**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# Effect of Window Size on Thermal Comfort in a Naturally Ventilated Auditorium

***Ibrahim Usman Haruna* [a], *Sulaiman Abubakar Babajo* [b]**

[a] Department of Mechanical Engineering, Federal Polytechnic Mubi, Adamawa State, Nigeria

[b] Department of Mechanical Engineering, Modibbo Adama University, Yola, Adamawa State, Nigeria

**A B S T R A C T**

The thermal comfort of the occupants in a naturally ventilated structure is significantly impacted by improper window sizing. The goal of this study is to optimize the size of the windows in the auditorium for the Faculty of Earth and Environmental Science (FEES) at Bayero University Kano's new campus. The objective function for optimization was Predicted Mean Vote (PMV). Solidworks software was used to create the auditorium model, and ANSYS Fluent was used to numerically calculate the PMV of the occupied room. The numerical findings demonstrate that the best PMV values of +0.28, +0.19, and -0.47 were produced by WWR in the 20% to 30% range, with the best PMV value of +0.19 being attained at 25% WWR. This 25% WWR can provide sufficient thermal comfort for auditorium occupants as the values obtained are within the recommendations of ASHRAE Standard 55. Structural engineers and designers may find this information helpful in making building design decisions.

**Keywords:** thermal comfort, auditorium, window-to-wall ratio, optimization.

## 1. Introduction

Buildings play an important role in creating a comfortable living environment. The auditorium is a space that requires a high degree of intellectual concentration. Under normal circumstances, a person spends about 25% of his day's time indoors, especially in public services. Therefore, student productivity, focus, morale, efficiency, and happiness are primarily functions of the internal environment (Kim et al., 2016, Ravat et al., 2017 and Sun et al., 2018). In this context, thermal comfort and indoor air quality (IAQ) are the most important indoor environments, so achieving thermal comfort in lecture halls is essential for improving student performance (Urge, Carlbeza and Serrano, 2015).

The state of being satisfied with the thermal environment is called thermal comfort. Therefore, providing thermal comfort for building occupants is fundamental. A comfortable building is one whose thermal environment satisfies 80% of her occupants (Kranteng, Essel and Nkurumah, 2015).

In thermal analysis of buildings, windows are considered a special type of component with a total heat transmission rate approximately five times that of other building components such as roofs, walls (Sun et al., 2016 and Lee et al., 2012). Windows account for up to 60% of the total energy consumption of a building envelope (Sun, Yupeng and Wilson, 2018). When designing modern buildings, designers tend to use large window areas for aesthetic requirements and visual comfort (Kiet et al., 2016). Increasing the window area of a building significantly increases the cooling load and consequently reduces the thermal comfort of the occupied space (Kiet et., 2016 and Almasrani et al., 2018). Window area, often expressed as the window-to-wall area ratio (WWR), therefore plays an important role in a building's energy use for cooling, heating, and thermal comfort (Yemo, et al., 2020).

Many studies have been conducted to examine the effect of window geometry on the thermal comfort and air quality of a naturally ventilated occupied space. The optimization of window opening design for thermal comfort in a naturally ventilated building was conducted by (Stravakakiset al., 2011). The thermal comfort indices predicted mean vote (PMV) and modified PMV obtained from the CFD-ANN coupled simulation was used to optimize the building window design. The authors stated that PMV was only suitable for air-conditioned rooms against the naturally ventilated room. Prakash and Ravikumar (2015) investigated the effect of roof vent and window wall vent in a room with windows on adjacent walls on the thermal comfort of a residential room. CFD simulation was used to determine the best position of the roof vent and the window wall vent, and the thermal comfort scenario in the room in these two cases was evaluated using PMV thermal comfort index. Rudraprasad and Sandhyata (2014) investigated the effects of window size and location on natural ventilation and thermal comfort in a residential building characterized by a hot and humid climate. Koranteng, Essel, and Nkurumah (2015) investigated the effects of window size and position on indoor comfort for residential rooms in Kumasi, Ghana using parametric simulation. Prakash and Ravikumar (2015) studied the thermal comfort and airflow characteristics of a residential room with adjacent window openings under a generalized position of window openings. Despite numerous studies conducted to investigate the effect of window size and position in a naturally ventilated building, a research is missing in the investigation of the effect of window geometry of a auditorium on the thermal comfort of the occupants. Therefore, this study is aimed at numerical investigation of the effect of window geometry on the thermal comfort of the occupants of a auditorium.

The two thermal comfort measures in the Fangers model are Predicted Mean Votes (PMV) and Predicted Dissatisfaction Rate (PPD). The PMV index predicts the thermal comfort of a space based on a 7-point ASHRAE scale of thermal sensitivity ranging from -3 to +3. A score of 0 is thermal neutrality (Koranteng, Essel, and Nkurumah, 2015).

The range of PMV values from -0.5 to +0.5 on the thermal sensitivity scale represents the range in which occupants are thermally comfortable. For this purpose, we numerically investigate the effect of window geometry in relation to the window-to-wall area ratio (WWR) on the thermal comfort of an auditorium using the PMV index.

## 2. STUDY building

The research building was the auditorium of the Faculty of Earth and Environmental Sciences (FEES) on the new campus of the Bayero, University Kano. The complex has his two auditoriums with a capacity of 120 people, one of which he considered for this study. The theater has a flow area of 263 m2, a volume of 1368 m3 and a compactness factor of 0.25. Because of the epileptic mains, it is most often naturally ventilated. The window-to-wall area ratio is about 10% (Sani, 2018). Figure shows a pictorial representation of the FEES Auditorium.

Figure 1: The FEES Auditorium of Bayero University, Kano

## 3. METHODOLOGY

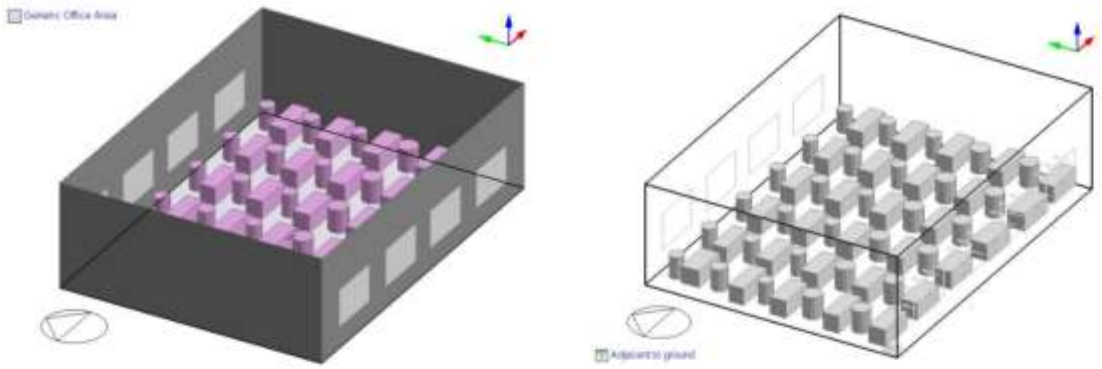
### *3.1. Numerical Study*

Numerical research was carried out in two stages:

(1) External CFD analysis of airflow through window openings under natural ventilation settings. (2) Internal CFD analysis to numerically determine the thermal comfort PMV inside the auditorium at a height of 1.1 m above the floor using ANSYS Fluent software.

### *3.1.1 Creation of model of the auditorium*

The auditorium was modeled using Solidworks software, the dimensions of the model are 20m x 13.2m x 5.2m and the door is considered an insulating wall. The auditorium is a single zone, and its block and zone levels are shown in Figures 2(a) and (b), respectively.



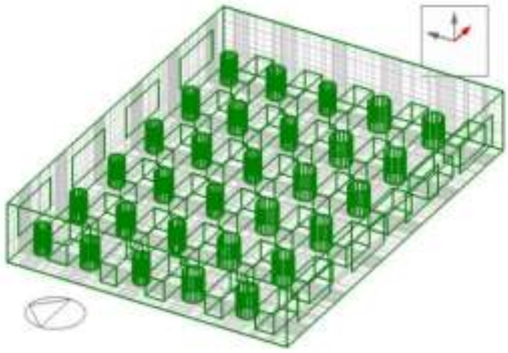
(a) (b)

Figure 2: Zone and Block Level of the Auditorium Model

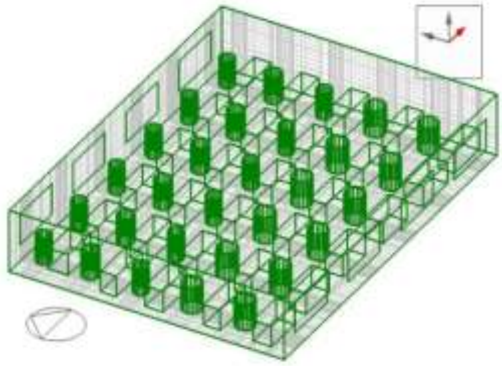
### *3.1.2 Mesh generation and sensitivity analysis*

Mesh generation and independence testing with good computational meshes are essential for a successful and accurate solution (Rahmati, Mohammad and Hoidarria, 2018). Studies have shown that an overall mesh that is too coarse will result in inaccurate solutions, while an overall mesh that is too fine will result in accurate solutions, but at the expense of computational time and cost. It can be illegal. Essentially, solution cost and accuracy are functions of power quality. A uniform rectilinear coordinate mesh was used to generate the mesh for the building model.

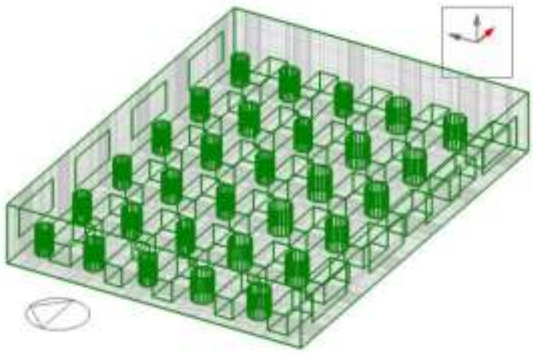
The mesh was generated using default coarse mesh parameters representing the geometry of a single zone model and containing the minimum number of elements required to satisfy the default mesh rules. A default mesh spacing of 0.300, grid line join tolerance of 0.0300, and 42147 elements were used, as shown in Figure 3(a). "Max. X size", "Max. Y size" and "Max. Z size". These refined meshes are shown in Figure 3 (b,c,d).



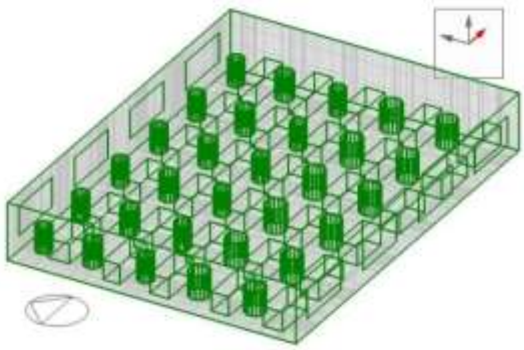
(a) Coarse mesh



(b) Refined mesh 1



(c) Refined mesh 2



(d) Refined mesh 3

Figure 3: Coarse and refined mesh of the geometrical model

On each grid (coarse and fine), the temperature distribution was measured at a height of 1.1 m above the floor, as recommended in (Ashara EE-55, 2010). This corresponds to the shoulders of a seated occupant. The coarse mesh of 42147 elements differs from the finest mesh of 634,256 elements by about 15%, while refined meshes 1 and 2 differ from the finest mesh by 3.2% and 1.3%, respectively. Therefore, a refined mesh 2 of 205917 elements was deemed sufficient for numerical simulation purposes.

### *3.1.3 Assigning the boundary conditions*

In this study, the boundary conditions employed for the CFD analysis are summarized in Table 1.

Table 1. Boundary conditions for internal and external CFD simulations

| Internal CFD Analysis | | External Analysis | |
|---|---|---|---|
| South window | Airflow rate: 78 l/s<br>Temperature: 27.4°C | | Grid spacing (m): 2.0000<br>Grid line merge<br>Tolerance (m): 0.2000 |
| Eastern wall | Fixed heat flux: 0.421 kW | | Velocity (m/s): 3.12 |
| Southern wall | Fixed heat flux: 0.238 kW | Wind analysis | |
| Other walls, ceilng and floor | Isenthalpic | | Direction : South |
| Occupants | One occupant, fixed heat flux: 8.11W/$m^2$ | | Exposure: Suburban |

| | | | |
|---|---|---|---|
| Equipment | 12 laptops, fixed heat flux: 3.37 W/m$^2$ | Site domain factors | Length (m): 3.00 |
| Metabolic rate | 1.0 met (58.2 W/m$^2$) | | Width (m): 3.00 |
| Clothing level | 0.5 clo (0.08 °C. m$^2$/W) | | Height (m); 1.40 |
| Zone air temperature | 31°C | | |
| Zone relative humidity | 62% | | |
| Number of sphere segments in mean radiant temperature calculation | 24 | | |

### *3.1.4 The governing equations*

The numerical method employed is known as a primitive variable method, which involves the solution of a set of equations that describe the conservation of heat, mass, and momentum.

The equation of mass conservation, known as the continuity equation, is given by equation 1 (Phonekeo Lopez and Guillimon (2016).

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \qquad (1)$$

The equation for momentum conservation is given in equation 2.

$$\frac{\partial}{\partial x_j}\left(\rho u_i u_j\right) = \frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i \qquad (2)$$

The equation for total energy conservation is given in equation 3.

$$\frac{\partial}{\partial x_i}(\rho u_i h) = \frac{\partial}{\partial x_i}\left(k \frac{\partial T}{\partial x_i}\right) + u_i \frac{\partial P}{\partial x_i} + \tau_{ij} \frac{\partial u_i}{\partial x_j} \qquad (3)$$

Where: $\rho =$ Density; $u_i =$ Velocity component in the $i$ direction; $P =$ Static pressure; $\tau_{ij} =$ Stress tensor; $x_i =$ Cartesian coordinate; $g_i =$ Gravitational acceleration in the $I -$ direction; $h$ =Static enthalpy; $k =$ Thermal conductivity; $T =$ Temperature.

Numerical CFD methods associated with the above set of equations specifically account for the most important environmental factors, including heat, temperature, mass, conservation of momentum, and where turbulence models are used. The equations consist of a set of coupled second-order nonlinear PDEs with the following general form, with the dependent variable given by Equation 4.

$$\frac{\partial}{\partial t}(\rho \emptyset) + \mathrm{div}(\rho u \emptyset) = \mathrm{div}(\tau \mathrm{grad} \emptyset) + \mathrm{S} \qquad (4)$$

The rate of change and convection are represented by the first and second terms on the left, respectively, and the diffusion and source terms are represented by the first and second terms on the right, respectively. Turbulence models are considered important in numerical modeling for describing flow behavior in thermal chamber climates [16]. Therefore, the standard k-e turbulence model, a method established in natural ventilation studies, was used in this study (Hughes, Calauti and Ghani, 2012). The upwind scheme was also used to discretize the transport equations.

### *3.1.5 Determination of airflow through the windows*

An external CFD analysis was performed to determine the airflow velocity through the auditorium windows. A 3D contour plot showing the CFD outdoor airflow around and into the building is shown in Figure 4.

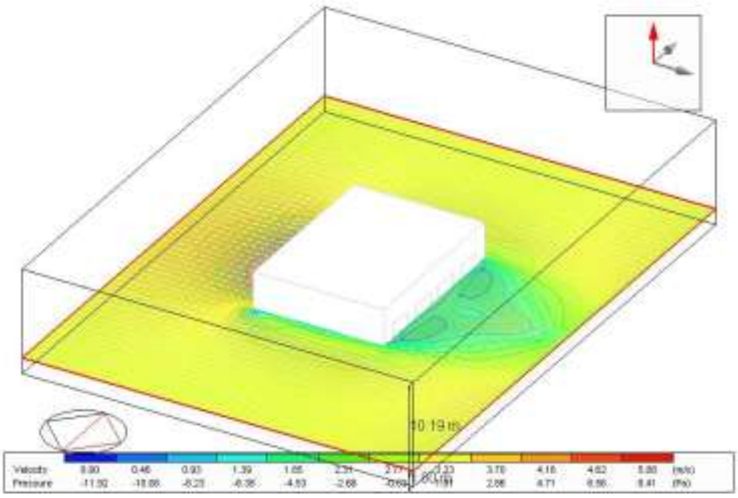


Figure 4: External CFD Analyses of the Airflow around the Building

#### *3.1.6 Model validation*

After mesh independence investigation, model accuracy was determined through a validation process. The model was validated by comparing the simulated PPD values with those obtained using the Center of Built Environment (CBE) thermal comfort tool.

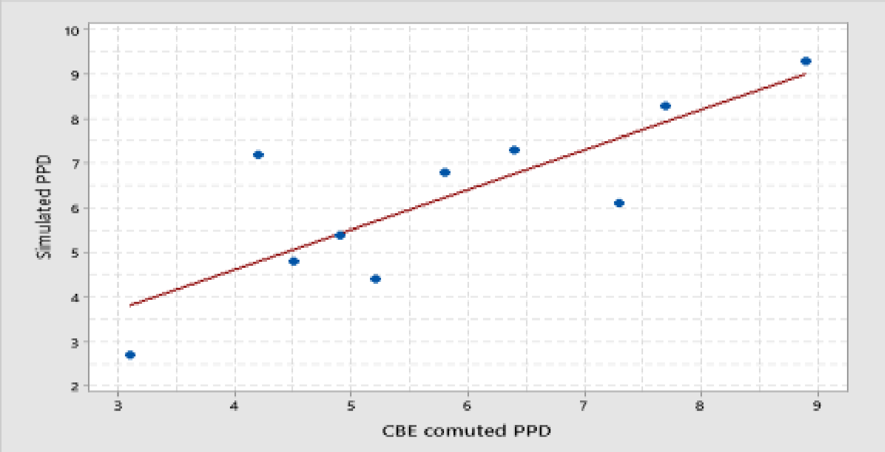



Figure 5: Comparison between Measured and Simulated Indoor Temperature

The correlation coefficient between the simulated PPD and the value obtained from the CBE tool at 95% confidence level using SPSS software was 0.813. A high correlation indicates the high accuracy of the building models used in this study.

### *3.2. Determination of Thermal Comfort of the Building Model*

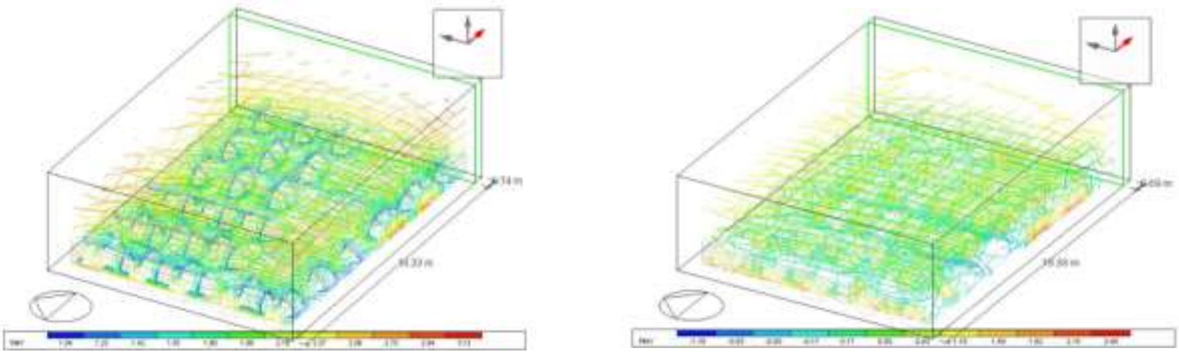
Indoor parameters such as temperature, relative humidity, air velocity, occupant clothing insulation, and occupant metabolic rate were obtained from experimental data in the FEES auditorium. These building interior parameters were used as inputs for his CFD simulations to determine the PMV Fanger's thermal comfort index.

### *3.3. Parametric Analysis of the CFD Model*

A parametric analysis was used in which the WWR was varied from 10% to 60% in 5% increments while keeping the boundary conditions constant. We then performed CFD simulations to determine the effect of the window geometry expressed as WWR. The thermal comfort of the auditorium occupants using the PMV index was used as the optimization objective function.

## 4. RESULTS AND DISCUSSION

The window geometry in a naturally ventilated building determines how comfortable the occupants of a space would be. The 3D contour plots of the PMV of the study building with representative WWR of 10%, 20%, 30%, 40%, 50%, and 60% are shown in Figure 6.



**WWR=10%** **WWR=20%**

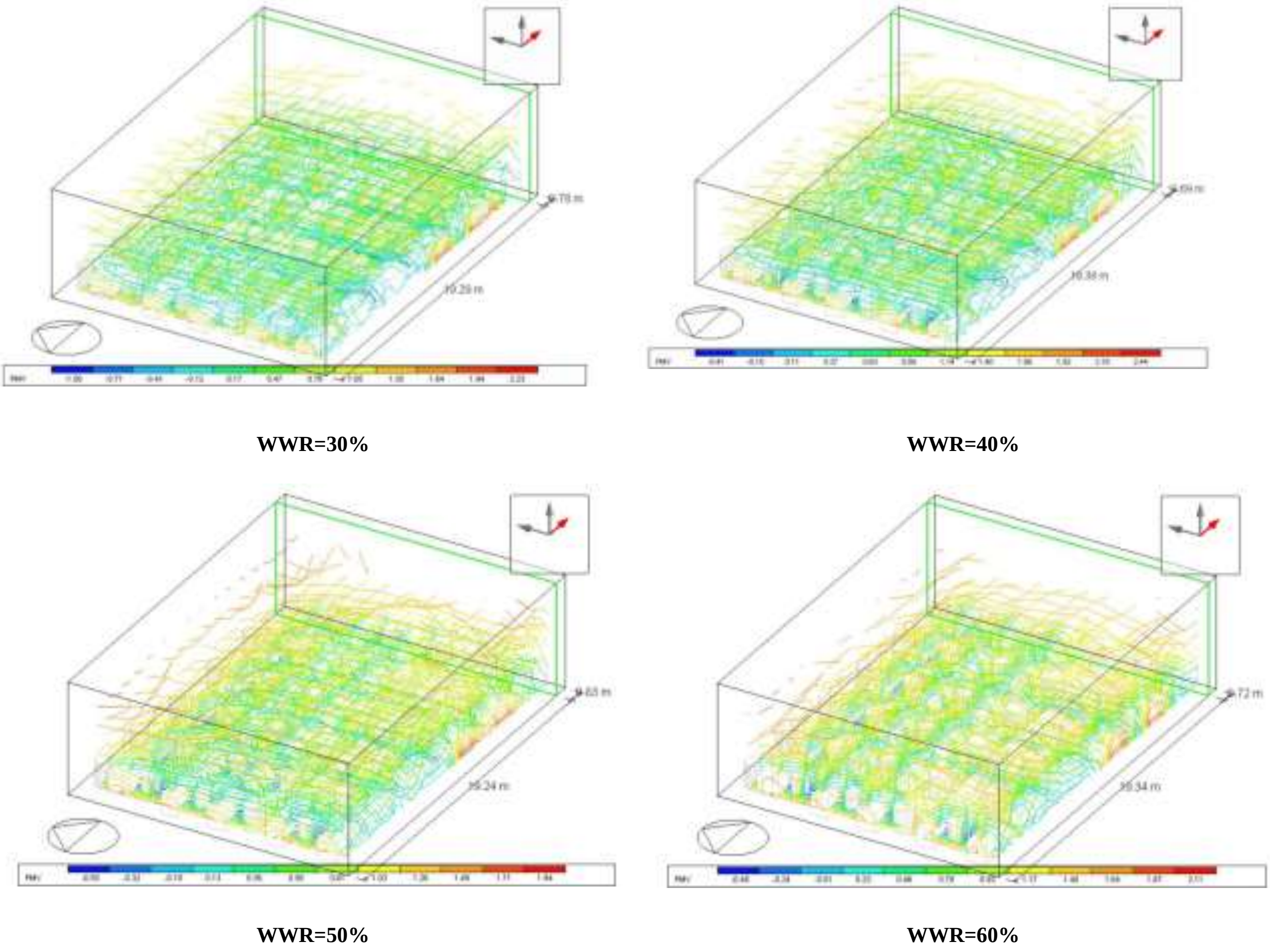



Figure 6: 3D Contour Plots of some selected WWR of the FEES Auditorium

The parametric simulated PMV values of the study building with WWR of 10% to 60% step 5% is shown in Fig. 7.

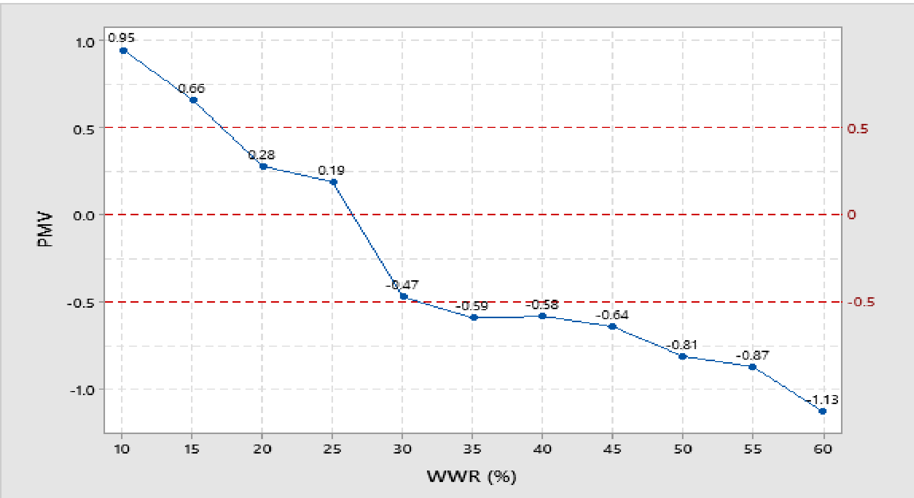



Figure 7: Plot of PMV vs WWR (%)

Selected 3D contour plot results of the parametric simulation of the FEES auditorium with WWR of 10%, 20%, 30%, 40%, 50% and 60% are shown in Fig. 6 for WWR PMV values. A range of 10% to 60% in 5% increments is shown in Figure 7. We find that the PMV values at 20%, 25%, and 30% WWR are within the thermal comfort band of -0.5 to +0.5, based on the recommendation of (Ashra-EE-55, 2010). This means that the thermal comfort of the occupied space improves when the WWR is in the range of 20% to 30%. However, as shown in the figure, the best results were obtained with a WWR of 25, as a PMV value of +0.19 is closest to thermal neutrality.

These results were consistent with a study reported by Korateng, Essel, Nkurumah (2015) who found that thermal comfort in naturally ventilated buildings improves when RHE is between 10% and 40%. Shaeli et al. (2019) and Lee et al. (2012) Another study agreed with this result and found that improvements in th ermal comfort and energy consumption are achieved in independent buildings when the WWR is between 20% and 30%, or exactly 25%. This finding is consistent with a WWR of 22% to 24% recommended for achieving thermal comfort in naturally ventilated buildings, according to Ashra EE-55(2010).

## 5. CONCLUSION

We numerically investigated the effect of window geometry in relation to WWR on the thermal comfort of residents of Bayero University Kano FEES. At PMV values of +0.28, +0.19, and -0.47, the WWRs that gave better results were 20%, 25%, and 30%, respectively. The best PMV value of +0.19 was obtained at a WWR of 25%. Therefore, using WWR in the range of 20% to 30% may improve thermal comfort for occupants of the FEES auditorium or other buildings with similar characteristics.

**REFERENCES**

Kim, S., Zadeh, P., Staub-French, S., Froece, T. and Cavka, B. (2016). "Assessment of the Impact of Window Size, Position and Orientation of Building Energy Load using BIM." *International Conference on Sustainable Design, Engineering and Construction* (pp. 1324-1332). Procedia Engineering.

Ravat, V., Shivakar, S., Biplab, D. and Sel, B. (2017). "Effect of Orientation of Window on Building Heat Load: Perspective of N-E India." *Material Science and Engineering.* India: IOP Conference.

Sun, Y., Yupeng, W. and Wilson, R. (2018). "A Review of Thermal and Optical Characteristics of Complex Window Systems and their Building Performance Prediction." *Applied Energy*, 729-742.

Urge-Vorsatz, D., Calbeza, L.F. and Serrano, S. (2015). "Heating and Cooling Energy Trends and Drivers in Buildings", *J. Renew. Sustain. Energy Rev.*, Vol. 41, Issue 1, p.85-98.

Koranteng, C., Essel, C. and Nkrumah, J. (2015). "Paaive Analysis of the Effect of Window Size and Position on Indoor Comfort for Residential Rooms in Kumasi, Ghana." *International Advanced Research Journal in Science, Engineering and Technology, 2*(10), 114-120.

Lee, M., Mui, K., Wong, L., Chen, W., Lee, E. and Cheung, C. (2012). "Student Learning Performance and Indoor Environmental Quality (IEQ) in Air-Conditioned University Teaching Rooms." *Building and Environment, 49*, 238-244. Retrieved from http://dx.doi.org/10.1016/j.buildenv.2011.10.001

Kiet Lau, A.K., Salleh, E., Lim, C.H. and Sulaiman, M.Y. (2016). "Potential of Shading Devices and Glazing Configurations on Cooling Energy Savings for High-rise Office Buildings in Hot-Humid Climates: The Case of Malaysia." *Inter. Journal of Sustain. uilt Environ,* Vol. 5, Issue 2, 387-399. https://doi.org/10.1016/j.ijsbe.2016.04.004

Al-Masrani, S.M., Al-Obaidi, K.M., Zalin, N.A. and Isma, M.I.A. (2018). "Design Optimization of Solar Shading Systems for Tropical Office Buildings: Challenges and Future Trends." *Sol. Energy*, Vol. 170, 849-872. https://doi.org/10.1016/j.solener.2018.04.047

Yemo, S., Kim, H., Hong, T. and Lee, M. (2020). "Determining the Optimal Window Size of Office Buildings Considering the Worker's Task Performance and the Building's Energy Consumption." *Building and Environment,* Vol. 177, 106872.

Stavrakakis, G., Karadimou, D., Zervas, P., Sarimveis, H. and Markatos, N. (2011). "Selection of Window Sizes for Optimizing Occupational Comfort and Hygiene based on Computational Fluid Dynamics and Neural Networks." *Building and Environment, 46*, 298-314.

Prakash, D. and Ravikumar, P. (2015). "Analysis of Thermal Comfort and Indoor Airflow Characteristics for a Residential Building Room under Generalized Window Opening Position at the Adjacent Walls." *International Journal of Sustainable Built Environment*, 42-57. Retrieved from http://dx.doi.org/10.1016/j.ijsbe.2015.02.003

Rudraprasad, B. and Sandhyata, S. (2014). "Thermal Comfort Inside Residential Building with varying Window Locations and Size." *Proceedings of 2014 1st International Conference on New Conventional Energy.* Kalyani, WB, India.

Sani, M. (2018). Measured and Perceived Conditions of Indoor Environmental Qualities (IEQ) of University Learning Environment in Semi-arid Tropics: A Field Study in Kano-Nigeria." *PhD Thesis.* Portsmouth: University of Portsmouth.

Rahmati, B., Mohammad, J..A. and Heidarian, A. (2018). "To study the Performance of a Hybrid Underfloor Air Dispersion System with an Improved Desk Displacement Ventilation System in a Small Office." *Appl. thermal Eng*., pp.861-872.

Phonekeo, P., Lopez-Jimenez, P. and Guillamon, I. (2016). "CFD Model Using for Natural Ventilation Study in the Local Building of Hot-Humid Climate in Vietiane Capital, Lao PDR." *International Journal of Energy and Environment, 7*(1), 37-48.

Parra, M. T., Villafruela, J. M., Castro, F. and Mendez, C. (2006). "Investigation of Different Ventilation Systems in Deep Mines using Numerical and Field Methods." *Build. Environment*, Vol. 41, pp. 87-93.

Hughes, B., Calautit, J. and Ghani, S. (2012). “The Development of Commercial Wind Catchers for Natural Ventilation: A Review.” *Applied Energy, 92*, 606-627. Retrieved from http://dx.doi.org/j.apenergy.2011.11.066

ASHRAE-55. (2010). Thermal Environmental Condition for Human Occupancy. Atlanta: American Society of Heating, Refrigeration and Air Conditioning Engineers.

Shaeri, J., Habibi, A., Yaghoubi, M. and Ata, C. (2019). “The Optimum Window-to-Wall Ratio in Office Buildings for Hot-Humid, Hot-Dry, and Cold Climates in Iran.” *Environments*, Vol. 6, 45. Doi:10.3390/environments6040045