The Perceptible Impacts of Building Envelope on Other Green Building Features: "A Review"

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ABSTRACT

Nigeria is a West African country with a climate classification of a tropical wet and dry climate with three weather conditions namely; warm, humid rainy season and a blistering dry season; with a brief interlude of harmattan in between the two. As such, Green building (GB) designs and constructions in Nigeria must be characterized by features that suit its weather and the environment. GB features include but not limited to the building envelope (BE), Energy efficiency, water Efficiency, Indoor environmental quality (IEQ), Day lighting systems etc. Such features/ components are integrated into the GB for various purposes and functions; as a whole they help solve sustainability issues within the built environment. The BE consists of structural materials and finishes that enclose space, separating inside from outside with a proportionate impact on other green features. The BE design is a specialised area of design and construction engineering practice that draws from many areas of building science and disciplines. With new trends emerging coupled with the shift toward timesaving standardization; this will necessitates mass customization of BE components. BE technology is important first in uniting the industry to overcome some of the factors and challenges that hinder innovation in buildings. The aim of this paper is to examine and assess the impacts of building envelope on other green building features with a view of ascertaining the impacts of the envelope on the GB concept as a whole. Reviewed literatures were used to identify, explore and examine the various green building features, the impact and the relationship of building envelope on such features within the context of Nigeria's built environment. The results showed that Building envelope have a significant impact on green building features such as Energy, Day lighting, Indoor environmental quality and water efficiency systems and strategies.

Keywords: *indoor environmental quality, green building management, building envelope, built environment, green features, impacts, Nigeria*

1. INTRODUCTION

Nigeria is the most populous African country located in western Africa; a former British colony till October, 1960 when it gained independence. Lagos (a coastal city) was then the capital city till December, 1991 before the seat of power was moved to Abuja within the Federal Capital Territory (FCT) in the same year. Geographically, Nigeria is located in West Africa with the southern part of the country having a long costal line with the Atlantic Ocean and the north with the Sahara Desert. Under Köppen climate classification, it features a tropical wet and dry climate with three weather conditions namely; warm, humid rainy season and a blistering dry season; with a brief interlude of harmattan in between the two (WECSI 2014, demographia.com; and Wikipedia.org). As such, Construction projects in Nigeria's built environment; be it Housing, Industrial engineering, Roads and other civil and infrastructural projects were affected by its weather, location and available construction materials. Like any other construction industry of a developing nation in the world, the industry in Nigeria also pollutes the environment.

These showcased the built environment impact (due to human activity) on resources, that is buildings have a significant impact on the environment, accounting for one-sixth of the world's freshwater withdrawals, one-quarter of its wood harvest, and two-fifths of its material (Eurostat, 2011); 40% primary energy consumption (Bauer et al., 2007). Structures also impact areas beyond their immediate location, affecting the watersheds, air quality, and transportation patterns of communities (Eurostat, 2011). The combination of these challenges gave birth to a new concept in design, construction/ renovation, operation and maintenance of buildings in conformity with sustainable practices known as sustainable/ eco/ high performance/ green buildings (Dalibi, 2014).

It is worthy to note that since the emergence of Sustainable/ eco/ high performance/ green buildings, there were so many attempts to clearly define it, with each Industry and discipline defining it from its own perspective. Below were some definitions:

- Green building (GB) refers to a structure that uses all processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from Siting to Design, Construction, Operation, Maintenance, Renovation and Demolition. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort (USEPA, 2009).
- Sustainable/ green buildings are those sensitive to the environment, resource and energy consumption, impact on people, financial impact and the world at large. While Zane et al, 2009; referred to the term "Green Building" as environmentally friendly practices from building design to the landscaping choices. It also encompasses energy use, water use, storm-water and wastewater re-use (Greg Kats, 2003).
- According to Dalibi, 2012; Green buildings (GB) are buildings designed, constructed and operated to provide optimum performance of the building with positive impact to the occupants and the environment by combining energy, water efficiency systems, Day Lighting strategies, Indoor Environmental Quality (IEQ) systems and efficient Building Envelope systems.
- The United States environmental protection agency as cited by Vatalisa et al., 2013; opine that "Although new technologies are constantly being developed to complement current practices in creating more sustainable buildings, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment through the goals of sustainable building such as life cycle assessment (LCA), energy efficiency and renewable energy, water efficiency, environmentally preferable building materials and specifications, waste reduction, toxics reduction, indoor air quality, smart growth and sustainable development, environmentally innovative materials and services
- Another definition by green building (GB) solutions is that: green building design and construction provide an opportunity to use resources more efficiently, while creating healthier and more energy-efficient homes and commercial buildings.
- "Green building (GB) is a holistic concept that starts with the understanding that the built environment can have profound effects, both positive and negative, on the natural environment, as well as the people who inhabit buildings every day. Green building is an effort to amplify the positive and mitigate the negative of these effects throughout the entire life cycle of a building (USGBC 2007).

Thus, from the above definitions, an adequate building envelope system is one of the features of GB. A Building envelope (BE) is the physical separator between the conditioned and unconditioned environment of a building including the resistance to air, water, heat, light, and noise transfer (Cleveland and Morris, 2009 and Syed, 2012). The BE is all of the elements of the outer shell that maintain a dry, heated, or cooled indoor environment and facilitate its climate control. Building envelope design is a specialized area of architectural and engineering practice that draws from all areas of building science and indoor climate control (Syed, 2012).

According to Straube and Burnett (2005), the functions of the BE can be separated into three categories:

- Support (To resist and transfer structural loads),
- Control (The flow of matter and energy of all types),
- Finish (Meeting human desires on the inside and outside).

1.1 Research problem

Over the years, many housing estates were developed by both the Public and the Private sectors or a partnership of both in Nigeria. However, Such Housing estate developments were insufficient in terms of demands; do not reflect the desired housing needs of the end-users; in most cases affordable but not qualitative; do not possess green building features (Dalibi et al., 2016). Though, green building construction practice is a new trend with insufficient data about building performance from currently operating sustainably designed buildings (BD&C 2003; ENSAR 2003; Andreau et al., 2004). It is also evident from some developers'/ clients' attitudes, as they are not fully inclined towards such projects due to lack of comprehensive data about the financial obligations with regards to Incorporating green features into renovation or proposed projects (Dalibi et al., 2016).

Casado (1996) stressed the importance of studying the potential environmental impacts produced by the use of certain building materials with the need to highlight the impact represented by the combination of these materials when used in a certain constructive assembly. Morris (2007); Asserted that "the cost for incorporating sustainable design elements will depend greatly on a wide range of factors, including:

- Building type,
- Project location,
- Local climate,
- Site conditions, and
- The familiarity of the project team with sustainable design.

In most cases, these factors have a relatively small but still noticeable impact on the overall cost of sustainability. Cumulatively, however, they can make quite a difference.

Hence, the need to examine the impact of BE on other GB features based on building type, project location, local climate, site conditions, and the familiarity of the project team with sustainable design; which is further compounded by the perceived synergetic effect of GB features in ensuring sustainability within the construction industry.

1.2 Research aim

The aim of this paper is to review the perceptible impacts of BE on other GB features within the Nigerian and global context with the view of improving the existing literature. Review of literatures in the eco/ green/ sustainable building field helps identify and narrow few environmentally sustainable passive and active elements or features of which the impact of BE will be examined upon.

2. METHODOLOGY

The main sources of data were journals, conference/ seminar/ workshop papers, text books, newspapers, magazines and the internet etc. which were used to review literatures in the green building field which helps identify and narrow few environmentally sustainable passive and active elements within the Nigerian and Global context.

Huedo et al., (2016), opined that environmental assessment of the building assemblies used for the envelope requires a scientifically rigorous methodology such as environmental impact assessment. The life cycle analysis (LCA) is the most suitable because it is an analytical procedure focused on evaluating the whole life cycle. LCA, however, it is an exhaustive, very laborious and complex process that must be carried out by highly skilled professionals and the time needed to apply it is often incompatible with the time available for producing designs. As a result, few life cycle analyses of buildings have been carried out in some countries. In the international context, a wide variety of tools based on the LCA methodology have been developed with the specific aim of aiding the planner in the sustainable selection of building assemblies.

These tools hardly apply outside the countries where they were developed since the environmental impact level caused by building materials and assemblies varies from one territory to another, due to the geographic placement of raw materials extraction and transformation plants in relation to the building location as well as to the possible differences in construction techniques (Mateus and Bragança, 2011).

3. LITERATURE REVIEW

3.1 Building envelope

GB is an integrated building system that encompasses all the efficiency systems (into a single system) for the purpose of sustainability. Sustainable design elements are gradually accepted in the mainstream of GB project design, as the major stakeholders (clients and end-users) are beginning to demand and value those features. It is important to note that, the advanced or innovative sustainable features can add significantly to the cost of a project and that these must be valued independently to ensure that they are cost and or environmentally effective when integrated together. Such elements include energy efficiency systems, water efficiency systems, day lighting systems, indoor environmental quality (IEQ) systems and building envelope systems etc. through the use of sustainable building materials.

The building envelope, also called building enclosure, shell or fabric, is the boundary or physical separator between un-conditioned or conditioned interior of a building and the outdoor environment. Building envelope, consisting of external walls, roofs, ceilings, floors, windows, and doors, regulates the flow of energy between exterior and interior of the building and plays a crucial role of both protecting building occupants from external environment by providing them comfort and by enhancing their productivity. Building envelope also plays a critical role in determining the amount of energy a building will use during its operation. The energy costs associated with the production and transportation and overall environmental life-cycle impacts of different envelope materials vary greatly (IEA, 2013).

Thus, to increase the sustainability of construction it is necessary to consider reducing both the energy consumption and the CO_2 emissions of buildings by improving the building assemblies that make up the building envelope. This envelope has to guarantee the quality of the environment inside the building, since the exchange between the inner and outer environment takes place through it. It is also the point where illumination, ventilation or heat flows act as fundamental design parameters (Haapio and Viitaniemi, 2008).

The use of materials and construction technique in building envelope widely differs between developed countries like Europe, USA, and developing countries especially those within the tropics (IEA, 2013). In almost all parts of the world, buildings used to be constructed using local materials to maximize comfort considering local climate. In warm-humid areas larger openings were provided in the buildings for natural ventilation for cooling etc. But, due to modernization and faster urbanization rate, the force of market economy and electronic media along with a change in socio-cultural outlook have made people accepting the gradual change in the building design and construction materials even in remote rural and semi-urban places (Sarkar, 2015a).

Present day construction practices utilize modern standardized building materials and construction methods that dominate the market in the country (Sarkar, 2015a and Sarkar, 2015b). Local climate and function of the building are the two foremost important parameters affecting building envelope design. The thermal loads of residential buildings are primarily external (from sun). The efficiency of building envelope design is significantly affected by the building configuration and foot print also (ibid).

3.2 Envelope and other GB features

Green building elements and features considered in this work as cited by Dalibi (2016), and also based on US EPA 2009; Gregg Kats 2003; Zane et al, 2009, Dalibi, 2012; Vatalisa et al., 2013; greenbuildingsolutions.com; USGBC 2007; include (but not limited to) the following; energy efficiency systems, water efficiency systems, day lighting systems, indoor environmental quality (IEQ) systems and the building envelope systems.

As such, the perceptible impacts of building envelope (BE) in this work also will be based on the following features and their sub-components:

- Energy efficiency systems,
- Water efficiency systems,
- Day lighting systems,
- Indoor environmental quality (IEQ) systems,

3.3 Impact of BE on green building energy efficiency system

Buildings are responsible for more than one third of the total energy use and associated greenhouse gas emissions, both in developed and developing countries (UNEP, 2014). Buildings consume a lot of energy all around the world and are responsible for high environmental pollution. However, the main focus is also put on new construction technologies to assure low energy needs of new buildings (Chwieduk, 2016).

Nowadays building envelopes are designed and constructed according to energy saving measures, with high quality of thermal insulation and high thermal capacity of construction elements. Heat flow through opaque external walls has been reduced significantly, and it takes a minor part of the total energy transport between the outdoor and indoor environment. The influence of solar radiation passing through glazing on the heat balance of a building is especially evident in new low energy buildings with high thermal resistance envelopes (ibid).

It is necessary to be able to establish relationships between these impacts and those produced throughout the lifespan of the building, due to both the actual materials used and the energy consumption linked to the building assemblies employed in the building envelope (Huedo et al., 2016). Residential and commercial buildings consume approximately 60% of the world's electricity (www.isi.fraunhofer.de; 2012) in Europe, the residential sector requires 27% of the total energy and it contributes proportionally to the emission of CO_2 (Nejat et al., 2015). Some studies show the impact of energy efficiency measures related to refrigerators, washing machines, air conditioners, televisions and heating and cooling service (Montejo and Pardo 2016; Arto et al., 2016).

Huang and Hwang (2015) studies of residential apartments in Taipei, have observed that cooling demand could increase of 31%, 59%, and 82% over current levels respectively for the 2020s, 2050s, and 2080s. Thus, they have underlined an urgent need to regulate the excessive use of cooling systems, also by remodelling existing buildings with passive design measures. Discussions and new solutions for energy efficiency in building sector are thus indisputable (Huang and Hwang 2015).

By using water piping system, the exterior to interior heat transmission can be reduced, which results in interior thermal comfort and reduced energy consumption by air conditioners. The heated water in the piping system is stored in an insulated water tank and is used for domestic hot water to save energy. Integrating a solar thermal plant with the building envelope reduces the high cost of electric grids, but also generates the electric power by buildings demand. (http://australia.energy.com, n.d.).

3.4 Impact of BE on green building water efficiency system

Demand in every area of water use in urban, industrial, and agricultural has increased, often because of mismanagement, overuse, and waste. This clearly indicates that mismanagement, overuse, and waste of water in buildings is a strong issue that needs proper and lasting solution in order to be water efficient (Gottfried, 1996).

In the average household, 68% of drinking water is used for washing and toilet flushing. Laundry and dishwashing actions account for another 19%. The remaining water volume is used for drinking and cooking and also for garden watering and cleaning (Bauer and Schwarz, 2007). As such, Water efficiency in green buildings can be achieved through the combination of the following: systematic rainwater utilization, water conserving appliances, grey water and black water systems

- Rain water use: Systematic rainwater utilization reduces drinking water consumption by about half. Rainwater can be used for flushing, washing and cleaning, as well as for watering the garden. This requires a rainwater tanks and additional piping system.
- Water conserving appliances and technologies: Effective ways to reduce water use include installing flow restrictors and/ or reduced flow aerators on lavatory, sink, and shower fixtures; installing and maintaining automatic faucet/ tap sensors and metering controls; installing low-consumption flush fixtures, such as high-efficiency water closets and urinals; installing non-water fixtures.
- Grey water and black water systems: Grey water is the waste water from households, stemming from shower, bathtub, bathroom sink and the washing machine and which, hence, is not contaminated with faeces or highly polluted kitchen waste water (black water). It only contains a moderate amount of soap residue and skin oil. The average household produces about 60 liters of grey water per day, per person. This type of water can be processed into usable water, which is safe from a hygienic point of view but does not have the same quality as drinking water. It can be used for toilet flushing, watering and cleaning purposes. This means, in effect, that drinking water is then being used twice.

3.5 Impact of BE on green building day lighting efficiency system

Day lighting is the practice of bringing light into a building interior and distributing it in a way that provides more desirable and better-quality illumination than artificial light sources, reduces electricity use and its associated costs and pollution and creates healthier and more stimulating work environments than artificial lighting systems and can increase productivity up to 15 Percent (Romm and Browning, 1994).

Day lighting significantly reduces energy consumption and operating costs. Energy used for lighting in buildings can account for 40 to 50 Percent of total energy consumption. In addition, the added space-cooling loads that result from waste heat generated by lights can amount to three to five percent of total energy use. Properly designed and implemented day lighting strategies can save 50 to 80 percent of lighting energy. Greater use of day lighting can also provide advantages for the environment by reducing power demand and the related pollution and waste by-products from power production. The greatest savings from day lighting occur during periods when sunlight is most intense, which coincides with periods of peak demand for heating, ventilating, and air-conditioning (HVAC) and refrigeration loads. Therefore, wider use of day lighting would reduce both the need for new peak demand capacity and overall power demand (Andersen windows 1993; Romm and Browning, 1994; Gottfried and Simon, 1996).

Day lighting requires the correct placement of openings, or apertures, in the building envelope to allow light penetration while providing adequate distribution and diffusion of the light. A well-designed system avoids excessive thermal gains and excessive brightness resulting from direct sunlight, which can impair vision and cause discomfort. To control excessive brightness or contrast, windows are often equipped with additional elements such as shades, blinds, and light shelves. In most cases, the day lighting system should also include controls that dim or turn off lights when sufficient natural light is available to maintain desired lighting levels. It is also often desirable to integrate day lighting systems with the artificial lighting system to maintain required task or ambient illumination while maximizing the amount of lighting energy saved. Recent day lighting innovations offer a wide range of advanced, highly efficient, and, in some cases, highly engineered systems. In reviewing these options, the practitioner should recognize that higher efficiency and improved day lighting performance may entail additional costs. The benefits of day lighting include improved visual quality, better lighting-colour rendition, reduced solar heat gain, and improved visual performance and productivity. These benefits can make any increased engineering and installation which costs a worthwhile investment for the building owner or employer (ibid).

The following include some of the day lighting strategies:

- Side lighting (Clerestories in form of windows etc.)
- Top lighting (Saw tooth, stepped monitored etc.)
- Sky lights (Horizontal openings in roof etc.)

New glazing technologies are also in use in green buildings which include:

- Spectral glazing materials
- Switch-able glazing materials
  - Photo-chromic glass
  - Thermo-chromic glass
  - Electro-chromic glass
  - Liquid crystal (LCD)

3.6 Impact of BE on green building indoor environmental quality (IEQ) system

People spend up to 90% of their time indoors, increasing their chances of exposure to pollutants and other indoor environmental stressors including noise, glare and uncomfortable temperatures (USGBC, 2007; WHO 2013).

The process or act of making the link between potential sources of pollution or discomfort and actual health and performance effects are very challenging tasks, involving the interaction of a complex array of variables within the building indoor. First, indoor pollutants may arise from many sources, indoor or outdoor, and may have chemical, biological, gaseous and/ or particulate elements. Second, these pollutants interact with a range of indoor conditions including varying levels of temperature, humidity, ventilation and occupant behavior. Third, levels of occupant exposure to indoor pollutants or stressors will vary based on circumstances, and actual physical reactions will vary not only by pollutant and its level but also by characteristics of the occupant.

The concept of Indoor Environmental Quality (IEQ) in green buildings is broad and complex because it encompasses a lot of design and construction factors. Such factors include but not limited to:

- Indoor air quality
- Thermal comfort (Heating, cooling and ventilation etc.)

- Lighting (Both electric lighting and day lighting)
- Acoustics etc.

It also includes access to views of the outdoors and all other factors affecting the full range of human sensory conditions inside the buildings.

4. ANALYSES, SUMMARY AND CONCLUSION

From above literature reviewed, it can be observed that any GB is an integrated building system where all the elements/ features impact each other in terms of functionality, usability, fitting and or assemblage. However, among the major elements/ features of GB identified in this paper were energy efficiency systems, water efficiency systems, day lighting systems, indoor environmental quality (IEQ) systems, the building envelope (BE) systems. The main focus here is the impact of BE on other features because it serve as the enclosure/ shell/ barrier between the exterior and the interior of any GB.

Several studies conducted reveal the impact of BE on other GB features summarised as follows:

- Energy efficiency system: The BE help in retaining the conditioning inside the GB while also preventing the outside weather condition coming inside. It also allows integrating and fixing of renewable sources of energy within its system. e.g. solar panels etc.
- Water efficiency system: The BE can incorporate additional piping works for grey and black water systems, so also the any additional tank and pipe works required for effective utilization of rainwater.
- Day lighting: The type and positioning of clerestories and glazing choices within the BE system highlights the high impact of BE on the day lighting system and strategies.
- Indoor environmental quality (IEQ): This encompasses indoor air quality, thermal comfort (heating, cooling and ventilation etc.), lighting (both electric lighting and day lighting), acoustics etc. Without an adequate BE system all the four subcomponents of IEQ will not be achieved. The control function of BE improves the indoor air quality, thermal comfort, lighting (especially day lighting) and acoustics within a building.

At this juncture, it is worthy to note that adequate BE system impact other GB features due to: the use of materials and construction technique in building envelope, it is also the point where illumination, ventilation or heat flows while also enclosing and separating the un-conditioned or conditioned interior of a building and the outdoor environment.

5. RECOMMENDATION

There is need for an in depth further study of:

- BE on each GB element/ feature over a long span of time to ascertain the actual impact of BE.
- BE impact based on the perception of professionals and other stakeholders
- Other green building features/ components/ elements should also be considered and researched on, so as to expose how they interact with each other.

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