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Practical Energy Saving Techniques For Multi-Storey Office Buildings In Accra, Ghana

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Abstract: The recent influx of glazing materials being used as curtain walls in Ghana has resulted in the increase use of energy to provide thermally comfortable interior spaces for occupant comfort. The 'glass box' phenomenon in Ghana has arisen due to contemporary architecture. The climate of Ghana (warm humid) makes it almost impossible for these multi-storey glass boxes to be ventilated naturally throughout the year.

The current study was aimed at finding means of significantly reducing the cooling loads of these multi-storey office buildings whilst ensuring thermal comfort. Four high rise office buildings in Accra were selected for the study. Several parameters ranging from efficient glazing, thermal mass, façade insulation, night ventilation etc were probed into towards the reduction of cooling loads.

The study revealed amongst others that reduced light loads of 2W/m^2 considerably decreased cooling loads in all the buildings. Efficient glazing with low solar heat gain coefficient also cut down on cooling loads by as much as 27%. Additionally, it was realized that external shading could reduce cooling loads and therefore architects must make a conscious effort to provide same when designing these buildings.

Keywords: Energy savings, Office buildings, Cooling loads, Greenhouse gases, Sustainability

1.0 Introduction

The building sector is responsible for more than one third of total energy use and in most countries; it is the largest greenhouse gas (GHG) emissions source. The Intergovernmental Panel on Climate Change (IPCC, 2007)assert that building related GHG emissions was estimated at 8.6 billion metric tons CO_2 equiv. in 2004, and could almost double by 2030 to reach 15.6 billion metric ton CO_2 equiv. In the United States (US) alone, buildings are responsible for half of the total GHG emissions with adverse impacts on the global environment, human health, and the economy (U.S. EIA, 2012). According to IPCC again as cited in (Roetzel et al., 2010), the largest use of energy in commercial buildings is space heating in colder climates and air conditioning in hot climates. Both are aimed to provide satisfying thermal comfort at the occupant's workplaces.

The recent energy crisis has made it necessary for researchers to find localized solution towards the reduction of energy consumption especially in high-rise commercial buildings. The "think globally act locally" (Moberg, 2005) notion brought about awareness and cooperation from the design discipline, where energy-efficient design has among the crucial design elements been taken into consideration by architects and designers.

In a typical office building, energy is among other factors, used to provide comfortable indoor conditions (in terms of lighting, air-conditioning, etc.), power office equipment and enhance the smooth running of office activities. Usually, lighting and air-conditioning are the major installations consuming much energy in office buildings. Lighting uses 15% of energy in commercial buildings, and large amounts of that energy can be saved by using well designed lighting controls that can take advantage of the natural light available (Galasiu and Veitch, 2006). In the UK, lighting account for between 13% - 16% of energy use and 18% - 25% of CO2 emissions in a typical office building (Energy Consumption Guide, 2000). In the United States (US), lighting alone accounts for 25% of the energy usage (Buildings Energy Data Book, 2007). The EIA (2006), in its international energy outlook, forecasts that energy use in the built environment will grow by 34% in the next 20 years at an average rate of 1.5% per year. In 2030, consumption attributed to the domestic and commercial sectors is forecast to be 67% and 33% respectively (EIA, 2006).

Air-conditioning use leads to an increase in the absolute energy consumed for space cooling, with attendant high peak electricity demand (Beggs, 2002). The large amounts of electricity consumed from thermal generating plants, releases large quantities of CO_2 and its emissions into the atmosphere (Amos-Abanyie, 2009).

Increasing number of commercial and public buildings in Ghana has their envelopes covered with large areas of glass facade for aesthetic appearance in recent years. However, in addition to consuming considerable amounts of energy, the large amount of solar radiation passing through the glass facade often causes occupants to experience thermal discomfort. According to Arens et al. (1986) as cited in Hwang and Shu (2011), an individual in contact with direct solar radiation can experience a heat gain equivalent of 11^oC rise in mean radiant temperature.

In Ghana, the current energy situation is worsening by the day as electric power demand has far outweigh the supply forcing the Electricity Company of Ghana to embark on a load shedding exercise across the country. This current condition dubbed in the local parlance as “dumsor” thus “light off, light on” has been very devastating on the populace causing a lot of enterprises which rely heavily on electric power for production to shut down. It is against this background that this study is being conducted. The objective is to identify those building design and operation alternatives that would reduce the cooling requirements of the office buildings within the climatic context of Accra, Ghana. Thermally relevant features and options related to glazing, shading devices and deployment schedules, thermal mass, night ventilation, efficient lighting and facade insulation were investigated into parametrically.

2.0 Literature Review

2.1 Windows/Glazing

Windows in buildings help in several ways to keep the building comfortable. Windows provide building occupants with the opportunity to view outside and it also allow fresh air into a building when it is opened. Al-Saadi (2006) and Datta (2001) together gives an apt description of glazed windows. They describe glazed windows as components that allow natural light, offer a visual communication with outdoors, reduce the structural load and enhance the aesthetic appearance of buildings. A shaded and well positioned window on a building can go a long way into reducing the energy usage of the building as reported by Szokolay (2004). Furthermore, the area of exterior wall to the area of windows/glazing can also affect the thermal conditions within a building, thus the window-to wall ratio (WWR) of the building.

In our part of the world today, (Ghana) the use of extensive glazing is the order of the day. Commercial buildings with high WWR have a damaging consequence on energy conservation. Seok-Hyun et al. (2013) confirms the aforesaid assertion and comments that ‘the WWR is increased by the trend in curtain wall because of its attractiveness. This increases the cooling load but decreases the heating load because of the season and solar radiation, which means that the proper WWR should be considered’. Manz and Menti (2012) commented on glazing in their report. The authors stated that ‘in terms of energy flows, glazing can be characterized by two parameters: Firstly, the total solar energy transmittance ‘g’, which denotes the share of the incoming solar energy, which is converted into heat inside the indoor space. Secondly, the thermal transmittance ‘U’ that describes how much heat is transferred through the glazing per square meter and Kelvin temperature difference between inside and outside. Whiles the WWR of a building plays an important role by aiding day lighting into a space (Tzempelikos and Athienitis, 2007); it is known to be the most influential parameter on energy demand (Pino et al., 2012). Bokel (2007) studied the effect of window position and window size on the energy demand for heating, cooling and electric lighting. The total energy demand was calculated with the dynamic thermal program Capsol which simulates the total yearly energy demand for lighting, heating and cooling. The study concluded that facades should have a WWR of about 30 % of the façade area, where the window is positioned in the top half of the facade. WWR between 20 to 40% is also very acceptable whiles greater WWR does not have any effect on the lighting loads. The study further asserted that when a window position is considered, it does have a significant effect on the primary energy demand for lighting (ibid).

2.2 Shading

Shading of opening/windows is one of the methods for reducing the energy consumption of buildings while ensuring views to the outside. Shading can be inside or outside. According to Seok-Hyun et al. (2013), ‘the ideal shading is to block solar radiation but achieve acceptable ventilation and view. In this regard, outside shading has more efficiency than inside shading. Inside shading leads to radiation between the shading and window. Outside shading blocks solar radiation before it reaches the window. Sometimes, installed options for external shading can be limited by high rise buildings or the characteristics of buildings. The design of the outside requires the azimuth of the sun, view, ventilation and maintenance to be considered’.

2.3 Thermal Mass

The thermal mass of a building material describes the ability of that material to absorb heat, store, and later release it to either outdoor or indoor. Thermal mass can delay heat transfer through the envelope of a building, and help keep the interior of a building cool during the day when the outside temperature is relatively high (Amos- Abanyie, 2009). When thermal mass is exposed to the interior, it absorbs heat from internal sources and dampens the amplitude of the indoor temperature swing (Chenvidyakarn, 2007). This is particularly beneficial during warm periods, when the internal heat gain during the day is absorbed. This helps to prevent an excessive temperature rise and reduction in the risk of overheating (Yam et al., 2003). A building with high thermal mass has the ability to absorb heat and provide a cooling effect which comes from the difference between the surface (radiant) temperature and that of the internal air. Szokolay (2004) accounts that absorptance/reflectance will strongly influence the solar heat input. Reardon (2010) agrees with Szokolay by asserting that porous materials with low specific heat exhibit low thermal mass effects. In addition, good thermal conductivity and low reflectivity are also required for effective passive cooling by thermal mass.

2.4 Night Ventilation

Night ventilation and natural ventilation are known to reduce the energy use in buildings around the world. For instance, Pfafferott et al. (2003) confirmed that night ventilation reduced the mean room temperature by 1.2 K during working hours for a building in Freiburg/Germany. So did Geros et al. (1999), who also found the average reduction of the indoor temperature, in an office building in Greece to be between 1.8 and 3 K after using night ventilation. Natural ventilation on the other hand can reach much higher ventilation rates than mechanical ventilation systems, which are especially designed for fresh air supply (Aggerholm, 2002). However, energy savings by natural ventilation can mostly only be evaluated when simulation tools are used as reported by

Schulze and Eicker (2013). A range of studies using measurements and simulations in schools and offices showed that air change rates between 5 and 22 per hour for cross ventilation and 1 - 4 for single-sided ventilation, could provide comfortable indoors whiles reducing energy used. (Fisch and Zargari, 2009; Breesch, 2006; and Eicker et al., 2006). Schulze and Eicker (2013) in their studies reported that 'simulations showed that night ventilation is only suitable in buildings with sufficient and accessible thermal mass of about 75–100 kg/m^2 of floor space. The internal gains have to be limited to 30 W/m^2 of floor area'. In a tropical climate, Al- Tamimi et al. (2011) observed that the improvements in comfort by natural ventilation ranged between 9% and 41% (Kuala Lumpur in April). According to the authors, in a temperate climate the improvements vary between 8% and 56%. A result which showed that natural ventilation has a good potential in both tropical and temperate climates (Haase and Amato, 2009). The current paper explores the implications of alternative design options for the thermal performance towards the reduction of energy used in four high-rise office buildings in Accra, Ghana.

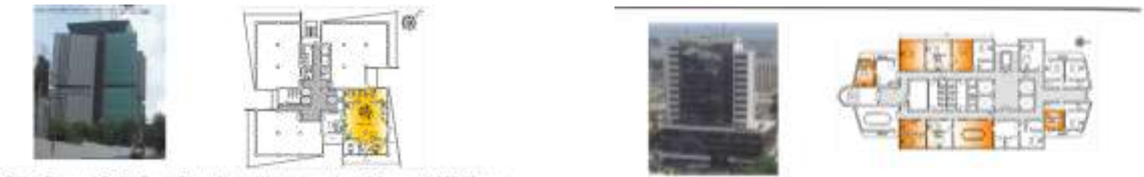
3. 0 Methodology and Description of the Case Study

Parametric simulation with the Thermal Analysis Software (Tas) was used as a means of comparing the thermal performance of the buildings. Tas is a suite of software products, which simulate the dynamic thermal performance of buildings and their systems (EDSL, 2014). It has a 3D graphics-based geometry input that includes a CAD link. Tas Systems is a HVAC systems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand. Tas combines dynamic thermal simulation of the building structure with natural ventilation calculations, which include advanced control functions on aperture opening and the ability to simulate complex mixed mode systems (ibid).

Four high-rise office buildings (with different orientations) in Accra, Ghana were selected as subjects for the study as illustrated in Fig.1. The glazing properties of the buildings, total internal gains for people, lights and equipment as used for the base case cooling loads is shown in Table 1.

Table 1: Overview of base case simulation scenarios

Parameters	R.T.	P.T.	H.T.	W.T.C.
Base case temp.(°C)	26	26	26	26
Occupancy Sensible (W/m²)	7	7	8	4
Occupancy Latent (W/m²)	1	1	2	0.8
Electric lighting loads (W/m²)	3	8	7	5
Infiltration-ACH (h^{-1}) Day-Night	1/0.5	1/0.5	1/0.5	1/0.5
Equipment Sensible (W/m²)	5	8	20	3
Window U_{value} ($W.m^{-2}.K^{-1}$)	2.8 (double glazing)	2.8 (double glazing)	5.6 (single glazing)	2.9 (double glazing)
Window g_{value}	0,5	0.6	0.7	0.6
Thermal mass	Tiled Acoustic ceiling	Tiled Acoustic ceiling	Tiled Acoustic ceiling	Tiled Acoustic ceiling
Shading Options	Internal blinds	Internal blinds	Internal blinds	Internal blinds



Ridge Towers (R. T.). South-East : North-West orientation 15 floors; 14,355.68sqm.

Heritage Towers (H. T.). East -West orientation 15 floors; 9,340.86sqm.

Premier Towers (P. T.). East -West orientation 13 floors; 10,263.00sqm.

World Trade Center (W.T.C.). South-East:North -West orientation 15 floors; 14,556.78sqm

Fig. 1: 3-dimensional and schematic plan views of the case study buildings

Eight glazing options were considered for the improvement simulation scenarios. Two shading options (internal and external) with varied deployment schedules, 4 façade insulation preferences were also probed into. Table 2 presents an overview of the various options that were studied. Since detailed and comprehensive outdoor weather information was not available, segments of a synthetic weather file for Accra was identified and used (generated via Meteotest 2008).

Table 2: Overview of all simulated improvement options

Parameter	Code	Description
Office Window Orientation	N-W	North-West windows at the R.T. and the W.T.C. buildings
	S-W;N-E	South-West and North East windows at the H.T. building
	S	South windows at the P.T. building
Glazing	$G_{0.5}$	Double glazing; g=0.5;U=1.7W$\cdot$m$^{-2}\cdot$K^{-1}
	$G_{0.4}$	Double glazing; g=0.4;U=1.8W$\cdot$m$^{-2}\cdot$K^{-1}
	$G_{PT0.4}$	Double glazing; g=0.4;U=2.8W$\cdot$m$^{-2}\cdot$K^{-1}
	$G_{0.3}$	Double glazing; g=0.3;U=2.6W$\cdot$m$^{-2}\cdot$K^{-1}
	$G_{0.2}$	Double glazing; g=0.2;U=1.6W$\cdot$m$^{-2}\cdot$K^{-1}
	$G_{S0.3}$	Single glazing; g=0.3; U=5.7W$\cdot$m$^{-2}\cdot$K^{-1}
	$G_{S0.24}$	Single glazing; g=0.24; U=5.7W$\cdot$m$^{-2}\cdot$K^{-1}
	$G_{S0.18}$	Single glazing; g=0.18; U=5.7W$\cdot$m$^{-2}\cdot$K^{-1}
Efficient electrical lighting loads	L_e	2W.m^{-2}
Day Time Ventilation	$DV_{m.1}$	Day/Night ACH = 10/0.5h^{-1}
	$DV_{m.2}$	Day/Night ACH = 10/10h^{-1}
Night Ventilation	$NV_{m.1}$	Mode 1; Day/Night ACH = 1/10h^{-1}; 6pm-6am
	$NV_{m.2}$	Mode 2; Day/Night ACH = 1/10h^{-1}; 9pm-6am
	$NV_{m.3}$	Mode 3; Day/Night ACH = 1/10h^{-1}; 10pm-6am
	$NV_{m.4}$	Mode 4; Day/Night ACH = 1/10h^{-1}; 12am-6am
	$NV_{m.5}$	Mode 5; Day/Night ACH = 1/10h^{-1}; 1am-6am
	$NV_{m.6}$	Mode 6; Day/Night ACH = 1/10h^{-1}; 2am-6am
Shading Option	SO_e	External blinds
	SO_i	Internal blinds
	BS_{PT11}	11am – 2pm

Blind deployment schedule	BS_{11}	11am – 4pm :South windows
	BS_{HT11}	11am – 5pm
	BS_{PT12}	12pm – 3pm
	BS_{12}	12pm – 5pm :SW windows
	BS_1	1pm – 5pm :SW windows
	BS_2	2pm – 5pm
	BS_F	8am – 5pm (Continuous deployment)
Thermal Mass	TM_a	Without carpet and acoustic ceiling (suspended ceiling)
Façade Insulation	I_5^1	With 50mm insulation outside only (U = 0.46)
	I_{10}^1	With 100mm insulation outside only (U = 0.24)
	I_5^2	With 50mm insulation outside and inside (U = 0.24)
	I_{10}^2	With 100mm insulation outside and inside (U = 0.12)

4.0 Results and Discussion

The Tables below show base case cooling loads for the buildings as well as the various reductions by each parameter. The total simulated annual cooling load for the base case of the R.T. building was 115.34kWh.m^{-2}.a^{-1}. The probed alternative of a more efficient glazing type with a better shading coefficient (0.3) resulted in a significant reduction of the base case cooling loads by 14.1% (Table 3). The effect was that only 30% of radiation could be transmitted through the glass as compared to the 50% at the base case scenario.

Table 3: Simulated annual cooling loads for the base case and individual parameters and their percentage difference to the base case (R.T. building)

Parameters	Total cooling loads (kWh.m^{-2}.a^{-1})	% increase/ decrease
Base case	115.34	100
$G_{0.5}$	110.51	-4.2
$G_{0.4}$	106.30	-7.8
$G_{0.3}$	99.07	-14.1
L_e	110.72	-4.0
$DV_{m.1}$	211.62	+83.5
$DV_{m.2}$	201.82	+75
$NV_{m.1}$	100.42	-12.9
$NV_{m.2}$	101.25	-12.2
$NV_{m.3}$	101.68	-11.8
$NV_{m.4}$	102.84	-10.8
SOe	109.32	-5.2
BS_{12}	109.32	-5.2
BS_1	111.02	-3.7
BS_2	112.74	-2.3
BS_F	104.67	-9.3
TM_a	119.04	+3.2
I_5^1	116.35	+1.0
I_{10}^1	115.91	+0.5
I_5^2	115.58	+0.2
I_{10}^2	115.31	0

By using more efficient lighting systems (Le), cooling loads could be reduced by 4%. This corroborates studies which have concluded that lighting gains has a positive effect on cooling loads (Yufan and Hassim, 2011: Galasiu and Veitch, 2006). Night ventilation could reduce the base case cooling loads by as much as 11% - 13% (Appendix D, Table 1) depending on the time of the night. Though $NV_{m.1}$ (6pm to 6am) reduced cooling loads considerably (12.9%), $NV_{m.2}$ (9pm to 6am) was found to be effective since the percentage reduction between the two was 0.7%.

Different external blind deployment times also led to the reduction of cooling loads by 2.3 to 5.2%. The position of the glazing was also considered for the blind deployments. From the simulation, it was noted that thermal mass, day time ventilation and the insulation of the facades rather increased the base case/initial cooling loads. As a result these parameters should not be considered when one wants to develop a scenario with the above factors.

Table 4: Simulated annual cooling loads for the base case and individual parameters and their percentage difference to the base case (W.T. C building)

Parameters	Total cooling loads ($kWh.m^{-2}.a^{-1}$)	% increase/ decrease
Base case	149.75	100
$G_{0.5}$	136.22	-9
$G_{0.4}$	123.95	-17.2
$G_{0.3}$	109.87	-26.6
L_e	139.18	-7.1
$DV_{m.1}$	267.35	+78.5
$DV_{m.2}$	255.92	+70.9
$NV_{m.1}$	135.94	-9.2
$NV_{m.2}$	137.63	-8.1
$NV_{m.3}$	138.30	-7.6
$NV_{m.4}$	139.91	-6.6
SOe	109.32	-5.2
BS_{12}	139.49	-6.9
BS_1	138.44	-7.6
BS_2	140.05	-6.5
BS_F	128.30	-14.3
TM_a	142.92	-4.6
I_5^1	143.33	-4.3
I_{10}^1	143.32	-4.3
I_5^2	145.10	-3.1
I_{10}^2	145.21	-3.0

The base case cooling load of the rectangular block was 149.75 $kWh.m^{-2}.a^{-1}$. As much as 7.1% reduction was simulated when efficient lighting was used (Table 4). Different time modes for night ventilation recorded percentage reductions from 6.6 % (12am -6am) to as much as 9.2% (6pm- 6am). Thermal mass reduced cooling loads by 4.6%, a 1.4% higher than that of the R.T. building. A combination of thermal mass and night ventilation led to a significant decrease in cooling loads of 13.5%.

The various glazing options probed into, led to cooling load reductions from 9% to 26.6%. This could be due to the shading that is provided by the verandah. According to Al-Tamimi et al. (2011), reducing the glazing to wall ratio helps reduce the cooling loads. A proper selection for the optimal area of the glass and applying natural ventilation system can reduce the negative effect of solar radiation in increasing the indoor air temperature (Al-Tamimi and Fadzil, 2010).

The use of external blinds at the south-east area from 1pm to 5pm did reduce cooling loads by 7.6% whiles from 2pm to 5pm also reduced the loads by 6.5%. In terms of form and orientation (Rilling, 2007) the W.T.C. performs better than the R.T. Adding insulation to the façade (5cm/10cm) reduced the cooling loads by 4.3%. This result could be due to the orientation of the building and also the tightness of the envelope (Koranteng, 2010). The result also agrees with Lauber's (2005) recommendation of using façade insulation to reduce cooling loads. This assertion however does not work for all buildings.

Table 5 show the result for the Premier Tower building. The curtain wall building had an initial cooling load of 126.2 KWh.m^{-2}.a^{-1}. The alternative improvement of using an efficient glazing reduced the cooling loads by 17.7%. Other glazing types were also explored with different shading coefficient values. Cooling loads were reduced by 4.6% to 15.8%. An efficient lighting gain of 2W/m^2 led to a decrease in the initial cooling loads by 10.2%. Night ventilation options did reduce cooling loads but inconsequentially (Table 5). External shading at 11am to 4pm did reduce cooling loads by 5.8%. Whiles façade insulation reduce cooling loads by 1.8% and 1.2% respectively for the 5cm and 10cm insulation material, a combination of façade insulation, night ventilation and thermal mass increase the cooling loads by 1.3%.

Table 5: Simulated annual cooling loads for the base case and individual parameters and their percentage difference to the base case (P.T. building)

Parameters	Total cooling loads (kWh.m^{-2}.a^{-1})	% increase/ decrease
Base case	168.44	100
$G_{0.5}$	154.23	-8.4
$G_{0.4}$	146	-13.3
$G_{PT0.4}$	141.79	-15.8
$G_{0.3}$	138.65	-17.7
L_e	151.24	-10.2
$DV_{m.1}$	281.57	+67.2
$DV_{m.2}$	281.09	+66.9
$NV_{m.1}$	167.62	-0.5
$NV_{m.4}$	167.34	-0.7
$NV_{m.5}$	167.39	-0.6
SOe	161.56	-4.1
BS_{11}	158.72	-5.8
BS_{12}	161.56	-4.1
BS_F	150.2	-10.8
TM_a	174.52	+3.6
I_5^1	165.45	-1.8
I_{10}^1	165.39	-1.8
I_5^2	166.42	-1.2
I_{10}^2	166.37	-1.2

The rectangular H.T. building oriented towards north-east and south-west had an original cooling load of 235.16 kWh.m^2.a^1. Results are outlined in Table 6 below. Different glazing types were explored. Single glazed window with solar heat gain coefficient of 0.18 and a u-value of 5.7 recorded a 25.4% reduction in cooling loads. This means that only 18% of radiation could be transmitted through the glass. In comparison with the use of efficient lighting which could reduce the cooling loads by 7.5%, it is recommended that the single glazing could be used (for medium height buildings, for very tall buildings, the high wind pressure may need double glazing) and the effect of it (in terms of not so much sunlight into the space) could be complemented by artificial light (energy efficient fixtures).

Table 6: Simulated annual cooling loads for the base case and individual parameters and their percentage difference to the base case (H.T. building)

Parameters	Total cooling loads (kWh.m^{-2}.a^{-1})	% increase/ decrease
Base case	235.16	100
$G_{0.18}$	175.44	-25.4
$G_{0.24}$	182.06	-22.6
$G_{0.3}$	189.37	-19.5
$G_{0.2}$	179.29	-23.8
L_e	217.60	-7.5
$DV_{m.1}$	332.75	+41.5
$DV_{m.2}$	318.90	+35.6
$NV_{m.1}$	222.05	-5.6
$NV_{m.4}$	220.26	-6.3
$NV_{m.5}$	221.33	-5.9
$NV_{m.6}$	222.58	-5.3
SOe	226.87	-3.5
BS_{11}	223.80	-4.8
BS_{HT11}	221.56	-5.8
BS_{12}	226.87	-3.5
BS_F	207.04	-12
TM_a	234.55	-0.3
I_5^1	250.06	+6.2
I_{10}^1	249.78	+6.2
I_5^2	252.51	+7.4
I_{10}^2	252.51	+7.4

H.T. had the highest base case cooling loads amongst all the case study buildings. It’s sealed inoperable windows, orientation, high window to wall ratio and no external shading, etc. could account for the high initial cooling loads. Possibly, the loads could have reduced if there was external shading. Other glazing alternatives investigated into resulted in the reduction of the cooling loads by 8.1% to 23.8%. Designing buildings with sealed windows and without reference to solar orientation, with high standards of comfort but without reference to operating costs, with the newest technology but without much sense of what tomorrow might bring must be reconsidered, as the non-sustainable use of resources poses a danger to humanity (Koranteng, 2010).

Various night ventilation times also led to a reduction in the base case cooling loads. As much as 6.3% was reduced by the night ventilation time of 12am to 6am. Thermal mass reduced cooling loads by 0.3%. The effect of thermal mass in a hot humid climate as documented by Cheng and Givoni (2008) has not worked so well here. Perhaps, this observation is so because the case study buildings lack the heavy massing that is important for heat transfer in thermal mass (Amos- Abanyie, 2009) and a high diurnal temperature difference (Szokolay, 2004).

Façade insulation applied to the building led to an increase in cooling loads by 6.2% (when the insulation was applied to just one side of the façade) and 7.4% (when the insulation was applied to both sides of the façade). The effect of uncontrolled ventilation or leakage through cracks in the building envelope also leads to increased cooling loads (Carmody et al., 2007).

5.0 Conclusion and Recommendations

The synergistic effect of all the factors that did reduce the cooling loads could greatly decrease the initial cooling loads and eventually reduce the energy used by these buildings. The installation of more efficient electrical lighting system has a positive effect in reducing the buildings' total cooling loads. From the above, cooling loads were reduced in all the buildings by the use of an efficient lighting gains (2W/m^2).

The study revealed that thermal mass, façade insulation, night ventilation (various times) depending on the orientation, form and building elements, have varied effect in reducing the total cooling loads.

From the study, it was also observed that the double glazing performs better than the single glazing. A single glazed window of $G_{0.18}$ led to a reduction in cooling loads by 25.4% whiles a double glazing of $G_{0.3}$ reduced cooling loads by 26.6%. This could be due to the insulation gas between the panes (aside their u-values).

Increased night time ventilation also led to a reduction in the initial cooling loads for all the buildings though the decreases were all below 10% except for the R.T. building. This could be due to the rather small diurnal temperature range in Ghana: the night temperature does not drop low enough to effectively cool the building mass.

It is recommended that architects should be mindful of the climatic condition in Ghana when designing multi-storey office buildings. In terms of choosing glazing types, such selection should not be based on immediate economic considerations but the long term effect of such glazing types. Building occupants and facility managers are informed to use energy efficient equipment and lighting systems since this has a great potential of reducing the total annual cooling loads of high-rise office buildings in Ghana.

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