heat gain in order to achieve a balance between such heat gain and admitting sufficient daylight without compromising the architectural and structural requirement of the building envelop (Al-Obaidin, Ismail, & Rahman, 2014). It is therefore the process by which heat is controlled from gaining access into the building through the building mass, maintaining indoor temperature and removing any heat gain by natural means. Heat modulation is one of the three widely accepted frameworks for passive cooling which are heat prevention, heat modulation and heat dissipation (Santamouris, 2009). This technique can be achieved in two ways: using the thermal mass of the building and a combination of thermal mass and night ventilation.

Thermal mass in reference to a building as defined by (Mikler, Biscol, Breisnes, & Labrie, 2009)means materials capable of absorbing, holding, and gradually releasing heat otherwise known as thermal energy to its surrounding space when there is a difference in temperature between the mass and the surrounding space. Researchers have found that homes with high-massexterior walls(such as adobe, brick, masonry (stone), concrete) in the hot climate require less energy for air conditioning than low-mass wood-framed homes with similar levels of wall insulation(Holladay, 2015). The effectiveness of thermal mass is in its energy storage capacity contained in materials used for walls, floor, windows, ceiling and roofing.

Form refers to the shape, visual appearance or configuration of an object ora building which constitutes the basic elements of architecture (Ching, 2015; Whole Building Design Guide, 2016). The form of a building is often described as the shape or geometry of the building but it should be noted that a form not only have height and width, it also has volume as a distinct character. Primary forms also known as solid forms or geometric forms include cube, cuboid, pyramid, cylinder, and cone (Yogapriya, 2015).

A hotel is defined as a public establishment offering travelers and temporary visitors two main services of accommodation and feeding based on payment (Lawson, 2008). Hotel facilities rank among the top five in terms of energy consumption in the tertiary building sector, even though no combined data is available on global energy consumption in the hotel sector (Hotel Energy Solutions, 2011). A hotel mainly uses its energy on space cooling, water heating, space heating, refrigeration, cooking, lighting, and other building services (Su, 2012).Naturally, the amenities that your hotel offers will significantly influence its energy use patterns. The specific energy consumption of a hotel is strongly related to the type of hotel, the location, the local environment and the form of the building (Keulenaer, 2015). This indicates that air conditioning amount to about 56% of the total energy consumption in this sector due to the climatic conditions experienced in the tropics.

2.0 Research Methodology

Computer simulation software- Ecotect was used to evaluate the thermal performance of the various building forms and the viability of the method/procedure adopted. This study was conducted for the composite hot humid/hot dry climate and the weather file for this region was used on Ecotect in order to simulate the building forms.

Computer simulations involve the use of special software to study the dynamic behavior of objects or buildings in response to conditions that cannot be easily or safely applied in real life scenario (Britannica, 2017). Autodesk Ecotect software is a computer simulation software that aids designers to evaluate a building's performance in relation to its environment. The variables used in the research were: building form, thermal performance, glazing and fenestration.

The five basic geometric forms having the same floor area and volume were modeled in Ecotect software with the same material assign to each form and their corresponding thermo-physical properties. The occupancy, activity level and appliances of all the forms were the same. Each form was simulated independently to generate the energy consumption. The simulations were carried out in three phases, these are: analysis of the effects of form on energy consumption, the effect of thermal mass on energy consumption and lastly the effect of glazing on the energy consumption.

i. Effects of form on energy consumption: The variables for this test will be the hourly temperature profile study and the annual heating and cooling load study. The best form that least consumes energy was chosen.
ii. Effects of material on energy consumption: materials such as concrete, brick and sandcrete block were used for the walls to test their cooling property on each form and the best material with the least energy consumption was selected. Simple concrete floor and use of tiles on concrete floor were compared and tested with best result selected, also, polyvinylchloride (PVC) ceiling, concrete ceiling and Plaster of Paris (POP) ceilings were tested and best results selected.
iii. Effects of glazing on energy consumption: The square form was used in this regard with variables of 20%, 40% and 60% window to wall ratio (WWR). Other variables include the glazing type and materials. Here, the effect of WWR and glazing material were analyzed and the best to this regard was selected.

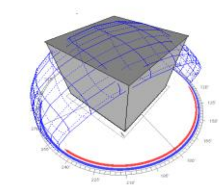
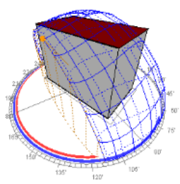
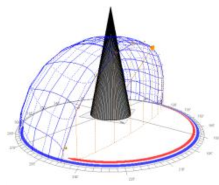
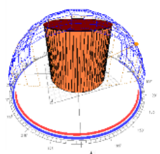
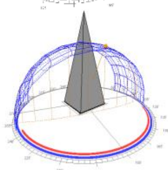
3.0 Data Presentation

3.1 Simulation Report

Basic geometric forms with certain parameters set as constant were used to analyze the effect of form on cooling load reduction.
The following assumptions were recorded for a five-star hotel:

i. All forms have the same floor area (144 m²) and volume (1728 m²). Site is assumed to be relatively flat, building form stands alone and it's un-shaded.
ii. The occupancy hour is from 0:00 to 24:00 all year round. Occupants' activity rate is 45watt and 12 m² per occupant in a typical hotel room.
iii. The comfort band taken for the hotel interior is set at 20˚C for cooling and 26˚C for heating.
iv. The lighting level was set as 300lux(S.I unit of illuminance) for typical hotel room.
v. Table 1 gives the details of the parameters that were used to carry out simulation.

Table 1: Geometric forms and assumed parameters for five-star hotel

Forms	Perspective view	Basic parameters	Area / Volume
Cube		L= 12m B= 12m H= 12m	Floor area: 144m² Surface area:864m² Exposed area:720m² Volume: 1728m³
Cuboid		L= 16m B= 9m H= 12m	Floor area: 144m² Surface area:888m² Exposed area:744m² Volume: 1728m³
Cone		R= 6.77m H= 36m	Floor area: 144m² Surface area: 924m² Exposed area:780m² Volume: 1728m³
Cylinder		R= 6.77m H= 12m	Floor area: 144m² Surface area: 799m² Exposed area: 655m² Volume: 1728m³
Pyramid		L= 12m B= 12m H= 36m	Floor area: 144m² Surface area: 1008m² Exposed area: 864m² Volume: 1728m³

Source: Authors (2017)

3.1.1 Effect of Forms on Energy Consumption:

The five geometric forms in table 1 were simulated and the results are presented below based on annual heating/cooling load. These geometric forms were simulated without openings and without materials applied on them.

3.1.1.1 Annual heating and cooling loads study

For all forms simulated no load was required for heating as all forms recorded 0Wh thus the total load is based on cooling demand for the building forms. Table 2 gives a summary of the total monthly cooling loads needed per annum. The result shows that the cylinder has the lowest cooling loads demand, followed by the cube, cuboid, cone and lastly the pyramid with the highest cooling load demand.

Table 2: Annual Cooling Loads

Months	Cube (Wh)	Cuboid(Wh)	Cylinder(Wh)	Pyramid(Wh)	Cone(Wh)
Jan	4218195	4283192	3884516	5424340	5048246
Fab	4941244	4903230	4504488	6210272	5422076
Mar	6076024	5948441	5548116	7616634	6337186
Apr	4389816	4329752	4076869	5698898	4517691
May	3537853	3490082	3320291	4647547	3493282
June	1980938	1987302	1902661	2729836	1909985
July	1590507	1557338	1495528	2143261	1548030
Aug	1263520	1242960	1207554	1784008	1337523
Sept	1085190	1096046	1034048	1536140	1218246
Oct	2789406	2841692	2617550	3796703	3264173
Nov	3380719	3500050	3167481	4437078	4163882
Dec	3553905	3662640	3314602	4636360	4410054
Total	38807316	38842724	36073704	50661080	42670372

Source: Authors (2017)

Figure 1 shows a graphical representation of the monthly energy demand for cooling each form respectively. From the figure, it is observed that the month of March has the highest cooling demands while the month of September requires the lowest cooling load.

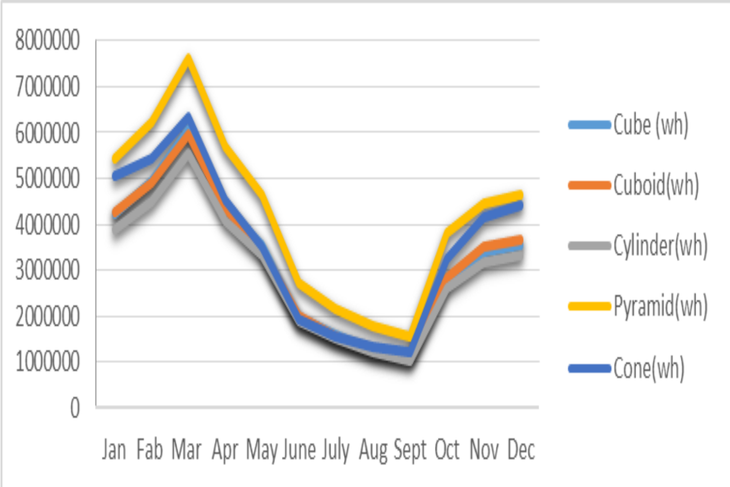


Figure 1: Monthly cooling loads for geometric forms

Source: Authors (2017)

3.1.2 Effect of Material on Energy Consumption

The thermo-physical property helps to determine the effectiveness of a material to serve as thermal mass. In this study the cube form is used as a base case to test the effect of materials on energy reduction for cooling. Materials are assigned to building components such as floor, wall, and ceilings. Different locally available materials are simulated and the best is selected and specified for usage.

3.1.2.1 Thermal property of walling material:

The U-value, admittance, solar absorption, visible transmittance, thermal decrement, thermal lag, density, specific heat and conductivity are the various properties that determine the thermal performance of the building. Selected walling materials are sandcrete block, concrete block and brick.

i. Comparative analysis between sandcrete block, concrete block and brick block: simulation of the cube form was done with alternating of the three chosen wall materials with same thickness of 230mm. The result is thus presented in Table 3.

Table 3: Comparative analysis of energy consumption between sandcrete, concrete and brick block.

Months	Sandcrete Block(Wh)	Concrete Block(Wh)	Brick Block(Wh)
Jan	4643566	2438087	1472228
Feb	5364295	2975151	1923176
Mar	6520740	3681886	2390770
Apr	4759131	2627044	1683783
May	3905887	2063441	1259215
June	2302391	973083	533393
July	1858146	782465	432996
Aug	1481234	652628	313048
Sept	1288584	486666	202267
Oct	3254062	1534928	920455
Nov	3913985	1919596	1231200
Dec	4079092	2013404	1225572
Total	43371112	22148380	13588103

Source: Authors (2017)

3.1.2.2 Thermal property of floor material:

The U-value, admittance, solar absorption, visible transmittance, thermal lag, density, specific heat and conductivity are the various properties used to determine the thermal performance of the building. Selected floor finishes are carpet finish, tiles finish, marble finish all laid on concrete flooring and exposed concrete floor.

i. Comparative analysis for selected floor types: exposed concrete floor, concrete floor finished in carpet, tiles and marbles all with concrete depth of 150mm were used in this analysis. Table 4 shows that the exposed concrete floor has the least energy consumption (13413510Wh), while the highest is the carpet (16604597Wh).

Table 4: Comparative analysis of energy consumption for different floor types

Months	Concrete Floor (Wh)	Marble floor (Wh)	Carpet floor (Wh)	Tile floor (Wh)
Jan	1456365	1472465	1800752	1474221
Fab	1903102	1924348	2391275	1926132
Mar	2365829	2392539	3021886	2394694
Apr	1662487	1684072	2089544	1684293
May	1242000	1259338	1573759	1261145
June	522497	533393	621788	534185
July	427956	432952	532535	433626
Aug	303248	313048	362602	313533
Sept	199762	202267	236995	204297
Oct	903924	920455	1097572	921662
Nov	1217752	1231251	1423463	1232517
Dec	1208587	1225572	1452424	1227081
Total	13413510	13591700	16604597	13607386

Source: Authors (2017)

3.1.2.3 Thermal property of different ceiling types:

The ceiling types selected are 8mm thick PVC (Poly Vinyl Chloride) ceiling, 12mm thick gypsum board and POP (Plaster of Paris) ceiling.

Comparative analysis for different ceiling types: Table 4.5 gives the comparative analysis for the ceiling types simulated. PVC has the highest energy consumption (13607386Wh), next is the gypsum board (13591700Wh), the POP has the least energy consumption (13413510Wh).

Table 5: Comparative analysis of energy consumption between gypsum board ceiling, PVCand POP ceiling

Months	Gypsum board(Wh)	PVC (Wh)	POP(Wh)
Jan	1408811	3438406	1411309
Fab	1846476	4010583	1851657
Mar	2298712	4896144	2306676
Apr	1611228	3513960	1615001
May	1205437	2866629	1205758
June	504867	1485695	499866
July	415960	1112944	413925
Aug	293701	908514	289310
Sept	195122	789471	195031
Oct	879372	2236260	872819
Nov	1165391	2961857	1164326
Dec	1162209	2913665	1154644
Total	12987286	31134128	12980322

Source: Authors (2017)

3.1.3 Effect of Glazing on Energy Consumption

The percentage of openings and glazing type affect the rate of energy consumption and consequently affect the cooling load of a building. Based on ASHRAE-IESNA's research (2004) it was recommended that for comfort of occupants the percentage of fenestration should not exceed 40% of façade area.

3.1.3.1 WWR (Window to Wall Ratio):

For simulation purpose WWR is varied from 20%, 30%, 40%, and 50% for building facades. The simulation result is recorded in Table 6. This shows that the smaller the opening the lesser the energy consumption and the more effective is the use of thermal mass. Variation in openings and orientation also plays a vital role as 20% opening was used for N/S façade while 30% opening for E/S façade indicated a higher energy demand than when it was reversed as 20% openings for E/S and 30% openings for N/S.

Table 6: Comparative analysis of energy consumption between 20%, 30%, 40%, 50%, 20%NS/ 30%EW and 20% EW/30%NSWWR.

WWR	20%(Wh)	30%(Wh)	40%(Wh)	50%(Wh)	20%NS/30%EW(Wh)	20EW/30NS%(Wh)
Heating	450432	908161	1420596	1746108	227413	271894
Cooling	72663456	85411232	100318144	110247248	60345356	53698348
TOTAL	73113888	86319392	101738744	111993360	60572768	53970244

Source: Authors (2017)

4.1.3.2 Glazing Types:

The monthly and annual simulation results are recorded in table 7 and table 8 respectively. SGAF= single glazing with aluminium frame, SGAFB= single glazing with aluminium frame and blinds, DGAF= double glazing with aluminium frame, DGLAF= double glazing with low-e(emissivity) aluminium frame.

Table 7: Monthly comparative analysis of energy consumption between different glazing types

Months	SGAF(Wh)	SGAFB(Wh)	DGAF(Wh)	DGLAF(Wh)
Jan	8581632	5856680	6486628	5139594
Feb	9410028	6901460	7146070	5901366
Mar	11035221	8390819	8431752	7087530
Apr	8265197	5944348	6294364	5148900
May	7122202	4870111	5389796	4290222
June	4649097	2792200	3492036	2593656
July	3643063	2334260	2712596	2057916
Aug	3001907	1708434	2246814	1627613
Sept	2744523	1481658	1954366	1365580
Oct	6212686	3864236	4660856	3508417
Nov	7297789	4726950	5428353	4207200
Dec	7720189	5099082	5744366	4469543
Total	79683536	53970244	59772236	47397536

Source: Authors (2017)

Table 8: Annual comparative analysis of energy consumption between different glazing types

Annual	SGAF(Wh)	SGAFB(Wh)	DGAF(Wh)	DGLAF(Wh)
Heating	824960	271894	215760	74799
Cooling	78858576	53698348	59772236	47322736
TOTAL	79683536	53970244	59987996	47397536

Source: Authors (2017)

3.2 Discussions of Results

Five geometric forms were simulated based on the effect of building form on energy consumption. Using the cylinder form over a cube form result in an energy savings of 7.6%, over a cuboid form by 7.7%, over a cone form by 18.3% and over a pyramid form by 40.4%. Similarly, Samuel (2015) carried out a research on "Evaluating the Effects of Building Forms on Thermal Comfort in Office Buildings in Hot Humid Areas". The study concluded that the cylindrical form is 5.6% less than the energy consumption for cone form, 9.7% for cube form, 12.9% for cuboid and 14.7% for pyramid. This shows that total cooling loads for simulated shapes increase by 14.7% from cylindrical to pyramidal form for a hot humid climate.

Hence a varying percentage of energy demand is saved from using a cylindrical form over the other geometric forms because of the differences in the exposed surface area of each form. It was observed that pyramid form has the highest energy consumption rate and the cylinder has the lowest, hence the cylinder form is further recommended as the best form to minimize cooling load requirement for hotel buildings in the composite hot humid/ hot dry climate.

In order to reduce the complexities of data, the cube form was used as a base case to simulate for the effect of material variations on energy consumption. For wall material, the sandcrete block, concrete block and brick were simulated and the sandcrete block had the highest energy consumption rate while the brick has the lowest. Therefore, brick is further recommended for use in this composite climate to maintain indoor comfort of occupants. Also, for ceiling materials, the POP ceiling is selected above the PVC and gypsum board because of its energy saving potentials. Furthermore, for flooring material the exposed concrete floor has the minimal energy consumption rate compared with tiles, marble and carpet. But due to very little variation between the exposed concrete floor and the marble floor, the marble floor will be selected because of its durability, aesthetics, and thermal performance.

The glazing size selected from the simulation result is the 20% EW/30% NS as it has the lowest energy consumption rate because minimal openings are required along the east-west axis because of large exposure to direct sun light. The glazing type selected is the DGLAF (double glazing low-e aluminium frame) because of its low u-value and low energy consumption rate. A final design with all these parameters puts in place is simulated to calculate the effect on energy consumption and it is presented in Table 9which gives a summary of the effect of materials and opening on energy demand for a cylindrical form.

Table 9: Percentage increase and decrease in HVAC(heating, ventilation and air conditioning) demand as parameters were changed.

Cylinder form	Without opening	With opening	DGLAF	Brick wall	Marble floor	POP
HVAC load (Wh)	36073704	51440944	35002632	24746512	24606608	22574612
Percentage savings (%)	0	42.6	-2.97	-31.40	-31.79	-37.42

Source: Authors (2017)

Table 9 shows that the cylinder form simulated without openings and material has 36073704Wh energy demand from HVAC and it is used as the base case. Introduction of 20%EW/30%NS opening increased the energy demand to 51440944Wh which is equivalent to 42.6% due to direct solar radiation on the form. By applying double glazing material to the opening, the energy consumption was reduced to 35002632Wh leading to a saving of 2.97%, when brick material was applied to the wall, the energy reduced to 24746512Wh and the percentage saving increased to31.40%, marble was applied to the floor and the percentage energy increase is brought to 31.79%, when POP was applied as the ceiling material energy saving increased to 37.42%.

4.0 Conclusion

The modulation of heat gain in a building plays a vital role in making the building energy efficient. This is achieved by taking into consideration the thermal mass of the building components in use which are floor, wall, glazing and fenestration, ceiling and roofing material. By using a material with a high thermal mass in a composite hot-humid/hot dry climate, the heat of a space can be modulated to provide comfort without or with minimal use of the active cooling system. The results indicated that brick wall provides best comfort for occupants in comparison to concrete and sandcrete wall with an energy saving of 28.43%. Also, a marble floor finish best provides comfort over carpet, tiles and concrete floor finish with an energy saving of 0.39%, Plaster of Paris (POP) ceiling serves best over Poly Vinyl Chloride (PVC) and gypsum board with an energy saving of 5.63%. The double glazing with low-e aluminum frame provides an energy saving of about 40% when used over double glazing, single glazing aluminum frame and single glazing aluminum frame with blinds. Thus, applying the principles of heat modulation in a building can considerable reduce the energy consumption of that building by 37.42% annually translating in to savings on the cost of running and maintaining the building.

Also, building form should be given adequate consideration in any energy efficient design in the composite hot-dry/hot-humid climate especially hotel buildings because of their high demand for energy to provide comfort for guests. Using a cylindrical building form over a cubic form can give an energy saving of 7.6%, over a cuboid form can give an energy saving of 7.7%, over a conical form by 18.3% and over a pyramidal form by 40.4%. This result indicates that using the right building form can give an energy saving of up to 40% for a building in the composite hot-humid/ hot-dry climate.

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