Global Journal of Engineering Science and Research Management

IS IT NECESSARY TO COOL RESIDENTIAL HOMES? A BIOCLIMATIC ANALYSIS OF WINDOW POSITION AND SIZES ON INDOOR COMFORT IN THE TROPICS

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KEYWORDS: Bioclimatic chart, tropical designs, cooling, thermal comfort, fenestrations.

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 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 climates. The current paper describes an investigation into the effect of window sizes (varied wall-to window –ratio) and it's positioning bio-climatically to determine which strategy could provide a better indoor environment for residential buildings in Ghana. A typical room of 3m x 4m was parametrically simulated using the Tas tool. Various window sizes with diverse WWR were then probed into with varying positions (low, middle and high) after the temperature and humidity values were plotted on the bioclimatic to determine which the air velocity that could be employed to provide comfort spaces for occupants. The results show that as the window sizes increases, the amount of air needed to provide comfort also increases. This increase in air velocity also results in several subjective feelings like irritation and annoyance. It is therefore advisable for residential buildings within the tropics to keep the WWR to the barest minimum as possible.

INTRODUCTION
It is said that energy in the form of electricity is being used in buildings for the comfort of its inhabitants, especially for artificial lighting, air-conditioning and other building equipment. According to Yang (2002), buildings account for about 40% of the global energy consumption and contribute over 30% of the CO_2 emissions. A large proportion of this energy is used for thermal comfort in buildings. Ghaddar and Bsat (1998) postulated that the residential sector alone in Lebanon, consumes about 47% of the total electricity produced, while the industrial sector consumes about 25% based on pre-war data of 1974. The authors explained that energy use for space cooling in Lebanese buildings dominates other uses during the summer months, particularly during peak electrical demand hours.

Within the United States, residential energy consumption has been shown to account for approximately 8% of the electricity and 3.5% of the natural gas consumption (Mardookhy, 2013). Additionally, Mardookhy adds that Heating, ventilation, and air conditioning (HVAC) system and lighting system are two major contributors to energy consumption in residential buildings with about 52-72% of the average energy consumed used to keep buildings at comfortable temperatures, provide hot water, and circulate fresh air indoors. Meanwhile, energy consumption in the residential sector is predicted to increase at the rate of 1.1% per year from 2008 to 2035 (U.S. Energy Information Administration, [EIA] 2011).

Accordingly, any energy consumption improvement in the residential sector can contribute to reducing greenhouse gas emissions, since the energy consumption in the residential sector correlates to the release of approximately 313.4 million metric tons of carbon dioxide (CO_2) annually into the atmosphere (EIA, 2012). Architecturally, the hot and humid region is one of the hardest climates to ameliorate through design. This is due to the high humidity and daytime temperatures that result in high indoor temperatures exceeding the ASHRAE summertime comfort upper limit of 26ºC for most of the year (Hyde and Sabarinah, 2008). Often times, the windows on the facade of the buildings aid greatly in the transfers of solar radiation into the interior spaces making it uncomfortable.

Against the dwindling status of Ghana's energy sector, the question is will it be prudent for one to cool residential spaces? When certain design considerations could be introduced to provide thermal comfort within internal spaces. For instance designing with the outdoor climatic parameters in mind (adaptive concept, bioclimatic chart etc.) could be helpful. Thus the use of natural ventilation can greatly reduced the amount of energy used in making indoor buildings comfortable. The study uses the bioclimatic charts to determine how comfortable our residential spaces are and if not what can be done to provide comfort within spaces.

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

LITERATURE REVIEW

Thermal comfort and the adaptive design

Thermal comfort has attracted a good number of studies due to the climate specific nature of the phenomenon. The American Society of Heating, Refrigerating and Air-conditioned Engineers (ASHRAE, 2004) defined thermal comfort as the condition of the mind that expresses satisfaction with the thermal environment. Furthermore, thermal comfort for individuals involves the body's capability of balancing its own temperature with the thermal environment. This thermal balance depends on the internal heat load and energy flow (thermal exchange) of the body, which is performed through the processes of conduction, convection, radiation and evaporation (perspiration and respiration).

Six parameters are therefore necessary for the measurement of thermal comfort. These are air temperature, humidity, air velocity and mean radiant temperature, metabolic rate, clothing insulation (Szokolay, 2004). The adaptive design strategies present opportunities by which naturally ventilated buildings could be made comfortable by considering the outdoor conditions. The ASHRAE Standard 55 defines an adaptive model (concept) as one that relates indoor design temperatures or acceptable temperature ranges, to outdoor climate (ASHRAE, 2004).

Over the years, a number of researchers have with come up with equations where the indoor temperature is a function of the outdoor temperature (ASHRAE, 2004: Nicol and Roaf, 1996: Auliciems and De Dear, 1986). Baker and Standeven (1996) explain adaptive opportunity as the measure of opportunity the building offers for the occupants to make themselves comfortable, whiles De Dear and Brager (1998) as cited by Darby and White (2005) explains the adaptive approach to be based on field surveys of thermal comfort and demonstrates that people are more tolerant of temperature changes than laboratory studies suggest: they consciously and unconsciously act to affect the heat balance of the body (behavioural thermoregulation). The current development of adaptive concept in thermal comfort research has underlined the importance of exploring same in different environmental contexts (De Dear and Brager, 2002: Brager and De Dear, 2000)

The authors further assess that occupant's control over the environment could vary significantly between working environment (offices) and living environment (houses). In their own houses, people play an active role in ensuring their living environment is as comfortable as possible. In comparison with offices, occupants in houses have more freedom (flexibility) to control their own personal and environmental conditions in the form of clothing adjustments, drinking more frequently, taking bath, opening of windows, and switching the fan or AC on, etc. Adaptive design concepts therefore involve the use of the psychrometric charts, bioclimatic charts, Mahoney Tables etc.

Bio-climatic Charts

The term "Bio-climatic architecture", refers to buildings that are designed to readily respond to the effects of the local environment in order to provide comfort conditions for their occupants (Elwefati, 2007). Since the selection of building passive thermal design strategies is based heavily on the local climatic conditions: suitable strategy for a given location can be made using bioclimatic charts.

According to Al-Azri et al., (2012), Oglyay's chart (Figure 1) has a constant comfort in the range from 20°C to 30°C. This comfort zone also corresponds to a relative humidity value of around 30% to 67% (medium humidity). The level of comfort is applicable to indoor spaces with the indoor level of clothing. The comfort zone is shown at the centre of Olgyay's chart in an aerofoil shape.

The chart takes into consideration levels of comfort that can be felt outside the comfort zone but in combination with ranges of the other environmental factors: mean radiant temperature, wind speed and solar radiation. Above the lower boundary of the zone shading is necessary to maintain reasonable level of comfort. Up to 10°C below the comfort zone, comfort can be retained provided that there is enough solar radiation to offset the decrease in temperature. Likewise, to retain comfort up to around 10°C above the zone, wind speed can offset the increase in temperature.

Evaporative cooling according to this chart is another means to retain comfort at high temperature values but low humidity. The effect of 0.5 m/s air-movements on thermal comfort has been reported by Nicol (2004): Gut and Ackerknecht (1993) to have a cooling effect of 1°C to 1.7 °C at a corresponding ambient temperature of 25°C to

30 °C. Thus the chart is not limited to only identifying whether a particular condition falls within the comfort zone, but it also provides recommendations on the speed of wind required to restore comfort at temperature above the comfort zone (Fig.2) and the quantity of solar radiation needed under lower temperatures.

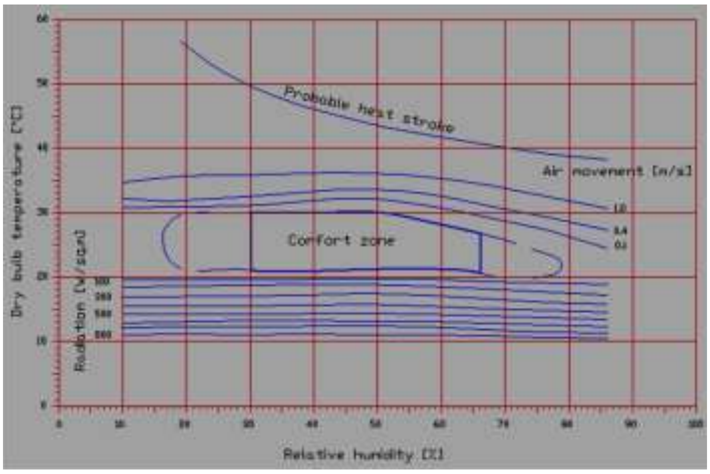

Fig. 1: Olgyay's Bioclimatic Chart (Szokolay, 2004)

Since Olgyay's chart (1963) only considers the outdoor conditions disregarding the indoors physiological considerations, it is only applicable for hot humid climates where there is minimal fluctuations between the indoors and the outdoors temperatures (Sayigh and Marafia, 1998). Conversely Olgyay's original chart was inappropriate for use in hot and dry regions where the indoor temperatures are significantly different from the outdoor temperatures. However, (Givoni, 1967, pp. 310-311), Arens et al. (1980; ref. Watson and Labs, 1983, pp. 33-34) updated the chart using the original format of the Olgyay's chart based on a comfort model developed by the J.B. Pierce Foundation.

By 1967, significant improvement of the bioclimatic chart had been done by Givoni (1967).This chart is based on the linear relationship between the temperature amplitude and vapour pressure of the outdoor air. Givoni's chart identifies the suitable cooling technique based on the outdoor climatic condition. In 1979, Milne and Givoni combined the different design strategies of the previous study of Givoni (1967) on the same chart. The resultant chart (Milne and Givoni, 1979) is currently used by many researchers and hence the motivation for this research. Five zones are identified on Givoni – Milne chart: thermal comfort, natural ventilation, high mass, high mass with night ventilation and evaporative cooling. Below is the new Givoni-Milne chart.

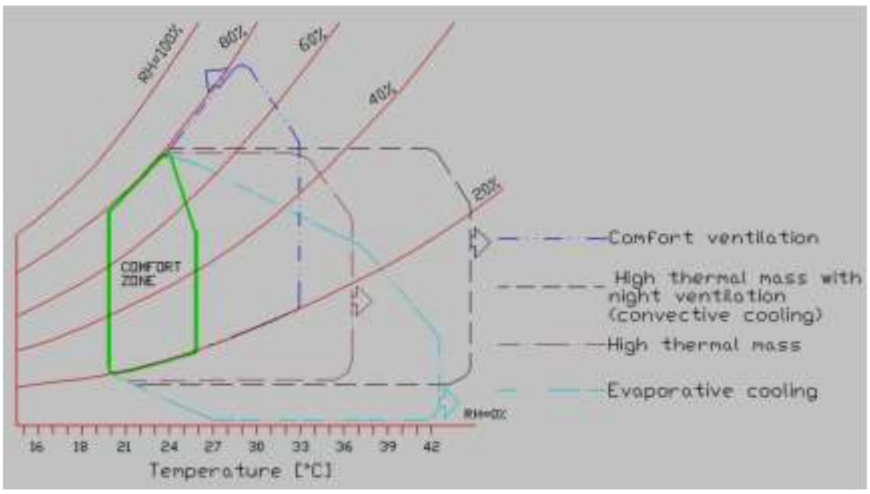

Fig.2: Comfort zone with recommended design strategies

Although both Olgyay and Givoni's chart have been discussed in the above literature, the current study only analysis temperature and relative humidity values within a typical room in the tropics on Olgyay's chart.

ISSN 2349-4506
Impact Factor: 2.265

Global Journal of Engineering Science and Research Management

METHODOLOGY

Parametric simulation with the Thermal Analysis Software (Tas) was used as a means of analysing the indoor comfort within a typical reference room of 3 x 4 x 3m^3 commonly used as residential rooms within the climatic region of Kumasi, Ghana (Figure 3).

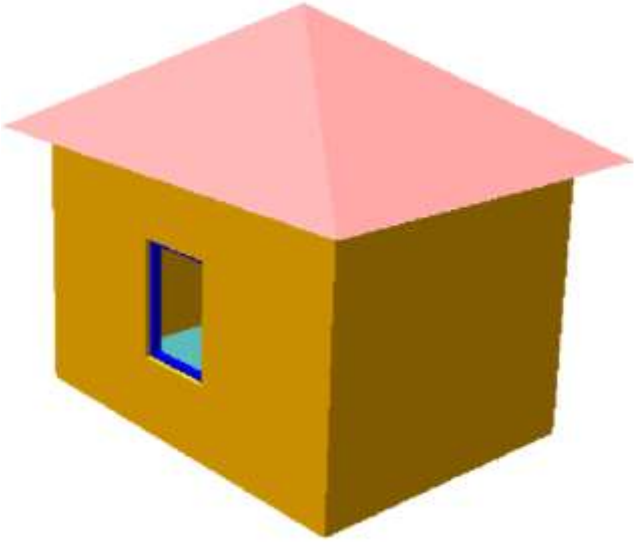

Fig. 3: Typical room structure in Tas

The room is usually occupied by a person or two (6W/m^2) and electric lighting load of1W/m^2. Equipment sensible heat is 16W/m^2 with ventilation rate of 15ach. The floor is made of concrete slab with tile finish. The ceiling is of a plywood finish with aluminium roofing sheets. Table 1 describes the material components of the room.

Table 1: Building fabric materials and their U-values

Building Components	Materials Used	U-value (W/moC)
Roof	Aluminium roofing sheets	1.27
Wall	200mm sandcrete wall with plaster	1.14
Window pane	4mm single glazed reflective glass	5.80
Window frame	Aluminium frame	5.88
Door panel	25mm hardwood panel door	3.20
Door frame	50mm hardwood	2.84
Floor	150mm concrete slab with 50mm screed	0.82

Mean, minimum and maximum temperature and relative humidity values from the simulation were plotted on each bioclimatic chart. Szokolay's (2004) method of using the mean maximun temperature with the afternoon relative humidity (RH) and then using the mean minimum temperature with the morning RH was used.

The influence of window sizes and position was investigated with 8 different window sizes with their respective Wall-Window-Ratio from 10 to 80% of the façade area with three window positions: low, middle and high on north and south orientations adapted from the work of Bokel, (2007). Figure 4 shows a graphical presentation of the various window sizes and positions.

ISSN 2349-4506
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Global Journal of Engineering Science and Research Management

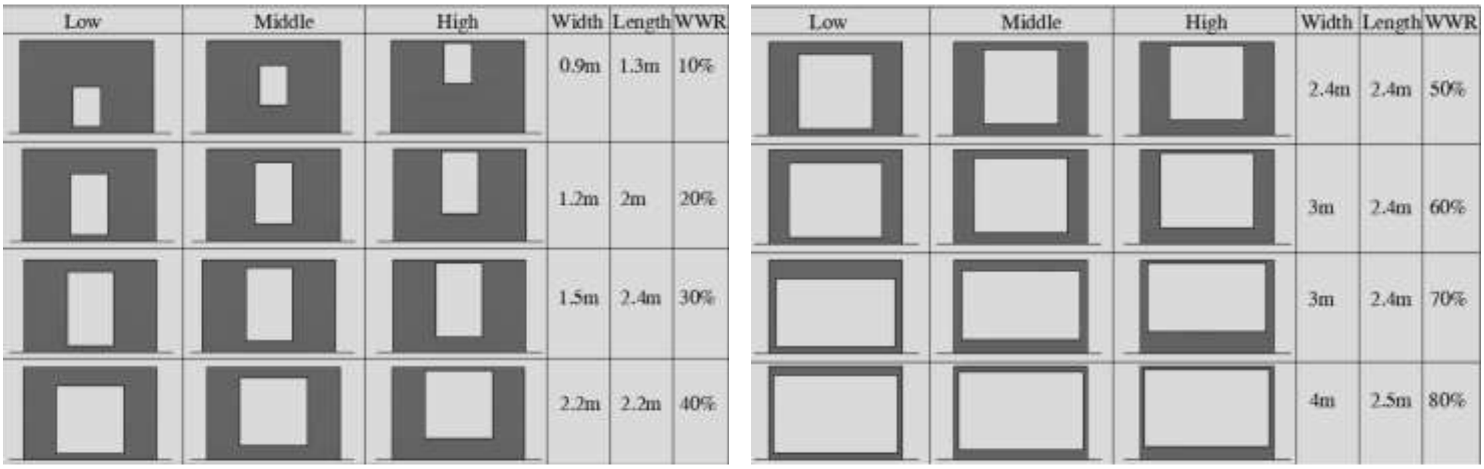

Fig. 4: Low, middle and high level window positions of all window sizes.

The low window position means that the window starts at the bottom of the façade which is 20cm off the ground, the mid window means that the window is situated exactly at the middle of the façade, and the high window position means that the window ends at the top of the façade which has 10cm ceiling space.

RESULTS AND DISCUSSION

Presented here are the summary results from the study. From the simulation, indoor temperature values recorded for low, middle and high positions were relatively the same. Similar results were recorded by Koranteng et al., (2015) where the specific positions of the various windows did not differ in terms of temperature and relative humidity values (Figures 4 and 5). According to Bokel (2007) however, the window position does have a significant effect on the primary energy demand for lighting when there is an active or passive user and day lighting system control. Therefore the position of windows on a façade will be based on other factors like good views, cost, demand for lighting etc. Figure 6 shows the average, maximum and minimum indoor temperature values for the various wall-to-window ratios (WWR). The figure shows a gradual increase in mean temperature of 0.1 as the WWR increases from 10% to 80% except with the 50 and 60% WWR where temperature values remain the same.

Figure 6 shows the average, maximum and minimum indoor relative humidity (RH) values for the various wall-to-window ratios. Similar trend can also be seen in terms of the RH values where the average values are moderately comparable.

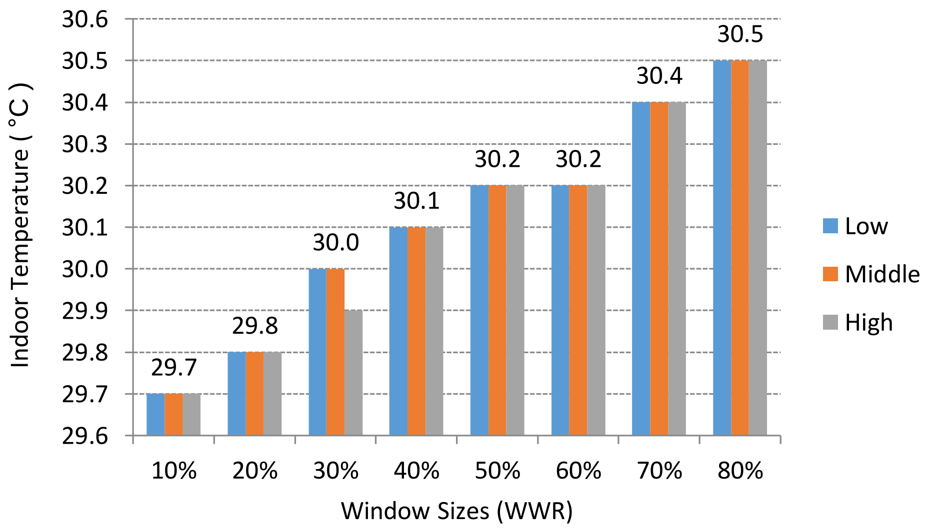

Fig. 4: Mean annual indoor temperature values for the various window positions and sizes.

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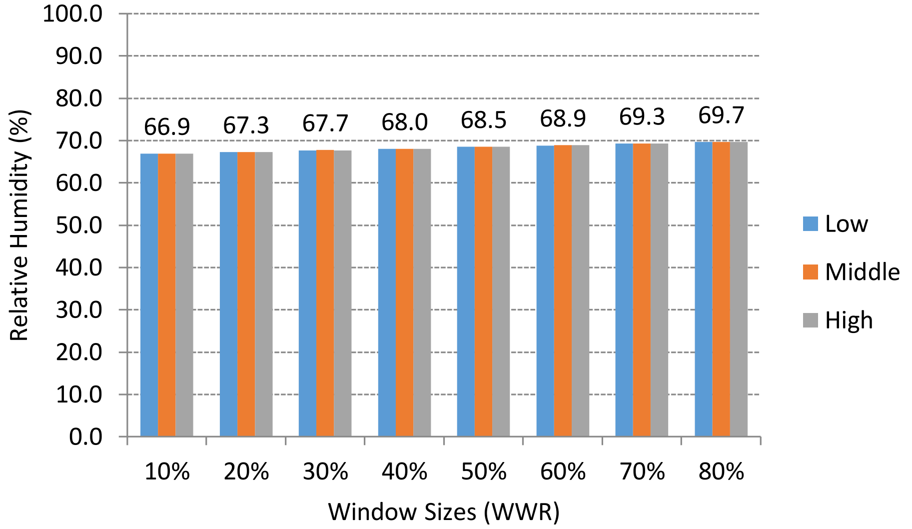

Fig. 5: Mean annual indoor temperature values for the various window positions and sizes

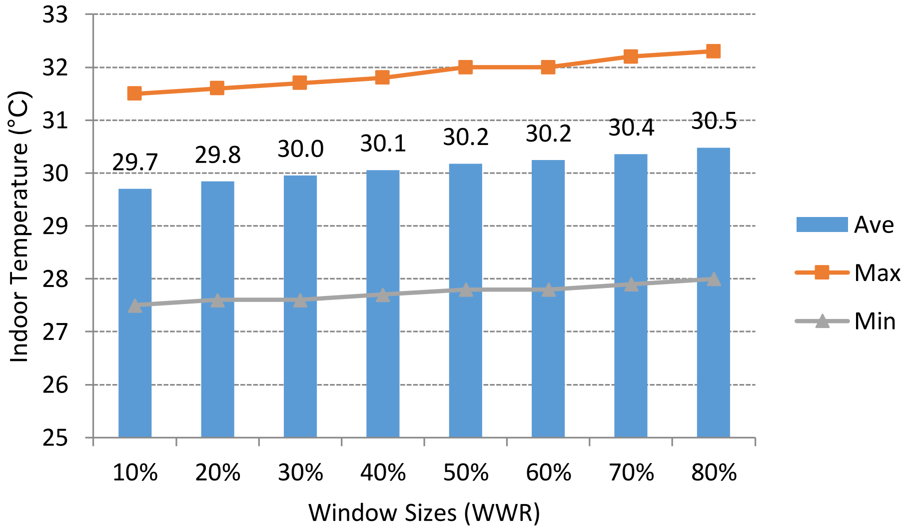

Fig. 6: Mean annual indoor temperature values for the various window positions and sizes

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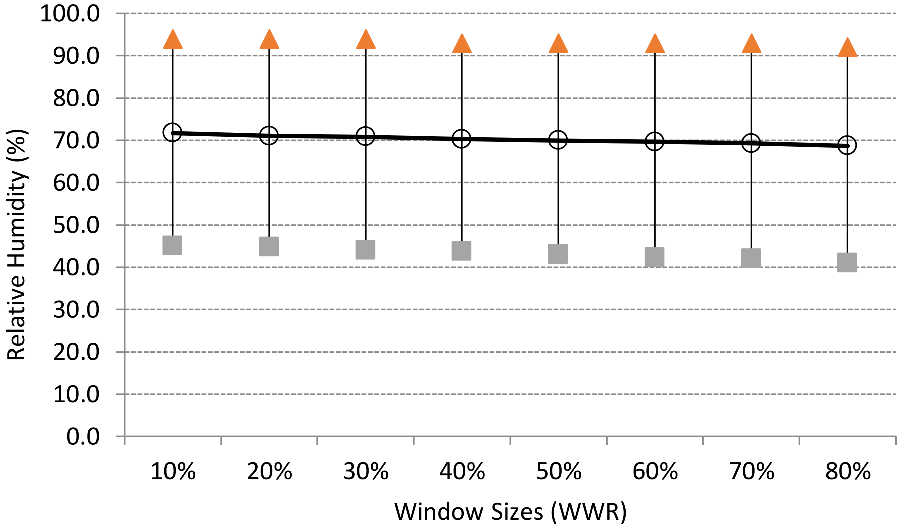

Fig. 7: Mean annual indoor relative humidity values for the various window positions and sizes

The comfort zone as has been recommended by the Givoni-Milne chart is located between temperature values of 20°C and 26°C with RH of 20% and 80%. By this, the typical room in terms of temperature is found to be very uncomfortable and therefore evaporative cooling which responds well with a better RH remains one of the strategies to use in achieving comfort. Givoni (1998) numerates a list of climate considerations for passive control of buildings. Olgyay's chart suggests that the comfort zone is between temperature values of 21°C and 30°C which is a much wider range than Givoni's. Relative humidity (RH) values as proposed by Olgyay are within 30% to 66%. As per Olgyay's chart temperature values within the typical room is comfortable when the WWR is within 10% to 30% even though the raise in temperature for the other WWR's are negligible. Relative humidity however is uncomfortable hence the introduction of the various air velocities (Szokolay, 2004).

Figures 8, 9 and 10 show a graphical representation for temperature and RH values for 10% to 30% WWR, 40% to 60% and 70% to 80% respectively on Olgyay's chart.

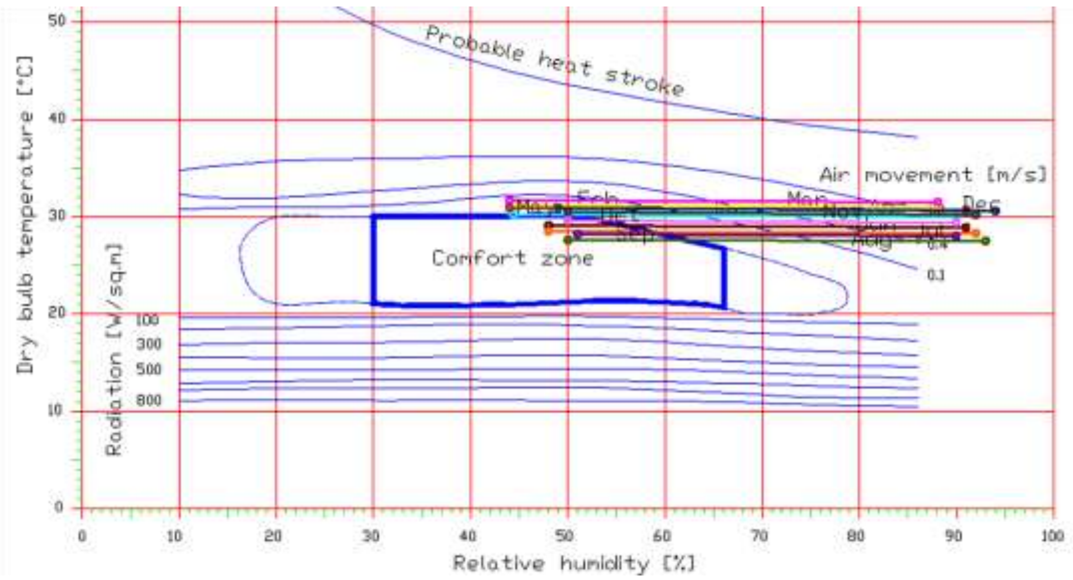

Fig. 8: Climatic condition as illustrated on Olgyay's chart for WWR of 10 to 30%

From the aforementioned figure, the minimum RH and maximum temperature values of 5 months (June, July, August, September and October) are within Olgyay's comfort zone. This means that, between 10 to 20% of the

ISSN 2349-4506
Impact Factor: 2.265
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representative days in these months, conditions within the building is comfortable. According to Olgyay (1920), air velocity of up to 1.0m/s could however be applied to induce comfort within the spaces. Szokolay (2004) illustrates the effects of these high air velocity values.

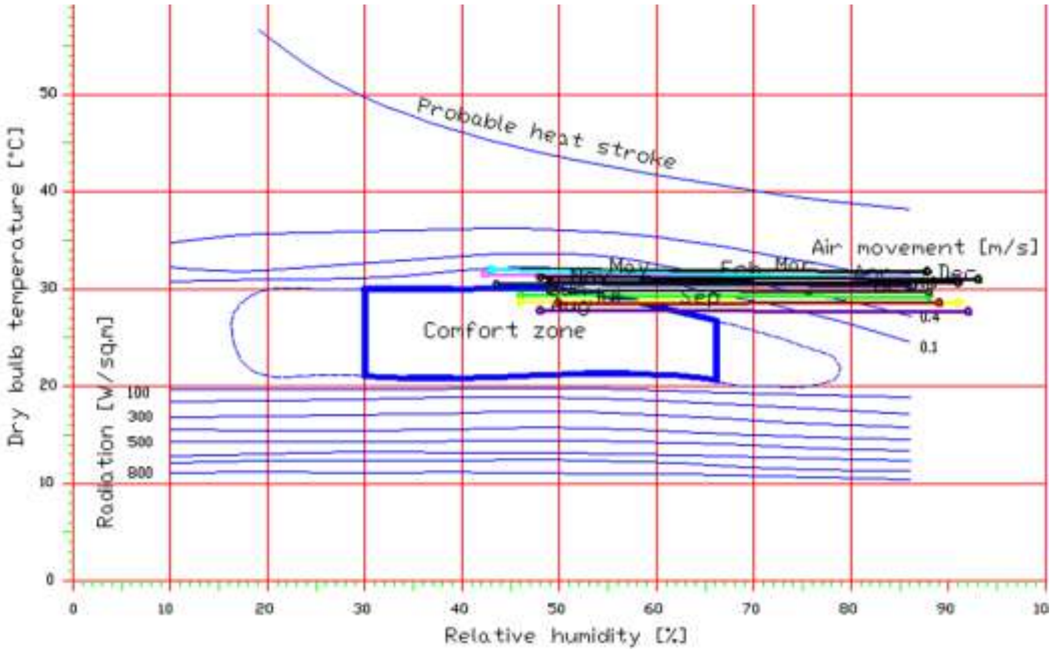

Fig. 9: Climatic condition as illustrated on Olgyay's chart for WWR of 40 to 60%

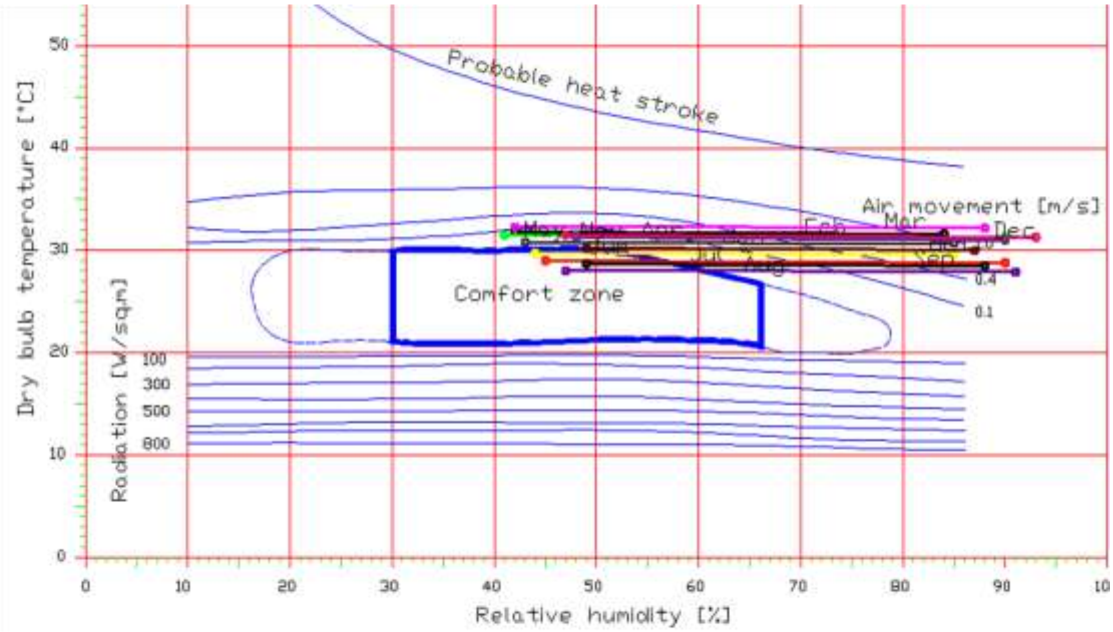

Fig. 10: Climatic condition as illustrated on Olgyay's chart for WWR of 70 to 80%

Figures 8 and 9 above show the typical condition for window-to-wall-ratio of 40 to 60% and 70 to 80% respectively. Both figures have the minimum relative humidity and maximum temperature values of the months of June, July, August and September falling within the comfort zone with the rest (8 months) outside the comfort zone. This could be as a result of the direct and reflected solar radiation falling on the wide WWR surface (Lauber, 2005: Heerwagen, 2004). The provision of air velocity of between 0.1 to 1m/s could improve upon the indoor conditions of the spaces. This will be possible with the installation of fans (Hyde, 2000). It is therefore apparent that a comfortable and a clean indoor environment can be achieved by the adoption of an effective ventilation system both in terms of providing thermal comfort and removing contaminated air (Alamdari, 1994).

CONCLUSION AND RECOMMENDATIONS

A bioclimatic analysis of the effect of window position and size on indoor comfort through parametric simulation has been performed. Indoor temperature and relative humidity values were plotted on Olgyay's chart to ascertain those months where conditions were favourable and those that were not. The study found out that as the window-to-wall-ratio decreases (10-30%), a greater percentage of the months within the year are comfortable. Again, the fraction of time (Thus, the ratio of the part of a specific month that is within the comfort zone) for window sizes between 10 and 30% is greater than the other sizes. Only four months out of the twelve for the year fall within Olgyay's comfort zone when window sizes are between 70 and 80% with a minimum fraction of time. Although air velocity of between 0.5 and 1.2m/s could be introduced into the space in order to provide comfort, these air velocity rates are known to also cause certain uncomfortable conditions for the occupants. In some cases, the health status of the occupants comes under attack. It is therefore recommended that building designers in the tropics should take seriously the localized climatic conditions in areas where their designs are built. Again, passive control measures (building orientation, cross ventilation, shape, size, shading etc.) should be given a special attention.

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