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Thermal comfort evaluation of high-rise buildings in Accra, Ghana

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ABSTRACT

The use of glass as a building material has greatly been taken advantage of over the past century. The beauty of the facade of any building is enhanced when glass is used as cladding, irrespective of the building's geographical location. Glass has the ability to gain heat quickly and dissipate it into any space. The objective of the study of high-rise buildings was to measure indoor thermal conditions, and interview, observe and question occupants in high-rise buildings in the city of Accra, Ghana. Their subjective opinions would help designers, facility managers and clients to understand and improve upon the quality of high-rise office buildings. The acquired data was processed using MS Excel application. Furthermore, the results showed that commercial high-rise buildings run on mechanical systems of ventilation and lighting with little or no provision for natural systems or shading devices. The effects are poor indoor conditions and discomfort to occupants during power outages. Moreover, building occupants need to be energy conscious and be trained in the operation of installed systems. The research also proposed that in subsequent years, policies should be put in place to check and regulate the use of building materials such as glass. Architects are entreated to research building materials not only for aesthetic purposes but also for functionality. In a tropical country like Ghana, mechanical aids may be difficult to be completely avoided in buildings, nonetheless, natural systems must also be taken into account.

Keywords: Building Occupants; Envelope; Energy Use; Thermal Comfort.

INTRODUCTION

The glass-clad high-rise building nicknamed as 'glass box' by architects and critics has caught on fast since the inception of Modern architecture in the late 19th century. Since its first use in the Crystal Palace of 1851, the glass trend seems to have come to stay.

Critics have questioned the sustainability of the glass box, as the carbon footprint of man increases, partly due to the high levels of mechanisation in these buildings. Despite this, tropical architecture has in recent times tended towards modernism; almost discarding whatever there may be left of the traditional architecture in the tropics. The designs of high-rise buildings seem to have simply been copied of an American or European journal. Obviously, no attention is paid to making these buildings' thermal comfort systems harmonious with their energy consumption. Air-conditioners are used so ubiquitously, that the impression is created that they solve the problem. Although thermal comfort needs may be met, energy consumption of glass boxes is shockingly high.

The purpose of this research is to study the thermal comfort conditions prevailing in high-rise office buildings. The subjective views of the occupants form the core of the study.

Much of the work that passes for architecture in the tropics today are unadulterated transplants from temperate countries, justified in the name of International Style [1]. Tropical architecture has fallen away from climate based design and has followed suit in an adaptation of modern trends in design and construction to climate. To serve as a panacea for the inconveniences the tropics produce, most buildings in tropical cities have adopted air- conditioning, disregarding its imminent effect on the climate. Furthermore, [1] have argued that the challenge goes beyond climatic considerations, to the problem of adapting to modern lifestyle and the transformation of local cultures to the modern city. The advantages of traditional architecture seem not to have caught the fancy of architects in the tropics. The typical architect in the tropics would rather work with principles and strategies of a certain style of architecture than employ scientific measures that would make a design sustainable [2]. The benefits the tropical climate offers have not been fully exploited by architects in the design of high-rise buildings.

It is important to realize that although a design can be placed in any part of the world, considerations must be given to the unique conditions that characterise the particular environment [3 and 4]. Thus, buildings must attempt to be in harmony with the environment and not only follow a certain architectural style per se.

Although it is possible to deal with issues of thermal comfort using technology aided means, the best and most economical way is to use the design itself [5, 6 and 7]. Thermal comfort as defined in the ISO 7730 standard is that condition of mind which expresses satisfaction with the thermal environment [8]. Thermal comfort can be said to be directly linked with productivity of occupants and as such should never be compromised and be achieved with minimal energy. Passive design strategies provide the benefit of achieving thermal comfort with minimal operating energy consumption [9 and 10]. The strategies, when incorporated, are arguably more economical than considering technology aided solutions. In this era of climate change and global warming, architects must make a conscious effort to produce buildings that will help abate these environmental changes.

It is estimated by experts that as high as a 60% global cut in greenhouse gasses and unsustainable practices is necessary to halt global warming, which seems to be a long way to go at present [11]. Buildings in use or under construction are generally known to be the greatest single direct source of carbon emissions. [12] has suggested that the building industry accounts for 40% of every nation's energy consumption. This means that the building industry could be responsible for 40% of the decline of Ghana's energy capacity. According to the energy production and regulation bodies in Ghana [13], the total amount of energy demand in the country as at 2007 was 10,152 GWh but the total available energy was 6611 GWh, which meant that the country had an energy deficit of 3541GWh in 2007.

It is widely recognised nowadays that the misuse of technologies that have high levels of energy consumption leads to the depletion of natural resources, and has created an internationalist architectural style whose most absurd representative example must be the sheer glass tower, where a constant interior temperature of 22 to 24^{o}C is maintained, although the outside temperature may be around 30^{o}C. Only a sheet of plate-glass separates the exterior and interior temperatures from one another and no matter how efficient the insulation, a high level of energy consumption will always be necessary to maintain the thermal difference. For the architects, it is easier to hand the problem over to electrical and mechanical engineers rather than attempt to find solutions by designing buildings that adapt to the environment [14]. [15] suggests that the first step to achieving sustainability is to reduce energy consumption by properly locating, orienting, insulating, employing natural ventilation and day lighting in buildings.
[16] affirm that since tall buildings consume massive energy, designers of the next generation of tall buildings must incrementally aim for "zero energy" design. In this approach, climate is used to an advantage and the building becomes a source of power. It is possible that tall buildings will someday even produce excess energy and transfer the excess to the city's power grid for use in other ways.

The Glass Association of North America [17] has explained that by just properly designing a building's fenestration to minimize heat loss or heat gain depending on the climate, will go a long way to positively affect occupants' comfort and building energy efficiency. Moreover, thermal comfort is a complex condition that determines the well-being of occupants, since numerous factors must be considered. Among these factors are the behaviour of occupants and their interaction with the environmental control systems. For instance, [18] and [19] observed that the operation of windows is a function of prevailing outdoor temperature. [20] concluded from studies of office buildings that at temperatures of more than 28.1°C, the frequency of opening windows increases. [21 and 22] concluded in their studies of office buildings that the operation of shades was a function of solar radiation on building facades. Furthermore, they noted that shades on the northern sides of buildings were operated less frequently than on the southern sides. [23] found out that shades were normally fully raised or lowered. Building occupants interact with available building systems in an attempt to attain thermal comfort.

This paper analyses the subjective views of occupants in high-rise buildings to ascertain their opinions on thermal comfort, building control systems, energy implications and their general perception. It is imperative to know environmental conditions prevailing in Ghanaian high-rise office buildings so that the lessons drawn could help (designers, facility managers and clients) improve upon their quality.

MATERIALS AND METHODS

The study was based on interviews, questionnaires, observations and thermal parameter measurements in four high-rise office buildings. The four office buildings (Premier Towers, Heritage Towers, GNAT Heights, and Cedi House) are situated in Accra, the capital of Ghana. These buildings, with the exception of the Cedi House (which is classified more tropical), are representative of the emerging glass boxes in the city. The applied cooling systems are typically central air conditioning systems. A general description of these buildings is given below.

Premier Tower

The Premier Tower is a multi-storey office building consisting of 13 floors. It is located opposite the Pension road, in Accra Central. It has a pyramidal form and its elongated sides are oriented towards the east/west. It has mostly multi-occupancy offices with few single occupancy offices with a single mode of thermal control. The lights and internal shading devices such as blinds are controlled manually. There are however no external shading systems. The external fabric is a fixed curtain wall system with no external windows.

Heritage Towers

The Heritage Towers function as an office block. It is a 15 storey building, located in the Central Business District of Accra. It has a rectangular form and its elongated sides are oriented towards the east/west. It has mostly multi-occupancy offices with few single occupancy offices with a single mode of thermal control. The lights and internal shading devices such as blinds are controlled manually. There are some external shading systems. The external fabric is a fixed curtain wall system with no external windows.

GNAT Height

GNAT Height is also a multi-storey office building consisting of 8 floors. It is located at Ridge, Accra Central. It has a rectangular form and its elongated sides are oriented towards east/west. It has mostly multi-occupancy offices with few single occupancy offices with a single mode of thermal control. The lights and internal shading devices such as blinds are controlled manually. There are however no external shading systems. The external fabric is a curtain wall system with some operable external windows**.**

Cedi House

Cedi House is a multi-storey office building consisting of 14 floors. It is located opposite the Liberia Road, Accra Central. It has a square form and its front facade faces west. It has mostly multi-occupancy offices with few single occupancy offices with a single mode of thermal control. The lights are controlled manually. It has no internal shading systems such as blinds. There are however external shading systems.

Monitored environmental data

Room temperature and relative humidity values were measure both inside (in a number of office rooms) and outside the buildings over a period of 4 weeks (April 1-30, 2011). The measurements were done using Hobo Sensors. The gathered environmental conditions were screened and processed in MS Excel application.

Interviews

Forty (40) occupants from the four case study buildings were randomly selected and interviewed. Only 34 out of the 40 were however adjudged to be responsive. The respondents (60 to 75% of the total occupants targeted [24]) completed questionnaires on personal profile, evaluation of indoor climate (thermal and visual conditions), building control systems (operation, accessibility and energy implications), as well as general perceptions. Their perceptions were based on long term aggregate opinions on indoor climate and building control systems.

RESULTS AND DISCUSSION

Respondents

In the Premier Tower, ten occupants were interviewed, only nine were however responsive. Out of this nine, 66.7% were male and 37.5% female. All the respondents were between the ages of 25 and 35, with 75% of the respondents having 55-65 working hours per week. The remaining 25% had 40-45 working hours per week. Only 22.2% of the respondents spent between 15-18 hours per week at their workstations, while 77.8% spent 20-42 hours out of their weekly working hours at their workstations. Less than 45% of their work was said to be performed on computers. This value was due to the fact that they spent most of their time on the field (marketing) and with other outdoor routines.

Fifty percent out of the eight respondents in the Heritage Towers were male and the other fifty percent, female. Seventy-five percent of them were between the ages of 25 and 35 years. A majority (87.5%) had a work schedule of

40 hours per week and the remaining 12.5% had a 48hr per week schedule.75% of them spent 25-40 hrs. per week at their workstation while only 25% spent 8-12 hrs. per week at their workstation. Work done on computers was assessed to be over 80%.

Out of a total of ten workers interviewed in the GNAT Heights, nine were responsive of which 77.8% were male and 22.2% female. An age range of 25-35 years was recorded for 55.6% of the respondents, 36-45 years for 22.2% and the remaining 22.2% were under 25 years. A work schedule of 40 hrs. per week was recorded for 77.8% of the workers while only 22.2% worked a 50 hrs. per week schedule.77.8% worked between 30-40 hrs. per week at their workstations while only 22.2% did so for 8 hrs. a week.

In the Cedi House, all respondents (8 in number) were male with 50% ranging from between the ages of 36-46 years. 25% were between in the age range of 25 to 35 while only 12.5% were between 46 and 55 years. The rest (12.5%) of the workers were recorded as being above 55 years. 75% worked 35-40 hrs. and the remaining 25% worked 15-30 hrs. per week.

Thermal Perception

The Premier Towers, Heritage Tower and GNAT heights will hereafter be referred to as the 'three glazed buildings' (TGB). General perception of indoor environment was recorded as agreeable by over 95% of the respondents (mean temperature recorded was 27°C with relative humidity value of 68%). In the Cedi House, all of the respondents found the thermal environment to be good (mean temperature recorded was 25°C with relative humidity value of 60%).

Air-conditioning in the TGB was found to be adequate by over 90% of the occupants while in the Cedi House only a little over 60% found theirs adequate. This may be due to the higher smaller multi-occupancy offices in the TGB than in the Cedi House where multi-occupancy offices are larger and with larger numbers (over 30) of people. The performance of the air-conditioners at smaller office spaces correlates with a similar study in office buildings by [25].

Building control systems

Fewer than 40% of respondents in the three glazed buildings could open their windows if required while a little above 85% of respondents in the Cedi could operate their windows. This is due to the provision of operable windows in the Cedi House. In the case of the TGB, windows, even if operable, were usually internal windows except in the case of the GNAT Heights, which had external operable windows, were 100% of the time rarely opened. Despite the above results, in both the TGB and the Cedi House, windows (where present) were most of the time not opened due to the use of air-conditioning systems. The ability to operate windows and shades is known to have positive effects on building occupants [2, 20, 22 and 21]

Energy implications

In the three glazed buildings, only 11.5% of occupants thought they could influence building energy consumption in the way they operated building systems. The remaining percentage either did not know if they did or did not think they could. In the Cedi House, only 25% thought they could influence building energy consumption while the remaining either did not know if they did or did not think they could. Generally, knowledge of the influence on building energy consumption was poor and as such, there must be some form of education.

Furthermore, 100% of occupants in both categories of buildings did not ventilate their offices in the morning before using air-conditioners. Occupants in the Cedi House usually set the thermostats to18-23°C. In the TGB a little over 95% of the occupants set their thermostats to between 18 and 26^{o}C. These set points show the effect of user behaviour on the energy consumption of buildings. The low set points may be due to the effect of heat absorption by the excessive glazing in the case of the TGB and the infiltration and exfiltration of air through the building envelope in the case of the Cedi House (main façade oriented towards the west). The work of [22] confirms the above results with regards to the behaviour of occupants.

In the TGB, 84.6% of the occupants did not switch off their air-conditioners during absence from their offices while all (100%) of occupants of the Cedi House did not do so at all. This behaviour will significantly influence the high energy consumption in these buildings. In addition to this, less than 40% of respondents in both building categories thought about energy conservation when operating building systems.

There was a higher preference for air-conditioned office environments than there was for naturally ventilated office environments. In the TGB, over 80% of the respondents preferred to work in an air-conditioned office environment. In the Cedi House, 63% of the respondents preferred to work in an air-conditioned office environment. It is not surprising that windows remain closed 100% of the time in the Cedi House, although proper shaded windows had been provided. Studies by [25] in low-rise office buildings had similar results on preference of building occupants. There seems to be a correlation in the results irrespective of whether a building is low or high-rise.

Energy flow consistencies

Power outages as pointed out by over 50% of respondents in the TGB occurred always in their offices. In the Cedi House, only 25% said it occurred always. Despite the varied answers, these results show that blackouts do occur and this could affect general productivity and comfort. This result further goes to show that Ghana's energy supply is constantly fluctuating and dwindling and hence the outages. Over 70% of the occupants in both building categories said the blackouts lasted from 5-60 minutes. This is quite alarming, especially for high-rise office buildings without operable windows. It is therefore not surprising that over 38% of the respondents in the TGB felt between warm and hot during power outages due to either the lack of operable windows to help ventilate and/or the culture of clothing (high clo-value) in these buildings. In the Cedi House however, only 12.5% of the occupants felt hot during outages. This lower figure in the Cedi House may be due to the provision of well shaded operable windows that help to ventilate in the case of blackouts.

CONCLUSION

Considering the tropical climatic conditions that exist in Ghana, architectural designs must as a necessity, conform to ecological strategies in order to achieve sustainable buildings.

The results as seen throughout this research have pointed out that there is a strong preference for air-conditioned spaces as opposed to the use of natural ventilation systems. This is evident in the use of air-conditioning (100% of the time) in the Cedi House which was originally designed to be a truly tropical building. Windows that were designed operable are always shut to make way for air-conditioning systems. Architects must therefore be tasked to produce more innovative, less costly and less energy consuming building.

The glazed buildings also guzzle up a lot of the nation's energy as they are solely dependent on air-conditioning systems. Provision of natural ventilation systems and shading systems in future buildings will help to lessen the energy consumption and improve comfort in office buildings. Also, existing and future high-rise buildings must be tasked to produce their own energy through the use of solar panels and other renewable energy sources as a way of reducing the load on the national energy systems. Adequate research and scientific tests need to be done before highly influential buildings such as high rises are put up.

There must also be a consideration of the adaptation of a culture of dressing that will not necessarily require low temperature set-points.

Generally, there must be a national vision towards green and sustainable architecture in Ghana. This will help prevent the continuing boom in the glass boxes that seems to currently characterise the working district of Accra.
Finally, efforts must be made to ensure that building occupants are trained in the operation of building systems and energy conscious behaviour to help improve the quality of office buildings.

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