IMPACT OF WINDOW-TO-WALL RATIOS ON THERMAL PERFORMANCE OF FULLY-ENCLOSED COURTYARD RESIDENTIAL BUILDINGS IN NIGERIAN TEMPERATE-DRY CLIMATE

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ABSTRACT

Scholars have agreed that achieving thermal comfort in the fully-enclosed courtyard house is very important because of its preference for habitation by people in tropical regions and, its suitability for household functions. The scholars have also concurred that the window-to-wall ratio (WWR) of the fully-enclosed courtyard residential buildings is a courtyard design variant that is vital to its thermal performance. This study therefore, seeks to study the impact of WWRs on the thermal performance of the fully-enclosed courtyard residential building in temperate-dry climatic region of Nigeria, using Kafanchan as a case study. The simulation approach was used to test the impact of four typologies of WWRs on the thermal performance of the fully-enclosed courtyard house. Integrated Environment Solution and Virtual Environment (IES-VE) is the simulation software used for the experiment. The software was validated before the simulation experiment by using Hobo Weather Data Logger (HWDL) to collect date in a field measurement in a case-study building in Kafanchan.The outcomeshows that, WWR has a significant impact on the indoor thermal comfort of the fully-enclosed courtyard residential building. The simulated WWRs (WWR4%, WWR7.5%, WWR12% and WWR16%) performed differently. WWR16%performed better than the remaining WWRs and this suggest that it is the best for a room area of 9m^2 in Nigerian temperate-dry climate. But, further simulation experiments using different typologies of room area(s) are needed to confirm whether WWR16% is optimum for the fully-enclosed courtyard building in the Nigerian temperate-dry climatic region.Understanding the optimum location windows to improving airflow patterns in the fully-enclosed courtyard building is required.Also, more simulation studies are required to make known the range of room area(s) for the most favorable thermal comfort condition.

Keywords: Courtyard; window-to-wall ratio; Simulation; Residential buildings; Thermal comfort

1.0 INTRODUCTION

Architecture is all about designing, constructing, and delivery of buildings for human spatial needs of activities and functions. Apart from delivering buildings that meet the human spatial requirements is the need for thermal conduciveness of the buildings. The thermal performance of the building, the courtyard building in particular is a vital issue to be considered. It is vital because the courtyard house can improve indoor thermal comfort provided that the architect understood its design variants and, applied such variants appropriately at the design stage of the courtyard building, the fully-enclosed courtyard residential building in particular. It is also vital because people in the tropics have a preference for courtyards buildings, especially the fully-enclosed courtyard building (Fatma *et al* 2016). Thermal comfort in the fully-enclosed courtyard residential building can enhance the well being and productivity of occupants of the building.

The preference for a fully-enclosed courtyard residential building is due to its abundant benefits to the building envelope and its occupants (Fatma *et al.*, 2016). According to Adeyemi (2008), a fully-enclosed courtyard house makes available seclusion space suitable for household activities such as; cooking, washing, children playground, family meetings and settling dispute among family the household. Also, the fully-enclosed court yard is a passive design element in architectural design for the reason that it improves day lighting in the building interior, increases air velocity, ventilation and shade (Berkovic *et al*,. 2012). Because of its ability to modify indoor thermal performance, it should be enhanced to improve thermal comfort and not to add to thermal discomfort which leads to thermal stress.

In this twenty first century, the necessity for thermally conducive residential buildings that will not add to the high level of carbon dioxide emission in the atmosphere, and thereby promote climate change is required (Lim *et al.*, 2008). All architects, most especially practicing architect should make tremendous contributions towards mitigating the challenge of carbon dioxide emission from buildings. The residential building in particular, should be the concern of all architects in the building industry because it constitute eighty seven percent (87%) of the built environment (Wang *et. al.*, 2005). It is required all architects reconsider their approach to the architectural design of buildings. The emphasis should be on zero tolerance for buildings emitting carbon dioxide for improved thermal performance. Kabiru (2011) advised that architects should seek to design climate-responsive buildings. Olotuah (2015) also advised that architects should through their architectural proposals add to the ongoing effort of reducing carbon dioxide emissions to the environment to better the climate.

According to Markus *et al*. (2020), the passive benefits of the fully-enclosed courtyard may not be achieved in a fully-enclosed courtyard house if the awareness of simulation is lacking. The fully-enclosed courtyard can enhance air velocity and ventilation in a building if its correlation with the WWR is understood. The WWR is an important courtyard design variant for the fully-enclosed courtyard building because it is vital to the thermal performance of the building. Markus *et al*. (2020) concluded that the simulation approach may be the only suitable option for testing, and understanding the impact of WWR on thermal comfort, and recommending the application of such to practicing architects.

Because of the high preference for the fully-enclosed courtyard residential building for habitation, its thermal performance should be paramount. Optimization related studies to enhance its microclimatic modifying potentials are required and, should be encouraged. The simulation method should be used to understand the impact of WWR on thermal performance, most especially in the temperate-dry climate of Nigeria. This study, therefore, seeks to study the impact of WWRs on the thermal performance of a fully-enclosed courtyard residential building in a temperate-dry climatic region of Nigeria, using Kafanchan as a case study.

2.0 LITERATURE REVIEW

Window-to-Wall Ratio (WWR) is a major courtyard design variant and its impact on thermal comfort should be understood (Bagneid, 2006, Markus & Duniya 2021). The relationship between the courtyard form and WWR of the building is another basic issue in courtyard building design. Scholars have emphasized that if the knowledge of the relationship is not lacking the courtyard can be a passive architectural design strategy indeed (Das, 2006; Jamaluddin *et al.,* 2014). Also, others like Chan (1995), Berkovic *et al*. (2012), Aldawoud and Clark (2008), and Yasa *et al*. (2010) have made some contributions in this regard.

Chan (1995) revealed that the application of the optimum WWR enables the courtyard building to cool itself naturally. Assessment of air flow in different courtyard forms with different WWRs was conducted by using the computational fluid dynamics simulation software. Courtyard Aspect Ratio

(CAR) of 0.33 and 0.66 were considered because they are the most commonly used in the city of Havana. Thermal performance evaluation of some rooms close to the courtyard was conducted. The study revealed that cross ventilation is important for indoor air flow. The courtyard sizes, the location of the room, the WWR, and the orientation are the major factors impacting on air flow and thermal performance. The study predicted that the WWR may have a significant impact on the indoor thermal performance of the building if its optimum is used. It concluded by recommending further simulation studies on different courtyard-forms with different WWRs for a conducive indoor thermal performance.

Berkovic *et al*. (2012) investigated thermal comfort in courtyards, the study used Envi-met 3.1 simulation software to determine the effect of wind and shading in a courtyard. The Courtyard Shape Factor(CSF) of 1:1, 1:2, and 2:1 were used to study wind movement by natural ventilation through openings at 3,000 and 5,000mm distance above the natural ground level. It was revealed that the openings allowed hot air and radiant heat penetration through them and thereby, increasing the air temperature in the courtyard. The CSF of 2:1 with 3,000mm opening was found to be more favorable than that of 2:1 with 5,000mm. Greater openings create a more uncomfortable condition. The study was conducted in a hot arid climate and that does not mean that the result applies to other climatic regions as well. Bagneid (2006) clarified that in courtyard building optimization, the openings around the courtyard wall are important design criterion. Berkovic *et al*. (2012) suggested the use of smaller WWR for conducive thermal performance of the courtyard building in the hot-dry climes.

Aldawoud and Clark (2008) aimed at investigating the impact of three design variables on energy consumption in courtyard buildings. The variables were the courtyard height, glazing type, and percentage of opening. Four glazing types with different WWRs were studied by using DOE2 simulation software. The result shows that the courtyard with 60% WWR was found to be the best while the 40%, 30%, and 20% performed poorly. These findings connote that the larger the opening, the better the performance. But, this result is at variance with Berkovic *et al*. (2012) opinion. Berkovic *et al*. (2012) opined that bigger adjacent openings favours the influx of unconducive microclimate from the external environment to the interior space of the building, thereby, resulting in a more unconducive indoor thermal condition. However, Aldawoud and Clark (2008) findings may be applicable in certain geographical locations such as the temperate-dry climatic region of Nigeria if their finding is substantiated.

Yasa *et al*. (2010) opined that adjacent openings such as window size and the CSF can significantly mitigate thermal discomfort in courtyard buildings. The effect of ventilation through window openings on the fully-enclosed courtyard building was tested by comparing two courtyard buildings, one with window openings facing the courtyard and the other without window openings. It was discovered that openings increase the speed of air flows inside the courtyard and the building. The size and location of the window openings in relation to the dimensions and proportions of the courtyard-form determine the velocity of air within the courtyard and the building interiors.

The above discussed studies used different simulation software to achieve their respective research aims, but, this study adopts the Integrated Environment Solution and Virtual Environment (IES-VE). The IES-VE simulation software is multi-facet software and can be used for different simulation experiments such as solar radiation, shading, thermal, energy and day-lighting (IES 2010). The tool has numerous applications such as the Model-IT; SunCast, Apache, Radiance, and Vista-Pro. It is also very useful to the architects in their architectural design (IES, 2010). Scholars as; Muhaisen (2006), Markus (2017), Leng *et al.*, (2012) have used the IES-VE simulation software in their respective studies.

Therefore, optimization of the courtyard building for effective indoor thermal performance will involve determining the optimum relationship between the courtyard and the window size. The window size can be determined by the WWR because the relationship between the openings and the wall of the courtyard space has to be established (Yasa, 2010). Consequently, determining the impact of WWR on the thermal comfort of the fully-enclosed courtyard residential building is required and, it is what this study aimed to achieve.

3.0 METHODOLOGY

The simulation method was used to achieve the aim of this study. IES-VE simulation software was used to perform all the experiments because of its SunCast Application (Leng *et al*., 2012). According to Leng *et al*., (2012) EnergyPlus simulation software could be used but, the SunCast Application of IES-VE which enabled additional shading analysis made it preferable for thermal comfort experiments in courtyard building. The simulation method requires that all simulation software should be validated before to the experiment (Leng *et al*. 2012).Validation of simulation software is the procedure that confirms the suitability, accuracy, and precision of the software. According to Leng *et al*., (2012), repeating the validation procedure for related studies in the same location may not be necessary because if it has been confirmed that the discrepancies between the software and the field measurement did not exceed the acceptable range, then, it remains a fact. Therefore, the procedure is not captured in this study because the author had validated the software in previous related studies in the same locality (Markus 2017, 2018, and Markus *et al*., 2020). Markus (2017)concluded that the IESVE is suitable for subsequent experiments on courtyard building simulation studies in the Nigerian temperate-dry climate because the discrepancies range was between 2.2% - 3.8%.

The simulation approach was used to achieve the aim of the study by using IES-VE software to perform all the simulation experiments. Four types of WWRs were tested with a room area of $9m^2$each. The simulated WWRs are; WWR4%, WWR7.5%, WWR12%, and WWR16%and these represent window area(s) of 600 x 600mm, 900 x 750mm, 900 x 900mm and 1200 x 1200mm respectively. The ModelIt Application of IES-VE was used to develop the WWRs into a model as shown in Figure 1. Four simulation experiments were conducted, each at a time interval of one hour, starting from 6am – 6pm. The equinox of 21st of March 2022 was the preferred date for the experiment because it is the hottest day for all locations in the tropics. Air temperature and relative humidity were studied. The acquired data were extracted from the software and imported into Microsoft Excel for analysis. Thereafter, the impact of WWRs on the thermal performance of the fully-enclosed courtyard house was determined and the optimum WWR was confirmed.

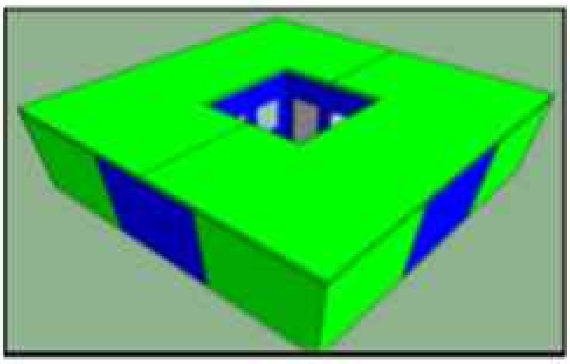

Fig.1 Showing the simulation model

4.0 RESULTS AND DISCUSSION

To evaluate the impact of WWR on the thermal performance of a fully-enclosed courtyard house, a model consisting of four types of WWRs was experimented. The WWRs include WWR 4%, WWR 7.5%, WWR 12%, and WWR 16%. The WWR 16% was revealed to be the best, the second best is WWR 12%, WWR 7.5% was the third-best and, WWR 4% was the worse. A rise in air temperature of 1.5°C, and a fall of -0.6°C were observed with WWR 4%, WWR 7.5, and WWR 16%, while relative humidity decline of -3% occurred. WWR 16% is the optimum. Figure 1 and 2 show the results. Generally, indoor air temperatureperformances become better as the WWR increases but, the relative humidity get worse.

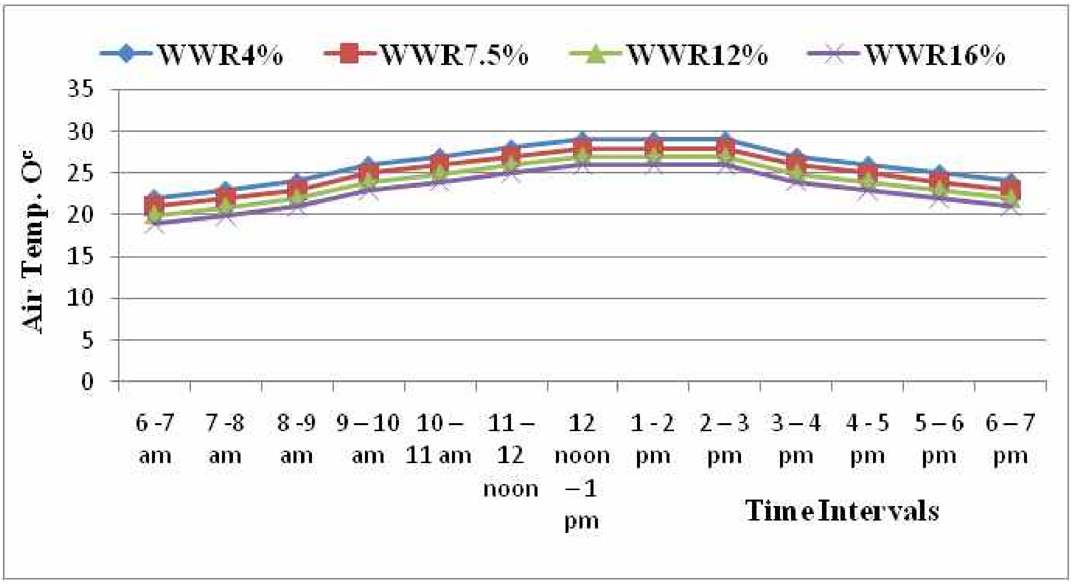

Fig. 1: Air Temperature Results of the Simulation Model

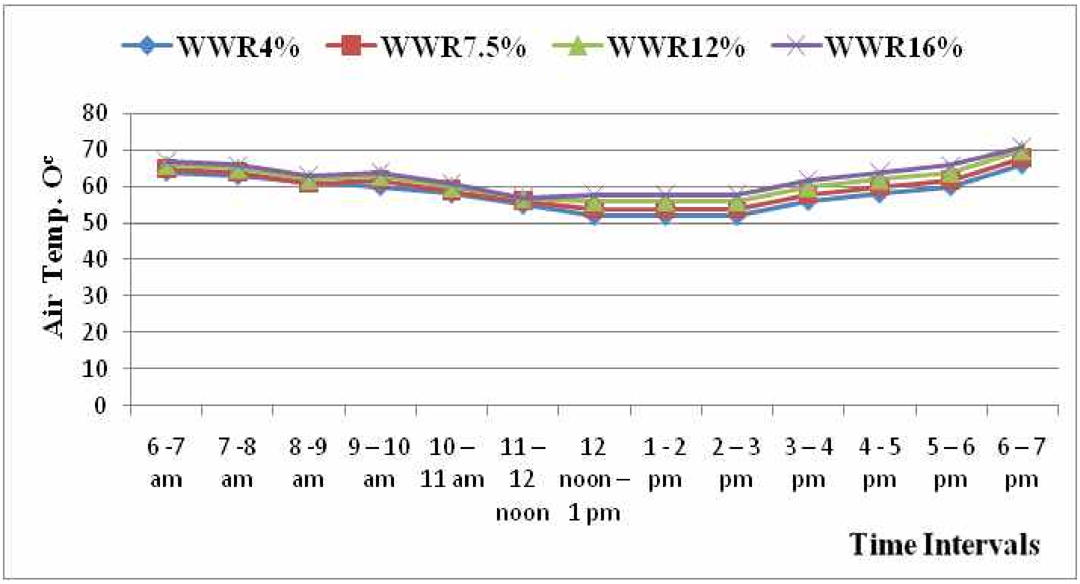

Fig. 2: Humidity Results of the Simulation Model

According to Mihir (2012), larger WWR provides better views than smaller ones. Aries *et al*. (2010) argued that a larger WWR enhances the perception of images, but, may cause thermal stress to the end-users of the building. Safarzadeh and Bahadori (2005) concurred with Aries *et al*. (2010) because such WWRs were found to be unconducive. But, Yakubu *et al*. (2013) explained further that, the required WWR range for efficient thermal performance is 25% - 40% in Malaysia. In their studies, Yakubu *et al*. (2013) established that the performances of the WWR which fall within the optimum WWR range may not alter the thermal condition of the building. Consequently, from their views, it can be established that if the optimum WWR range is not exceeded, the indoor thermal performance of the space should be the same despite the type of WWR used. Based on this opinion, the performance of WWR 16% is reasonable. Nevertheless, further studies to confirm the optimum WWR range for the temperate-dry climatic region of Nigeria are required. Larger WWRs should be tested to confirm what the exact optimum range for the region is. None the less, this study shows that the optimum range starts from 16% upward.

The results connote that the WWR 16% could impact the thermal performance of a fully-enclosed courtyard building by reducing the indoor air temperature. It also connotes that the larger the opening, the better the performance. However, Berkovic *et al.* (2012) opined that bigger adjacent openings favor the influx of unconducive microclimate from the external environment to the interiors of the building causing more unconducive indoor thermal performance.

The result of this study, therefore, concurred with that of Aldawoud and Clark (2008). It is applicable in the temperate-dry climatic region of Nigeria. On the other hand, WWR 4% and WWR 7.5% cannot be recommended because they add negatively to the indoor thermal performance of the building rather than optimizing it.

5.0 CONCLUSION

Conclusively, the result of this study has shown that WWRs have a significant impact on air temperature and thermal comfort as well as the relative humidity. It has also revealed that WWR16% is the optimum because it has a better thermal condition in all the WWRs experimented. But further experiments are requiredto test other room area(s) because only $9m^2$ was considered in this study. Understanding the optimum location to windows for improve airflow patterns in the fully-enclosed courtyard building is also required. Finally, more simulation studies are required to make known the range of room area(s) for the most favorable thermal comfort condition within the temperate-dry climate of Nigeria.

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