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Passive Analysis of the Effect of Window Size and Position on Indoor Comfort for Residential Rooms in Kumasi, Ghana

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Abstract: The amount of solar radiation through the fenestration of a building into the interior space is a key factor in assessing the indoor comfort and the eventual energy used in cooling off these spaces. In predominantly hot humid regions like Ghana which receives sunlight all year around, buildings and for that matter windows should be oriented to minimize solar gain and maximize natural ventilation. Windows are possibly the most complex and interesting elements in every habitable structure. Heat loss and heat gain through a window will not only depend on the type of window and its properties alone but also the size and the position of the same. This paper describes an investigation into the consequence of window sizes (varied wall-to window –ratio) and it's positioning on indoor thermal comfort 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). The result showed that the ideal window to wall ratio for achieving almost comfortable indoor conditions should be between 10 to 40%. Meanwhile, the various positions of the windows did not seem to have any effect on the indoor temperature values since all the values were the same. The study should lead to an improved residential design with appropriate window sizes and correct positions which will ensure indoor comfort and thereby reducing the total energy used in cooling.

Keywords: Window size, Thermal Comfort, Passive, WWR, Tropical region.

1. INTRODUCTION

Ever since the world's energy crisis in the 1970's, it has become paramount for countries to find ways of reducing its energy usage in all aspects. 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 (Yang, 2012). One area where energy used could be reduced within the building and construction industry is through the use of natural ventilation (Hassouneh et al., 2010). Apart from natural ventilation, the use of zero energy to provide comfort within indoor spaces has its health benefits (Wolkoff, 2012). The main medium through which fresh outdoor air can ventilate an interior space is the fenestration window.

In the building sector, the increased use of air-conditioners, inefficient curtain walls and sliding windows, and the lack of sustainable design principles, especially in office buildings have contributed to the present energy situation (Koranteng, 2010). The overall energy performance of a window assembly is dependent not only on the glazing and frame materials themselves, but on a number of architectural and interior design decisions (Carmody et al., 2007). Most often than not, building designers make such decisions based on the cost involved in providing such elements.

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 26^{o}C for most of the year (Hyde and Sabarinah, 2008). Givoni (1994) reported that in hot humid regions the provision of effective cross ventilation under the local wind direction is the major factor that may affect the building orientation. Air movements inside a building depend not only on external wind velocity, but also largely on the architectural parameters. Architectural means for achieving this aim include conventional design element such as position and orientation of building, roof shape, balcony configuration, type and location of windows, partition and furniture arrangement (Al-Tamimi et al., 2011).

It is also possible that the window size and its position will also affect air movement inside the spaces thereby affecting the comfort within. The potential of the solar penetration through windows in hot climate, and its effect on the elevation of the indoor temperature, depends greatly on the orientation of the windows (Givoni, 1994).

In the present study, parametric numerical simulations were conducted to investigate the outcome of window size, where it's positioned on the façade on indoor comfort. The objective is to ascertain an ideal window size and position and for residential windows towards a thermally comfortable indoor spaces.

2. LITERATURE REVIEW

2.1 Windows/Glazing

According to the Carmody et al. (1996) a window has been defined as an opening in a wall, door and roof of a

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building or a vehicle that allows the passage of light and, if not closed or sealed, air and sound. The window as a building element has come a long way from its non-existence in primitive homes to a single shutter and a glass pane even for residential homes in contemporary architecture. Al-Saadi (2006) and Datta (2001) together present an apt description of 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.

Windows contribute significantly to both heating and cooling energy consumption of residential buildings. For instance Yoo et al. (2005) stipulated that that almost 30% (or 0.11 quads, 0.12 EJ) of the total energy needed to condition residential buildings is attributable to heat transfer through windows

Windows, doors, and skylights have a significant impact on the thermal performance of the building envelope. Windows can also have a strong influence on the use, productivity, and comfort of the people who occupy the building (Al-Tamimi et al., 2011). Study reported by Jinghua (2008) showed that heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration. It is up to 40% (Al-Tamimi et al., 2011) in hot summer and cold winter zone. Carmody et al. (2007) stipulate that high performance windows have benefits such as increased comfort, reduced condensation problems, heat gain control without losing light and view, reduced fading from ultraviolet light etc. The authors' further comment that cost for mechanical equipment in the house if situation warrant that is also reduced by high performance windows.

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).

A study by Gyimah and Tetlow (2014) concludes that 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 and with the building more aesthetically pleasing, the value of the building goes up in terms of price' (pp.30). From the conclusion above, it has become imperative that researchers come up with the appropriate glazing type, sizes, position and orientation that will minimize the sun's effect within the interior spaces of residential buildings.

2.2 Thermal Comfort and Passive designs

All humans within an indoor space might want to feel comfortable if surrounding conditions begin to suggest discomfort. Pino et al. (2012), defines thermal comfort as the physical and psychological wellness of an individual when temperature, humidity, and air movement conditions are favourable for the activity that has to be developed. According to Indraganti (2011), people either modify the environment or adapt themselves behaviourally or do both to remain comfortable in a thermal environment, through several adaptive control actions. It is when these adaptive measures fail or is insufficient that the active measures such as the use of air-conditioners are introduced.

Brager and De Dear (2000) suggested that current development of adaptive concept in thermal comfort research has underlined the importance of exploring same in different environmental contexts. 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. The comfort of individuals in their homes also depend on which part of the planet they find themselves and the prevailing weather conditions that is pronounced around the area.

Climate responsive design (passive designs) of buildings is important not only because of the comfort and energy saving implications for its users, but also because it helps preserve valuable resources in our planet (La Roche and Liggett, 2001). The ASHRAE Standard 55 defines adaptive model as one that relates indoor design temperatures or acceptable temperature ranges to outdoor climate (ASHRAE, 2004). By this definition, natural ventilation is greatly valued in adaptive designs. Frontczak et al. (2012) in their study asserted that, respondents valued natural ventilation highly and it was very important for them that they could open a window in their home. Temperature control by natural ventilation is often the only means of providing cooling when mechanical air-conditioning is not available (Rofail, 2006).

Thermal comfort designs basically looks at how equilibrium would be achieved with a space; thus individuals would not be too warm or too cold. This phenomenon is the neutrality temperature. According to Hyde (2000), the comfort zone is 2°C below and above the neutrality temperature. Szokolay (2004) has set the comfort zone for 90% acceptability to be 2.5°C above and below the neutrality temperature, after Auliciems (1981) who did set the comfort zone for 90% acceptability to be Tn (+ -) 2.5°C and 80% acceptability to Tn (+ -) 3.5°C for both naturally ventilated and artificially ventilated spaces.

$$Tn = 17.6 + 0.31 * To.av \quad \text{Eq. 1}$$

Where: Tn is the neutrality temperature
To.av is the mean monthly outdoor temperature

The recommendations by ASHRAE Standard 55 (ASHRAE, 2004) postulate that the acceptable summer time temperature range should be 23-26°C. This should however ensure that at least 90% of occupants are thermally satisfied. Air temperature is often taken as the main design parameter for thermal comfort (Adebamowo and Akande, 2010). Heidari and Sharples (2002) have also suggested that air temperature alone is a good indicator of thermal comfort.

2.3 Tropical Buildings

Lauber (2005) and Givoni (1997) both assert that a building in the tropics means a confrontation of construction and function with extreme climatic condition. The climatic elements in tropical climate have both negative impact and positive impact to the building design. The most common impacts caused by the climatic parameters of tropical climate are temperature, relative humidity, solar radiation, rainfall and prevailing wind. Jamaludin et al., (2014) further affirm that in tropical climate, the solar heat and rainfall initiate continuous evaporation of the human body due to high amount of solar radiation received in the equatorial region. These excessive solar radiations cause discomfort condition of indoor environment in buildings. The authors therefore suggest that solar control design should be incorporated into building to reduce heat surplus from solar radiation.

The optimum orientation of residential building area in tropical climate is facing east or north and its major openings can greatly influence the solar heat gain according to Chauchan and Shah (2008). The authors suggest that North and east orientation has less direct solar direction towards the building envelope and therefore more windows should be placed at this orientation in order to allow natural ventilation. This however contradicts Szokolay (2004) who suggest that east and west facing walls should not have windows to avoid heat input. In the indoor environment, natural ventilation strategies could be categorised into cross ventilation, single-sided ventilation and stack ventilation to induce air movement in the building (Chung and Ahmad, 2014). This means that windows will have to be placed either on one side or two sides of the facades.

Rajapaksha et al., (2002) also assert that the indoor thermal environment is much affected by local climate, and therefore air movement through the building is necessary to decrease indoor discomfort due to overheating conditions in tropical climate. Whiles Kubota and Ahmad (2006) conclude that in warm and humid climates, external air movement assists in controlling the indoor environment, Jamaludin et al. (2014) emphasise that in recent times, occupants are likely to use air conditioners in achieving comfortable indoor environment in tropical climate. Such reliance on mechanical systems for health and comfort levels increases the energy consumption in residential buildings (Uno et al., 2012).

3. 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 1).

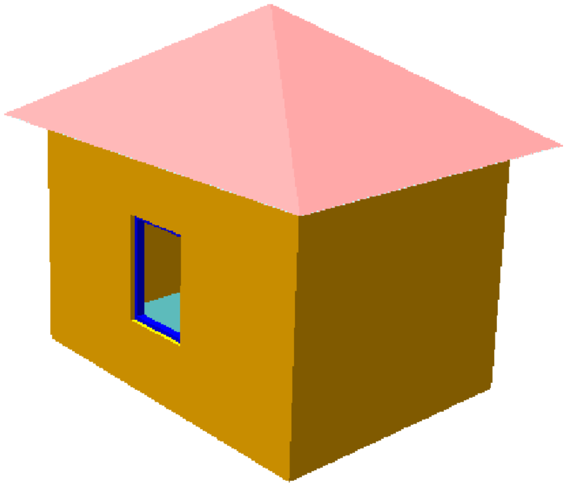

Fig.1: Typical room structure in Tas

The room is usually occupied by a person or two ($6W/m^2$) and electric lighting load of$1W/m^2$. 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 temperature values calculated were compared first with the ASHRAE (2004) summer comfort temperatures of 23- 26°C and then with the adaptive model based on the work of Auliciems (1981) and the recommendation by Szokolay (2004) for 90% acceptability was used to derive the comfort zone for Kumasi (See Table 2).

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Table 2: Neutrality temperature for 90% acceptability: (Tn = 17.6 + 0.31 * To.av)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
To.av.	26.5	**28.6**	28.4	27.9	27.6	26.6	25.5	**25.3**	26.0	26.4	27.0	27.3
Tn + 2.5	28.3	**29.0**	28.9	28.8	28.7	28.3	28.0	**27.9**	28.2	28.3	28.5	28.6
Tn	25.8	**26.5**	26.4	26.3	26.2	25.8	25.5	**25.4**	25.7	25.8	26.0	26.1
Tn - 2.5	23.3	**24.0**	23.9	23.8	23.7	23.3	23.0	**22.9**	23.2	23.3	23.5	23.6

Where T_o.av is the mean outdoor temperature; and Tn is the neutrality temperature. 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 3 shows a graphical presentation of the various window sizes and positions.

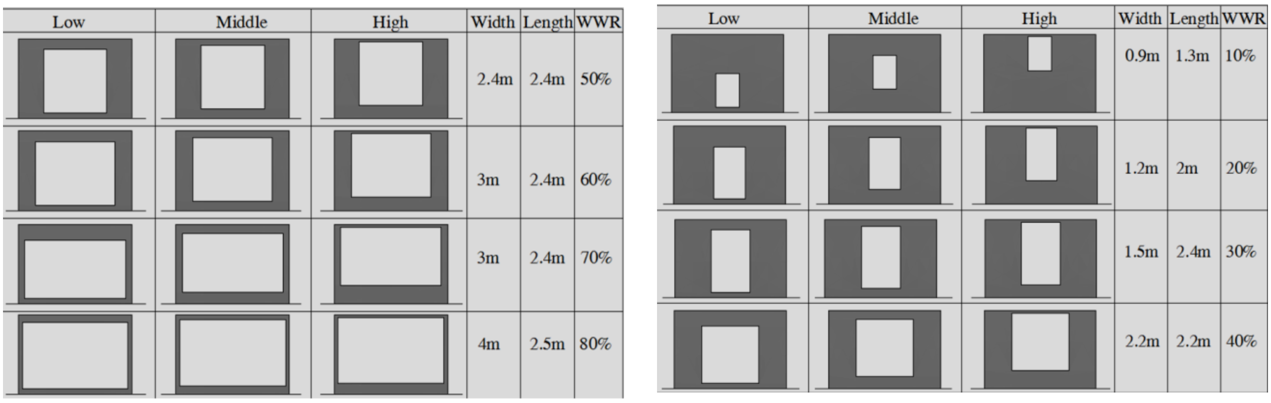

Fig. 3: Low, middle and high level window positions of all window sizes.

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.

4. RESULTS AND DISCUSSION

The results of the simulation are shown in the Figures below. Figure 4 shows the mean annual indoor temperature values for the various window positions with respect to their sizes.

From the graph above, it is clear that window positions do not matter so much in terms of indoor temperature values since low, middle and high level windows all recorded the same temperature values from the simulation. 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.

Table 3 shows the mean monthly indoor temperature values for the various window sizes.

Although the Table shows a gradual appreciation of the temperature values as the window sizes increases, two basic elucidations can be given. First, seasonal climatic changes do affect temperature values and secondly, window-to-wall ratio (window sizes) also affects indoor temperature values. Fabi et al., (2012) however confirmed in their studies that aspects closely related to the type and size of the windows and its placements within façade affect the effectiveness of natural ventilation.

From the Table, ideal window sizes for residential buildings can be said to be between 10-40%. Bokel (2007) stipulates 20-40% for office buildings. Roche and Milne (2004) also assert that smaller window sizes perform better than larger ones in terms of building comfort. Since general conditions are more favourable during the raining season, temperature values also fall steadily from the months of July through September (Table 4) for all window sizes. The dry season presents a hotter environment.

Al-Tamimi et al., (2011) also concluded in their studies of a tropical country that there were significant decreases in indoor air temperature in rooms when glazed area ratio of windows was changed from 50 to 25%. According to Rathi (2012) the size, shape and location of a window have also been evaluated to affect the amount of ventilation as well as having psychological impacts on the occupants of the buildings. Psychological contentment is at its ultimate level when the proportion of windows is between 15 to 30% of the wall area (Imamoglu and Markus, 1973).

Figure 5 show results when the neutrality temperature which has been derived from the adaptive model (Table 2) is compared with the indoor temperature values simulated.

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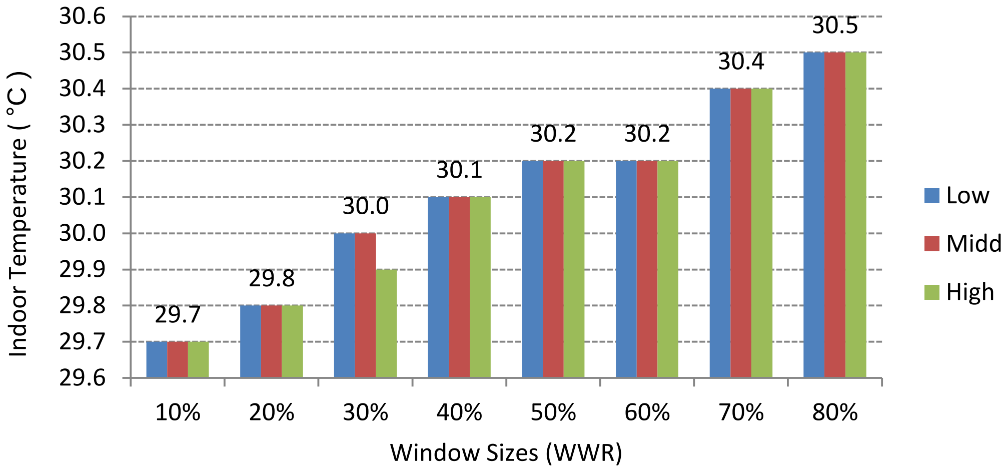

Fig. 4: Mean annual indoor temperature values for the various window positions and sizes.

Table 3: Mean monthly simulated indoor temperature values for various window sizes

Months	Window Sizes							
	10%	20%	30%	40%	50%	60%	70%	80%
JAN	30.0	30.1	30.2	30.3	30.5	30.5	30.7	30.8
FEB	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.8
MAR	31.5	31.6	31.7	31.8	32.0	32.0	32.2	32.3
APR	30.7	30.8	30.9	31.0	31.1	31.2	31.3	31.4
MAY	30.7	30.8	30.9	31.0	31.2	31.2	31.3	31.5
JUN	28.9	29.0	29.1	29.2	29.4	29.4	29.6	29.7
JUL	28.3	28.4	28.5	28.6	28.7	28.7	28.9	29.0
AUG	27.5	27.6	27.6	27.7	27.8	27.8	27.9	28.0
SEP	28.0	28.1	28.2	28.3	28.4	28.5	28.5	28.7
OCT	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.2
NOV	30.2	30.4	30.5	30.6	30.7	30.8	31.0	31.1
DEC	30.6	30.7	30.9	31.0	31.1	31.2	31.3	31.5

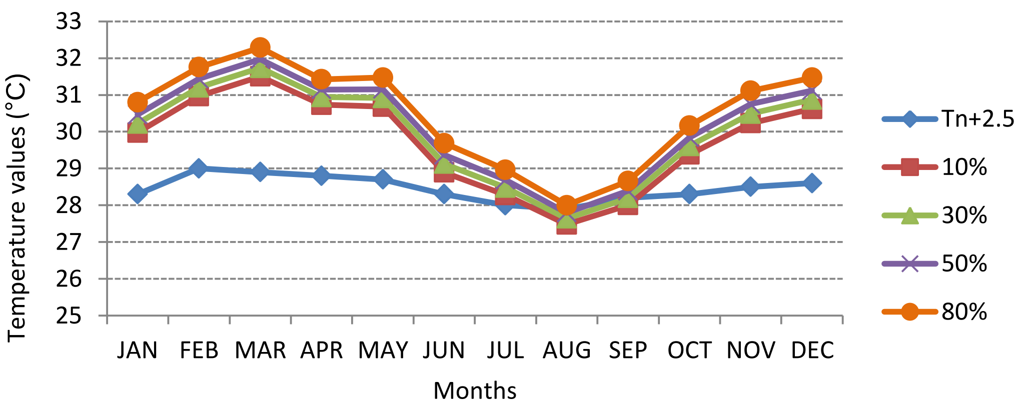

Fig. 5: Upper limit of neutrality temperature compared with simulated temperature values.

The Figure shows how the various window sizes performed in comparison with the neutrality temperature. The closest set of windows to the neutrality temperature is the 10 and 30% which occurs during the wet season (May-September). Other factors such as shading, window materials, facade insulation, and thermal mass all have to be explored to know their synergistic effect on building indoor comfort.

The maximum, minimum, mode and quartile ranges are presented in Figure 7. From the diagram, window sizes up to 40% seems plausible for residential buildings since it indoor temperature values are reasonably within ranges purported by some thermal comfort researchers for tropical climates.

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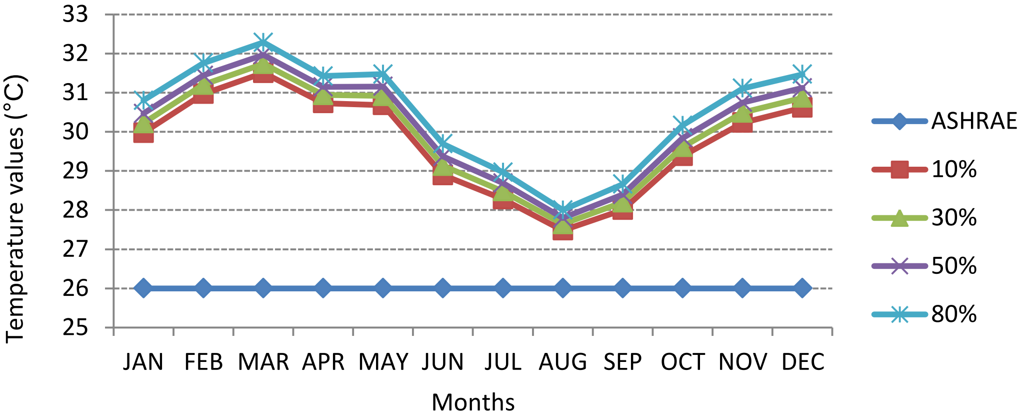

Fig. 6: ASHRAE comfort temperature compared with simulated values.

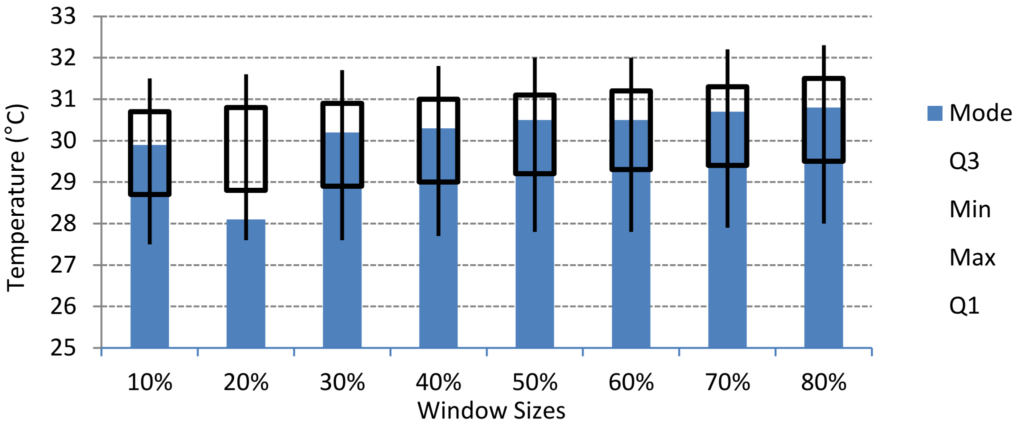

Fig. 7: Mean values for simulated temperature values

5. CONCLUSION AND RECOMMENDATIONS

Through parametric simulation, the effect of window sizes and position on indoor temperature has been studied. The study have shown that in terms of internal temperature comfort, the position of windows on building facades have no effect though other researchers have documented on the effect of window position on other parameters like primary energy demand for lighting and the amount of ventilation. The study has also shown that window sizes between 10-30% are ideal for residential buildings though 40% is tolerable. The adaptive model which relates the outdoor localised climate to the indoor seemed closed to the simulated indoor temperature values. In effect, attention should be paid to adaptive measures such as orientation, shape, shading etc when designing and building. It is also recommended that the use of shading devices like overhangs (walls and roofs), awnings and fins can be used to control solar gain and thereby reduce indoor comfort. Additionally, other parameters such as window orientation and sizes, position and orientation should also be studied towards the modelling of an ideal window for tropical buildings.

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