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Passive cooling consideration in the effective planning and design of public buildings in Nigeria

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Abstract: The rapid increase in the growth of Nigerian cities as a result of mass rural-urban migration has led to a demand for more public buildings. The ongoing campaign on sustainability backed up with the statistics that confronts us daily have necessitated the need to deliver more environment-friendly public buildings. This study is aimed at enhancing sustainable utilization of energy through passive cooling in the planning and delivery of public buildings with optimum design condition for users' comfort in Nigeria. The objectives are: (i) to identify the factors that enhances the passive performance of a building (ii) to measure these factors through case study survey and post occupancy evaluation of three existing public buildings (iii) to arrive at optimum design conditions using passive cooling in public buildings. Findings showed inadequate consideration of the design strategies that enhance the passive performance of a building due to dependence on the active cooling means in public buildings visited. The paper recommended a policy framework for the planning of public buildings and canvassed the need for professionals in the built industry to consider how key design strategies can be considered in the early stage of their design decisions that will lead to sustainable public buildings.

Keywords: Energy, passive cooling, policy, public buildings, thermal comfort

Introduction

According to recent statistics, the building industry accounts for more than 40% of the total energy consumption (Edward, 2012; Santamouris, 2005). While the awareness on climate change continues to intensify, it is needful to cut energy consumption to a reasonable amount because the quality of urban life and the global environmental quality of cities is dependent on net energy consumption (Santamouris, 2005). Consequently, energy efficiency is now a basic requirement for the designing professions (Roaf and Hancock, 1992). Going forward, active cooling which involves the use of air conditioners to maintain thermal comfort in a building needs to be critically reconsider for a passive approach for an effective planning and delivery of building projects (Ghiaus and Roulet, 2005).Passive cooling strategy employs a non-mechanical means to achieve a comfortable indoor temperature (Kamal, 2012; Larsen, 1998). Passive cooling helps to reduce the temperature of buildings without need for energy or power consumption (Taleb, 2014). Some of the passive cooling strategies include: solar shading; insulation; induced ventilation techniques (such as solar chimney, air vents, and wind tower); relative cooling; evaporative cooling; and earth coupling among others (Adewumi, 2012; Santamouris and Asimakopolous, 1996). However, due to the differences in climate and technological know-how, the passive cooling strategy adopted for use in a particular region may not be applicable for use in another context (Taleb, 2014). For example, design solutions employed in the tropics is likely to be a misfit in a temperate region.

This paper attempts to investigate how passive cooling consideration can enhance effective planning and design of public buildings with optimum design condition for users in Nigeria. This is with the rationale that building occupants are not passive in relation to their thermal environment as they tend to seek comfortable environments (Humphreys, 1992; Lush, 1992). The choice of public buildings is justified on the basis its energy demand is higher compared to residential buildings (Liu et al, 2012). Other sections of the paper include: section 2 which is a critical review on passive cooling identifying the factors that enhances the passive performance of buildings; section 3 explains the methodology of the study while section 4 highlights the results and discussion of findings; and section 5 gives the conclusion and recommendations.

Theoretical concepts of passive cooling

Passive cooling operates with the principle of preventing heat from entering into the building or removes it once it has entered into the building (Kamal, 2012). This principle helps to reduce energy consumption from peak cooling load. Ability to maintain a cool environment during warm periods is crucial for optimum utilization of human resources and productivity (Santamouris and Asimakopolous, 1996). With its environmental, indoor air quality, and economic benefits, the passive cooling of a building can be enhanced by its passive performance which is a function of its:

(i) Planning and design and;
(ii) Passive cooling strategy.

Planning and design

Jackson and Jackson (1997) suggested the following design attributes which define the passive performance of a building as explained:

Building Orientation
A building's orientation is its position with respect to the geographical coordinates. Proper building orientation increases the energy efficiency of a building which makes the building cheaper to maintain as it reduces the chances for the need for heating and cooling systems. Givoni (1994) asserts that the main consideration in building orientation is the positioning of its windows. High penetration of solar energy through large openings in a hot weather can increase the indoor temperature causing thermal discomfort and increasing the building's cooling load. A south-facing window will most times receive most sunlight while a north-facing window will only have it on few occasions in the early morning and late evening (Littlefair et al, 2000). A detailed site analysis is therefore essential early at the planning phase which will provide adequate information on temperature, wind, humidity, rainfall, and solar radiation among others.

Building shape
The geometry of a building in terms of its width, depth, and height determines its passive performance. To enhance passive cooling, buildings should be compact with surface area of its external envelope been kept as small as possible so as to reduce the heat flow into the building.

Windows and opening sizes

Size of windows needs to be considered to optimise passive cooling in a building. Large openings tend to admit more solar radiation than smaller ones. Givoni (1994) posited that heat gain through windows per unit area is much higher than through walls or roof especially in the absence of sun shading devices. Building design in a tropical area should aim at minimizing heat gain indoors and maximizing evaporative cooling (Lawal et al, 2012). Ventilation rate should be kept to the minimum required for health to reduce the heating of the interior by the outdoor air. Proper ventilation can improve thermal condition in indoor spaces and decrease energy consumption of air conditioned buildings (Santamouris, 2005; Routlet, 2005; Roaf et al, 2007)

Shading characteristics of building

Shading devices are essential for reducing the heat (solar radiation) entering buildings which helps to improve thermal comfort and reduce cooling loads (Littlefair et al, 2000) by blocking 90% of solar radiation. Shading devices can either be adjustable or fixed. The latter which are architectural elements provide means to articulate building facades while the fixed which can either be external or internal are operable. Examples of shading devices include overhangs, colonnades, movable screen and shutters.

Passive cooling techniques

In hot climates characterized with high solar radiation all through the year, passive cooling is one of the most difficult problems to solve. The simplest and the most effective solution for active cooling is to introduce air conditioning. However, as these systems do incur high initial cost with huge operational cost for installation, energy and maintenance, a passive cooling system is more desirable. Givoni (1994) identified the following seven passive cooling strategies: (i) comfort ventilation; (ii) nocturnal ventilation cooling; (iii) radiant cooling; (iv) direct evaporative cooling; (v) indirect evaporative cooling; (v) soil cooling; (vi) cooling of outdoor spaces.

Methodology

Case study and survey research designs were adopted in order to achieve the aim of this study. The study entails site visit to selected public buildings using events hall as a representative sample. This is justified on the basis of its high cooling load demand compared to other public buildings in Nigeria. Emphasis in the course of the case study was on:

(i) The passive performance of the building in terms of its building orientation; shape; windows and openings sizes; and shading characteristics of building;
(ii) The passive cooling techniques of the building

Sequel to the case study, a Post Occupancy Evaluation was conducted in a survey where self-completed questionnaires were administered to investigate the level of thermal comfort achieved by building users. This was conducted in the rainy season (April-October); harmattan (December- January); and the dry season (November to March). Since Nigeria falls within the tropics where the climate is seasonally damp and very humid, the atmospheric weather condition of the study location ranges between 28^0C to 32^0C. The thermal comfort was measured in qualitative terms based on the perception of each of the respondents which were randomly selected. The public buildings are:

(i) *Mapo city hall Ibadan*
(ii) *Archbishop Abiodun Adetiloye Hall, Ado-Ekiti, Nigeria*
(iii) *Lagos city hall, Lagos Nigeria*

Results

Mapo city hall, Ibadan Nigeria

This section of the paper presents the result from both the case study conducted and the post occupancy evaluation (POE) which investigated respondents' perception of thermal comfort.

Building orientation and shape
The hall covers an approximately 3810.24 square meters on the site. The main building mass is oriented in the east west direction allowing maximum solar radiation.

Window size and openings
The use of large openings in place of windows at the ground floor enhances more ventilation as it aids air flow. According to the design of the building, the north and south elevation on the ground floor level has no windows except these openings. Windows are only placed at the gallery floor level (see figure 1).

Shading characteristics of building
The deep verandah and balcony at the ground floor and upper floor serves as a shading device. Tropical climate requires consideration for effective shading device for building elevations and passive cooling for users comfort. The hall employed basically for its elevations, horizontal shading device with the use of long and deep verandahs supported with columns (see figure 2). There are no window hoods in any of the elevations.

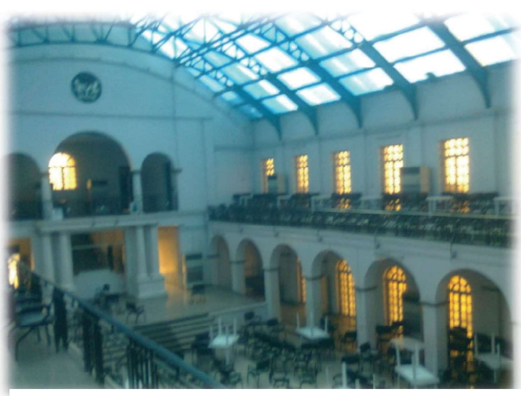

Figure 1: The interior view of the hall
Source: Researcher's field survey, 2012

Figure 2: Long and deep verandahs as a shading device

Passive cooling strategy
The hall employed both active and passive cooling techniques in achieving thermal comfort for the occupants. However despite the building's design which encourages passive cooling, the hall makes use majorly the active means of cooling with the aid of standing fans and the split unit air conditioning system. There are 22 number split unit air conditioning systems equally placed on both sides of the building interior.

Post occupancy evaluation
A total number of 120 post occupancy evaluation questionnaires were administered, 115 questionnaires were retrieved out of which only 80 are regular users of the hall whose responses will be used for the post occupancy evaluation of the building. During the rainy season, 57 respondents (71.3%) achieved thermal comfort by passive cooling, 46 (16.3%) did not and 10 (12.4%) were unconcerned. In the harmattan season, 46 (57.5%) achieved thermal comfort, 25 (31.3%) did not and 9 (11.2%) were unconcerned. However for the dry season of the year, 39 (48.8%) achieved thermal comfort, 34 (42.5%) did not, while 7 (8.75%) were unconcerned.

Archbishop Abiodun Adetiloye hall, Ado Ekiti Nigeria

Building orientation and shape
The main building mass is oriented in the N-S direction presenting minimal solar radiation on the building façade

Window size and openings
Some windows especially at the gallery level have hoods of little thickness which to some extent block solar radiation from entering the building interior.

Shading characteristics of building
Cross ventilation was adopted to enhance air flow within the building interior. This was also aided with the use of high level window in a process known stack effect. To shade incoming solar radiation, the building employed for most of its elevations deep verandah of about 2.4metres supported with columns (see figures 3 and 4).

Figure 3: The air-conditioning unit of the hall
Source: Researcher's field survey, 2012

Figure 4: The deep veranda of the hall
Source: Researcher's field survey, 2012

Passive cooling strategy
Despite the building design, it still relies on both the active and the passive cooling techniques to enhance thermal comfort for its occupants. The active cooling systems are the split type air conditioning unit and hanged mechanical fans. Although the building is cross ventilated, the active cooling system is used most of the time for comfort.

Post occupancy evaluation
A total number of 100 post occupancy evaluation questionnaires were administered, 90 questionnaires were retrieved out of which only 60 are regular users of the building whose

responses will be used for the post occupancy evaluation of the building. During the rainy season, 45 respondents (75%) achieved thermal comfort by passive cooling, 9 (15%) did not and 6 (10%) were unconcerned. During the harmattan season, 39 respondents (65%) achieved thermal comfort, 13(21.7%) did not and 8 (13.3%) were unconcerned. 38 (63.3%) achieved thermal comfort, 17 (28.4%) did not while 5 (8.3%) were unconcerned during the dry season.

Lagos City Hall, Lagos Nigeria

Building orientation and shape

The building approximately occupies about 9214 square meters on site.

Shading characteristics of building

The only noticeable shading device noticed are the deep roof overhang and the columns supporting the roof deck (see figure 5). Also at the approach view on the first floor is a deep rectangular canopy which shades the lobby leading to the banquet hall.

Figure 5: The deep roof overhang of the hall
Source: Researcher's field survey, 2012

Figure 6: Use of courtyard in the hall
Source: Researcher's field survey, 2012

Passive cooling strategy

The design of the building is such that passive cooling should be adequate with the incorporation of two courtyards of about 420 square meters each (see figure 6). However, the building operates entirely with active cooling. In fact there is a chiller pump room which supplies all the floors in the building the required fresh air through a central control unit. At times, the two courtyards are used to achieve thermal comfort of occupants

Post occupancy evaluation

A total number of 180 post occupancy evaluation questionnaires were administered, 170 questionnaires were retrieved out of which only 145 are regular users of the building whose responses will be used for the evaluation of the building. During the rainy season, 96 respondents (66.2%) achieved thermal comfort by passive cooling, 37 (25.5%) did not and 12 (8.3%) were unconcerned. During the harmattan season, 91 respondents (62.8%) achieved thermal comfort, 40 (27.6%) did not and 14 (9.6%) were unconcerned. However for the dry season of the year, 80 respondents (55.2%) achieved thermal comfort, 47 (32.4%) did not while 18 (12.4%) were unconcerned.

Discussion

The average thermal comfort of respondents varies with the three seasons of the year. Except for the Mapo city hall, the post occupancy evaluation indicates that respondents attained thermal comfort more in the rainy season. Findings showed that building design is a crucial factor that enhances the thermal comfort level of building occupants. The Adetiloye hall recorded the highest percentage of respondents that achieved thermal comfort with an average of 68% of respondents all year round. Lagos city hall had 61% of respondents while Mapo city hall had 52%. The minimal solar radiation experienced by the Adetiloye hall due to the building's orientation helps to reduce the cooling load. The hall also adopted the stack effect which enhanced adequate air flow in and out of the building. The two courtyards enhances air flow in and outside the Lagos city hall which helps to maintain a good air flow. The Mapo city hall recorded lesser percentage due to the building design and orientation which allows high solar penetration into the building interior.

Aside from the building design, the use of natural landscape elements was also observed to contribute to good microclimate of the events hall visited. This also aids the thermal comfort of building users. At the Mapo city hall, non-usage of landscape elements especially plants and shrubs resulted to the low microclimate condition of the site (see figure 2). This is not ideal as landscape elements are vital in maintaining a good microclimate. The conscious landscaping of the Archbishop Abiodun Adetiloye and the Lagos city Halls is commendable with diverse plant types, shrubs which contributed immensely to the good microclimate of the site (see figures 7 and 8).

Figure 7: The Archbishop Abiodun Adetiloye hall
Source: Researcher's field survey, 2012

Figure 8: The landscape design of the Lagos city hall

Passive cooling needs to be well thought of at the early stage of the design process. This undoubtedly should continue at the design phase till the completion of the entire building project. Passive cooling if well-conceived and thought of can help to realise the cooling load thereby enhancing the utilisation of energy and most importantly the thermal comfort of building occupants at certain seasons of the year without the use of active or mechanical cooling means. What is needed to enhance passive cooling in Nigeria is a policy framework which advocates for assessing the 'passive cooling passport' of a building especially public building prior to its approval for physical development. This will in a way undoubtedly compel professionals in the built environment to consider the following recommendations among others which will enhance passive cooling in the design of public buildings: (i) Buildings should be properly oriented so as to reduce solar heat gain in the building interior. Orientation towards wind breezes will enhance natural and cross ventilation; (ii) Glazing area and in fact glass performance should be optimum. It is advisable to use low E- glass to avoid having buildings behave like a greenhouse; (iii) Shading is expedient for solar control performance. Windows should be large enough where there is no direct solar radiation and vice versa; (iv) Landscape elements enhance passive cooling in the design of public buildings.

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