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REDUCTION OF COOLING LOADS IN MULTI-STOREY GLAZED OFFICE BUILDINGS IN GHANA: GHGBC VERSUS ARCHITECTURAL DESIGN PARAMETERS

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ABSTRACT

Within the tropics, cooling is inevitable during certain times of the year. This is as a result of the intense solar radiation that hits the interiors of our spaces mostly due to unsustainable design practices. A number of researchers are of the view that the tropical regions are the hardest to ameliorate through design due to the harsh weather conditions. With this situation, occupants are likely to use air conditioners in achieving comfortable indoor environment in tropical climate. This observation will definitely affect the cooling loads for the building. The current paper describes an investigation into cooling load reductions where the Ghana Green Building Council (GHGBC) parameters (such as orientation, geometry, fabric, building form etc.) were compared with architectural design parameters such as night ventilation, thermal mass, efficient lighting and facade insulation among others. A glass box (totally glazed building) called the XGL building in Accra was used as the case study with parametric simulation (using the Tas tool) as the methodology. The results indicated that the base case cooling loads for the XGL building was 300.04kWh.m2.a1. This was the total cooling loads for the building in its existing capacity. Whiles the GHGBC parameters led to a reduction of the above value to 293.78 kWh.m2.a1 representing 2%, the architectural design parameters significantly reduced the base case cooling loads by 38%, thus 186.04 kWh.m2.a1. It is recommended that sustainable design principles should be practised. Again, more experiment should be conducted for empirical evidence rather than using parameters from other countries.

Keywods:- *Cooling loads, Glazed buildings, GHGBC, Tropics, Architectural design parameters.*

I. INTRODUCTION

Commercial buildings in recent times have taking on a new trend. In the wake of 21st century civilization, fully glazed commercial buildings have become the order of the day. In Singapore, fully glazed systems have been used mainly for the reduction of the lighting energy consumption by making full use of day lighting and also the provision of full external view (Wong et al., 2005).

In Ghana, the afore-stated reasons also hold for the reasons why builders have gone into fully glazed buildings. There is also the aesthetics aspect. More often than not, these glazed materials are not accompanied with sustainable design practices and as such more energy tend to be used in creating comfortable interior environments (Koranteng, 2010). According to the United State Energy Information Administration (US: EIA, 2011), the building sector in the United States represents an excellent opportunity to achieve large scale energy reductions, especially through commercial buildings as they account for 19% of the total consumption.
Buildings, no matter the type are supposed to provide shelter for human activities. These buildings are commonly exposed to the harsh conditions of the weather and therefore designers have to make sure their designs are well protected from the weather conditions. In most cases, these buildings have to heavily rely on mechanical ventilation in order to provide indoor comfort for occupants. The demand for thermal comfort, or tolerable internal environment, results in an increasing demand for cooling in buildings for most parts of the year.

Azar and Menassa (2012) have asserted that over the life cycle of buildings, more than 80% of the total energy is consumed during the operation phase and is highly dependent on the build design, especially the sizing of the mechanical and electrical systems. It is therefore important to focus on the operation phase of buildings as it is crucial to achieving long-term energy savings. The green star office v1 rating tool is currently being evaluated to be adapted by the Ghana Green Building Council from the Green Building Council of South Africa (GBCSA). 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 current paper presents the findings of a parametric study towards the reduction of cooling loads comparing the GHGBC and other architectural design parameters. The aim of the study is to find out by how much

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cooling loads can be reduced when the GHBGC parameters are used and when other design parameters are also used.

There are many aspects of buildings that designers tend to turn a blind eye on when on the drawing table. Aspects like orientation, shading, form and envelope all affect the internal conditions of the buildings once it's been built.

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.

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'. Lim et al. (2012) and Sherif et al. (2012) studied the visual comfort performance of complex fenestration systems in Malaysia and Egypt respectively. Both studies reported that shading devices (blinds and solar screens) are able to reduce daylight glare effectively.

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. 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 et al., 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 (Al-Najem. 2010; Lam and Li, 1999). Other features like thermal mass, night and natural ventilation all have been studied with their benefits well documented.

II. MATERIALS AND METHODS

Parametric simulation was the primary method used in the investigation with the Thermal Analysis Simulation (TAS) tool as the software. With this, a multi-storey office building which is a representative of the current trend of office building design was selected as a case study case study (Fig. 1). The building was further simulated in the software. Table 1 show the base case internal conditions, that of the GHGBC and the conditions from literature that was used for the simulation. In the the green star SA-office v1 tool, geometry, fabric, orientation, building form, insulation, glazing and shading were all mentioned but no details were given as to what to do with these parameters. For instance with shading, it says that "one is to ensure that all shading of windows and external building fabric are precisely represented". The question is what if there is no shading? This is where the factors from literature come in where each consideration is probed into to come out with more effective designs.

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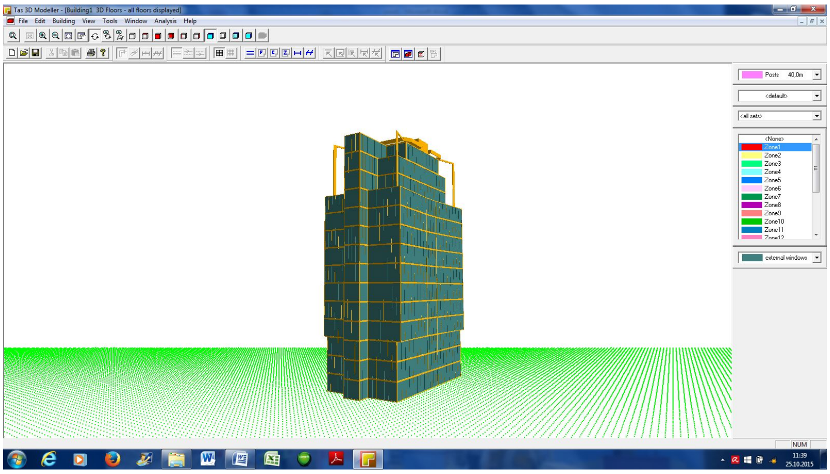

Fig. 1: Existing XGL building with its Tas modelling

The image shows the building at its location in Accra, the capital of Ghana. It was also chosen due to its 100% glazed facades with no external shading as well as representing the current trend of Ghanaian office building construction.

From the study of Simons (2015), seven parameters were found to significantly reduce the cooling loads for some multi-storey office buildings within the same geographical area. The parameters (efficient glazing, efficient lighting load of $2W/m^2$, night ventilation, external shading, blind deployment time, thermal mass and façade insulation) were adapted and simulated using the XGL building to ascertain how much each would reduce the initial cooling load. The internal design temperature used for this investigation was 26°C instead of the 24°C proposed by the Green Star Council, South Africa. This was to encourage the efficient use of energy and to assuage risks of global warming. Furthermore, this value also has been proposed by the ASHRAE (2004) as the maximum temperature for summer comfort.

Table 1: Internal conditions of the base case, GHGBC recommendation and literature findings

Parameters	Base case	GHGBC	Literature findings
Base case temp.(°C)	26	24	26
Occupancy Sensible (W/m²)	7	15	7
Occupancy Latent (W/m²)	1	-	1
Electric lighting loads (W/m²)	8	12	2
Infiltration-ACH (h^{-1})	1/0.5	8	1/10 (9pm-6am)
Equipment Sensible (W/m²)	20	11	20
Window U_{value} ($W.m^{-2}.K^{-1}$)	5,6 (double glazing)	Same as base case	2.8 (double glazing)
Window g_{value}	0,77	Same as base case	0.3
Shading	Internal blinds	As building is shaded	External shading
Thermal Mass	No consideration	Same as base case	Consider thermal mass

The base case present the parameters that were recorded and working within the building whiles the GHGBC factors are enshrined within the South Africa Green Building handbook which Ghana wants to adopt. The literature findings are those features that have been experimented on with some factors performing better than others.

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III. RESULTS AND DISCUSSION

Figure 1 represents the simulation results of all three parameters that were tried out. It was realized that the building had a very high equipment load due to the number and types of gadgets that were found.

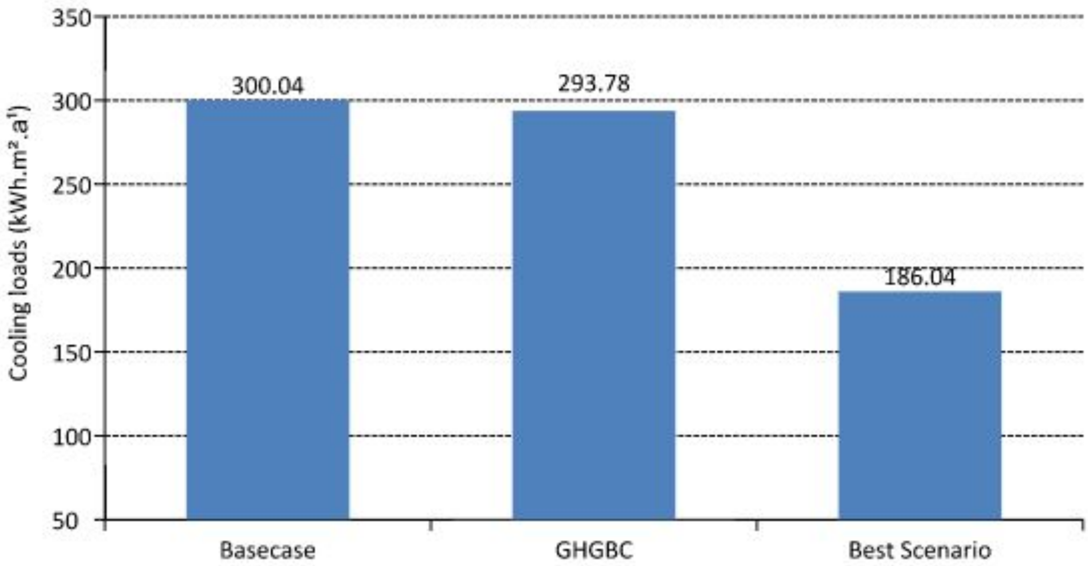

Fig.1: Annual cooling load comparison between base case, GHGBC and best scenario from literature

The base case cooling load was found to be 300.04 $kWh.m^2.a^1$, an assessment which can be as a result of the extensive use of the air-conditioners, office equipment and lighting (lighting loads from the Table was $8W/m^2$). This corroborates the findings of Tenaga (2005). The author pointed out that figures from energy audits conducted on offices in Malaysia indicated that the electricity use in commercial buildings was primarily attributed to the air conditioning, artificial lighting and office equipment, with 52-60%, 18-42% and about 22% of the total consumption respectively (Tenaga, 2005). Additionally, the energy audits and surveys of fully air-conditioned commercial buildings in typical commercial buildings in subtropical Hong Kong have revealed that the lighting and air-conditioning account for 20–30% and 40–60%, respectively, of the total electricity use (Chan, 1994). What this means is that energy use in terms of electricity payment, is very high.

There was just a 2% reduction in the base case cooling load when the GHGBC recommendations were applied and simulated. This result could be due to the low internal temperature set point. Hwang and Shu (2011) share in this assessment and posits that the energy authorities of Taiwan have recommended that the cooling set-point should be 26°C or above. In their experiment, the authors found out that when internal temperature was set at 24°C, 25°C and 26°C, the accumulated energy consumption at 25°C and 26°C during the cooling period was respectively reduced by 11% and 13% in the current building design, compared with the space controlled at a set-point of 24°C. The other internal parameters were calculated from the area of the building and therefore could be seen to be a fair representation of what the building is.

The XGL building is especially high in cooling loads in comparison with other contemporary multi-storey office buildings within the same geographical area. Simons (2015) in a parametric simulation analysis documented the base case cooling loads for four buildings. In the libretto of the author, the initial cooling loads for the buildings ranged from 115.34 to 235.16$kWh.m^2.a^1$. The major raison d'être for this enormous difference can be primarily related to the WWR of the XGL building (which is 100% in this case). It was also found out that only four out of the seven parameters simulated did have a significant effect on the reduction of the initial cooling loads. These were efficient glazing, efficient lighting load of $2W/m^2$, night ventilation and thermal mass. Whiles external shading and blind deployment time neither reduced nor increased the base case cooling loads, façade insulation did augment the initial value insignificantly by 0.2%. The synergistic effect through

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the positive combination of the various parameters from literature led to a major reduction of the base case cooling loads. Percentage reduction of 38% was recorded which is equivalent to 114kWh.m^2.a^1 reduction in cooling loads

Figure 2 show the monthly per unit area cooling loads for all three scenarios.

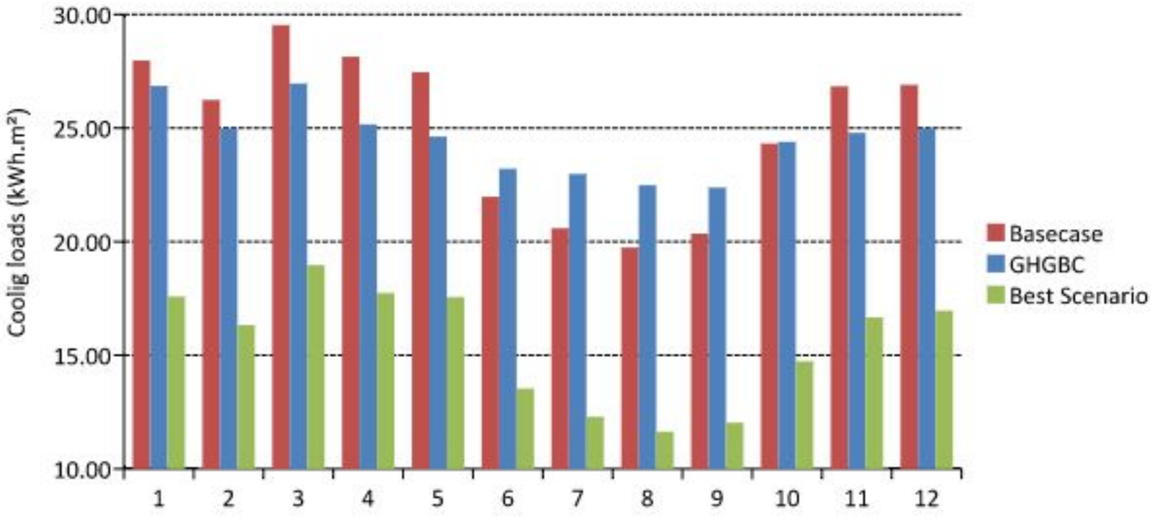

Fig. 2: Monthly cooling load per unit area comparison between base case, GHGBC and best scenario from literature

The base case, GHGBC and other recommendations from literature (BS) together show a very wild dispersion of cooling loads for the XGL building. The figures show the fact that the Council's recommendations inconsequentially reduce the initial cooling loads whilst the parametric combination of factors with empirical values could greatly reduce the base case cooling loads. Again, the internal temperature set point of 26°C contributed immensely to the differences. The indication is that at 26°C, energy usage can be greatly reduced but occupants should be asked if they feel comfortable.

The curtain wall envelope type also could have accounted for this high base case cooling load. An inventory of energy use in 123 Swedish office buildings of different age revealed that office buildings have an energy intensity of 210 kWh.m^2.a^1 in average, with a high electricity use by square meter (93kWh.m^2.a^1 excluding heating) (Statens energimyndighetenen, 2010).

The energy used for the base case scenario, GHGBC, and the best scenario were calculated. The calculation was based on the current unit cost of electricity which was multiplied by the total cooling load the building consumed for each setting.

Table 2: Estimated Annual Energy use for the XGL Building

Building	Floor area (m^2)	Cooling load (BC) (kWh.m^2.a^1)	Cooling load (GHGBC) (kWh.m^2.a^1)	Cooling load (BS) (kWh.m^2.a^1)	Efficiency of cooling systems	Annual energy use (BC) (kWh)	Annual energy use (GHGBC) (kWh)	Annual energy use (BS) (kWh)
XGL	559.5	300.04	293.78	186.04	2.60	436,468.19	427,361.77	270,632.39

Table 3: Estimated Annual Energy cost and savings based on the GHGBC

Building	Unit cost of energy	Annual energy cost	Annual energy cost	Annual energy	Annual energy

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	(Dollars)	(BC) (Dollars)	(GHGBC) (Dollars)	savings (GHGBC) (Dollars)	savings (GHGBC) (kWh)
XGL	3.7	1,614,932.30	1,581,238.55	33,693.75	9,106.42

Table 4: Estimated Annual Energy cost and savings based on improvement form literature (BS)

Building	Unit cost of energy (Dollars)	Annual energy cost (BC) (Dollars)	Annual energy cost (BS) (Dollars)	Annual energy savings (BS) (Dollars)	Annual energy savings BS) (kWh)
XGL	3.7	1,614,932.30	1,001,339.84	613,592.46	165,835.80

The estimated energy use of the case study building has been calculated and presented (Tables 2, 3 and 4). These calculations have been done for the base case (BC), the recommendations based on the GHGBC and the best improvement scenario (BS) from literature. The efficiency of the split unit air-condition systems (Ander, 2014) was factored into the calculation of the annual energy use.This was multiplied by the cooling loads per kilo Watt hour and the total area of the floor studied. It is estimated that in a year, 436,468.19kWh of energy is used in the building. The application of the recommendations of the GHGBC led to a marginal reduction of the aforesaid value to 427,361.77 kWh (2.1% reduction). Through the application of the various improvement factors, there was a reduction of the base case value to 270,632.39kWh representing a 38% decrease in energy used annually.
For calculating the annual energy cost, the current unit price of electricity for commercial buildings (GHC14) which is equivalent to 3.7 USD (current BOG rate for Cedi to Dollar is GHC 3.8 to USD 1) was used. The annual energy cost of the building could be reduced by USD 33,693.75 for the GHGBC and USD 613,592.46 for the literature recommendation (Table 3 and 4).

IV. CONCLUSION AND RECOMMENDATIONS

As far as energy efficient designs are concerned, it can be concluded that the case study building is not efficient at all. When it was compared to other contemporary buildings within the same geographical area, cooling loads for the former was high by about 65 $kWh.m^2.a^1$.

Recommendations in terms of glazing properties, internal design temperature, internal loads, external shading, infiltration, etc. proposed by the GHGBC were simulated to ascertain how much of the initial cooling loads could be reduced thereby making the building energy efficient. Astoundingly, the combination of these improvement factors led to only a 2% reduction of the base case cooling loads. It is therefore clear that the internal design temperature of 24°C leads to high cooling loads. The upper limit of ASHRAE summer comfort temperature of 26°C performed better towards the reduction of cooling loads. This temperature is also acceptable to occupants since satin the tropics, office occupants are susceptible to higher temperature values than the 26°C.

Parameters which have been probed into and presented in literature were simulated. The factors included and efficient glazing with a solar heat gain coefficient of 0.3, effective lighting loads of $2W/m^2$, night ventilation and thermal mass. It must be emphasised that not all the parameters led to a reduction in cooling loads for the case study building. Factors like external shading, and timing with respect to the deployment of internal blinds which led to a decrease in cooling loads in other buildings within the same location did not have any effect at all on the current building. Facade insulation when applied led to a rather slight augmentation of the initial cooling load. There was however a 38% reduction in the base case cooling loads when those parameters that worked were simulated together. From the study, it can be concluded that the installation of more efficient electrical lighting system has a positive effect in reducing the buildings' total cooling loads.

There was a clear improvement in the initial cooling loads for the building when glazing with higher shading effectiveness (specified via g-value) was considered. From the study, it's clear that the u-value does not play a

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minor role in reducing the cooling loads. Glazing type $G_{0.3,}$ which has a low g-value but a high u-value was the glazing used in the scenarios simulation. As in this case, the visual transmittance is not too low (0.3) and therefore daylight usage potential (reduction in electric energy for lighting) is not compromised.

The study conclude that the Ghana Green Building Council cannot adopt the entire document of the Green Star Council-South Africa as a working document in Ghana without conducting any study to find empirical basis to it. Though the document can be adapted as a head start, a number of studies will have to be undertaken by researchers in Ghana to better understand the local climate, different glazing and their properties, orientation, buildings internal conditions, building typologies etc. in order to create a document that could become a tool for energy efficient multi-storey commercial buildings in Ghana.

REFERENCES

1. *Al-Najem, A.A. (2010). The Effects of Orientation, Ventilation and Varied WWR on the Thermal Performance of Residential Rooms in the Tropics. Available at http://www.ccsenet.org/journal/index.php/jsd/article. Accessed 9/08/2013.*

2. *Al-Tamimi, N. A. M., and Syed Fadzil,S. F., (2011). Thermal Performance Analysis for Ventilated and Unventilated Glazed Rooms in Malaysia (Comparing Simulated and Field Data). Indoor Built Environ, (20) 5; pp. 534–542.*

3. *American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2004). Thermal environmental conditions for human occupancy, ASHRAE Standard 55, Atlanta, GA: ASHRAE*

4. *Ander, G.D., (2014). Windows and Glazing. National Institute of Building Sciences.*

5. *Azar, E., Menassa, C.C., (2012). A Comprehensive Analysis of the Impact of Occupancy Parameters in Energy Simulation of Office Buildings. Energy and buildings. www.elsevier.com/locate/enbuild. http://dx.doi.org/10.1016/j.enbuild.2012.10.002*

6. *Bojic M., Yik F., (2007). Application of advanced glazing to high-rise residential buildings in Hong Kong, Building and Environment 42; pp 820–828.*

7. *Bokel, R. M. J., (2007). The Effect of Window Position and Window Size on the Energy Demand for Heating, Cooling and Electric Lighting. Proceedings: Building Simulation 2007, pp 117-121. Accessed 12/06/2014 at www.ibpsa.org/proceedings/BS2007.*

8. *Bosschaert, T., (2009). Energy and Cost analysis of double and triple glazing. Available at www. Except.nl. Accessed on 13/10/2014.*

9. *Boyce, P., Hunter, C., and Howlett, O., (2003). The benefits od daylight through windows. Rensselaer Polytechnic Institute.*

10. *Carmody, J., Selkowitz, S., Arasteh, D., and Heschong L. (2007). Residential Windows. Third Edition. W.W. Norton Company, Inc., 500 Fifth Avenue, New York, N.Y.10110.*

11. *Carbon Cops, (2007). Transferring Energy Usage. Available at www. Concertinafoilbatts.com/renshade.htm. Accessed on 12/02/2014.*

12. *Chan, A. L. S., (1994). Development of Guidelines for Energy Efficient Operation of Fully Air-Conditioned Buildings in Hong Kong, MPhil Thesis, City University of Hong Kong, Hong Kong.*

13. *English Heritage, (2012). Energy Efficiency and Historic Buildings: Secondary glazing for windows. Available at www.english –heritage .org.uk. Accessed on 15/09/2014.*

14. *Green Building Council of South Africa (2010). Green Star SA Eligibility Criteria.*

IJERMS
International Journal of Engineering Researches and Management Studies

15. *Hwang, R. L., Shu, S.Y., (2011). Building envelope regulations on thermal comfort in glass façade buildings and energy-saving potential for PMV-based comfort control. Building and Environment, 46: pp. 824-834*

16. *Karlsson, J., Karlsson, B., Roos, A., (2001). A simple model for assessing the energy performance of windows. Energy and Buildings, 33 (7): pp. 641–51.*

17. *Koranteng, C., (2010). The Energy Performance of Office Buildings in Ghana, Journal of Science and Technology, JUST, 30(2): pp 114-127.*

18. *Lam, J., Li, D. H. W., (1999). An analysis of day lighting and solar heat for cooling dominated office buildings. Solar Energy, 65 (4), pp. 251-262.*

19. *Lim, Y.W., Kander, M. Z., Ahmad, M. H., Ossen, D. R., and Abdullah, A. M., (2012). Building Facade Design for Day lighting Quality in typical government Office Buildings. Building and Environment, 57;pp 194-204*

20. *Manz, H., Menti, U.P., (2012). Energy performance of Glazing in European Climates. Renewable Energy (37); pp; 226-232.*

21. *Manz, H., Brunner, S., Wullschleger, L., (2006). Triple vacuum glazing: Heat transfer and basic mechanical design constraints. Solar Energy 2006;80: pp. 1632-1642*

22. *Nicol, F., Humphreys, M., and Roaf., (2012). Adaptive Thermal Comfort: Principles and practice. New York: Routledge.*

23. *Pino, A., Waldo, B. W., Escobar, R., Pino, F.E., (2012). Thermal and Lighting Behaviour of Office Buildings in Santiago of Chile. Accessed 25/10/2012 from www.elsevier.com/locate/enbuild .*

24. *Salmon, C., (1999). Architectural Design for Tropical Regions, First Edition, John Wiley & Sons, Inc., New York, pp. 124 - 125.*

25. *Seok-Hyun, K., Sun-Sook, K., Kwang-Woo, K., Young-Hum, C., (2013). A Study on the Proposes of Energy Analysis Indicator by the Window Elements of Office Buildings in Korea. Accepted Manuscript. Journal of energy and buildings. Accessed on 20/05/2013 from DOI: http://dx.doi.org/doi:10.1016/j.enbuild.2013.12.061.*

26. *Sherif, A. H., Sabry, H. M., Gadelhak, M. I., (2012). The impact of changing solar screen rotation and its opening aspect ratio on Day lighting availability in residential desert buildings. Solar Energy, 86; pp. 3353-3363.*

27. *Simons, B., Koranteng, C., and Ayarkwa, J., (2015). Simulation-based Assessment of the Thermal Performance of High-rise Office Buildings in Ghana. British Journal of Applied Science & Technology. 8(2): pp. 165-179.*

28. *Statens energimyndighetenen., (2010). Energi i våra lokaler: Resultat från Energimyndighetens STIL2-projekt, Delrapport från Energimyndighetens projekt Förbättrad energistatistik i samhället. Available at www.energimyndigheten.se/stil2. Accessed 27/01/2011*

29. *Tadeu, A. J. B., and Mateus, D. M. R., (2001). Sound transmission through single, double and triple glazing. Experimental evaluation. Applied Acoustics 62; pp. 307-325. Available at www. Elsievier .com/locate/apacoust. Accessed on 19/11/2014.*

30. *Tenaga, S., (2005). Building Energy Performance in Malaysia. EE Seminar- How to take advantage of it, Kaula Lumpur.*

International Journal of Engineering Researches and Management Studies

31. *Tiberiu C., Virgone, J., and Iordache, V., (2011). Study on the Impact of the Building Form on the Energy Consumption. Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November, pp. 1726-1729.*

32. *Tzempelikos, A., Athienitis, A.K., (2007). The Impact of Shading Design and Control on Building Cooling and Lighting Demand, Solar Energy 81 (3): pp. 369–382.*

33. *U.S. EIA,(2011). The International Energy Outlook 2011, U.S. Energy Information Administration.*

34. *Wong, N. H., Wang, L., Chandra, A. N., Pandey, A. R., and Wei, X. (2005). Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. Energy and Buildings, (37): pp. 563-572.*

35. *Yilmaz, Z. (2007). Evaluation of Energy Efficient Design Strategies for Different Climate Zones: Comparison of Thermal Performance of Building in Temperature Humid and Hot-Dry Climate. Energy and Buildings, 39 (3): pp. 306-316.*