AN EXPERIMENTAL ASSESSMENT OF THE EFFICIENCY OF GLAZING TYPES USED AS CLADDING MATERIALS FOR MULTI-STOREY OFFICE BUILDINGS IN GHANA

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Abstract
Architecture all over the world in recent years has embraced the extensive use of glass as a cladding material for high-rise structures. Multi-storey structures in Ghana have seen it fair share in this growing phenomenon. Experimental results on the effectiveness of the glazing types used for the cladding is presented and discussed in this work. The aim of the study was to establish the effectiveness of the glazing types towards the reduction of thermal discomfort and cooling loads in high rise office buildings in Accra, Ghana. The simulation technique with the use of the Tas simulation tool was used in this study. The methodology used was the case-study, where a multi-storey structure was selected and used in the running of the experiment. The analysis showed that in terms of cooling loads, the single glazing performed poorly. Though the triple glazing was the best, economically, the double glazing could be used instead. In terms of solar gains, the single glazing again was the poorest. It is recommended that the selection of a glazing type for any multi-storey structure should be done after an elaborate simulation. This will help in the determination of the total cooling loads for the building in order to reduce the extensive use of energy which has become one of the scarcest commodities in Ghana at the moment.

Key words: Simulation, Glazing types, Multi-storeys, Office buildings, Cooling loads.

INTRODUCTION

Glass has been used by humans for many centuries. Extensive use of glass as facade material dates back to between the 19th- 20th centuries where high-rise buildings and skyscrapers became possible. Regardless of the glass being used for windows, façade or interior partitions, glass connects the space, improves the quality of space, and transmits sufficient light. It however tends to compromise on the thermal comfort levels within the indoor spaces whilst it could provide an excellent visual and lighting effect for the occupants.

Usually, mechanical ventilation is used in the alleviation of thermal discomfort. This practice has been known to have a negative effect on occupants. Hoes et al. (2009) for instance asserted that occupant perception of so-called 'sealed, centrally air-conditioned buildings with open plan floor layouts that provide minimal adaptive opportunity', with no option for opening windows, is negative. Apart from the occupants' perception, the use of energy in providing comfort becomes a burden. Savic et al. (2013) posits that energy savings in buildings is one of the most important architectonic challenges of our age.

Eicker et al. (2006) emphasized that high rise buildings are considered to consume the highest level of energy due to their higher embodied energy, thus: cooling, lighting and lifts as well as energy for maintenance and cleaning. Generally, buildings in the Tropics with extensive glazed windows also consume high levels of energy. A building in the Tropics means a confrontation of construction and function with extreme climatic conditions (Lauber, 2005; Givoni, 1997). Discomfort is found most of the time due to the high temperatures and relative humidity levels (Tenorio, 2007).

In Ghana, the growth in demand for energy is amongst other factors caused by the numerous air-conditioned commercial buildings being constructed especially in the Metropolitan cities of Accra and Kumasi. The current power crisis facing the nation as a whole and affecting all building types makes it imprudent for these commercial buildings to use that huge amount of energy in cooling its interior spaces. Ghana's energy problem (a.k.a dumsor dumsor: meaning 'off ,on' 'off, on') which has persisted for some time now does not look like a thing of the past since the citizenry still experience frequent power cuts.

Against this background, the main aim of the current study is to establish the effectiveness of the glazing types used for multi-storey office facade cladding towards the reduction of thermal discomfort and cooling loads in high rise office buildings in Accra, Ghana.

LITERATURE REVIEW

The study reviews literature on glazing types, thermal comfort and simulation as a tool for assessing energy usage in multi-storey commercial buildings.

Single Glazing

Single glazing is where there is only one pane of glass assembled. It can be viewed as the outer layer and at the same time the inner layer. Carmody et al. (2007) assert that, single glazing allows the highest transfer of energy whiles permitting the highest day light transmission. Single-pane windows are impractical in heating-dominated climates (U.S Energy Information Administration [EIA], 2009). A single-pane window with a metal frame has about the same overall U factor as a single glass pane alone. (U.S EIA, 2009). The Department further asserts that Single-glazed windows characteristically suffer from water condensation problems and the formation of frost on the inside surface of the glass in winter.

Double Glazing

Double glazing involves double-pane units which can be assembled using different glass types for the inner and outer layer (Carmody et al., 2007). Double-glazing puts a sealed air gap between the window glass and the second layer of glazing, and the air acts as an insulating layer to keep heat from passing between (English Heritage, 2012).

Double-glazing can stop around 35% of heat loss in winter and around 10% of heat gains in summer, compared to a normal single glazed window (Carbon Cops, 2007). This means it's a good choice for windows in cold climates, or windows that are south-facing or highly shaded. These percentages can be increased by using special kinds of glass. Double glazing is a good way to reduce heat transfer through windows, because it traps a layer of still air between two panes of glass, and the air does the insulating (Carmody et al., 2007). If, instead of air, there's a layer of special-purpose gas, the insulation and sound-proofing qualities can be increased further. According to Carmody (2011), double glazing reduces heat loss (as reflected by the U-factor) by more than 50% compared to single glazing. The significant contrast between Carbon Cops (2007) and Carmody (2011) may be dueto the composition of the glazing itself.

Although U-factor is reduced significantly, the Visible Light Transmittance (VLT) and Solar Heat Gain Co-efficient (SHGC) for a double-glazed unit with clear glass remain relatively high. Tiberiu et al. (2011) posits that the glazing area does not directly influence the thermal comfort but the energy consumption which is connected with the indoor conditions. (Bojic and Yik, 2007) compared different types of glazing and found that the cooling consumption may be reduced by 6.6% if using double-pane glazing (low-e).

Triple Glazing

Triple glazing can take the form and standard double glazing unit with an extra pane glass inserted in the cavity between the other two glass planes (Manz et al., 2006). The two chambers that are created reduce convection and allow for a higher insulation value than with double glazing alone. The chambers can contain air or be filled with gas that will increase the insulation properties of the unit.

A triple glazed unit is not necessarily thicker than a double glazed one, but it is considerably heavier. This therefore incurs cost for fabrication, storage, transportation, handling and placement (Karlsson and Moshfegh, 2006). Carmody (2011) shares in the above cited opinion. Bosschaert (2009) in his experiment on the energy and cost analysis of double and triple glazing concluded that the transmission value of the triple glazed does not remove so much solar gain compared to the alternative glass unit.

Again, triple glazed units are of high quality though there are some triple glazed units that perform worse than double glazed units. This observation could be due to the make-up of the glass (chemical composition) used. Tadeu and Mateus (2001) make the assertion that triple glazing offers no significant improvements over double-glazing; the improvements are not significant if we are looking at situations where the larger air chamber in the triple glazed solution is the same as the air chamber in the double glazed solution.

There is however other glazing types which are more to do with the coatings on the glass. Various types include the tinted glazing, low-emittance coatings, insulated glazing, reflective coatings, laminated glass etc (Savic et al., 2013: Rathi, 2012: Carmody et al., 2007). Gyimah and Tetlow, (2014) posits that cooling loads can be reduced in the tropics by using solar heat reflective glass developed by the Japan's National Institute of Advanced Industrial Science and Technology (AIST) as windowpanes. This glass can reflect more than 50% of solar heat rays (infrared) and simultaneously transmit 80% or more of visible light rays. Rathi (2012) also reveals that traditional tinted glazing often leads to reduced visual transmittance and usually not compromised upon solar heat gain coefficient which can decrease glare by reducing the apparent brightness of glass surface, but it also reduces the amount of day lighting in the room.

Within the warm humid climatic Region of Ghana, the properties of the glazing materials also have much to play as far as indoor comfort is concern. For instance, according to Khai (2014), glazing systems with lower Solar Heat Gain Coefficient (SHGC) are more effective in reducing undesired heat gain as compared with higher SHGC's. As such, in hot climates, SHGC is critical for buildings and are sometimes given higher priority than U-value for windows. Rathi (2012) in his study defined SHGC as the ratio of solar heat gain through a window to the solar radiation striking the outer surface, for a given incidence angle (usually perpendicular to the glazing surface) and environmental condition (indoor and outdoor temperature, wind speed etc.).

Rathi (2012) commented that U-Value represents the performance of the entire window unit including the glazing, frame and spacer material. Often two U-values are used to classify windows- the glazing U-value and total U-value of the window. Wasley and Utzinger (1996) write that, the overall U value is dependent on a number of variables. It depends on the size of the glazing, where the smaller the window unit the higher the ratio of perimeter to area and the more the edge effects dominate the performance of the whole.

Thermal Comfort

Occupants in any formal (office) environment would always want to feel comfortable in order to give off their best in terms of productivity. Comfort and discomfort in an internal environment are major concerns for occupants in multi-storey buildings. Pino et al. (2012) defined thermal comfort as the physical and psychological wellness of an individual when temperature, humidity, and air movement conditions are favourable for the activity that has to be developed. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 2004) in 2004 defined thermal comfort as the state of the mind which expresses satisfaction with the surrounding environment. Szokolay (2004) also defined thermal comfort as the condition of mind that expresses satisfaction with the thermal environment which requires subjective evaluation. From all of the above definitions, six parameters have been accepted to affect the thermal comfort within an indoor space. These are: air temperature, mean radiant temperature, relative humidity, air velocity, metabolism rate and clothing insulation of the occupants. Various authors have established the fact that air temperature and relative humidity are the two most important parameters concerning thermal comfort. According to Huang et al. (2012) in relation to temperature and relative humidity values, the thermal environment affects occupants' sensation of "warm" or "cool" and "humid" or "dry", and is considered to be the environmental factors to which people pay the most attention to. Koranteng (2010) found that occupants in low-rise office buildings in Ghana had adapted to high relative humidity levels and therefore found maximum relative humidity levels of 80% – 85% acceptable, if temperature values did not exceed 29°C. In heavily glazed office buildings, the thermal comfort is compromised most of the time. Occupants tend to rely fully on mechanical ventilation which has a huge toll on the energy supply in Ghana. Thermal comfort can be measured with the Predicted Mean Votes and the Percentage of Occupants Dissatisfied (PMV-PPD) scale after Fanger (1970). On the scale of -3 through +3 (cold to hot), the percentage of occupants who are uncomfortable can be known.

METHODOLOGY

The TAS simulation software was used as a tool for assessing the different glazing types used for multi-storey office buildings. Three glazing types were used in the experiment: thus the single, double and the triple glazing. A single case multi-storey office building located in Accra was selected for the simulation exploration, thus the XGL Tower. It's a 13 storey fully glazed structure with a basement for parking and storage. The selection was based on the following rational:

- It's 100% glazed façade, all of which is exposed to the outdoor climate with no external shading;
- Representative of current design trends in Ghanaian high-tech office buildings; and
- Located within a fast growing commercial suburb within the capital city of Ghana.

Below (Figure 1) is the situation of the XGL building in Accra, Ghana.

Figure 1: Location and external view of case study building.

In the TAS (EDSL,2008) simulation programme, the 3d modeller was used to model the building by first drawing out the building plan with the information gathered on the building elements and spaces as well as the original drawn out designs of the building (Figure 2).

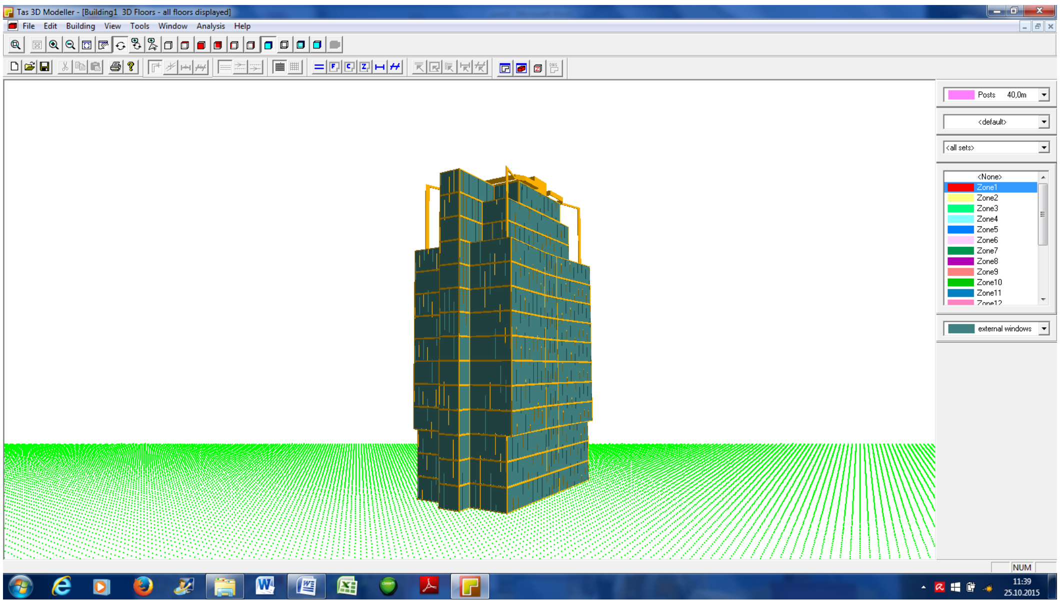

Figure 2: Model of the XGL Building in Tas (Author's construct)

The weather file from Meteotest (2008) was used to run the simulation and the output data was exported back into the MS Excel application to calculate mean and hourly values. The software, PMV calc v2 was used to calculate the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied occupants (PPD) after Fanger (1973). This was achieved by inputting the clothing values, metabolic rates of the occupants, air velocities, indoor temperatures and relative humidity values of the occupied spaces.

RESULT AND DISCUSSION

Figure 3 show the total simulated cooling loads for the year per unit area for the three glazing types. The various cooling loads for each month in indicated in Figure 4.

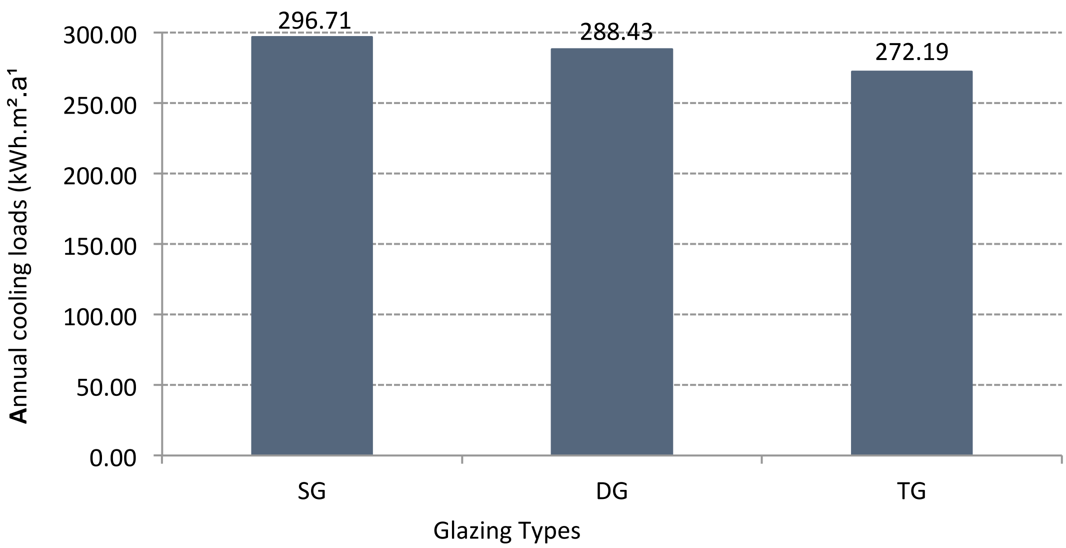

Figure 3: Cooling loads for different glazing types in a year

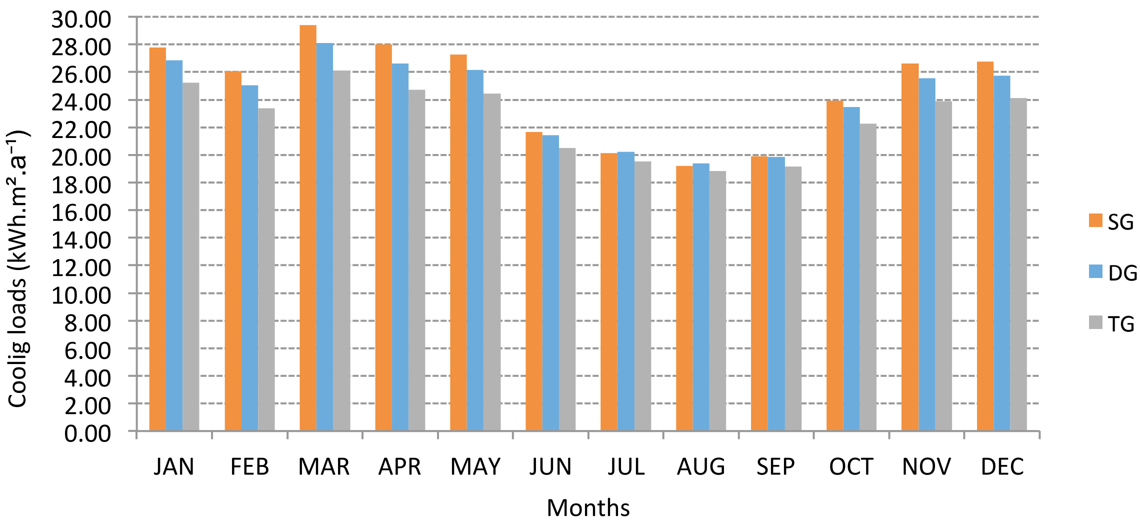

Figure 4: Cooling loads per unit floor area for each month

From the Figures above, it is clear that the use of single glazing leads to a higher cooling load at the end of the year (296.71 $kWh.m^2.a^{-1}$). The difference in cooling loads between the triple and double glazing is twice as much as that between the double and single glazing which is 8.28 $kWh.m^2.a^{-1}$. This finding is in tandem with the assertion of Carbon Cops (2007) which posited that double glazing can stop around 35% of heat loss in winter and around 10% of heat gain in summer, compared to a normal single glazed window. In the case of the current study the latter has been verified. Again, Wong et al. (2005) performed an investigation on the effects of double glazing facades on energy consumption, thermal comfort and condensation and compared these to single glazing facade systems used in Singapore. Bojic and Yik (2007) also compared different types of glazing and found that the cooling consumption may be reduced by 6.6% if using double-pane glazing (low-e).

The simulation results showed that double glazed facades are able to minimize energy consumption as well as to enhance thermal comfort. Comparing these three glazing types in terms of cooling loads, the triple glazing seems to have performed slightly better than the double glazing since its cooling load reduction was just 6% lower than that of the double glazing. Tadeu and Mateus (2001) argument of triple glazing offering no significant improvements over double-glazing is therefore justified. Considering the cost for fabrication, storage, transportation, handling and placement (Karlsson and Moshfegh, 2006) of a triple glazing system, an efficient double glazing system could be used to achieve almost the same results as if it was a triple glazing.

Furthermore, the effect of the various glazing types on cooling loads can also be affected by prevailing climatic conditions. From Figure 4, it can be seen that towards the middle to the end of the raining season (July-September) in Ghana which is generally characterised by lower outdoor temperature conditions, differences in cooling loads between the three glazing types is almost insignificant. From the simulation, triple glazing effectively reduces the annual cooling loads but economically, the double glazing is better than the triple glazing.

Figure 5 shows the average outdoor and indoor air temperature range as well as the minimum and maximum values.

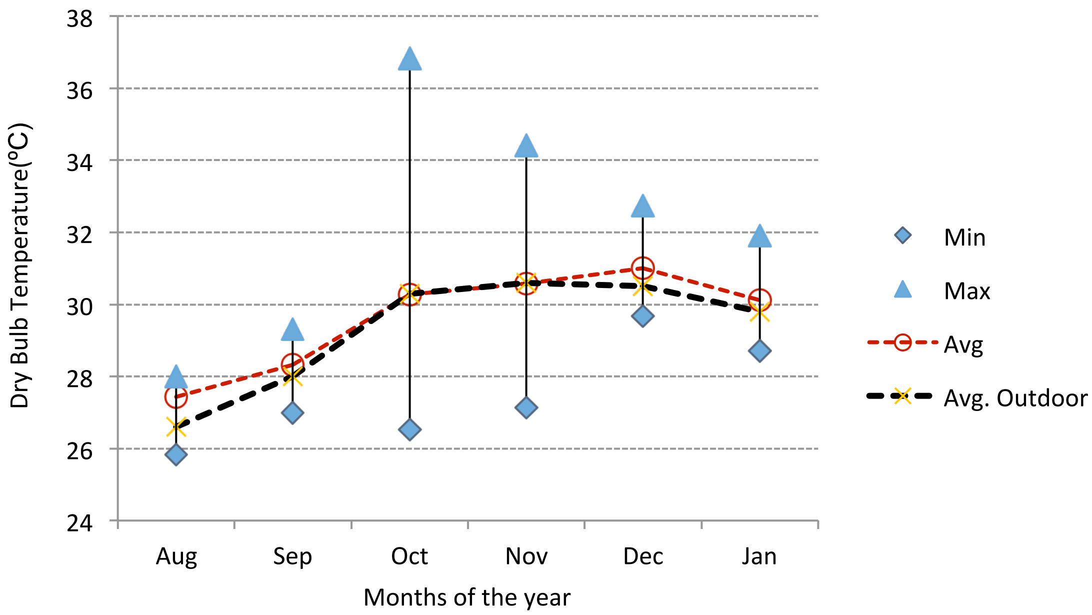

Figure 5 :Measured indoor and outdoor temperature values within the case study building

From the graph, there is an indication that the indoor temperature values are slightly higher than that of the outdoors. This could probably be due to the 100% wall-to-window ratio (WWR) of the glazing as well as the internal loads. Al-Najem (2010) in his study asserted that, heat gain through the exterior window accounts for 25% - 28% of the total heat gain. The orientation of the building could also be a cause. The properties of the glazing used (U =2.9 W/m^{2}K and SHGC =0.80). The indoor temperature values suggest that the interior spaces are uncomfortable since temperature alone can be used to determine the thermal condition of an indoor space (Heidari and Sharples, 2002). Adebamowo and Akande, (2010) proposed that air temperature is often taken as the main design parameter for thermal comfort. Hence it is essential for occupants' well-being, productivity and efficiency.

Kim and De Dear (2012) used the Kano Model to differentiate between Indoor Environmental Quality (IEQ) factors that impact overall satisfaction in negative, positive or in both directions. They concluded that 'temperature' and 'noise' had predominantly negative impact on occupants' overall satisfaction when expectations were not met. According to Huang et al. (2012) in relation to temperature and relative humidity values, the thermal environment affects occupants' sensation of "warm" or "cool" and "humid" or "dry", and is considered to be the environmental factors to which people pay the most attention to. The maximum temperature was recorded in October which was 36.8ºC with the minimum in August which was 25.6ºC. According to literature, highly glazed façades, often with poor shading often result in excessive solar gains and highly varying heating and cooling loads (Tzempelikos and Athienitis, 2007). Solar gain values are illustrated in Figure 6.

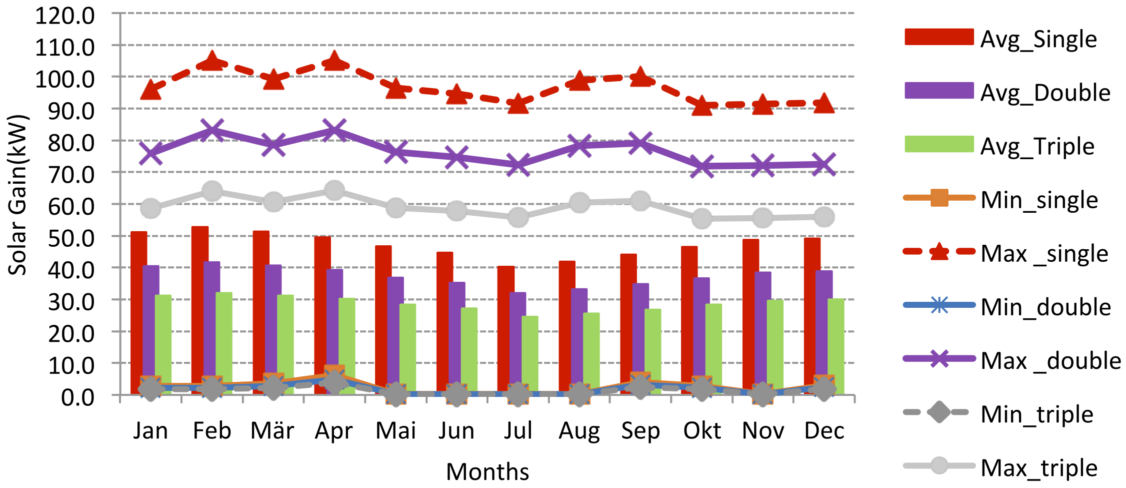

Figure 6: Average, minimum and maximum solar gains simulated for the different glazing types

In terms of solar gains, the single glazing recorded the highest. This could be attributed to the one pane of glass that separates the indoor from the outdoor. Usually, heat gain is measured by the orientation of the building but the type of glazing and the admixtures that are coated on them can also block solar radiation from entering into the indoor space. A typical single glazed unit with clear glass could transmit about 86% of solar heat into an office space whilst that of a double glazing is around 76% (Carmody et al., 2007). The addition of a tint unto the glass does help in the reduction of the heat transmitted by at least 14%. A usual triple glazing could pass on about 50% of the heat gain into the interior space. Meanwhile if the glazing is coated with a low- solar-gain low-Emittance coating, the 50% is further reduced to about 33% (Carmody et al., 2007). Solar radiation in the building converts into the heat gain and then contributes to buildings cooling load. The four basic properties of glazing that affect radiant energy transfer are- transmittance, reflectance, absorptance and emittance.

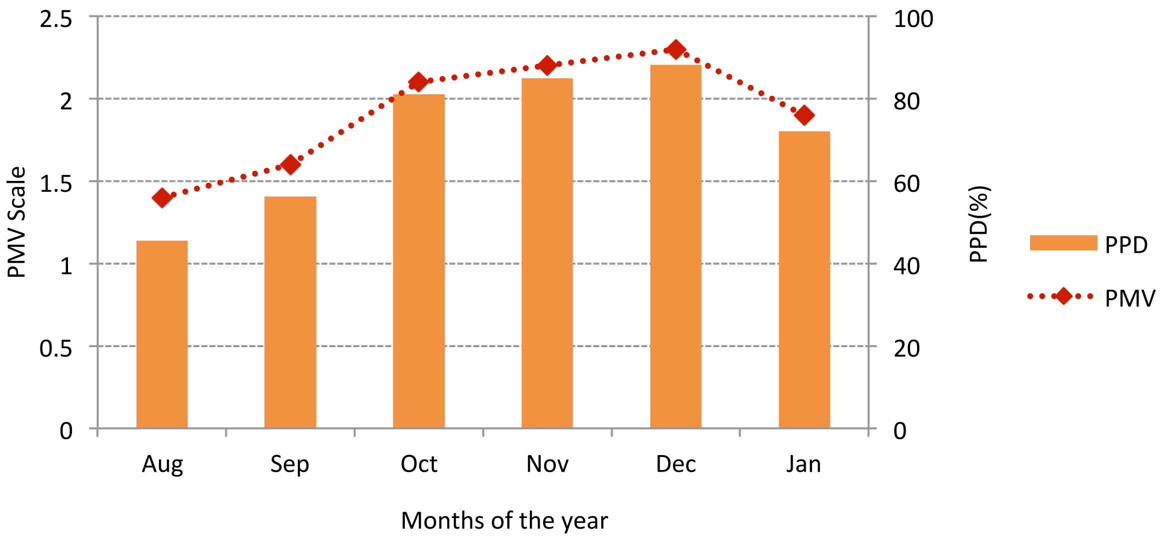

Figure 7 : PMV-PPD values for the case study building

Figure 7 illustrate the PMV-PPD values for the XGL building. The months of September to January according to the chart show an uncomfortable condition with PMV ranging from 1.6 to 2.3 which interprets as warm to hot. The chart again show a PMV-based PPD of 88%. This value is much higher than the (ISO 7730, 2005) standard regulation of 15%. The XGL building in terms of PMV is also outside the range proposed by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 2009) which is from -1 to +1 (slightly cool through neutral to slightly warm).

Table 1: ASHRAE thermal sensation scale after Fanger

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

CONCLUSION AND RECOMMENDATIONS

The efficiency of the various glazing types used for multi-storey office structures has been analyzed. The aim was to establish the effectiveness of the glazing types towards the reduction of thermal discomfort and cooling loads in high rise office buildings in Accra, Ghana. The methodology was parametric simulation with the use of TAS as the tool. The findings showed that single glazing leads to a higher cooling load at the end of the year. Meanwhile, the difference in cooling loads between the double and triple glazing was found to be 16.24 kWh.m².a^{-1} whiles the difference between the double and single glazing is 8.28 kWh.m².a^{-1}. Additionally, due to the high percentage of PPD, occupants might be tempted to lower the air-conditioning set points and this could have a huge toll on the energy usage of the building. Generally office occupants in the tropics have a tolerant attitude in relation to indoor thermal conditions.

It is recommended that building designers make a conscious effort in researching about glazing materials before they specify them to make sure that energy efficient (properties) products are being used. Again, architects are to note that within the warm humid climate of Ghana, a 100% window- to-wall ratio only become 'glass boxes' sucking all the energy to cool itself. Wall-to-window-ratio of around 30 to 40% has been proposed to be the optimum.

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