JENRM, Vol. I, No. 1, 29-35, 2014
Research Article

Achieving energy efficiency and aesthetics through windows in the Tropics

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Abstract
The world today is faced with climate change issues and due to the activities man has been involved in over the years. World leaders have become very concerned with this and lot of measures are been laid down to mitigate this. The built environment is a major contributor since its construction process, materials used and even the daily operation uses a lot energy which is a major concern. Architects are therefore challenged with creating a balance between their traditional aesthetics of buildings and energy efficiency. This research therefore seeks to find out how this balance can be achieved in the tropics through the use of different window pane properties. The study therefore sought to identify developments of windows with regards to their pane properties to see how both aesthetics and energy efficiency can be achieved. Literature was reviewed to find out the current situation and then a case study building analysed for results. The case study buildings were then modified to see the effect of each modification. Comparative analysis was done with the original buildings and the modified buildings and it was found that reflection was a key to achieve both aesthetics and energy efficiency. Other factors had impact and influence on the aesthetics and energy efficiency but reflection stood out of the lot.

Keywords
Energy efficiency — Aesthetics — Buildings — Windows — Tropics

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Content

Introduction

Windows contribute immensely in achieving natural lighting and ventilation in the tropics. However, aesthetics cannot be compromised when talking about windows. Aesthetics of a window can be defined as how pleasing a window is in a wall of a building. They come in different shapes, sizes, colours and textures and if care is not taken in choosing windows, facades may become unattractive as well as non energy efficient. Although aesthetics of windows is essential, energy efficiency is a key principle in achieving sustainable energy. Sustainable energy is the use of less energy by products and manufacturing processes. Even though renewable energy is environmentally friendly, its usage must be lessened for sustainability. This is why renewable energy and energy efficiency are sometimes said to be ”a couple” in sustainable energy. Both resources must be given equal attention in order to stabilize and reduce carbon dioxide emissions. The carbon foot prints by the built environment can drastically be reduced when buildings are carefully designed for low energy consumption. The quality of a building may be determined by the degree of comfort enjoyed by the people using it. Adequate use of natural lighting and ventilation can positively contribute in providing this comfort (Kasule, 2000). This is very important especially in the tropics where technology is low. As designers of building, it is always desired that aesthetics is achieved. Boring facades can be designed with windows to make them very attractive. Architects are therefore confronted with the problem of designing energy efficiently and achieving aesthetic facades in the tropics. Research has proven that windows contribute to a higher percentage of heat loss or gain in a building. This brings about discomfort and therefore energy is used for either cooling or heating for comfort. In the USA, over 3% of total energy consumption is lost through windows, in Sweden this figure is 7% (Menzies and Wherrett, 2005). This is because windows mostly have higher U-values compared with other building fabric elements. The inception of the Kyoto Protocol and its joint commitment with the United Nations

Framework Convention on climate change has brought a new light to the built environment. The focus of the protocol is to reduce and limit the emissions of six green house gases. Buildings contribute to the emission of carbon dioxide (CO_2) which is among the listed gases. (EU, 2002). The awareness of less energy use in buildings became greater and therefore a lot of strategies were sought. This legislation brought a shift into low emissivity (Low-E) glass in Europe which has been in existence for almost 20 years. "Low-E" glass has the ability to reflect heat back into a building whiles allowing appreciable light into it as well. This is very good because it solves the issue of heat loss through windows and natural lighting is also achieved. This transmission of heat into the building can cause over heating in summer. In the tropics where cooling is mostly needed, the applicability of this glass is questionable. One can argue that Low-E glass can be turned inside out so that it rather prevents heat from outside in the tropics from entering the building. This is not a good option because when the coatings of Low-E glass are exposed to weather conditions, it deteriorates. A paper by Barry and Elmahdy in 2007 concluded that Low-E glass with high solar heat gain coefficient should be used for areas with heating loads higher than cooling loads (Barry and Elmahdy, 2007). The possible option of using Low-E glass in the tropics must be one with a very low solar heat gain coefficient. Since more cooling is required in the tropics, this option can be tried in this research for conclusions. 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 percent of solar heat rays (infrared) and simultaneously transmit 80 percent or more of visible light rays. This means very good natural lighting can be achieved with this glass and therefore saving energy on lighting during the day. Most Tropical regions are now developing thus less technology is available. Majority of the research and engineering of windows are done by researchers in the temperate regions due to technological advancement and development. Due to the climatic difference, most research findings and theories on windows are not applicable to the tropics. The window types mostly used in these regions are sliding, sashes, hinged and bay windows. These windows are designed to reduce the amount of heat losses from the building whiles encouraging heat gains. A tropical building for optimal comfort encourages less heat gain and more heat losses to prevent overheating and to achieve thermal comfort. In Ghana, almost all newly built residential estates have their windows as sliding. These windows are made up of aluminium frames and glass with low resistivity to heat. Just the material composition allows so much heat into the buildings and this makes them very uncomfortable to live in unless one uses a fan and in some cases air-conditioning. This shift is attributed to the aesthetic value of these windows. With the building more aesthetically pleasing, the value of the building goes up in terms of price. Therefore estate developers use this as a means of marketing their buildings. The question however asked is how comfortable or energy efficient are these homes? This research therefore investigates if both aesthetics and energy efficiency can be achieved simultaneously in the tropics by window pane properties? Majority of tropical countries are now developing and therefore do not have the capacity to manufacture. They end up importing these windows, materials and technology which might not be compatible with their climate. This research analyses the existing and most dominant glazing material on the market now which is Low-E glass for energy efficiency in the tropics. Other options such aesthetics is considered with the use of Low-E glass for better performance in the tropics. The focus of this research is to evaluate window fenestration or pane properties for better aesthetics and energy efficiency. This research is beneficial and has a lot of impact in the tropical regions of the world. Achieving both aesthetics and energy efficiency in buildings makes the aim of designing buildings in this 21st century possible. This is because the quality of buildings is not only now seen from the aesthetic angles but also its energy efficiency. The world has come to the realisation that the energy consumption in building has to be reduced. Findings of this research are beneficial to clients, building owners and architects as a way to save money through energy consumption costs.

1. Materials and Methods

There are different methods that can be adopted for this research but the chosen and most appropriate one for this research is the case study approach. This was used to assess the different estate houses as designed by the different estate developers. The purpose of adopting a case study approach was to illuminate the general by looking at the particular and to study an issue in detail. (Denscombe, 2007)

1.1 Data and Variables

Both quantitative and qualitative data were gathered mainly through desk study (as secondary source) and field survey (as primary source). According to Burns and Groove (1993), qualitative research which is descriptive in nature is useful in providing detailed analysis of research attributes such as behaviour, opinions, perceptions and knowledge of a particular individual or group on the phenomenon. In this regard, people of different backgrounds were asked about the aesthetics and comfort of the estate and buildings with emphasis on windows as part of the field survey. For this research the variables used are the macro and micro climate, the entire estate, the building fabric of chosen house and the windows in the building. The climate and the estate for this research cannot be controlled or changed and therefore these are classified as uncontrolled variables. Even though the building fabric can be modified or changed, they are deliberately kept constant in this research, in order to observe the effect of another independent variable which is the windows. With the windows being an independent variable, dependent variables such as emissivity, reflectance and transmittance of windows is the focus.

1.2 Procedure

The initial step or method that was carried out before any design or simulation work was done is collation of data. Most of the data that is be used for this research is secondary data. These include weather data, building design and fabric material standards, guidelines and literature relevant to this research. Case study buildings were purposively sampled from the estate developers for this research. These buildings were drafted in AutoCAD based on the exact specifications as built on these estates. With all specifications known, the building is then simulated in chosen software for the heating or cooling loads. The simulation of this research was done in Energy plus. Energy plus is a building simulation software programme of the United States Department of Energy (DOE) and this is promoted through the Energy Efficiency and Renewable Energy Office (EERE). It has become widespread and it is used all over the world (Fumo et al., 2010). With all parameters being the same, the window material constituent is then changed and simulated again. The result of the existing buildings was then compared to that of the modified ones for discussion in terms of energy loads. Prior to this, data from Energy plus is tabulated and plotted in appropriate graphs or bar charts. These are followed by write ups which explain further the picture drawn from all the graphs, charts and tables. Graphisoft Archicad was used for photorealistic impressions of the existing buildings and then the different modifications of the windows proposed. At every stage of modification, the original and the modified is compared for the one with a higher aesthetic value. Qualitative data from occupants and developers was analysed to know their views on aesthetics.

1.3 The Case Study Building

The chosen estate, VALCO Estates at Tema community 12 in Ghana is among the most recent developments and has been in existence for about 15 years. This as the name implies is for VALCO (Volta Aluminium Company Ltd) and this was built purposely for their staff. The buildings mostly adhere to the standards of tropical building design. With regards to orientation, the rectangular plan has the longer sides facing either the north or south. The perimeter of a house is approximately 12 meters by 9 meters ($108m^2$), but since it is a semi-detached structure, the full block is 24 meters by 9 meters ($216m^2$) . There are two bedrooms in one house and both share one toilet and bath. One of these two bedrooms is bigger and assumed to be the masters' bedroom. The other spaces are a living room and kitchen. The two key spaces under study had windows on both the north and south elevation making it possible for cross ventilation if natural ventilation is adopted. The windows at both elevations of each space are all sliding windows with a gold coloured aluminium frame and reflective glass. The materials used the building was mostly the basic standard materials used in Ghana for the construction of houses. Due to the fact that the building is simulated in Energy plus, the thermal properties as well as the U-values needed to be known. A research was done on these materials to know these properties for use. The building in focus was modelled in Google Sketch Up which had an Open Studio plug-in for simulation. The orientation in Google Sketch Up was done with the south facing building and then later followed by the north facing buildings.

Figure 1. Plan of the Case study building showing spatial arrangement.

Table 1. Building Fabric Material and their U-values.

Building Component	Material Used	U-Value (W/moC)
Roof	Aluminium Roofing Sheets	1.273
Walls	200mm sandcrete wall with plaster	1.135
Window pane	4mm reflective glass	5.798
Window frame	Aluminium frame	5.878
Door Panel	25mm hard wood	3.196
Door frame	50mm hard wood	2.848
Floor	150mm concrete slab with 50mm screed.	0.282

The data above shows that windows have the highest U-value and therefore confirms the fact that it is the most vulnerable of all the building components.

2. Results

With the aim of this research being to evaluate window fenestration or pane properties for better aesthetics and energy efficiency, the results were discussed using comparative analysis. The results which were mostly in tables were plotted into graphs and charts for clarity and better presentation.

2.1 Analysis of Energy Efficiency of Case Study Buildings

The energy load of the case study building was simulated for using the materials in table 1 above. The focus of the results was focussed on mainly the cooling load profile. The

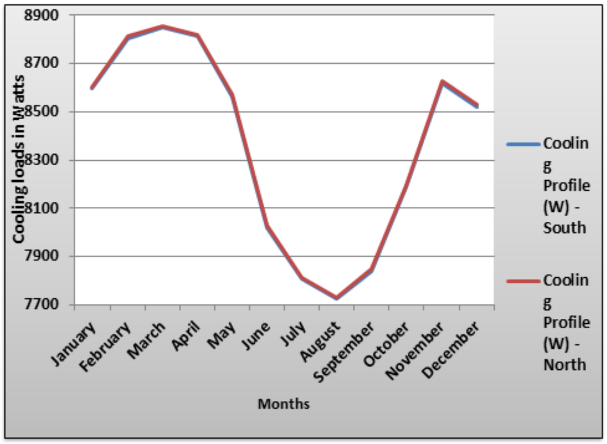

Figure 2. Comparison of Energy loads for south and north facing buildings

data output tabulated showed that there was no change in the heating load of both orientations. For this reason only the cooling loads of both orientations were compared. The story continued with the cooling loads of the north facing orientation recording higher loads than the south. It is quiet minimal and this accounts for the line graph of both almost overlapping. The link between solar gains, internal temperatures and the energy loads then becomes established and confirmed. For this reason therefore, one does not need to analyse all data from solar gains through internal temperatures before comparing data on energy loads. Energy load analysis can be done straight knowing that it is the solar gains that increase the internal temperatures and therefore the energy load derived. No matter how minimal the cooling load difference is, the south facing buildings can be said to be more energy efficient than the north facing buildings. Design features such as the porch can be adapted on the north facing facades to make them more energy efficient, but that is not the focus of this research. This research seeks to modify window glazing properties for a more energy efficient building which also meets the aesthetic standards of occupants.

3. Discussion

3.1 Modification of Case Study for Energy Efficiency

The content and comparative analysis of both south and north facing buildings showed that the changes caused a very marginal increase in the cooling load. This means that one building can be taken to represent the entire estate due to the close match

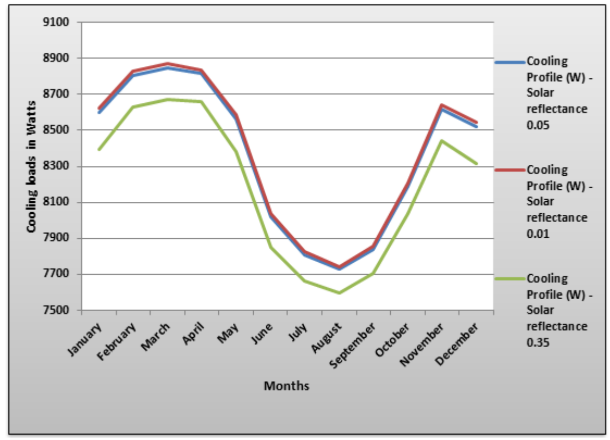

Figure 3. Comparison between 0.01, 0.05 and 0.35 solar reflectance

with data. For this reason, comparative analysis was done with one south facing building. Below is a table with modification data on the window of the building.

Table 2. Window properties and their modifications

Window Property	Original Data	Modified Data 1	Modified Data 2
Solar reflectance	0.05	0.01	0.35
Solar transmittance	0.58	0.05	0.95
Emissivity	0.84	0.45	1.0

The modification was done by changing one variable (window pane property) at a time whiles the others remained constant. This is to know the effect of that Solar reflectance cannot be ignored when talking about solar gains into a building. Figure 3 shows a reduction of cooling loads when the solar reflectance was increased. This is because solar rays are reflected and therefore there is definitely less solar gains leading to less energy needed to cool the building. Cooling loads decreased with the increase in solar reflection. Solar reflection is very important when it comes to solar gains which at large affect the cooling loads of tropical buildings. Cooling loads is at its highest peak in the month of March due to the fact that the sunshine hours in that month are higher than all the other months. This is reversed in August where we have a low peak due to low sunshine hours. This is evident in all analysis for the months of March and August. Solar transmittance is when solar heat rays (infrared) are transmitted into a space of a building and this why it is linked with reflection. Whatever heat rays (infrared) that is deposited on the window after reflection is transmitted into the building due to temperature difference of the outside and inside of the glass. The above figure shows that when

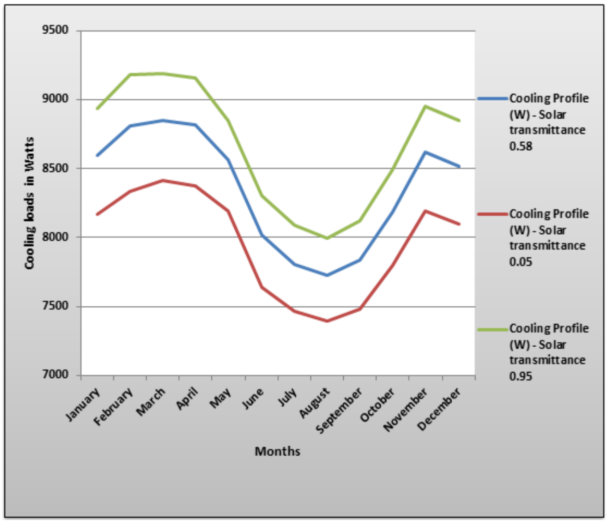

Figure 4. Comparison between 0.05, 0.58 and 0.95 solar transmittance

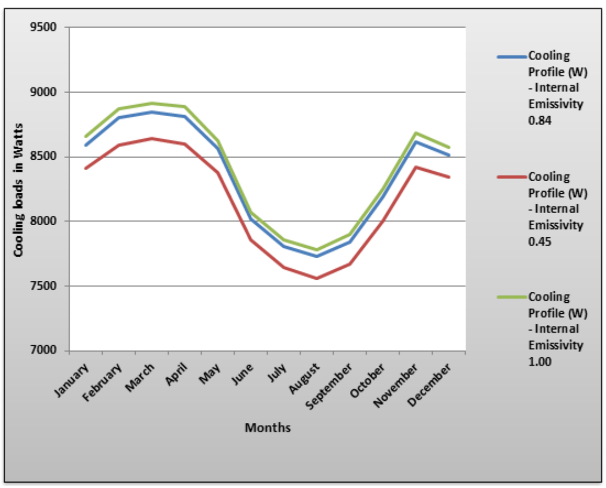

Figure 5. Comparison between 0.45, 0.84 and 1.00 internal emissivity

the solar transmittance value was increased from 0.58 to 0.95, the cooling load also increased with an average margin of 335 Watts throughout the year. The direct opposite happened when the solar transmittance was decreased from 0.58 to 0.05.This means that less solar transmission leads to less solar gains, lower temperature internally and then finally giving a lower cooling loads. Internal emissivity on the other hand is how much heat is given off by the space through the internal surface of the glass. From figure 5 above it can be seen that when the internal emissivity is high, the cooling load increases and then when it is low, it decreases. As discussed earlier, emissivity is short wave heat energy in focus. Therefore with most of heat found within spaces as short wave energy, a high internal emissive glass reflects most of this short wave back into the space making them hotter. This accounts for the increase in internal temperatures which definitely needs more energy to cool down the building. It is therefore very important to know the emissivity of a glass to be chosen depending on what is to be achieved.

3.2 Modification of Case Study for Aesthetics

The analysis and discussion of the aesthetics of the case study buildings were done in two folds. The first part dealt with analysing data from interviews conducted on the study site for information. The second part made use of 3D photo impressions to see how aesthetically pleasing the building is.

3.2.1 Interviews

A lot of data was gathered from the interviews done with the residents and developers. The idea was to gather as much data as possible and not go back to bother the parties involved in the course of the research. Out of the 50 households in the estates, only 40 could be interviewed being 80% of the total. 28 households (70%) chose the estate because of the aesthetics whiles the remaining 30% was spread over other reasons. Even though about 70% of households chose the building because of the aesthetics, it was also found that most of them had issues with comfort. The developers confirmed this and this was also attributed to the windows. The households that were comfortable were those who had installed air conditioners in the houses. The use of air conditioners increased energy consumption and therefore it had become a major issue but since this research was not ventilation in focus, this was left.

3.2.2 3D photo impressions

3D photo impression of the existing building was modelled and the exact window properties assigned to it to see its aesthetics. A photograph could have been taken for this purpose but for a more appropriate comparison with modifications, the photo impression of all scenarios is better because they are all on the same platform. The 3D impression in figure 6 depicts how aesthetically pleasing the estate building is. The panes level of reflection makes one see the environment in the windows giving it a picture effect. The reflection also attracts the eye to the building because it creates an illuminating effect. Some school of thought thinks otherwise. But as the saying goes “beauty lies in the eyes of the beholder”, this reflection argument is

Figure 6. 3D impression of existing building

Figure 7. 3D impression of existing building with decreased reflection

Figure 8. 3D impression of existing building with increased reflection

subjective. Issues raised from the interview however such as comfort levels not achieved due to ventilation is a concern. Only a small percentage of the households were comfortable and these houses use air conditioners. These air conditioners are high energy consumers and therefore the question raised is: has energy efficiency been achieved? This question draws attention to ventilation and the use of this window. In other not to deviate from the scope of this research, the focus was drawn back to the aesthetic comparison and the glazing property changes. With Graphisoft Archicad having parameters for changing the reflection level of each material, the reflection of the glass was decreased and increased to see its aesthetics effect.

The images clearly show that figure 8 looks more aesthetically pleasing than figure 7. In addition, reflection of the window in figure 8 looks more attractive and catchy.This proves why a higher percentage of households chooses the angle of aesthetics to be at the window reflection level.

4. Conclusions

This research sought to achieve energy efficiency and aesthetics simultaneously in tropical buildings. The advent of glass has brought a lot of aesthetics into buildings but it is a contributory factor for heat gains and losses. Even though aesthetics and energy efficiency were looked at separately, this research has brought out one common variable that binds both issues. From the findings and discussions, the reflection of the glass seems to be at both ends. The reflection of glass makes a building have more aesthetic value. This was seen with the photo impressions as discussed earlier. The choice of the building by owners was also greatly influenced by the reflective glass that the buildings already had. For energy efficiency, it became clear that as the reflection increases, the amount of heat energy deposited on the glass decreases and therefore there is less heat energy to be transmitted into the building. This is very important because even though tropical design guidelines advices for windows to be hidden from the sun by recessing them, the architect sometimes find it very challenging to do so. This therefore makes the design of the architect become quiet liberal since less energy would be needed to cool down the space in focus. In a nut shell, a reflective glass of a window is a key in achieving energy efficiency and aesthetics in the tropics.

Acknowledgments

Authors are very grateful to the University of Nottingham for granting me the technical ability and platform to conduct this research. A special appreciation goes to all staff of the department of Architecture and built environment who contributed greatly to this research work. We also appreciate all staff and residents of VALCO estates Ghana for opening up their doors and giving me information to undertake this study. Without your help, this research would not have been possible.

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