ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS: A CASE STUDY OF 1004 FEDERAL HOUSING AUTHORITY ESTATE, VICTORIA ISLAND, LAGOS

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Abstract

Globally, energy consumption in buildings takes up the largest proportion of world's energy production. This consumption is more in developing countries including Nigeria and Least Developed economies than the developed worlds. Researches are therefore, currently been geared towards reducing energy consumption due to the global problem of insufficient energy needed to meet the demand and the attendant environmental issues associated with the production based largely on fossil burning. In Nigeria, consumption in buildings takes up about a third of the total electricity production with Lagos accounting for the larger percentage of the total energy production due to the fast rising population, teeming economic growth and increased rate of construction across the state. This paper thus investigates the energy consumption in residential buildings (1004 Federal Housing Authority Estate), in Lagos state. Survey analysis approach was adopted in this work. Field trips to the study area were conducted, measurements were taken and questionnaires were administered to occupants. The design features of the buildings were analyzed. The household equipments and the occupants were also taken into consideration. The work also analyze the present electric energy use for cooling and lighting typical residential buildings of upper income households in Lagos and the possible energy savings by adopting certain energy efficient features (in wall) in the case study building. The enveloped thermal transfer value (ETTV) equation was utilized to account for the quantity of heat taking into the building through the buildings envelop. Building wall of 200mm concrete thickness plastered with 13mm cement thickness in and out was used in the study. Result obtained indicates that doubling the thickness of external walls, reduces the cooling load of the building and hence reduces its total energy consumption. The total envelop energy of the building obtained was found to be 64.98W/m^2, while 57.60 W/m^2 was obtained when perlite was used in wall plastering in place of the cement with same thickness. Improvement of energy efficiency in residential buildings was also achieved through series of demonstration works carried out in the analysis using ETTV equation. The study established that the perlite plaster has a lower thermal transmittance value (U-value) when compare to that of cement hence a better energy reducing material option in building construction. The impact of ETTV on the energy consumption of residential buildings leading to a reduction in building heat load was also established in the study.

Keywords: Energy Efficiency, Survey Analysis, Perlite, ETTV, Residential buildings, 1004 Federal Housing Estate, Lagos.

Introduction

More than 90 per cent of our time is spent in buildings i.e. either in the office or at home. Energy used in buildings (residential and commercial) accounts for a significant percentage of a country's total energy consumption. This percentage depends greatly on the degree of electrification, the level of urbanization, the amount of building area per capital, the prevailing climate, as well as national and local policies to promote efficiency.

Space heating, space cooling and lighting, which together account for a majority of building energy use in industrialized countries, depend not only on the energy efficiency of temperature control and lighting systems, but also on the efficiency of the buildings in which they operate. Building designs (in terms of orientation) and materials have a significant effect on the energy consumed for a select set of end users.

The energy efficiency of a building is the extent to which the energy consumption per square metre of floor area of the building measures up to established energy consumption benchmarks for that particular type of building under defined climatic conditions. These benchmarks are applied mainly to heating, cooling, air-conditioning, ventilation, lighting, fans, pumps and controls, office or other electrical equipment, and electricity consumption for external lighting. The benchmarks used vary with the country and type of building.

A building is made up of a wall (which is the frame work or support) to which other components such as windows, doors .ceiling etc is attached to. The walls of different patterns or design are made up of different materials such as clay, cement, stones or wood according to architect's or owner's design.

The measure of heat loss through a material, referred to as the heat transfer co-efficient U-Value, is used as a way of describing the energy performance of a building. The U-value refers to how well an element conducts heat from one side to the other by rating how much the heat the component allows to pass through it. U-values also rate the energy efficiency of the combined materials in a building component or section. A low U-value indicates good energy efficiency. Windows, doors, walls and skylights can gain or lose heat, thereby increasing the energy required for cooling or heating. They are the standard used in building codes for specifying the minimum energy efficiency values for windows, doors, walls and other exterior building components.

Frequent power disruption and load shedding in Nigeria, over ten hours a day, amid hot and humid conditions have made the life of city people miserable. Recently, residents have alleged that they are experiencing three to five-hour long power cuts, three to four times a day on an average (The Daily Star, 2009). The load-shedding situation continues to worsen as the excessive heat drives people to use more electricity at homes and offices. According to the report of Punch Newspaper (2012), the power situation in

Nigeria has taken a serious turn due to the inadequate generation of electricity. The country has been experiencing a shortfall of about 735.8MW of electricity from 4,517.6MW in December 2012 to 3,781.8MWs in October 2013. (Premium times, 2013). This later declined by 218.8MWs to give 3,563MWs by December 2013. Lagos alone is being provided with 1000MWs against a demand for about 1800MWs.(ThisDay 2013), It is assumed that this demand would rise to 2200 MWs during the peak summertime, from mid March to mid October when electricity use goes up to its highest level because of hot weather as well as a huge need for irrigation.

An extensive literature review consisting of different journals, books, researches and related websites was undertaken to establish the basic passive principles for designing energy efficient residential buildings. Below is the list of aspects for energy efficient residential buildings that has been arrived at from the literature review and is based on the context of Lagos:

1. Planning aspects:

Site analysis

Building form

Building orientation

Room orientation

Landscaping

2. Building envelope:

External wall

Thermal insulation

Building material

Roof

Windows

− Size

− Orientation

− Shading device

− Natural ventilation

− Daylight

2.0 Methodology and case study

The study was extended to three main phases. The first phase defined the theoretical framework for this study. In addition, it identified the methodology of analysis and issues that were investigated in the case study. This phase, mainly a desk study, encompassed extensive literature reviews of books, journal papers, researches and documents to identify energy efficient of residential building principles that could be used for the context of Lagos.

The second phase involved a field trip to Lagos. The fieldwork consisted of visits to the instrumental case study with embedded units and interviews with the residents of the case study building. The case study is the 1004 Housing Estate on Victoria Island, Lagos. Quantitative and qualitative data were collected from the case study building. All the information that was analyzed during this phase was intended to fulfil the structure outlined in theoretical framework formed in the first phase.

The third phase comprised of a desk study for the second time to analyze and evaluate the data from the first and second phase studies using quantitative and qualitative methods. The data on energy use of different flats/units in the building were analyzed quantitatively and the design features of the apartment were analyzed both quantitatively and qualitatively according to the basic design principles laid out in the theoretical framework.

Energy efficient principles that were identified through literature review were summarized and analyzed quantitatively to determine the energy savings of all the features that could be applied in the context of Lagos. Calculations were then made to see how much energy the flats surveyed in the case study building could save, by adopting the energy efficient design principles.

Issues investigated/ units of analysis

Apart from the design aspects that were identified in the theoretical framework, the following

issues in the case study apartment have also been investigated:

energy use practices of households (appliances used, energy used by those appliances)

energy use for cooling and lighing in typical multi-storey residential buildings of Lagos

cooling load analysis of the households

general living pattern of the households

Data gathering strategies

Data gathering strategies were divided into a mixture of qualitative and quantitative approaches.

The following different combinations of data gathering strategies were adopted:

physical survey of the case study building

semi-structured interviews

quantitative calculation of energy use

architectural drawings of the case

quantitative statistics from newspaper clippings.

Envelope Thermal Transfer Value (ETTV)

The ETTV takes into account the three basic components of heat gain through the external walls and windows of a building. These are:

heat conduction through opaque walls,

heat conduction through glass windows,

solar radiation through glass windows.

These three components of heat input are averaged over the whole envelope area of the building to give an ETTV that represents the thermal performance of the whole envelope.

The ETTV formula is given as follows:

$$ETTV = 12(1\text{-}WWR)U_w + 3.4(WWR)U_f + 211(WWR)(CF)(SC) \qquad 1$$

Where;

ETTV : envelope thermal transfer value (W/m^2)

WWR : window-to-wall ratio (fenestration area / gross area of exterior wall)

U_w: thermal transmittance of opaque wall ($W/m^2\,K$)

U_f: thermal transmittance of fenestration ($W/m^2\,K$)

CF: correction factor for solar heat gain through fenestration

SC: shading coefficients of fenestration

The thermal transmittance or U-value of a construction is defined as the quantity of heat that flows through a unit area of a building section under steady-state conditions in unit time per unit temperature difference of the air on either side of the section. It is expressed in $W/m^2\,K$ and is given by:

$U = \frac{1}{R_T}$ 2

$Where\ R_T =$ is the total thermal resistance and is given by:

$$R_T = R_o + \frac{b_1}{k_1} + \frac{b_2}{k_2} + \ldots + \frac{b_n}{k_n} + R_i$$ 3

Where;

R_o : air film resistance of external surface (m^2 K/W)

R_i: air film resistance of internal surface (m^2 K/W)

k_1, k_2, k_n : thermal conductivity of basic material (W/m K)

b_1, b_2, b_n : thickness of basic material (m)

3.0 Results and discussion

Building orientation

The long axis of the building runs east-west, i.e. the facades on the north and south are bigger than the east and west elevations. The orientation of the case study building is in line with the recommendation of Gut and Ackerknecht (1993) and Wong and Li (2007). It has been established that the best orientation for buildings in tropical climates is for the longer axis of the building to lie along east-west direction to avoid solar heat gain.

Room orientation

The orientation of each room in each individual flat surveyed will not be discussed as the planning of each type of flat is basically the same throughout the building. Rather, the orientation of rooms in the three bedroom flat will be discussed.

Table.1: showing the rooms' orientation in three bedroom flat

Living	Dinning	Master bedroom	Bedroom2	Bedroom3	Kitchen	Toilet
North	Central	South	North	North	South	South

The orientation of bedrooms and living room in this type of flat is good because none of these rooms is located in the west. According to Gut and Ackerknecht (1993), stores and other auxiliary spaces should be located on the disadvantaged side, mainly facing west. The kitchen too is well positioned except for the dining space that does not have a proper orientation in all flat types. Gut and Ackerknecht (1993) pointed out that bedrooms can be located on the east side because it is coolest in the evening.

External wall and building material

Both external and internal walls have a cement plaster over the concrete blocks and white wall finishes. According to Cheung *et al*. (2005) it is possible to save 12% on cooling energy by using white or light colour external wall finishes. Hence, this building is therefore successful in saving 12% on cooling energy because of the light colour external wall finishes.

Thermal Insulation

In general, residential buildings in Lagos do not have insulations because it is considered expensive and difficult to maintain. In the case study building, neither walls and windows nor roofs, have any type of insulation.

Roof

The roof is flat, about 100 mm thick. It is made of reinforced concrete slab with weathering course and neat cement finish.

Windows

The window to floor area ratio (WFR) of the three bedroom flat was calculated by dividing the area of the window by the area of the floor. Similarly, the window to wall area ratio (WWR) in the different units was calculated by dividing the window area by floor area.

Table 2: Window to floor area ratio (WFR) and window to wall area ratio (WWR) of rooms in 3 bedroom Flat apartments

Rooms	Window orientation	Floor area (m^2)	Window size(m^2)	Wall area (m^2)	WFR	WWR
Master bedroom	South wall	12.87	3	12	0.23	0.25
Bedroom2	North wall	12.21	2.6	10	0.21	0.26
Bedroom3	North wall	10.82	2.52	9.3	0.23	0.27
Living room	North wall	14.1	2.1	9.5	0.15	0.22
Kitchen	South wall	5.8	1.5	6	0.26	0.25

The windows on the north of the flats are effective in allowing day light and airflow because of their orientation. As a result, the lights in these units need not to be kept on throughout the day.

For proper cross ventilation, Mathur and Chand (1993) recommend windows located diagonally opposite to each other. However, only the living room of all the three flat types in this building have provision for cross-ventilation through two pairs of windows located on side walls. As the location of the outlet is very far to the inlet, most of the space inside the room is affected by the air current.

Shading devices

Shading devices are not necessary needed in this building. The building is built to ensure protection from the rain and solar heat gain. The figure below shows the balcony of the building, which also serve as the shading devices in all the floors. The windows in the case building were built inside the balcony.

Survey of The Various Households Equipment

Information: Each building is identical and so is each floor. On each floor, there are 6 flats of 2 bedrooms and 12 flats of 3 bedrooms except for the 3rd, 5th, 7th, 9th, 11th and 13th floors that have additional one bedroom flat.

Table 5: Household equipment for three bedroom apartment

Fittings/type	Sitting room	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom	Passage	total
13amps socket	96	72	72	72	48	4	48	412
15amps socket	12	12	12	12	12	12	Nil	72
Lighting fittings	48	24	24	24	12	24	36	192
Air conditioner	12	12	12	12	Nil	Nil	Nil	48
Water heater	Nil	Nil	Nil	Nil	Nil	12	Nil	12
Cooker	Nil	Nil	Nil	Nil	12	Nil	Nil	12

Envelope Thermal Transfer Value (ETTV)

Case study building

From the building's plan, the ETTV is given as;

$$ETTV = 12(1\text{-}WWR)\,U_w + 3.4(WWR)\,U_f + 211(WWR)(CF)(SC)$$

$$ETTV = 64.98 W/m^2$$

Re-designing the building with less heat gain

The cement in the case study building is replaced with perlite, the ETTV then gives;

ETTV=57.60

4.0 Conclusion and recommendation

This study has identified, apart from other energy efficient building features that doubling the thickness of external walls or using a different plaster will improve the energy efficiency of residential buildings, in the context of Lagos, Nigeria. In this work, it was established that using perlite plaster in place of the cement plaster, improved the cooling inside the building, thereby

making the building to be more energy efficient. It is recommended that perlite, with less thermal transmittance value (U), should be used for wall plastering instead of cement.

References

Cheung, C.K., Fuller, R.J. & Luther, M.B. 2005. Energy-Efficient Envelope Design for High-Rise Apartments. *Energy and Buildings*, 37 (1): 37-48.

Gut, P. & Ackerknecht, D. 1993. *Climate Responsive Building: Appropriate Building Construction in*

Tropical and Subtropical Regions. Switzerland: SKAT.

Mathur,V. K. & Chand, I. 2003. Climatic Design for Energy Efficiency in Buildings. *IE (I) Journal-AR*, 84 (2003): 33-39.

Nigerian's Newspaper; Premium times (2013), Punch Newspaper (2012), The Daily Star (2009).

Wong, N.H. & Li, S. 2007. A Study of the Effectiveness of Passive Climate Control in Naturally Ventilated Residential Buildings in Singapore. *Building and Environment*, 42 (3): 1395-1405.