IJAAR PUBLISHING®

Engineering Research Journal | ISSN: 2782-8212
Vol. 4, Issue 9 (September, 2024) | www.ijaar.org/erj

OPTIMIZING WINDCATCHER SUPPLY OUTLET PLACEMENT FOR ENHANCED PERFORMANCE IN BEDROOM ROOFTOP INSTALLATIONS

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Abstract.

The optimum placement of a windcatcher supply outlet on the rooftop of a building in relation to the occupant breathing zone in the context of indoor air quality (IAQ) is imperative. This study attempts to determine the optimum location of the windcatcher supply outlet on the rooftop of a bedroom for enhanced IAQ. The building model was created using DesignBuilder software while computational fluid dynamics (CFD) was employed for the parametric simulation using air change effectiveness (ACE) as the optimization objective function. The rooftop was strategically divided into nine parts where the windcatcher were numerically installed. The results show that the windcatcher supply outlet directly above the occupants sleeping region (bed) was the optimum because at that location, the ACE in the occupants breathing zone was 1.08. This information could help engineers to optimally position the windcatcher supply outlet on the rooftop of a bedroom building or any other building with similar attributes.

Keywords: Indoor air quality, bedroom building, windcatcher, rooftop, mean age of air, air change effectiveness

Tizhe, C. & Haruna, I.U. (2024). Optimizing Windcatcher Supply Outlet Placement for Enhanced Performance in Bedroom Rooftop Installations. *Engineering Research Journal*, *4*(9), 11-20. DOI: 10.5281/zenodo.13844064

INTRODUCTION

Buildings play an important role in creating a comfortable living environment. Windcatcher are passive systems that operate purely on natural ventilation settings. Mahsan *et al*. (2017) defined wind tower or windcatcher as a vernacular natural ventilation technique that is mounted on the construction roofline or façade-mounted to capture air flowing at high speeds and channel it down into the inner environment of a building. Windcatcher is a common architectural feature that gained popularity many years ago (Ionesco *et al*., 2015; Abd Wahab *et al*., 2018). Being passive systems, they operate without requiring mechanical or electrical power inputs. Windcatcher are installed on any kind of building and they are capable creating a satisfactory environment to the occupants from air quality and thermal comfort point of views.

Buildings are designed with multifaceted openings such as windows, vents, etc with the primary reason of creating a healthy environment for the occupants. Unlike these openings, windcathers have more advantages than these openings (Montazeri & Azizian, 2009; Abd Wahab *et al*., 2019). In a dense urban context, the windows efficiency is low, and windcatchers can be an efficient superseded solution for supplying the required ventilation rate. Drach (2009) has researched a three-storey house with inadequate natural ventilation. The results of this paper indicate that adding a windcatcher improved natural ventilation in the house. Unlike window openings, windcatcher have a relatively higher pressure coefficient (Montazeri & Azizian, 2009). Windcatchers can be used to provide ventilation in basements and can reduce the fluctuation of temperature in the indoor space (Reyes, 2015).

Many studies have been conducted to enhance the performance, efficiency and effectiveness of windcatchers. Ghaemmaghami and Mahmoudi (2021) investigated the performance of windcatcher divided into x-blades, +-blades, and H-blades. The results showed that the windcatcher with the H-blades division performed better. Montazeri (2011)investigated the performance of windcatcher with cylindrical cross-section and different number of openings. The results show that two-sided windcatcher has the best performance. Sheikhshahrokhdehkordi *et. al*. (2020) investigated the windcatcher of different height. According to the results, increasing the height leads to a decrease in the mass flow rate. Afshin *et al*. (2014) performed a study where a windcatcher-integrated building was investigated along with the neighbor buildings with different heights. The results of this study dictate that the existence of a building with low height in the neighbourhood (with a height of 0.5H of windcatcher and distance of 0.75H of windcatcher) can increase the ventilation rate. However, the existence of higher buildings has a reverse effect. Mak *et al*. (2005) carried out a study about the performance of a four-sided windcatcher at 0^o, 15^o, 30^o, and 45^o wind angles. The windcatcher at 45^o wind angle had the most sensitivity and had less sensitivity toward velocity at 0^o wind angle. Bahadori *et al*. (2008) compared two new types of windcatcher with traditional windcatcher: windcatcher with wet columns and wet surfaces. The results show that these new types have higher performance than the traditional models. Despite numerous studies conducted to investigate ways of enhancing the performance of the windcatcher, a research is missing in the investigation of the effect of the optimum windcatcher supply outlet position on the roof. Therefore, this study is aimed at the optimization of the windcatcher supply air outlet on the roof for enhanced indoor air quality a sleeper compartment situated at the room centre.

STUDY BUILDING

The research building was a 4m long, 3.5m wide, and 3m high bedroom located in Sharada Industrial Estate, Kano, Nigeria. The room has only one adult male occupant. The block where the bedroom was located was shown in Figure 1(a).

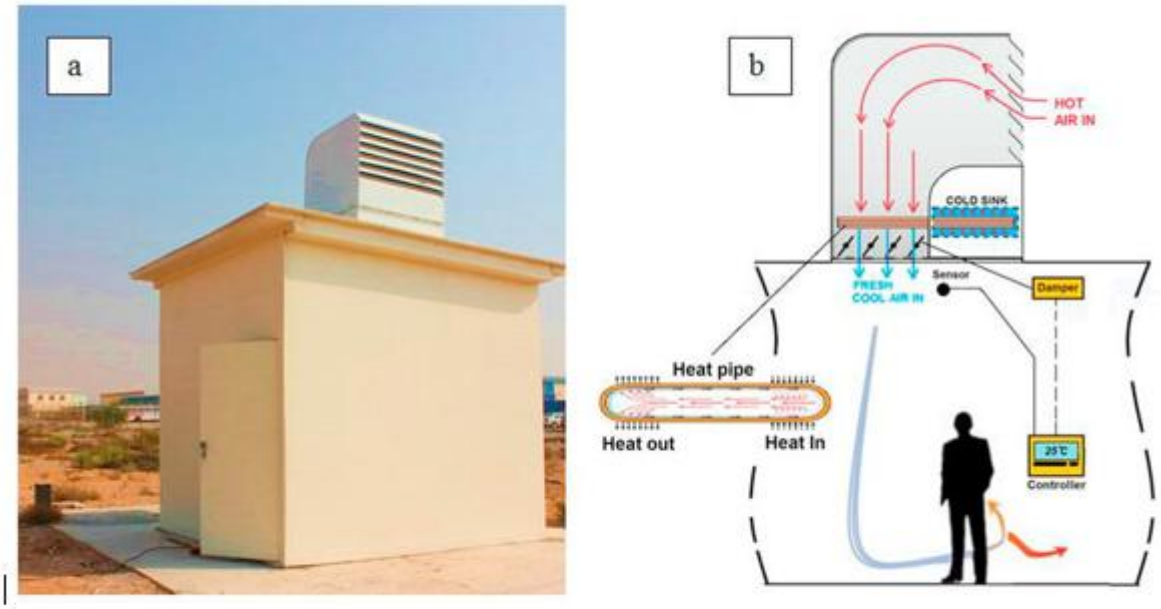


Figure 1: Rooftop-Mounted Windcatcher

METHODOLOGY

In this study, the methodological approach used are logically presented.

Creation of 3D model of the bedroom building

The model of the bedroom building dimensioned 4m by 3.5m by 3m was created using DesignBuilder software. The zone level of the bedroom model was shown in Fig. 2.

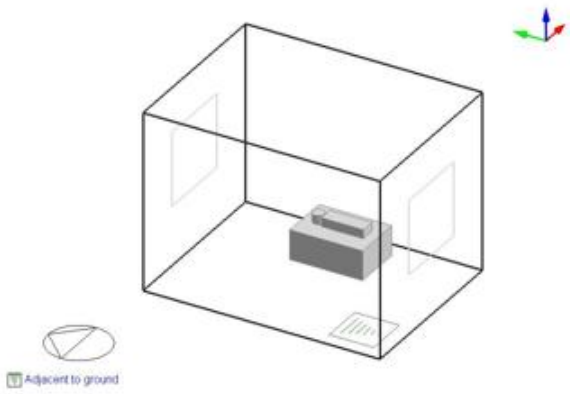
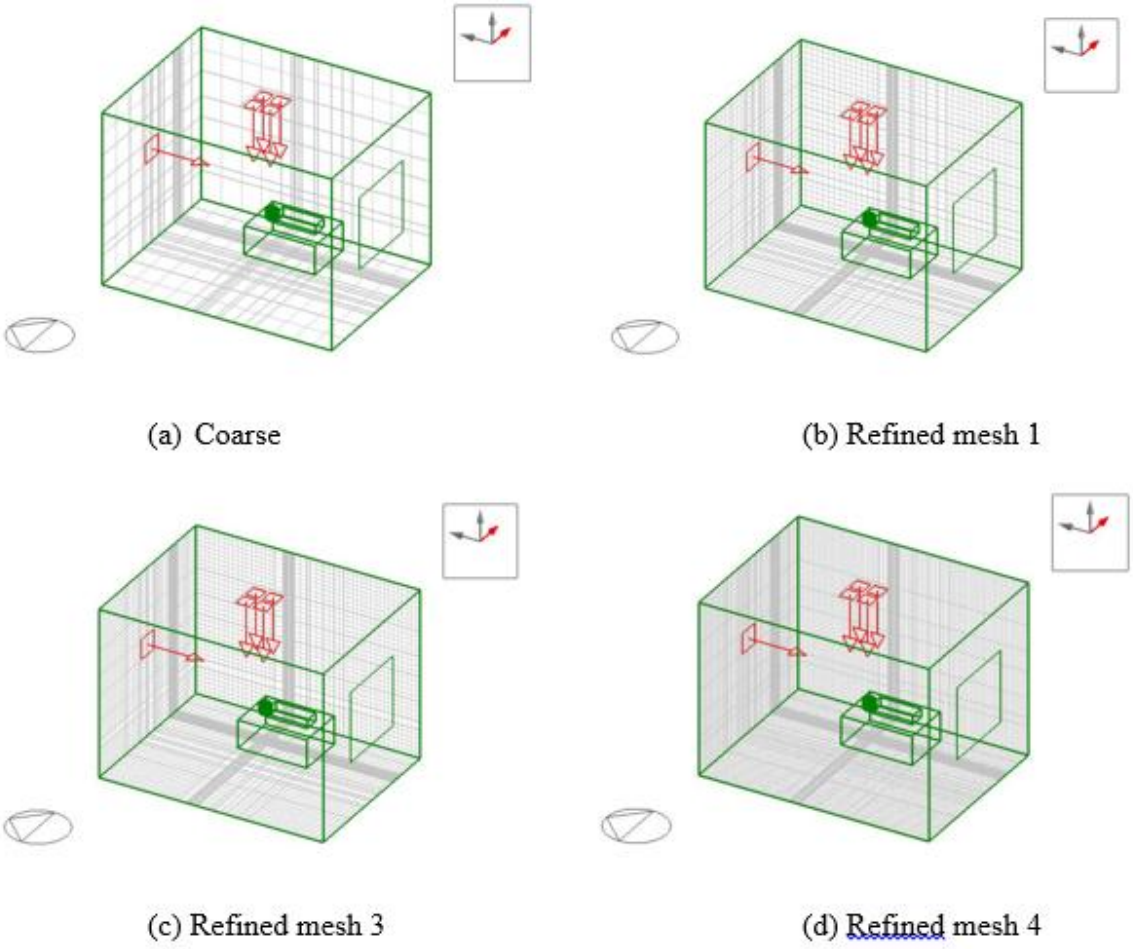


Figure 2: Zone Level of the Bedroom Model

Mesh Generation and sensitivity analysis

Mesh generation and independence testing with good computational meshes are essential for a successful and accurate solution. 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. 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 2592 elements were used, as shown in Figure 3(a). To ensure mesh independence, three more refined meshes with 40392, 72080 and 280440 elements were generated by using the "Max. X size", "Max. Y Size" and "Max. Z Size" have been set. These refined grids are shown in Figure 3 (b, c and d).



(a) Coarse (b) Refined mesh 1

(c) Refined mesh 3 (d) Refined mesh 4

Figure 3: Coarse and refined meshes of the geometrical model

The Boundary Conditions

In this study, the boundary conditions employed for the analysis are divided into two: for external CFD analysis and for internal CFD analysis. Boundary conditions for internal CFD analysis are: windcatcher outlet airflow rate 27.4 L/s, temperature 24℃, South window: Airflow rate 72 L/s and temperature 28.2℃ ; Eastern wall and Southern wall: fixed heat flux

0.341 kW and 0.201 kW respectively; Other walls, ceiling and floor: Isenthalpic; Occupants One occupant, fixed heat flux: 8.11W/m^2; Occupants One occupant, fixed heat flux: 8.11W/m^2; equipment 1 laptop, fixed heat flux: 3.37 W/m^2; metabolic rate 1.0 met (58.2 W/m^2); Clothing level 0.5 clo (0.08 ℃. m^2 /W); zone air temperature 31.3℃ Zone relative humidity 60%; Number of sphere segments in mean radiant temperature calculation 24 2.2.4. The external boundary conditions are: grid spacing (m): 2.0000; grid merge tolerance (m): 0.2000; velocity (m/s) 3.24; direction : south; exposure suburban; Site domain factors: Length (m) 3.00, Width (m): 3.00, Height (m) 1.40.

Model validation

After the grid independence, the accuracy of the model was determined through a validation process. The model was validated by comparing the measured values of the bedroom temperature of the study room equipped with the windcatcher with the simulated interior temperature from the CFD model. Figure 4 shows the comparison between experimental and simulated internal temperatures.

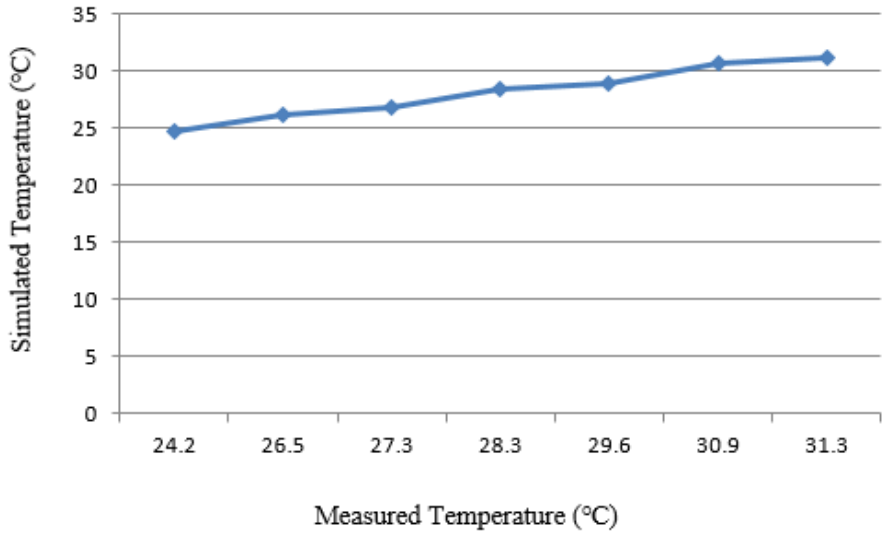


Figure 4: Comparison between Simulated versus Measured Temperatures

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The coefficient of correlation between the measured and the simulated temperatures at a 95% confidence level is 0.914. The high correlation between the measured and simulated temperatures indicates the high accuracy of the building model used for this study.

Determination of Air Change Effectiveness

DesignBuilder software was employed to map out the breathing zone of the sleeping occupant. The software calculates the ACE by adding the ACE 'breathing region' to define the parts of the CFD domain to be considered as part of the ACE calculations. The regions were added by specifying the coordinates of the origin and the dimensions of the region. In this study, the coordinates of the origin and the dimensions of the breathing zone were presented in Table 1 and this complied with ASHRAE Standard-62.1 (2007) recommendations for breathing zone specifications.

Table 1: Breathing Zone of the Occupied Space

Coordinate of Origin		Dimensions(m)	
X	12.844	Length	1.874
Y	12.408	Width	1.926
Z	0.767	Height	0.90

Parametric analysis of the CFD model

DesignBuilder parametric analysis was employed by keeping the boundary conditions constant while varying the windcatcher supply outlet on the top of the roof from LB, LC, LT, CB, CC, CT, RB, RC, and RT, which were at uniform interval as shown in Figure 4.

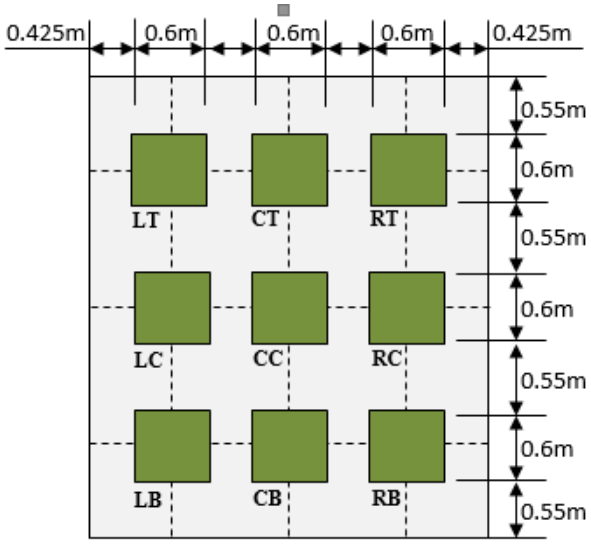


Figure 4: Positioning of the Windcatcher Supply Outlet on the Rooftop

The bed was situated in the bedroom directly below the RC. DesignBuilder CFD simulation was then carried out to determine the effect of the windcatcher supply outlet on the IAQ using the MAA and ACE as the performance criteria. The numerical results of the MAA for the different positions of the windcatcher supply air outlet are shown the 3D-contour plots in Figure 4. The numerical results of the ACE for the aforementioned windcatcher positions are presented in Table 2.

RESULTS AND DISCUSSION

The results of the parametric simulations of the MAA in the sleeping occupants' breathing zone of the office building with the windcatcher outlet position varies from LB, LC, LT, CB, CC, CT, RB, RC, and RT are shown in Figure 5.

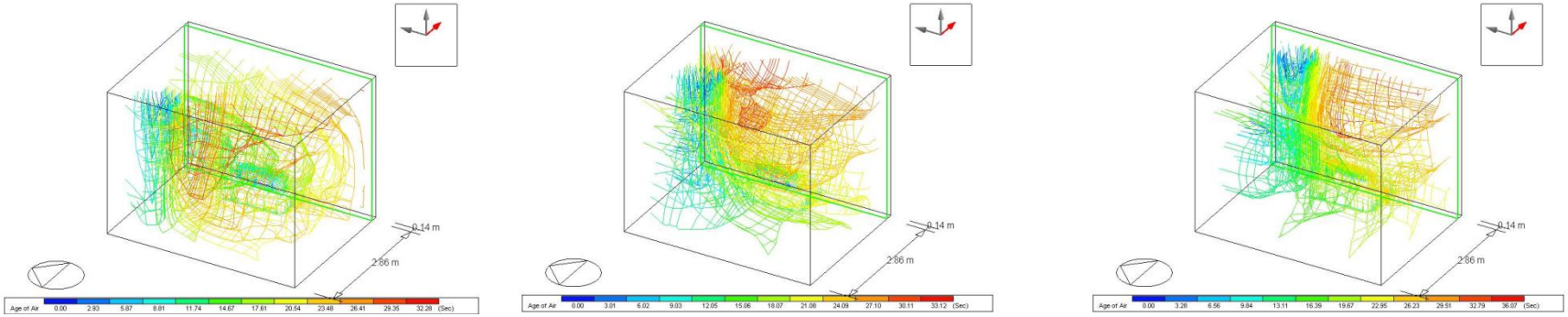


Figure 5: 3D Contour Plots of MAA

The numerical results of the ACE of the parametric simulations are presented in Table 2.

Table 2: Parametric Results of MAA and ACE

S/N	Windcatcher Outlet Position On Rooftop	MAA (s)	ACE
1	LB	34.62	0.78
2	LC	32.88	0.82
3	LT	34.06	0.80
4	CB	31.51	0.86
5	CC	33.37	0.81
6	CT	28.29	0.96
7	RB	30.48	0.89
8	RC	25.03	1.08
9	RT	29.75	0.91

From the MAA 3D contour plots in Figure 5, it can be seen that the value of windcatcher supply outlet at RC has the lowest value of 25.03 seconds. This might be attributed to the air being directly supplied into the breathing zone of the occupant. This is in consonance with the works of Jun *et al*. (2018) and Hamdani *et al*. (2017) who in separate studies found that the supply of air directly into the breathing space of occupants enhances the air quality. The pattern of the airflow in the bedroom as evident from the CFD 3D contour (Figure 5) show that the airflow through the window only slightly influences the dynamics of the airflow. In essence, the MAA can be considered a function of the radial distance from the occupant breathing space. This finding is supported by Ramy (2013) who highlighted that diametric distance should be considered in estimation of MAA.

The highest ACE was 1.08 which was obtained from the windcatcher supply outlet directly above the sleeper region. The higher the value of ACE the better the air quality since for a perfectly mixed ventilation, ACE = 1.0. Hence, better indoor air quality in the breathing zone was achieved in this location. This might be attributed to the fact that the air from other outlet locations tends to be relatively more contaminated before reaching the occupant breathing zone. This is in consonance with ASHRAE Standard 62.1 which stated that the ACE and by extension the air quality decreases with the air resident time.

CONCLUSION

The optimum location of the windcatcher supply outlet on the rooftop of a bedroom was determined using computational fluid dynamics. ACE was used as the optimization objective function for the parametric simulation. The optimum position of the windcatcher on the rooftop was at the right centre location which was directly above the occupant bed. The ACE in the breathing zone of the occupant was 1.08. Therefore, in a bedroom building equipped with the windcatcher system, an enhanced IAQ could be achieved by locating the outlet directly above the sleeping zone of the occupant. This information could help building designers and engineers to locate windcatcher supply outlet for achieving indoor air quality in a bedroom building or any other building with similar characteristics.

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