



Towards the Reduction of Cooling Loads in Ghanaian Glazed Office Buildings: Orientation as a Recommendation by the Ghana Green Building Council (GHGBC)

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Keywords: cooling loads, glazing, office buildings, GHGBC, orientation.

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Towards the Reduction of Cooling Loads in Ghanaian Glazed Office Buildings: Orientation as a Recommendation by the Ghana Green Building Council (GHGBC)

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Abstract- Designing to make use of the climatic conditions of the site has always been a challenge; especially when buildings are to be naturally ventilated. The current study examines how effective orientation is as a parameter for the reduction of cooling loads in multi-storey office buildings. The approach is experimental in nature where a case-study building was selected and a parametric simulation with T as the software was applied. The results indicated among others that while the annual cooling load for the actual orientation is 288.43kWh.m².a¹; there is an 11.81kWh.m².a¹ reduction when the orientation is 270° away from the actual of 0°. Again, in terms of cooling loads per unit floor areas, the 270° angle performed better. This indicates that if attention is paid to orientation and aspect ratio as parameters during the design of a structure, it would go a long way in ensuring that the design behaves sustainably. It is recommended that the orientation along the north and south axis should be adhered to as it aids in the free flow of natural ventilation through the indoor spaces.

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1. INTRODUCTION

Present-day architecture and the advancement of technology have led to the recent influx of heavily glazed commercial buildings all over the world of which Ghana is no exception. Although this development has become the trend for the 21st century design, given the warm-humid climatic condition of Ghana, the energy needs to mitigate the negative effects of this turn of event has become burdensome. In the wake of the worsening energy crisis burdening Ghana at the moment, the challenges that these glazed buildings poses cannot be met in terms of the provision of thermal comfort while reducing cooling loads.

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). A building's envelope/facade is one component that when thoughtfully designed, can reduce energy use in the building or otherwise. Arasteh et al. (2006) indicated that in recent years, the classical fenestration system concept is changing with the development of high technology buildings with curtain wall systems. With the advent of glass technology, current trends of office buildings involve large glazed facades without any sustainable design principles such as shading, orientation etc.

According to Pino et al. (2012), the size of glazed area on a building highly influences the energy demand. A totally glazed façade building might reach up to 155kWh/m² a year on total cooling and heating demands. On the contrary, in a building with a window to wall ratio (WWR) of 20%, with external solar shading and selective glazing, demand might be as low as 25kWh/m² a year. Bulow-Hube (2001) also reported that many modern buildings have taken advantage of glass transparency in their design to create a clear view to the outside. When using a high window-to-wall ratio (WWR; ratio of the glazed area with respect to the total area of the exposed envelope), occupants commonly might feel thermal and/or visual discomfort and they will apply their own strategies to mitigate this problem. Tzempelikos and Athienitis (2007), in their study recommended a solution to the above-stated problem. The authors commented that the use of modern glazing, with low solar transmittance and U values, can mitigate this problem but it does not necessarily solve it.

The green star office v1 rating tool is currently being evaluated to be adapted by the Ghana Green Building Council. It is based on the Green Building Council of South Africa's office v1 rating tool (Alfris, n.d.). Significantly, the tool is to influence the design of office facilities by minimizing the impact of buildings on the environment, (Green Star SA office v1 rating tool fact sheet). The rating tool consists of eight categories and an innovative grouping. Four aspect of the rating tool which is directly related to the building and the

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environment are: Indoor air quality, energy, emissions, and materials. Again aspect of the general modelling parameters for the Green Building Council of South Africa (GBCSA) include: Weather data, and building envelope (geometry, fabric, orientation, building form, insulation, and glazing etc.) (Green star SA -v1, 2010).

Orientation has been thought of as one of the major contributing factors of thermal comfort within indoor spaces. Szokolay (2004) specified that east and west facades should not have windows as these facades are known to contribute greatly to heat gains within buildings. The current study assesses orientation as a factor for reducing cooling loads in glazed office buildings in Ghana. The aim is to find out how effective is orientation as a factor to be considered for cooling load reductions.

II. LITERATURE REVIEW

Literature covering this study would include orientation, thermal comfort and tropical architecture. These subject areas will help readers become conversant with the main theme.

a) Orientation

The orientation of a building eventually determines how much energy it would use to provide thermal comfort for its occupants'. Seok-Hyun et al. (2013) affirms that the amount of sunshine is affected by the orientation of a building. During summer, the amount of sunshine at the East and West is small but the west requires a larger cooling load in the afternoon because of the afternoon sunshine. The South has a larger amount of sunshine but the solar radiation can be blocked easily by shading. Salmon (1999), establishes the fact that "buildings should be able to respond to changes in climate by the rejection of solar heat and have the thermal integrity to maintain internal comfort, despite the influence of climatic forces acting on the building envelope. Salmon (1999) however establishes that, analyses of sun paths and wind directions have shown that elongated buildings should be oriented to the South. In addition, the best orientation for wind is the Southwest whilst a compromise of 22.5° (south-southwest) should give the best orientation.

Contrary to Salmon's view, Lauber's (2005) recommendation was that the best orientation for buildings in the Warm and Humid countries should be +/- 30° from the prevailing wind direction. The author further states that the shell of air-conditioned buildings must be insulated, windproof and made airtight. This suggests an orientation away from the prevailing wind direction, but there is no precise direction for air-conditioned buildings from Lauber.

Szokolay (2004) also has a different proposal from the above mentioned authors. Szokolay suggested that in order to ensure maximum cross ventilation in a building, the major openings should face within 45° of

the prevailing winds. All the above suggestions from these authors are for free- running (naturally ventilated) buildings since in mechanically ventilated buildings, the outdoor conditions do not fully have any effect on the indoor. Hawkes (1996) posited that designers should orient spaces to the direction of the prevailing winds. Aspect ratio which is the ratio of the longer dimension of an oblong plan to the shorter (Szokolay, 2004), is seen to have a relationship with the orientation of a building. Szokolay further explains that depending on the temperature and radiation conditions, North and South walls should be longer than the East and West with an aspect ratio of about 1.3 to 2.0 (op cit).

b) Thermal Comfort

Thermal Comfort has a number of definitions from various researchers. ASHRAE (2004) defines thermal comfort as the state of the mind which expresses satisfaction with the surrounding environment. Likewise Pino et al, (2012) also in their study on thermal and lighting behaviour of office buildings in Santiago of Chile, defines 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.

Thermal comfort is dependent on more than the net balance of heat energy, just as visual comfort is dependent on more than an adequate quantity of light. The sensation of comfort is based on ambient air temperature, on relative humidity, on air motion such as drafts caused by infiltration or convection, and on the temperature and emittance of the surfaces of the space (Wasley and Utzinger, 1996). All of the above definitions are synonymous since they all include the environmental factors (air temperature, air velocity, air humidity and radiation) and the behavioural or personal factors (activity and clothing).

Van Treeck (2011) again in his book, 'Indoor thermal quality performance prediction' assert that the thermal comfort perception for all people all over the world living in different climates and in cultural diversities appears to be statistically uniform if similar environmental and personal parameters are taken into accounts (ASHRAE 2004; De Dear and Brager, 2002; Fanger 1970).

The glass surface temperature impacts the thermal comfort of the occupant who stays near the window; in summer period, the glass surface temperature is higher than the other surface areas and vice versa for temperate climate (Hamza, 2008). According to ASHRAE (2004) there is no difference between inside thermal conditions for comfort during summer and winter periods. However, the preference of an inhabitant for thermal comfort may change during the day. The body has a lower temperature rhythm in the early morning hours and a higher one in the

late afternoon. There are also specific thermal comfort standards in air-conditioned buildings.

In most thermal comfort studies, temperature have been indicated as the most important parameter since it is temperature that actually determines how occupants feel within spaces. Air temperature is often taken as the main design parameter for thermal comfort. Hence it is essential for occupants' well-being, productivity and efficiency (Adebamowo and Akande, 2010). Heidari and Sharples (2002) have suggested that air temperature alone is a good indicator Beizae et al. (2012) in their study in UK during the summer found a mean temperature value of 23.9°C in office buildings with a range of 21.6°C to 26°C. Additionally, there was an average PMV value of -0.25 with a range of -1.6 to 0.5 (between cool to neutral).

From a study in Iran by Heidari and Sharples (2002) comparatively analyzing long and short term thermal comfort surveys, the authors reported that during the two short-term studies, the indoor air temperatures ranged from as low as 15.4 °C to as high as 32.7 °C with an average of around 30 °C in the hot season and around 20°C in the cool season.

For the long-term study, the mean indoor temperatures during each month of the survey, ranged from approximately 20°C during January to 29 °C during August. The results indicate that in Iran, there are two main seasons, with the cool season around January to March and the hot season occurring from June to August. Ghana's climatic condition is contrary to that of Iran. There are two major seasons in the country: the rainy/cool season (around June to late September) and the dry/hot season (November to late April).

In Ghana, the hottest month of the year is March/April just before the rainy season while August is the coolest. In the southern part of the country, the highest mean monthly temperature of about 30°C occurring between March and April and the lowest is 26°C in August (Amos-Abanyie, 2009). Furthermore, comfort temperature as seen from above tends to be higher in tropical Regions (Li et al., 2010).

c) *Building Envelope and Tropical Architecture*

The envelope of any building is the exterior fabric that protects the building's interior from the harsh conditions of the outdoor climate. In other words, the envelope of a building acts as a shell in the transfer of heat from the external (exterior) to the internal (interior) and vice versa. A building's envelope therefore is constituted by the glazing or window area, the door, and the outer wall areas. According to Levine et al. (n.d), the effectiveness of the thermal envelope depends on

- the insulation levels in the walls, ceiling and ground or basement floor, including factors such as moisture condensation and thermal bridges that affect insulation performance;
- the thermal properties of windows and doors; and

- the rate of exchange of inside and outside air, which in turn depends on the air-tightness of the envelope and driving forces such as wind, inside-outside temperature differences and air pressure differences due to mechanical ventilation systems or warm/cool air distribution.

On air- tightness of an envelope, Seok-Hyun et al. (2013) point out that air tightness is important to the performance of windows because this blocks the air flow causing a difference in the indoor and outdoor temperature of buildings. In particular, the windows and outer wall must be of an integrated construction. If it is not an integrated construction, air flow can occur as a result of the different pressures, which can cause heat loss. In modern day construction, it is unfortunate that building envelope designs are developed to meet the client's requirements without much concern to the local climate and with no objective to conserve energy (Al-Tamimi and Syed-Fadzil, 2011). An analysis of the building energy consumption in Hong Kong, Singapore and Saudi Arabia for example gives a result that, the building envelope design, accounts for 36%, 25% and 43% of the peak cooling load respectively (Seok-Hyun et al., 2013; Al-Najem. 2010).

In the tropical region, climatic factor notably affects the microclimate and indoor thermal comfort in a building. Challenges in sustainable buildings are to reduce the input of resources such as energy, materials and water and waste production (Jamaludin et al., 2014). Low or still air movement with high temperature and relative humidity can cause thermal discomfort.

Glazing façade openings makes sense only when rooms are completely air-conditioned. According to research, east and west-facing walls and windows are the most important to shade, as solar heating is most intense on these orientations (Ossen et al., 2008). Solar shade and size are therefore the two factors used in determining openings in the tropics (op cit). The window to wall ratio and shading of windows has also been probed by researchers (Pino et al., 2012) as effective in achieving high energy performance of windows in the tropics. This is corroborated by Binarti, (2009). Buildings in warm and humid climate should be open and filter the climate in a multitude of ways that requires optimization of the relationship between the site, climate and briefing requirements (Jamaludin et al., 2014).

III. METHODOLOGY

The Tas simulation software was used as a tool for assessing the different orientations specified in the Green star SA -v1 handbook. It specifies four orientations thus; the actual (orientation of the building), actual + 90°, actual + 180° and actual + 270°. 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.

The situation of the XGL building in Accra, Ghana with an external view is shown in Figure 1.

In the T as (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 (Fig. 2).

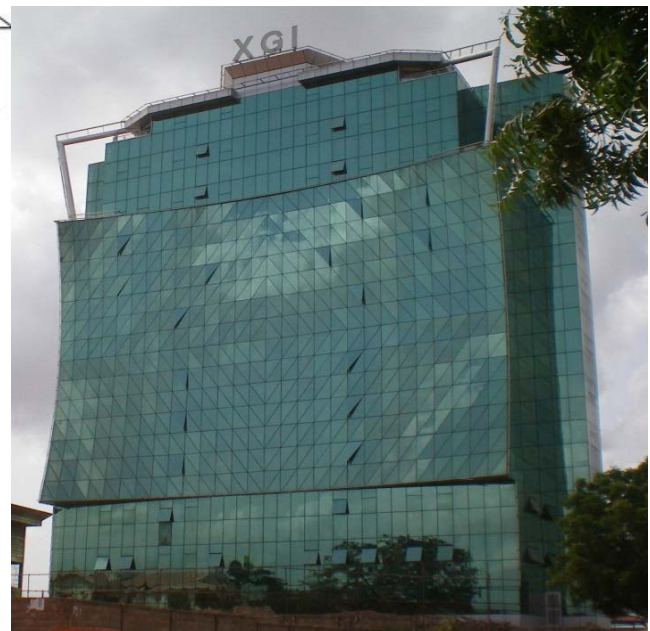


Fig.1 : Location and external view of case study building.

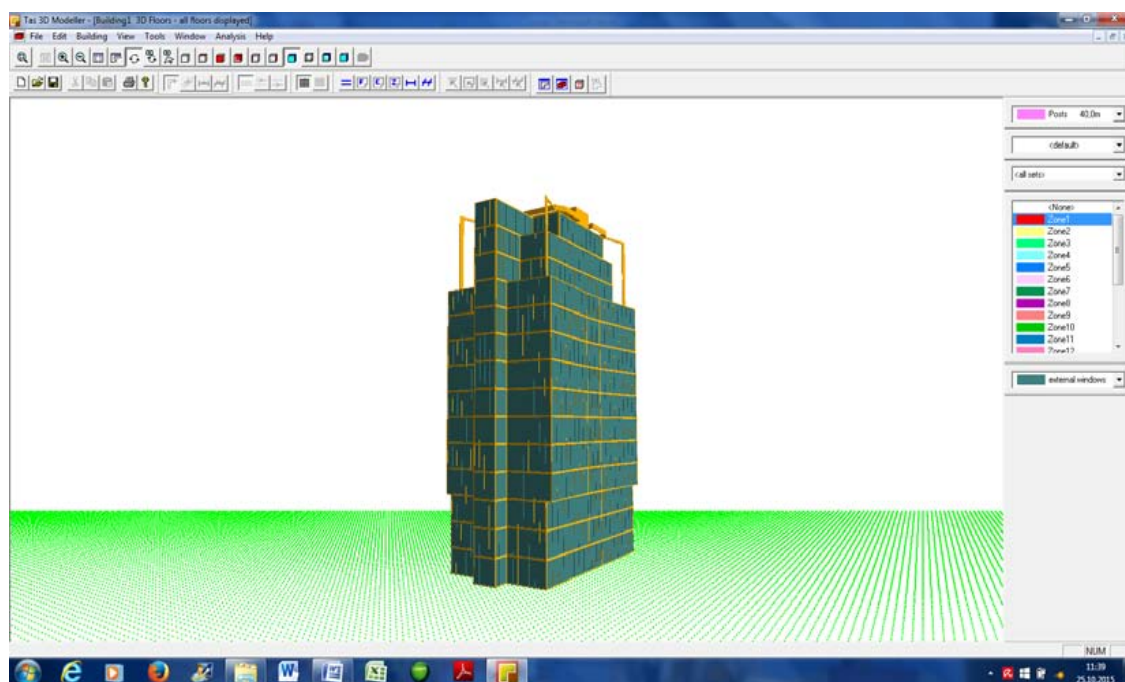


Fig. 2 : Model of the XGL Building in T as (Author's construct)

IV. RESULTS AND DISCUSSIONS

Presented here are results from the simulation assessment. The GHGBC handbook which is based on the Green Star Council of South Africa specifies that aside the case study building's orientation; other orientations should also be simulated. The specified orientations are the actual orientation plus 90 °, actual +180 ° and actual +270 °. The simulated results show different cooling loads for the diverse orientations. Figure 3 shows the annual cooling loads for the different

orientations whilst figure 4 illustrates the cooling loads per unit floor area for the various months.

The orientation of the case study building is 0° with the longer sides facing north and south. The annual cooling load for the actual orientation is 288.43kWh.m².a¹. When the orientation is changed by adding 90° to the actual, the cooling load increases by 5kWh.m².a¹. Even though the building is 100% glazed all round, and east-west orientation increases the cooling loads.

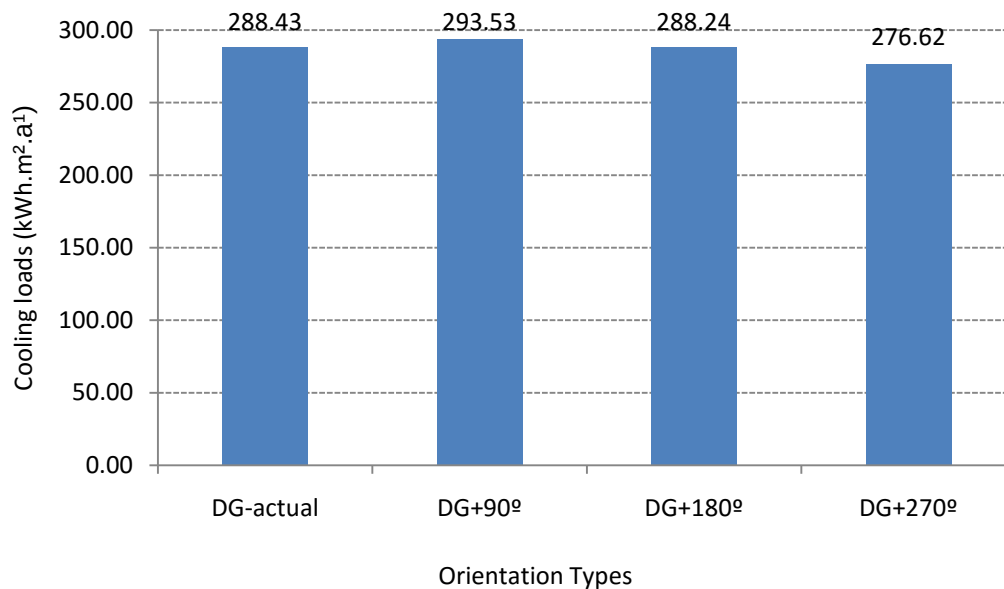


Fig. 3 : Annual cooling loads for the different orientations

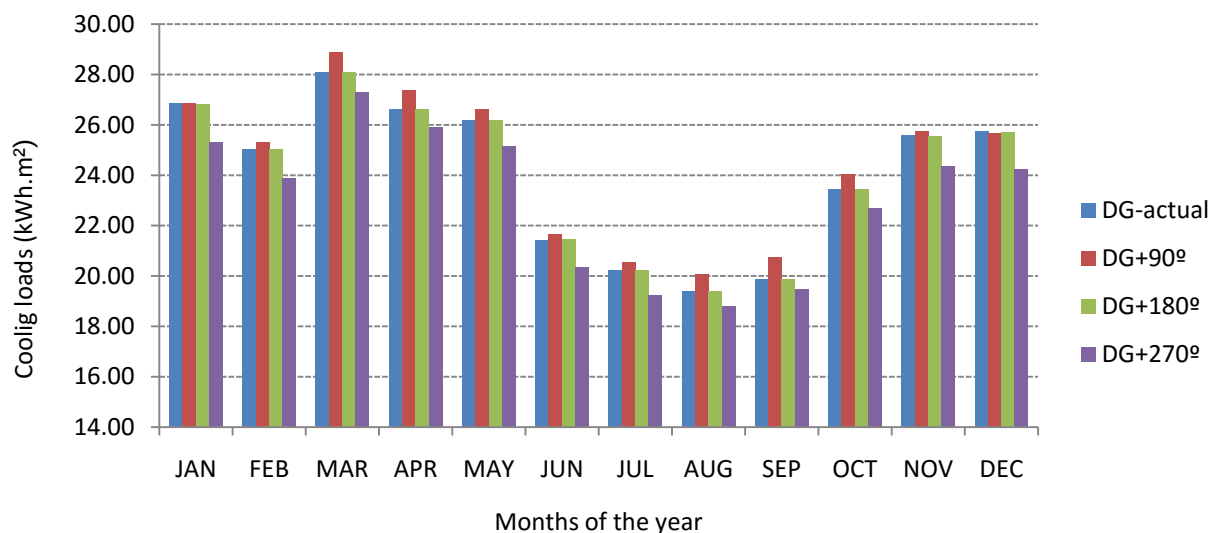


Fig. 4 : Cooling loads per unit floor areas for each month

Since the building has no overhangs, there is no protection for the glazing materials. According to Rathi (2012), south, east and west orientations should be designed for windows with deeper overhangs for

protection against direct heat gain. The larger size of windows for these orientations could be designed with sun control devices to gain protection in summer. The author further posits that the window openings and

overhangs should be designed specific to direction of exposure of the wall. The north side can be provided with large windows and shallow overhangs since this orientation will provide natural daylight without direct solar heat gain.

Szokolay (2004) explained that depending on the temperature and radiation conditions, north and south walls should be longer than the east and west with an aspect ratio of about 1.3 to 2.0. Lauber's (2005) recommendation was that the best orientation for buildings in the Warm and Humid countries should be $\pm 30^\circ$ from the prevailing wind direction. The author further states that the shell of air-conditioned buildings

must be insulated, windproof and made airtight. This suggests an orientation away from the prevailing wind direction, but there is no precise direction for air-conditioned buildings from Lauber. If the eastern orientation is shaded, perhaps the cooling loads would be reduced.

Figure 5 show the solar gains for each orientation. The east and west orientations (SG+90 and SG+270) have the highest solar gains. A study conducted by (Lam et al., 2008) on the impact of solar radiation on facades in the tropics revealed that the north and south has the lowest sun intensity and this varied from 43.6 W/m^2 and 74 W/m^2 respectively.

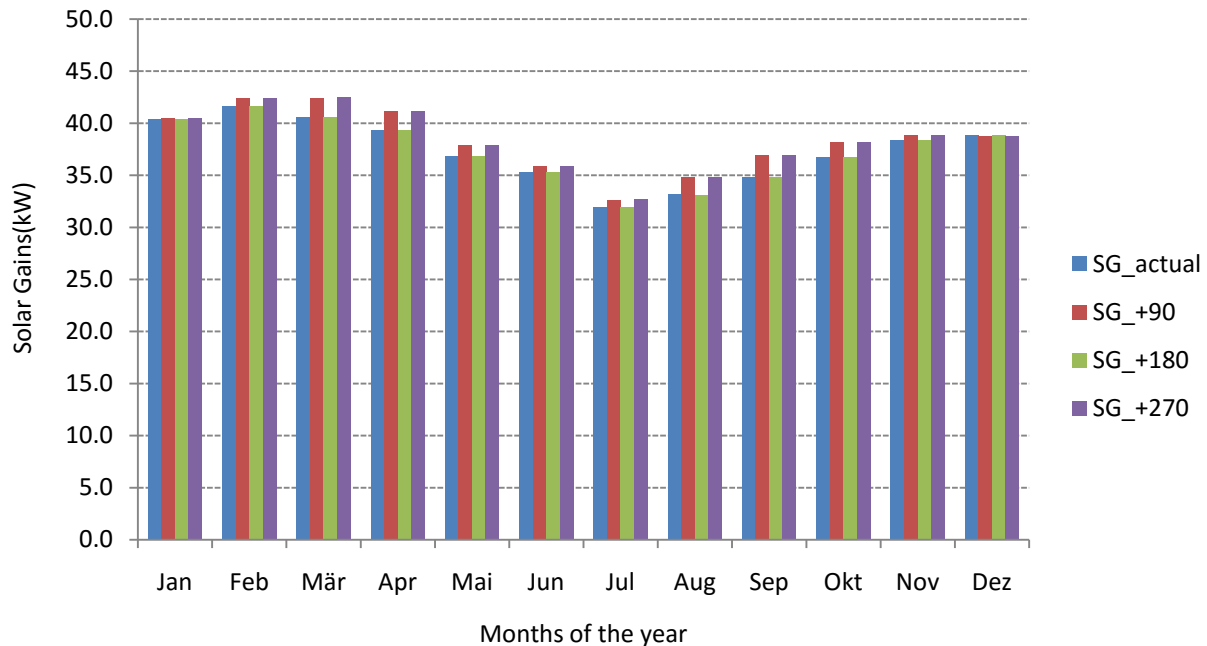


Fig. 5 : Simulated solar gains from the different orientations

The eastern and western facades received the highest intensities and this varied between 86.1 W/m^2 and 89.6 W/m^2 . Per these results, it could be deduced that the optimized orientation of buildings is to orient away from directions with high solar radiation. This finding corroborates that of Lam et al. (2008). From the findings, all the facades have high solar gains. This is as a result of the absence of external shading and roof overhangs which could provide some protection against the sun's rays. Solar heat gain plays a major role in determining the thermal performance of a building and increasing or decreasing solar gains can be of crucial importance in design problems (Bouchlaghem, 1996). Khakzar (2014) also hypothesises that solar radiation enters through the external skin on the south face and heats the air in the cavity between the double panes. A large window area means a hefty hot surface. The Center for Sustainable Building Research (CSBR, 2011) stated that East and west are usually the least favorable orientations since they permit little control over solar

radiation. Ossen et al. (2008) also share an akin opinion. A south orientation is most likely to permit day lighting throughout the school day, although the indirect and ambient light through north-facing glazing can also be substantial.

Together with intense solar radiation, this will cause any occupant seated close to the window to suffer extreme discomfort. Hwang et al, (2009) suggests that changing the glazing area may have a positive impact on thermal comfort, but lowers other aspects of comfort, such as visual comfort in this studied case. Lam and Hui, determined that in cooling dominated office buildings in Hong Kong, the solar heat gain accounts for just over 50% of cooling loads due to building envelope heat gains (Lam and Hui, 1993). They suggested that most parameters like WWR and SHGC which related to building load vary linearly with the total building energy consumption.

V. CONCLUSION AND RECOMMENDATIONS

Orientation as a recommendation by the GHGBC has been the subject of an intensive simulation in the current study. The aim was to find out how effective orientation is as a factor to be considered for cooling load reductions. The results show that considering the current building with double glazing, a 270° orientation reduces the cooling loads by 11.81kWh.m².a¹ in comparison with the base case cooling loads. In terms of the cooling loads per unit floor area, the 270° again provided the minimum cooling loads. However, solar heat gains were high for the 90° and 270° orientations. It is therefore important to determine the maximum permissible areas of glass and the glazing type to be used in buildings when heat gain by solar factor is part of the design criteria.

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