ENERGY EFFICIENT BUILDING ENVELOPE DESIGNS FOR INSTITUTIONAL BUILDINGS IN EAST AFRICA

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ABSTRACT

To date, insufficient attention has been afforded to the design and energy performance of Institutional buildings in East Africa. As a result most Institutional buildings in the region do not incorporate the issue of energy efficiency at the design, construction and utilization stages. Institutions are amongst the major consumers of energy in any country most of which is utilized within buildings, thus a thorough critique of the building envelope is necessary to reduce energy wastage within them. The aim of this paper is to present findings of the comparative study carried out on Institutional buildings at Strathmore University-Nairobi, Kenya and Makerere University-Kampala, Uganda. The study mainly considered the effect of building envelope designs and orientation to the energy consumption of the buildings. ECOTECT, a Building energy performance analysis tool was employed to quantify the effect of both the conventional and Energy Efficient Building Envelopes to the overall energy consumption of the buildings. The research findings show that the overall energy consumption of Institutional buildings could easily be reduced by about 40% through the design of envelopes suited to the micro-climate of the particular site, proper selection of construction materials vis-a-vis their thermal performance, extensive use of day-lighting, wise utilization of water and good building waste management systems as well as utilization of Energy Efficient Appliances within the building. The study also revealed that integration of a Building Management System would significantly reduce resource utilization within the building.

Key Words: Building Envelope, Energy Efficiency, East Africa, Energy Efficient Building Envelope (EEBE), Building Management System (BMS).

1. INTRODUCTION

The need for energy conservation is a real challenge, worthy of everyone's attention. Many Institutional buildings in East African countries do not incorporate the issue of energy efficiency at the design, construction and utilization stages. Usually land plot size and availability dictates the building's orientation and massing[1].

[1] Building massing refers to the building's lay out and general volumetric size and shape in relation to the prevailing landscaping of its location and neighboring structures.

Energy efficiency in the built environment can make significant contributions to a sustainable energy economy. In order to achieve this, greater public awareness of the importance of energy efficiency is required and Institutions of Higher learning are best placed to champion such initiatives. In the short term, issues that need to be properly addressed include demand side management i.e. behavioural change of consumers, new efficient domestic appliances, building technologies, legislation quantifying building plant performance, and improved building regulations. There are many technology options for improved energy performance of the building fabric and energy systems. The adoption of small-scale renewable technologies embedded in the building fabric also reduces on the energy demand of the building thus having a positive impact in climate change issues.

A building is a physical structure whose fundamental purpose is to provide shelter for some activity that could not be carried out as effectively, if at all in the natural environment. Such an activity may involve people, a mix of people and machines etc. All such activities require to some degree, protection from external elements, and may require a specific range of environmental conditions and a specific set of service facilities if they are to be carried out successfully [1]. Institutional buildings in Universities are therefore required to provide a conducive environment for the conduct of educational services such as delivery of lecturers to students, computer laboratories, libraries for study, and offices for lecturers, etc. All these require a thermally and visually comfortable environment.

The building envelope is the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation. By acting as a thermal barrier, the building envelope plays an important role in regulating interior temperatures and helps determine the amount of energy required to maintain thermal comfort. [2]. Building energy consumption is also climate dependent and factors such as building orientation, values for insolation levels, prevailing wind speeds and their patterns, outdoor and indoor design temperatures etc. The mere knowledge of these facts can make the maintenance of a building much more affordable at no extra cost during the construction phase.

East Africa is classified to have tropical climatic conditions which are mainly hot and dry throughout the year. The major concern of the building envelope designers in this case is minimization of external heat transfer to the building interior. This might involve minimizing direct solar radiation on walls, minimizing area of wall exposure and provision of insulation in walls and roofs to keep out heat, etc. Additionally, studies have shown that proper building envelope design can result in significant energy savings [3].

With the building construction industry continuing to grow at a very fast rate as evidenced by an increase of 35.3% in cement consumption between 2005 and 2009 [4], it is imperative to consider energy efficiency right from the design and construction of buildings to their utilization.

2. RESEARCH OBJECTIVES

2.1 Main Objective

The main objective of this paper is to present the findings of a comparative study carried out to analyse the energy performance of green building envelopes and conventional ones so as to recommend models of building designs that can lead to reduced energy use during the construction phase as well as during use and maintenance stages of Institutional buildings in East Africa.

2.2 Specific Objectives

i) To collect and document data on the various building/construction materials in use and their layout in the building envelope for both conventional and green buildings.
ii) To analyse the energy performance and resource utilization of Efficient Building Envelopes (green buildings) and show savings when compared with conventional ones.
iii) To recommend codes of practice for building envelope construction (walls, roofs and windows) and integration of building management systems (BMS) necessary in achieving sustainable Institutional buildings.

2.3 Research Questions

In carrying out this study, the questions below had to be addressed:
i) What are green buildings and how are they constructed?
ii) Which construction materials are generally used during the construction of Institutional buildings in East Africa?
iii) What are the thermal properties of the commonly used building envelope construction materials?
iv) What is the effect of climatic conditions on the thermal performance of the building envelope?
v) How are energy efficient building envelopes designed?

3. METHODOLOGY AND SCOPE

The study considered the prevailing institutional buildings set up at Makerere University, Kampala-Uganda and Strathmore University, Nairobi-Kenya where the first certified green buildings in EA are in their final third phase of construction. Three elements of the building envelope i.e. walls, windows and roofs were considered.
Characteristics of various building materials and their layout in the built environment were studied to determine their thermal performance. Data on prevailing local climate the energy consumption of the buildings was collected and analysed using METEONORM, a global meteorological database for applied climatology. Day lighting and rain water harvesting were considered coupled with the integration of BMS for optimizing utilization of resources in the buildings. Use was made of ECOTECT to study the effect of building orientation on overall building energy consumption also in relation to the construction materials used. For Makerere University, the new Faculty of Computer and Information Technology (CIT) was selected due to its almost 24 hr-occupancy while for Strathmore University, the completed Management Science Building (MSB) was selected since it has already been registered with the US Green Building Council for certification as a green building by LEED (www.usgbc.org/LEED).

3.1 Conceptual Frame work

Figure 1 below depicts how the various factors prevailing during a buildings' life cycle inter play to achieve efficient energy utilization in relation to the building envelope. The subject of this research was Energy Efficient Building Envelope design, thus the path that leads to EEBE is clearly highlighted in red.

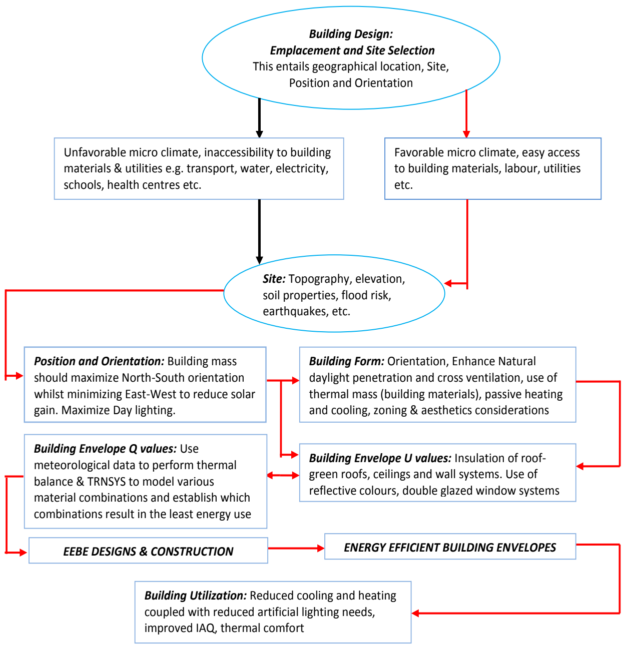

Figure 1: Conceptual Framework

3.2 Equipment Used in the Study

A lux-meter was used to measure the illumination levels in the buildings. A power quality analyzer was used to measure the total Electrical power demand for the CIT building while data from the MSB was remotely captured using the BMS installed.

4. RESULTS

The following paragraphs summarize the results obtained during the study in relation to the research questions and specific objectives of the study.

4.1 CONSTRUCTION MATERIALS

4.1.1 MSB, Strathmore University

The MSB lay out and foundations were constructed using well shaped stone with no exterior finish. Curtain-walling was carried out using 12mm clear glass. The windows are aluminium framed fitted with 6mm clear glass. The entire floor is of porcelain and ceramic tiles while the interior is of cement and plaster finish. The calculated thermal transmittance, U-value through the wall combination is approximately $6.1Wm^2K^{-1}$ which provides good thermal storage. The window glass U-value is $6.25X10^{-3}$ Wm^2K^{-1} while that of the glass curtain walls is 0.0125 Wm^2K^{-1}.

4.1.2 CIT building, Makerere University

CIT was constructed using 200x400x200mm concrete blocks with 25x150x75mm clay face bricks finishing. Both tinted and clear glass was also used in the curtain walling with cement-plaster finishing on the interior. The lecture room floor is of PVC tiles while the corridors are made of terrazzo floor. The calculated thermal transmittance, U-value through the wall combination is approximately 1.7 Wm^2K^{-1} which ensures that minimal heat is transferred to the building interior. The window glass U-value is $3.125X10^{-3}$ Wm^2K^{-1} while that of the tinted glass curtain walls is $2.125X10^{-3}$ Wm^2K^{-1}.

4.2 CLIMATE

Meteonorm software was used to acquire climate data of the project sites. It extrapolates weather data from the nearest weather stations from the location specified and gives results relevant to the site of the project. Also, the data is created using 20-year measurement periods so there is very little variation from the current averages.

4.2.1 Nairobi, Kenya

Nairobi is at an altitude of 5889 feet above sea level and has got a sub-tropical highland climate that is mainly hot and dry with temperature ranges of 12 to 27°C. The average wind speed is 3.5 ms^{-1} with an average irradiation of 1402 Wm^{-2}. The relative humidity goes up to 71%.

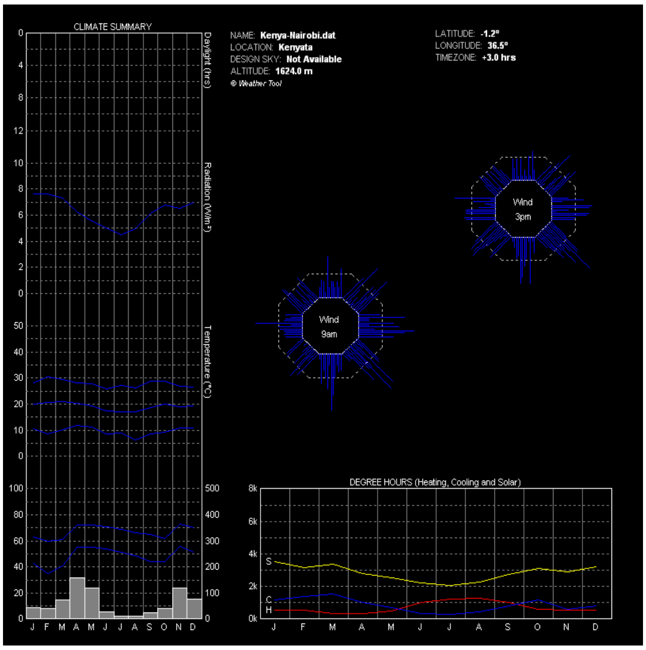

Figure 2: Summary of local climate in Nairobi.

4.2.2 Kampala, Uganda

Just like Nairobi, Kampala has got tropical climatic conditions except that there is higher humidity of up to 80%. The average wind speed is 2.7 m/s with temperature ranges of 16 to 31 °C. The mean solar radiation is $1224Wm^{-2}$.

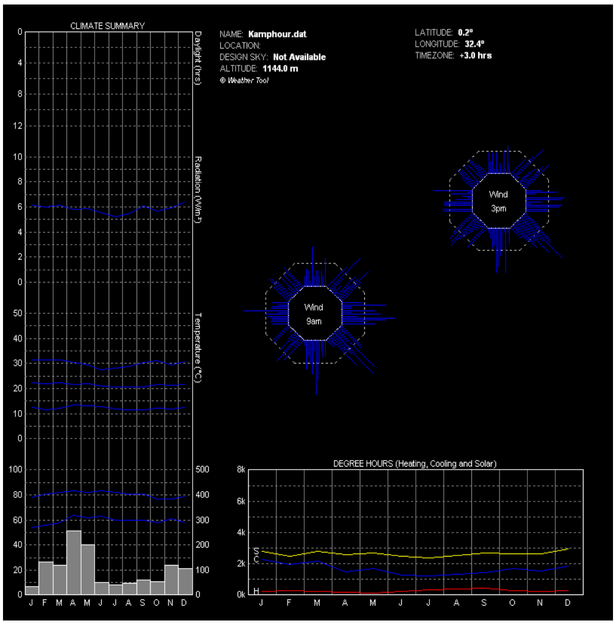

Figure 3: Summary of local climate in Kampala.

4.3 BUILDING DESIGN

4.3.1 MSB Building

The Management Science Building of Strathmore University covers an area of approximately 4570 square meters with four floors above ground and a basement. The main building mass is oriented in the North-South direction, presenting minimal direct solar radiation on to the building façade. The windows are made of aluminium frame and 6mm clear glass; they are also in set thus being shaded by the building design and roof overhang. There is maximum integration of day-lighting into the building design as evidenced by the 12mm clear glass curtain walling system that was employed. The western façade of the building is shaded by a neighbouring building while the eastern side has roof over hangs and in set windows, permitting minimal solar radiation into the building. As a result, the students never suffer from glare at any time of the day.

Another key design feature is the extensive use of natural ventilation in the building and the roof is a slab structure with a coating of poly-ethene and tar, with a polished aluminium foil top finish to maximize reflectivity of solar radiation and thus minimize heat gain on the slab. Figure 4 below shows a 3-D model of the building lay out.

Figure 4: 3-D Model for the MSB Layout.

4.3.2 CIT Building

The Faculty of Computer and Information Technology at Makerere is a vast building complex having six floors. The building is oriented in the North-south directions with the entrance canopy facing south. The façade is made up of clay-brick finish and glass. The building mass is in square form with no void opening which leads uncomfortable indoor conditions in the lecture rooms. The building has extensive use of Air Conditioning for the computer laboratories and server rooms. Most of the glass on the building façade is blue tinted; this has led to extensive use of artificial lighting throughout the day. Students complain of too much heat from noon till evening, this is attributed to the fact that a lot of heat is transmitted through the eastern and western facades which also have glass yet natural ventilation is limited to the window openings, thus limited air circulation in the building interior.
The roof of CIT is a pitched structure made of clay tiles which has excellent thermal properties. Figure 5 below depicts the general layout of the building.

Figure 5: CIT Building Layout.

4.4 ENERGY SOURCES & CONSUMPTION

4.4.1 MSB Building

The MSB's main source of energy is electricity from the national grid. It is also supplied by a stand-by generator for emergency loads in case of main power cuts.

The peak load for the MSB during the recording period was about 8.5kW as is depicted in figure 4 below. This is attributed to the integration of extensive use of day-lighting. The major loads are the server and computers which are placed in each lecture room to facilitate the use of projectors and lighting. The annual Energy cost is estimated at 85MWhrs.

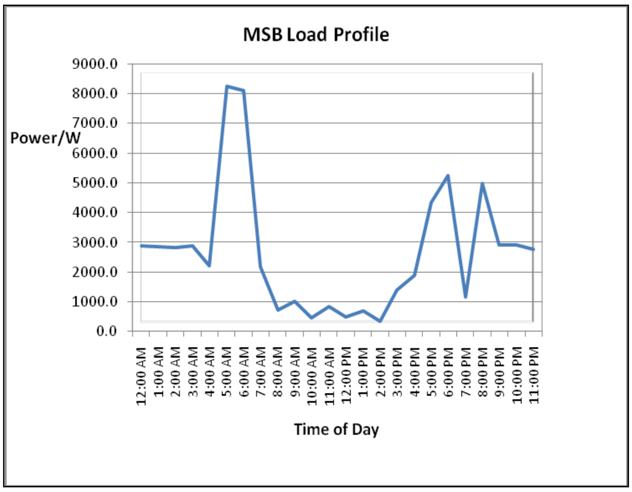

Figure 6: Load Profile of MSB on a typical Week day.

4.4.2 CIT Building

The faculty of CIT operates almost 24 hours daily-7 days a week and the biggest loads are lighting and computer. Lights in all computer laboratories, corridors and most lecture rooms operate for 24 hours. Figure 5 below depicts a typical load profile for the building on a typical week day. Annual Energy consumption is estimated at 880MWhrs.

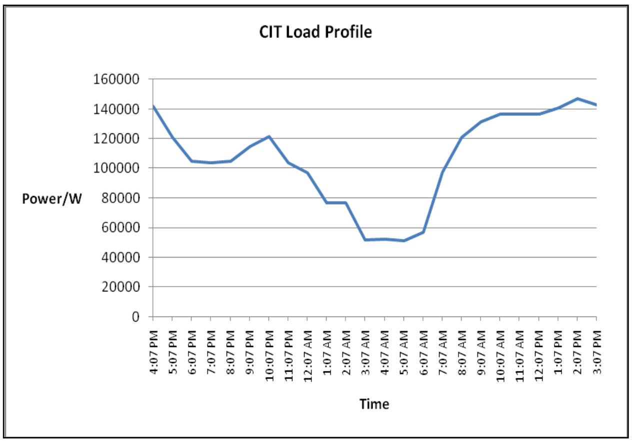

Figure 7: Load Profile of CIT on a Typical Week day.

4.5 BUILDING MANAGEMENT SYSTEM

The CIT building does not have any BMS integrated into it, therefore all resource utilization is manual i.e. user controlled. This has led to wastage of resources for example having the corridor lights ever on even when not necessary.

On the other hand, the MSB building at Strathmore University has a BMS integrated into it to control the resource utilization. The BMS used is based on SNAP PAC System Architecture with OPTO-SNAP controllers. User defined control-programming was used to define the functioning of the various components such as motion detectors, power cards and lighting control. Here lighting control is highlighted as it is directly affected by the building envelope designs.

The Strathmore MSB system uses room orientation and time-of-day to disable lighting fixtures that are close to the windows when sufficient natural lighting is available. It also disables all lighting in individual rooms when the BMS Motion Detectors indicate that the area has been vacated.

The MSB building a full-building voltage stabilizer was installed to help protect all electronics, including the light ballasts from the recurrent voltage fluctuation on the National Grid.

5. DISCUSSION

It is important to note that the CIT building has more floors and covers a much bigger area than the MSB. Even if they were to have the same design features, the CIT building would still consume much more power than the MSB. However the situation is aggravated by the lack of some key energy efficient building envelope design features for the CIT building as discussed in section 4.3.2 above. The study shows that the MSB design integrated various Energy Efficient key features such as natural and cross ventilation, proper building mass orientation, use of passive cooling features such as the stack effect, shading of windows etc.

The MSB utilizes 4ft-28W T5 fluorescent tube lighting with A2 rated electronic ballast and makes approximately 80% lighting energy saving due to the integration of day light into the building design and use of electronic lighting controls such as motion detectors and power cards linked to the BMS. CIT utilizes 32W magnetic ballast fluorescent tube fixtures that are run almost 24 hours a day, thus a lot of energy consumed is attributed to the big lighting load.

Rain water from the building roof is harvested into underground water storage tanks at the MSB and then treated before being pumped to the various water taps in the building. An estimated 95% water needs for the building are met using the harvested rain water. As a way of enhancing proper waste management, an incinerator is in place to burn the non-recyclable waste as well as provide heat energy when required. On the other hand, CIT has water storage tanks at the top without utilization of the rain water. Gutters just channel the rain water off the building into the gazetted drainage. Also there is no proper waste management system in place.

It is recommended that artificial ventilation is incorporated at the top of CIT to produce a stack effect so as to improve on the air circulation and enhance student thermal comfort in the building. Daylight features should also be included in spaces close to corridors to reduce the use of artificial lighting.

5.1 RECOMMENDED CODES OF PRACTICE

As a key output of this research, the codes of best practices out-lined below are recommended to be followed during the design, construction and utilization of institutional buildings in E.A.

5.1.1 Site and Building Orientation

Building orientation entails sun exposure, wind speed and direction, noise & pollution and Shape of the building. In EA, building orientation can have a great impact on costs of lighting and cooling. Depending on the building orientation there are three main aspects that should be considered; daylight, solar gains and shading. Computer modelling techniques allow tracing the path of the sun through the sky for each day of the year. Figure 8 below was produced using ECOTECT.

Figure 8: Sun-path diagram for Uganda

Proper orientation of buildings will reduce solar heat gain into the building interior. Orientation towards wind breezes will enhance natural and cross ventilation. However, there is a risk of increased infiltration that must be addressed.

5.1.2 Envelope and Façade Design

The building constructions and materials used must have acceptable U values (; this could be achieved through

optimization of insulation where need arises. Heat and moisture movement within the building fabric should be localized. The building must be air tightness and its thermal mass effective so as to reduce need for heating during cold months. Glazing area and glass performance should be optimum. Low E glass should be used to avoid having buildings behave like a greenhouse.
Shading should also be done for solar control performance and windows should be large enough, located in positions where there is no direct solar radiation.

5.1.3 HVAC system Performance

Buildings in the East Africa region rarely require any heating, except in a few locations; therefore attention should be paid to the air conditioning systems. Building design features should ensure that as little as possible heat is allowed into the building to avoid big cooling loads. Extensive use of cross-ventilation and use of Perspex roofing with vents that can create a stack effect in so as to maximise air circulation within the building will greatly reduce the cooling load. An analysis must be made to design a cooling system for the hottest day scenario. Use of other techniques such as evaporative cooling in less humid areas can cost less than having vast air-conditioners. Infiltration within the building should also be avoided to lead to more efficient utilization of AC's where they are used.

The Strathmore MSB incorporated Evaporative Cooling ducting and provisions for the whole building, but the systems have been deployed only at the basement open office areas since natural ventilation has proven sufficient to ensure high Indoor Air Quality (IAC) that far exceeds LEED requirements in all other areas of the building.

5.1.4 Daylight requirements

The importance of daylight for psychological reasons and especially in educational buildings cannot be over emphasized. During the design of Institutional buildings, care must always be taken to ensure that during day, lighting requirements are met with natural daylight as much as possible. As a standard, rooms are expected to be day lit for a maximum depth of about 6m from the faced, provided the façade is glazed for about 50% of its wall area [5]. Daylight entering a building will pass many obstacles whose design will affect the quality and quantity of natural light that eventually reaches the working top. All these factors should be considered during the design stage and a balance must be struck without letting undesired solar radiation into the building interior.

6. CONCLUSIONS

Energy Efficient building design is not just the result of applying one or more isolated technologies. Rather, it is an integrated whole-building process that requires advocacy and action on the part of the design team as well as top management throughout the entire project development process. The whole-building approach is easily worth the time and effort, as it can save over 30% in energy costs over a conventional building.
Integrating energy efficiency, renewable energy, and sustainable green design features into all new and existing Institutional buildings should become a top priority for management and government so as have buildings that require less resource utilization, are more environmentally friendly and comfortable for the occupants. In order to achieve this, energy conservation laws and building codes of practice must be put in place throughout the EA member countries.
The findings of this study also show that further research still needs to be done in order to develop a complete overall guide for the design of EE institutional buildings in East-Africa.
As a summary, some basic energy-saving techniques that can be used to reduce building energy use are given below;

- Siting and orienting the building configuration and massing to reduce loads.
- Reducing cooling loads by eliminating undesirable solar heat gain.
- Reducing cooling loads by using passive cooling techniques.
- Making use of natural light as a substitute for (or complement to) electrical lighting.
- Extensive use of natural ventilation whenever possible.
- Using more cooling equipment to satisfy reduced loads.
- Integration of computerized building management systems.

ACKNOWLEGEMENTS

The authors wish to acknowledge the technical design and construction team at Strathmore University led by Eng. Raul Figueroa for the support rendered when the research was being carried out at Strathmore Business School.

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