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ORIENTATION OF HOTEL ROOM SPACES FOR ENERGY CONSERVATION IN HOT-DRY CLIMATE OF BIRNIN KEBBI, NIGERIA

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ABSTRACT

Purpose: Hotel buildings in the hot-dry climate were observed to be using heavily air conditioning units as a way of maintaining human comfort at desirable levels. This has led to increase in pollution and high electricity bills for the hotel owners. This study is therefore aimed at identifying an ideal room orientation for low energy consumption for hotel buildings in the hot dry climate of Birnin Kebbi.

Design/methodology/approach: The study employed a quasi-experiment approach using Autodesk Ecotect software to simulate a model selected from a typical hotel room grid of 3800mm length x 6000mm width and 3000mm height using Birnin Kebbi data files.

Findings: Results of the simulation show that the South-facing room consume less energy (269kWh/m^2) followed by North-facing (404kWh/m^2) and then the East-facing room layout (481kWh/m^2), while West-facing room layout (489kWh/m^2) having the highest energy consumption.

Originality/value: This research will serve as a guide to designers of hotel buildings trying to minimize energy. Adhering to these guidelines will help to substantially minimize the overall building energy consumption and also help in deciding the best materials suitable for use in remaining room orientations likely to have adverse effect.

Keywords: Building orientation; energy conservation; hot dry climate; severe weather condition.

1. INTRODUCTION

According to Sue et. al, (2009), severe weather conditions in Hot-dry climate which is exacerbated by climate change necessitates new measures in the form of adaptation in order to minimize this impact. To limit the negative consequences of this severe weather on societies, greenhouse gas emissions have to be reduced (mitigation) or humans have to develop ways of adapting to the effects of the Severe Weather conditions (adaptation) (Stephane et. al, 2011). However, these two options have not been given equal consideration as adaptation has long been neglected in the climate change debate

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(Stephane et al, 2011). This imbalance is indicative of the real difficulties inherent in adaptation, like the treatment of uncertainty on the future impacts of climate change or a certain number of methodological problems (Stephane et al, 2011).

Vulnerability to severe weather is considered to be high in developing countries, due to social, economic and environmental factors that amplify susceptibility to negative impacts and contribute to low capacity to cope with and adapt to climate hazards (Neil and Kulkarni, 2007). In addition, projected impacts of climate change are generally more adverse in low latitudes, where most developing countries are located, than in higher latitudes, because of the high level of vulnerability (Neil and Kulkarni, 2007). Thus, there is an urgent need for the developing world to understand the threats of Climate Change so as to formulate policies that will prompt actions that will lessen its risks.

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), the forecasted a probable rise in temperature of between 1.8oC and 6.4oC and a possible rise in temperature of between 1.1oC and 4oC. It also forecasts that sea levels around the world will rise by 18 - 59 cm at the end of the 21 century due to thermal expansion, melting glaciers, ice caps and the polar ice sheets. From the joint study conducted by Climate Research Analysis Group, University of Cape Town, South Africa and the Institute of Ecology and Environmental Studies at Obafemi Awolowo University, Ile-Ife, Nigeria, (2011) the findings suggest a warmer climate in the hot-dry regions of Nigeria in the near future. The strongest scenario projects a temperature increase of 0.04oC per year from now till 2050. With respect to foregoing issues a good building orientation is one of the adaptation strategy that will help in mitigating the severe weather conditions caused by climate change. It is a method of positioning a building in relation to seasonal variations in the sun path as well as prevailing wind patterns, to take advantage of passive and active solar radiations, in order to heat or cool and illuminate the building spaces (Figure 1). The relative position of the sun is a major factor to be considered for reduction of heat gain in buildings. This makes accurate orientation of Buildings as fundamental factor for consideration in passive cooling design and energy conservation.

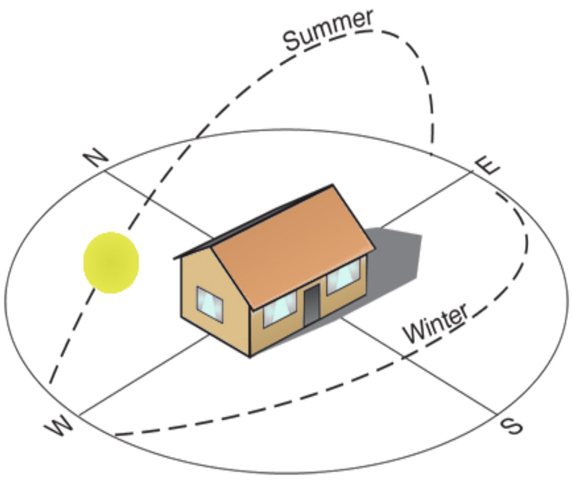


Figure 1: Building orientation in relation to sun path in winter and summer. (Ecowho.com, 2016)

With rising energy costs, it is becoming increasingly important to orient buildings in such a way that solar heat gain is reduced to the minimum in hot-dry climates. Thus, building orientation is a crucial consideration of passive cooling that can be incorporated into virtually any new home design (echowho.com, 2016). A study conducted by Batagarawa, Musa, and Lawal, (2015), shows that Cooling in hotel buildings accounts for the highest energy consumption with an average of 51% of the total electricity consumed across six (6) hotel buildings within hot-dry and hot humid climate of Northern Nigeria followed by non-lighting appliances with 36% and finally lighting fixtures account for the lowest energy consumption of 13%. Another result by Batagarawa et al; (2015), also show that the average electricity consumed per meter square (m^2) in buildings is approximately 303kWh. Furthermore, epileptic power supply in Nigeria requires hotel building owners to resort to alternative power supply by using backup generators to meet the demand of their customers, this has negative impact on the environment as well as cost of operating of hotels in general (Batagarawa *et al;* 2015), Particularly in North-western Nigeria like Kebbi state.

Cities like Birnin Kebbi located in the northern part of Nigeria are particularly prone to severe weather because of its proximity to desert and increasing agricultural and industrial activities (Blessing, *et al*., 2012). Severe weather conditions in the above named area has caused many building materials to perform well below their intended purpose, hollow sandcrete block construction is among these affected materials, yet it gain popularity due to its structural stability than adobe wall construction (Progress, 2011).

2. REVIEW OF RELATED LITERATURE

The effect of Climate change has affected energy production, delivery and consumption in the World. The Increases in temperature has increase energy demand, as well as changes in the ability to produce electricity and deliver it reliably. Climate change has also caused significant variation in the outdoor/indoor design conditions, cooling and heating loads which impacts design and selection of the cooling equipment (Shahram, Karami and Pasdarshahri, 2010). A report by Wilbanks et al, (2008), shows that if a nation's climate warms by 1.8°F, the demand for energy used for cooling is expected to increase by about 5-20%. Statistics has shown that: 40% of the world energy is being consumed by buildings (World Sustainable Conference, 2008) and as a result, more techniques are required to be put in place that can reduce energy consumption to minimum. This has resulted in the emergence of numerous organizations with a mission to promote sustainability-focused practices in the building and construction industry such as World Green Building Council (WGBC), Intergovernmental Panel on Climate Change (IPCC) and Global Environment Facility (GEF).

Until recent years, energy conservation has been relatively low priority to building owners and investors. However, with dramatic increase in awareness of energy use, energy conservation is fast becoming part of real estate management design and operation strategies (Omer, 2008).

In line with sustainable development goals, it is critical for practitioners to develop sustainable building techniques, especially in climates where so much energy is required for cooling spaces (Monna & Masera, 2013). The analysis of the effect of orientation in the hot dry climate, underline the problem of overheating caused by excessive solar radiation which 'facilitates' heat gain and causes discomfort and often associated with heat related diseases in this type of climate (Monna & Masera, 2013).

Figure 2: Movement of heat through walls as result of solar radiation (Solar Energy Environment, 2016)

Birnin Kebbi like other cities within the hot-dry climate of Nigeria, has the problem of hot-dry air and very low relative humidity of less than 20% and a difference in air temperature of average high and average low is between 24ºC – 33 ºC (NIMET, 2012). The average solar radiation, air temperature and relative humidity for Birnin Kebbi is shown in Table 1.

Table 1: Average solar radiation, air temperature and relative humidity for Birnin Kebbi.

Month	J	F	M	A	M	J	J	A	S	O	N	D
Average Solar radiation Wh/m²	8580	8326	8205	8028	7802	7816	6785	6165	7037	7845	8485	8266
Min average air temp ºC	16.7	19.1	23.0	25.8	26.5	24.7	23.1	22.3	22.2	21.8	19.1	16.6
Max average air temp ºC	33.1	35.6	38.4	39.7	38.1	35.6	32.5	30.9	32.5	35.6	35.9	33.3
Average air temp ºC (min/max)	24.9	27.3	30.7	32.7	32.3	30.1	27.8	26.6	27.3	28.7	27.5	24.9
Average relative humidity, %	< 20					> 20					< 20	

Source: weather.com, (2017)

The humidity level of Birnin Kebbi ranges from 16% to 40% (NIMET, 2012). Therefore, it is necessary to take adequate measures in designing for this type of climate, especially taking cognizance of orientation of room spaces to avoid overheating, which could result in excessive use of energy for cooling. To achieve thermal comfort in buildings, The American Society for Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 2015), proposed a suitable quality level for an indoor environment. This is represented in Table 2.

According to BSO (2007), an unventilated air layer is one in which the construction does not allow air flow through the air cavity into the building from the outdoor environment. The ability of a building element to prevent heat gain in to the building interior spaces is described in terms of its thermal transmittance (U-value) which is expressed as the transfer of heat in watts per square meter of area per degree difference in temperature. Table 3 shows different thickness of air layers in cavity walls with their thermal resistance in different directions of heat flow

Table 2: Indoor environmental quality level according to ASHRAE

Season	Comfort temperature	Comfort temperature range	Relative humidity	Air velocity
Summer	24.5 °C	23 – 26 °C	30 – 65%	0.25 m/s
Winter	22 °C	20 – 23.5 °C		0.15 m/s

Table 3: Thermal resistance (m^2K/W) of unventilated air layers for high emissivity surfaces.

Thickness of air layer mm	Direction of heat flow		
	Upwards	Horizontal	Downward
0	0.00	0.00	0.00
5	0.11	0.11	0.11
7	0.13	0.13	0.13
10	0.15	0.15	0.15
15	0.16	0.17	0.17
25	0.16	0.18	0.19
50	0.16	0.18	0.21
100	0.16	0.18	0.22
300	0.16	0.18	0.23

Source: BSO (2007)

The thickness of a hollow sandcrete block cavity is within the range of 10mm to 100mm which gives a horizontal heat flow range of 0.15 to 0.18 through the air layer (stagnant air), represented in m^2K/W for an unventilated cavity space of sandcrete block.

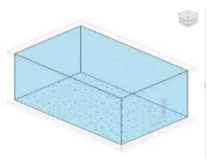
3. Methodology

This study uses a hotel room space where a steady energy supply is required throughout the day for the comfort of occupants. It employed a quasi-experimental approach using Autodesk Ecotect software to simulate the effect of hotel room space orientation on energy consumption in a proposed 3D model. The model full description is stated in table 4. It is a single thermal zone.

Table 4: Specimen model description and input data

- Comfort temperature: 20 – 26 °C
- Thermal zone / Floor area: 3.8m x 6.0m = 22.8 m^2, height: 3m
- Cooling operations: 24 hours.
- Walling: 230mm hollow Sandcrete block wall.

- Relative humidity 50%
- Openings: 0.9mx1.5m single glazed window with aluminium frame
- 0.9mx2.1m wooden panel door
- Floor: suspended conc. Flr.
- Roof: 150mm concrete slab with asphalt.



Each of the four-room layout undergoes the processes of settings, in both zone management and material properties. In the zone management, the rooms were selected as 'zones' while in the material management, each zone is given a material property. Under the material property, the thickness, R-Value and the admittance properties of the walling material is imputed after which the simulation is ran in the Ecotect software which automatically calculates the solar absorption, thermal decrement, thermal lag and the weight of the materials. This process is shown in Figure 3, other data required for this analysis is the location weather file, (Birnin Kebbi weather file) in this case. This helped in determining an accurate result. The calculation is in accordance with BSO (2007) guidelines for calculating thermal resistance and thermal transmittance (shown in Table 3).

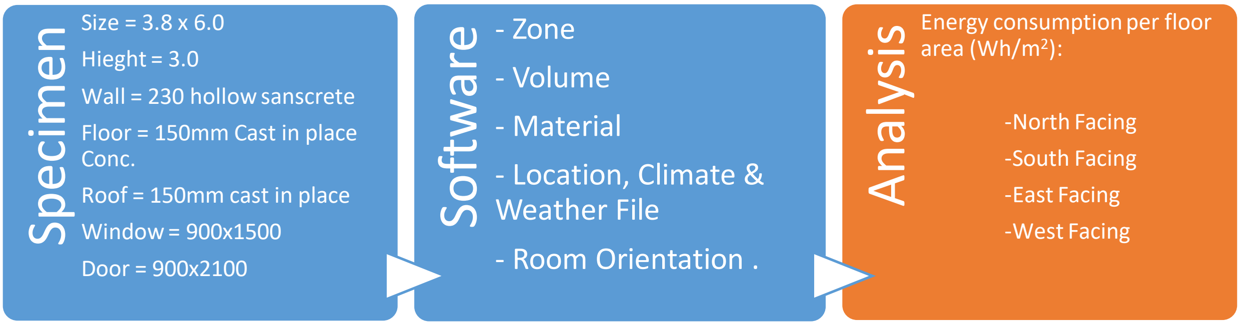


Figure 3: Analysis process / requirements, and results display

4. Results, Analysis and Discussion

The model was developed using Autodesk Revit Architecture with a typical hotel room grid described earlier in Table 4 as a minimum requirement by World Tourism Organization (WTO, 2007). The floor space was tagged and volume and also checked according to specified room height. It is then exported as gbxml format which is a recognizable format for Ecotect software as shown in Figure 4.

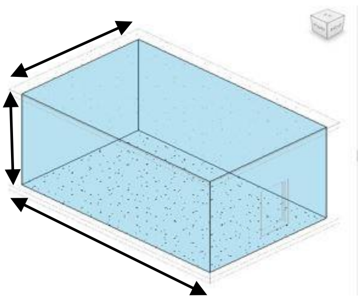


Figure 4: 3D model of a typical room space used for simulation in Autodesk Revit software

4.1. Model description

The room layout is named according to the direction in which its longer side faces on the cardinal points (Figure 5), and finally simulated using Autodesk Ecotect software; four orientation layouts were simulated:

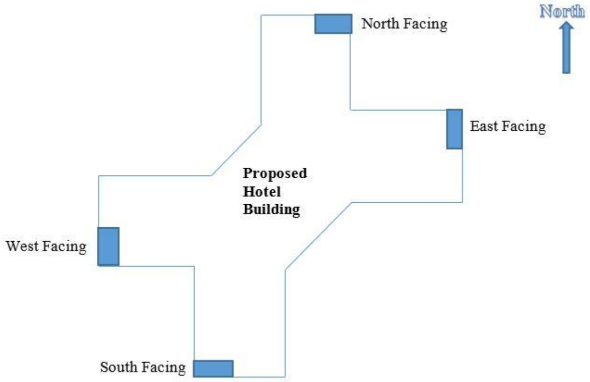


Figure 5: Room layout position on the proposed building prior to determining room orientation that consumes more energy

North facing room, South facing room, East facing room and West facing room. The solar radiation study performed in the Autodesk Ecotect software provided an early indication of the spaces optimal orientation with respect to the sun. The results show that the South-facing room layout consumes less energy followed by the North-facing. East facing room layout and West-facing consume more energy than the other two layouts. The South-facing has the total annual energy consumption of 268.53kWh; West-facing layout has 489kWh; North-facing has 404kWh as its annual consumption, and lastly East-facing layout has 481kWh as shown in Figure 6.

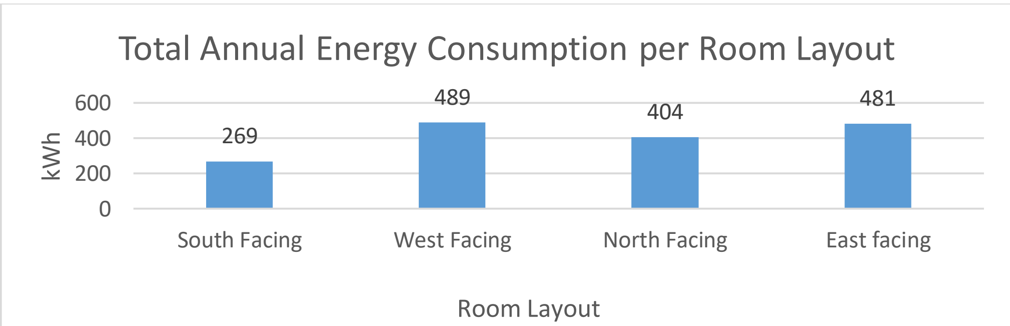


Figure 6: Determining the room layout that consumes less energy, south facing exhibits lower consumption than other room layout

Plotting the monthly comfort/discomfort chart further displays the monthly energy consumption pattern. South-facing layout recorded the lowest monthly consumption with its highest energy consumption recorded in the month of March as 435kWh/m^2 and the lowest is the month of September as 86kWh/m^2.

West-facing layout recorded the highest monthly consumption of all the four layouts: with the peak consumption of 687kWh/m^2 in the month of March and 198kWh/m^2 in August. East-facing layout is next to West-facing layout with 589kWh/m^2 in the month of March and 151kWh/m^2 in September. North-facing layout exhibits similar pattern with the south-facing layout where its peak consumption is 681kWh/m^2 during the month of March and 196kWh/m^2 in September. See Figure 7.

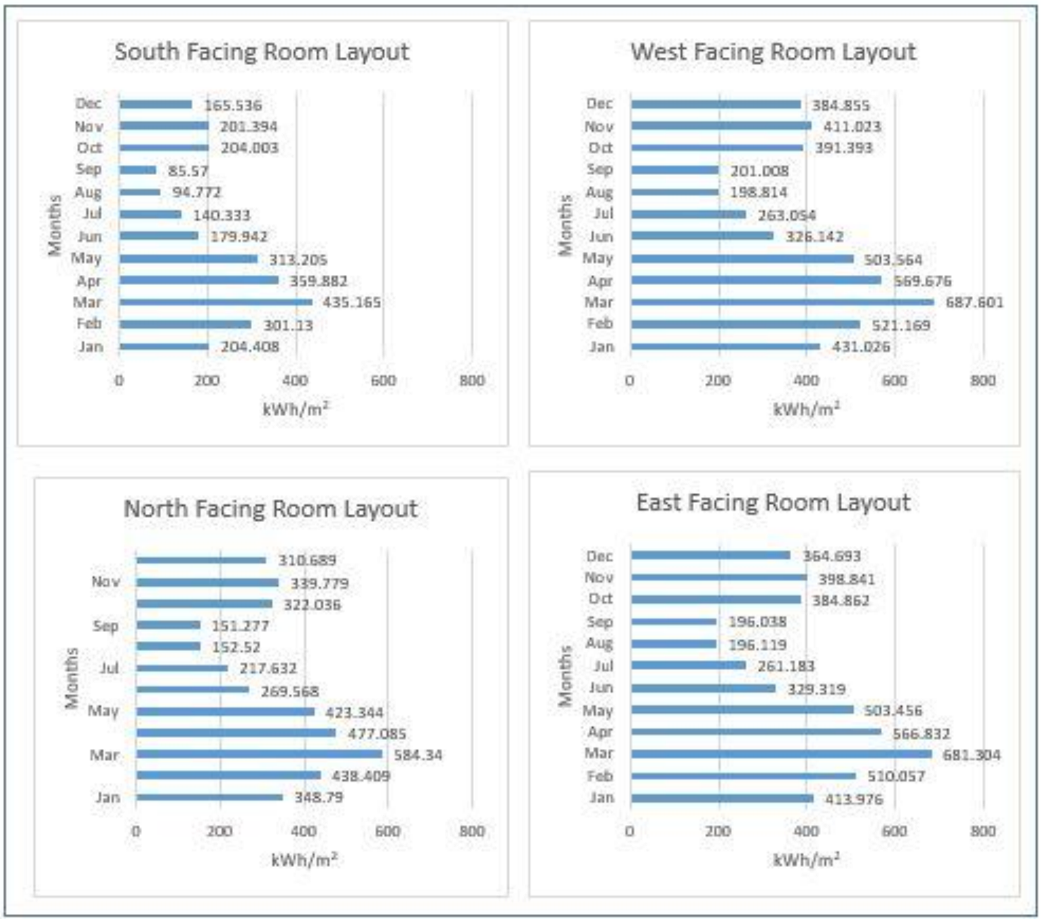


Figure 7: Monthly consumption pattern across the four room layouts

The results show that, there is a potential energy saving in orienting hotel rooms space when the longer side faces towards south direction, it will increase energy conservation up to 14.2%. When compared with the study conducted by Batagarawa *et. al.*, (2015), this recorded an average of 260.4KW within the range of 85.57kWh/m2 to 435.2kWh/m2 therefore considering this layout in the design of hotel rooms would enhance both energy conservation and cost of fixing and maintaining of mechanical air conditioning system, thereby minimizing emissions of Green House Gases (GHG) to the environment.

5. CONCLUSION

The paper presents result for ideal room orientation for low energy conservation in hotel buildings in the hot-dry climate of Birnin Kebbi. The study identified the ideal layout for energy conservation, by testing different orientation of four room spaces along the cardinal points. The research has suggested that orienting a room space along south-facing layout in hotel design will provide a potential energy savings in energy consumption of up to 14.2%. The South-facing room layout consumes less, followed by the North-facing, then East-facing room layout with West-facing room layout having the highest energy consumption. This serve as a guide to designers of hotel buildings trying to minimize energy consumption. The study is able to conclude that proper orientation of hotel room spaces with South-facing layout will greatly reduce energy consumption, so long as it is to be sited within the hot-dry climatic region of Nigeria.

6. RECOMMENDATIONS

Hotels as an enterprise organization mainly for profit making, anything that can lead to profit loss need to be avoided, energy consumption by the use of electric energy for comfort within the building under study (Hotel) may affect the profit gain. In order to avoid foregoing issues, the study recommends as follows: The Government is advised to hasten the process of actualizing Green Building Council (GBC) in the country, this can go in-line with global environmental sustainability; Architects should lay more emphasis on hotel building orientation to avoid high energy consumption, specifically longer sides of the hotel room spaces should face southern direction as much as possible.

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