



INVESTIGATION OF AIRFLOW FOR NATURAL VENTILATION IN THE TYPICAL MEDIUM-RISE HOUSING CLUSTER IN SOUTHEASTERN NIGERIA

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Abstract

Wind-driven natural ventilation depends on the microclimatic conditions of its environment. In urban streets, it is affected by the ambient wind flow and air temperatures. In this study, field experiments were carried out in selected streets of a typical medium-rise housing cluster in southeastern Nigeria. The study aimed to understand the characteristics of air flow within this housing category, and to better evaluate the potential of natural wind-driven ventilation in this class of settlement. Wind speed and directions in the middle of selected streets were measured continuously. In parallel, the undisturbed climatic conditions above the street canyon were recorded as well. The general conclusion is that inside the streets, the potential of natural ventilation for both single and multi-branch type configurations is reduced, while that of continuous street configuration (without intermediate intersections) provided a higher potential for natural wind-driven ventilation. This is mainly due to the internal interference and reduction of wind speeds inside the street canyons. Generally, universal meteorological information gotten from unobstructed areas in cities are used in the design of buildings; thus, the significance of this study outlines the importance of obtaining microclimatic information in pre-design stages.

Keywords: Natural ventilation, wind driven ventilation, cluster housing, street ventilation, passive ventilation, ventilation study.

1. Introduction

Natural ventilation for use in passive designs is hugely dependent on microclimate conditions of urban surroundings. The study indicates that this condition is affected by ambient wind flows, solar radiation, and ambient air temperatures. In recent years, several studies on air circulation in streets have been performed by physical and numerical simulations. These studies focused on such parameters as street geometry (including height/width ratios), street patterns and orientation. Many researchers proposed that at the micro level, the urban space geometry is mostly responsible for the microclimate difference (Mihalakakou, et. al, 2026; Oke, 1988; Bourbia & Boucheriba, 2010; Andreou & Axarli, 2012; Yoshida et. al, 1991). Those responsible for the design of urban spaces are mostly unfamiliar with the thermal comfort problems originating from the distinctive relationship between urban forms and local climatological conditions (Gomez et. al, 2013). Consequent to this, many urban settlements do not respond to related climatic conditions. The common practice for urban and building designers involves the use of universal meteorological data. However, these data are obtained from stations that are located in unobstructed areas of the city, like airports or isolated fields. Previous studies have shown that the use of inappropriate wind and temperature data in the design of urban buildings may result in inaccuracies regarding the airflow in urban buildings (Geros et. al, 1999). Investigation into urban airflow identified the structure of urban wind field as characterized by the development of a two-layer vertical structure. As air flows from the rural to the urban environment, it must adjust to the boundary conditions defined by the cities,

and these results to the development of the urban canopy sub-layer (obstructed sub-layer) which is extended from the ground surface up to the buildings height, while the urban boundary layer (free surface layer) is extended above the roof tops. The canopy sub-layer possesses its own flow characteristics that is mainly driven or determined by the interaction of the flow field above and the local effects such as building geometry, street patterns, urban traffic, natural topography and other local features like the presence of trees and landscaping structures. Generally, it is observed that wind speed in the canopy layer of the urban structure is seriously decreased compared to the undisturbed wind speed. Because of the reduction of the wind speed in urban street structure, there is significant limitation to the extent of which natural ventilation can be applied in dense urban environments (Santamouris, 2001). Understanding the flow pattern and wind speed in urban street structure is therefore necessary for analyzing the natural ventilation potential for buildings in cities.

Due to impacts of urbanization, conditions like the heat island effects in cities coupled with global warming, has contributed to the increase of the peak cooling loads and electricity load necessary for building space cooling purposes, owing to this, it is significant to optimize building and urban space designs in terms of energy demands that considers local microclimates.

Many cities in Africa (especially sub-Saharan Africa) suffer from unplanned urban sprawls. These situations often arise from uncontrolled or poor developments. However, as the cities develop, they eventually become formalized and thus end up becoming major components of the urban development. Owing to the poorly planned conditions, build clusters raised in these areas face the huge challenges of poorly oriented plans, thereby raising houses that may face challenges of accessible wind flow for ventilation and hence, increasing reliance on electricity for cooling needs in high temperature seasons.

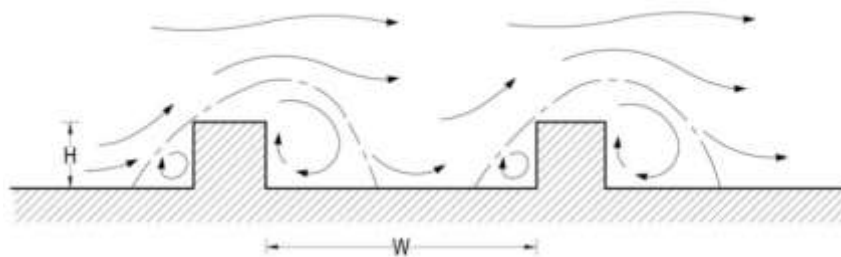
This paper presents the situation in one of such areas, showcasing a typical high density residential settlement in Enugu (southeastern Nigeria). This study is done in order to provide information on the characteristics of airflow and microclimate conditions in street as it affects airflow for natural ventilation in such poorly planned housing clusters.

2. Study background

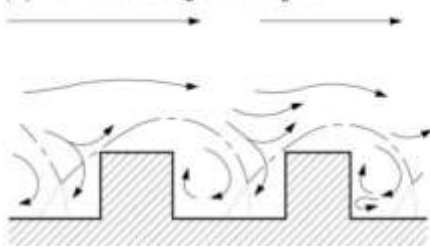
The ambient air temperature at street levels in urban spaces often influences the energy load of the building environment and therefore determines the cooling potential of available natural and hybrid ventilation techniques. Concurrent thermal phenomena as well as recurrent vortices that often develop at street corners frequently dominate the air flow patterns inside streets of settlements. Likewise, as solar heating of building exterior facade systems creates surface temperature differences, which also impacts the air temperature conditions within the streets of settlements, such air temperature systems eventually generate local upwind along warmer sides of building facades and form downward flows on the opposite side (Georgakis & Santamouris, 2006). Furthermore, when wind speeds are small, thermal effects come into play within the surrounding environment; buildings tend to be warmer than the surrounding air, and depending on the intensity of heating, either the approach wind or the thermal convection dominates. The degree of the thermal change is dependent on many factors, which may include the anthropogenic heat flux in the streets, sky view factor, and the albedo of the building surfaces (Tseng, et. al, 2006; Kim & Baik, 1999; Fernando, 2010). Also, the distribution of the air temperatures recorded at the top and at the different floors of buildings inside the streets of urban settlements indicated that temperatures above the street are often higher during the daytime than the corresponding temperature inside the streets. Lower air temperatures within the streets were observed as the penetration of solar radiation is limited owing to the depth of the street blocks. The lower temperature may be attributed to the mixing phenomena inside the

street tunnels that tend to regulate the air temperature (Sakakibara, 1996). This shows that the air temperatures in the streets of urban building settlements are mostly governed by more complex factors than normal ambient surface temperature despite the impacts of the local street configurations. When the airflow on an envelope surrounding the building is stressed, three main zones of disturbance are generated, namely: isolated rough flow, wake interference flow, and skimming flow (Mihalakakou, et. al, 2026). Eddy vortex are formed in front due to flow down the windward face, while behind, a lee eddy is generated, which is drawn into the cavity of low pressure due to flow separation from the sharp edges of the building top and sides, as shown in Figure 1. These levels of airflow systems are necessary in the assessment of wind-driven ventilation in urban buildings.

(a) *Isolated roughness flow*



(b) *Wake interference flow*



(c) *Skimming flow*

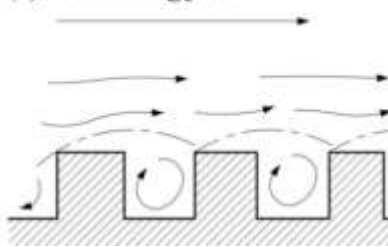


Figure 1. The different airflow systems in urban streets within and over the buildings. (Source: Oke, 1988)

The Street configurations in cities are often structured to serve the basic conventional functions of accessibility and circulation. The configuration of the local streets in the study area is defined by urban planning classification (Akubue, 2019). These classifications are embedded in the structure of the high-density, medium-density, and low-density settlements. This study is focused on a high-density district with medium-rise building clusters

2.1 Description of study site

The field study in this work was conducted in Enugu city, which is located in the Southeastern part of Nigeria with geo-location as 6.26° North and 7.29° East. The national census of 2006 recorded the population of Enugu city to be 722,664, quartered in a total of 28 residential layouts. The predominant human activity in the city is characterized as administrative (Ofomata, 2002). Enugu city's climate is classified as a tropical rainforest with a derived savannah. Set on an altitude of 304.7m above sea level, its climate is characteristically humid, and this humidity is oppressive between March and November, as indicated in Figures 2 and 3 (Reifsnyder & Darnhofer, 1989). The average maximum temperature is 34.9°C, with an average low of 22.3°C; the annual mean temperature is 26.7°C. Typical of the rest of West Africa, the rainy and dry seasons are the only weather periods in Enugu. The average hourly wind speed in Enugu experiences significant seasonal variation over the course of the year. The

windier part of the year lasts for 7 months, from March to September, with an average wind speed of 5.5m/s. The windiest month of the year is August, with an average wind speed of 7.1m/s. The wind direction comes relatively from the west for 10 months (monsoon season), from January to November, with a peak percentage of 75% in July. Additionally, the wind direction comes from the north for 2 months (Harmattan season), from November to January, with a peak percentage of 41% in January. The wind data used in this study were obtained from the Nigerian Meteorological Agency (NIMET), at a height of 10 m (see Figure 4). The surroundings of the measurement sites can be characterized as typical urban land-use, with residential housing. The street orientation affects the street microclimate (Oke, 1988); hence, the site considered has an average of three-storey buildings (4 floors) with a NE-SW street-axis orientation along an asphalt road.

The medium-rise building heights in the location are averagely 16.5m on either side of its streets. The effective width of the streets is 18m, thus yielding a height to street width ratios (H/W) of about 0.92.

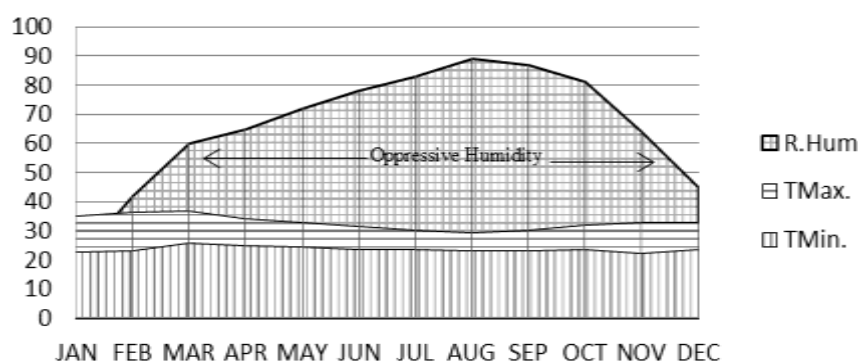


Figure 2. Average climatic data of Enugu city (Source: NIMET, 2025)

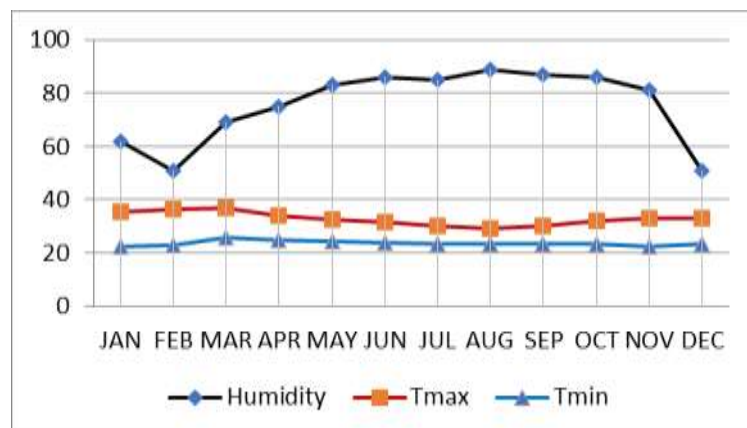


Figure 3. Average monthly temperature and relative humidity of Enugu city during the year of study (Source: NIMET, 2025)

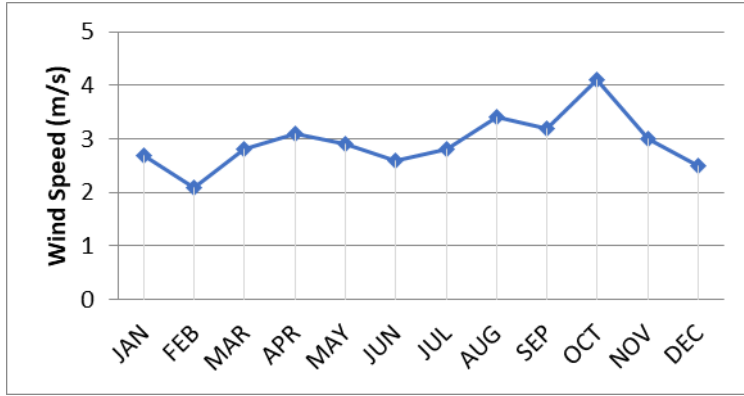


Figure 4. Average monthly wind speed of Enugu city during the year of study. (Source: NIMET, 2025)

The district considered for the study is characterized by medium-high-rise buildings. Medium-rise buildings are defined as buildings that fall within the range of 4 to 10 floor heights. The Achara layout district in Enugu city (indicated with the red circle in Figure 2), is notable for its cluster of 4- to 5-storey high buildings, which are all apartment buildings or residential blocks of flats (Figure 5b).



(a)



(b)

Figure 5. (a) Aerial map of Enugu city, showing the study area in red circle, (b) typical street view of the Achara layout district (study area)

2.2. Study Methodology

This study adopted an experimental research approach relative to similar cases taken from Mihalakakou et. al (2026) and Andreou et. al (2012). The research process involves the investigation/measurement of physical (existing) conditions within distinctively different configuration. The aim is to identify the most effective configuration for improving wind driven natural ventilation. For the purpose of this research, field investigation was conducted in order to ascertain the extent of the physical wind current available for driving ventilation within the streets of the selected district. To obtain the values necessary for this study, a set of data logging instrument (thermo-anemometers –AZ 9871) was utilized to measure wind velocity, relative humidity and temperature within and outside the selected classrooms.

Magnetic compasses were used to measure the wind directions while a digital still camera was utilized in taking photographs of streets under study. A 30.6m fibre-glass and 3.6m metallic tape were used to measure external dimensions of the street widths. This equipment was operated by a selected group of students placed systematically at significant points within the study area. By introducing students to the consequences of non-utilization of ambient microclimate conditions in building designs, awareness and methods of recording and documenting microclimatic elements were created. The groups took turns to ensure proper records were taken. During the exercise, the study coordinator ensured synchronized timing for measurements and collation of data collected from the participants.

The required data taken during the study were the air temperature, wind speed (velocity), wind direction, and air humidity values. The month of August was picked for this study, owing to its significance as the month with the highest annual wind speed in Enugu city. The values of the field measurements at each assigned point within the streets were used for comparative analysis to ascertain the significance of the available wind force within each street zone. The recorded wind speeds are identified as the contingent wind force (post obstruction) that these streets depend on for natural ventilation.

Validation and Reliability of the data logging instrument: The data logging instrument stores up to 12,000 readings for data analysis. Its Reliability capacities are as follows:

Velocity (FPM: feet-per minute) 98 to 4930ft/min and Velocity (MPS: meter-per sec) 0.1 to 20m/s, Air Velocity Accuracy: $\pm 3\%$ ± 0.2 m/s, with response time of 1second, Air Volume: 0 to 99,999 CFM, Temperature Range: -15°C to 60°C ; Temperature Accuracy: ± 1.1 degrees F; Humidity Accuracy: $\pm 3\%$ and Dew Point: -15°C to 60°C .

The measuring points were as follows:

Each of the Anemometers and Compass was held at each of the points (points 1-18) outside at 3m high above the ground along the middle of the street in the area for survey and totally free from obstruction.

2.3. Justification and Limitations of Study Area

Studies from Bobkova et. al (2024), classified Street configurations in cities as often structured to serve the basic conventional functions of accessibility and circulation. The configuration of the local streets selected for this study area is defined by urban planning classification (Akubue, 2019). These classifications are embedded in the structure of the high-density, medium-density, and low-density settlements on which this study relies. A medium-rise housing cluster clearly represents a high-density zone. The district selected provides the most distinct representation for the cluster classification and is also logistically feasible to navigate for the collection of required data by participants.

By confining the study to this specific area, the research is made logically practical and easily manageable within available resources for the study. Similar studies in temperate climates by Mihalakakou et. al (2026) and Andreou et. al (2012), which formed the baseline references for this study, highlighted a critical gap in the climate differences relative to the tropical environment, as is the case in this specific location, thereby justifying the research gap that this study will fill.

2.4. Field Investigations

The measurements for this study were performed at selected locations for the assumed windiest month of the year (August). The point of this is to evaluate the wind flow and wind direction across these selected points for the characteristic climate month and for 6 hours of the selected non-rainy day. Due to security preference, the daylight hours of a working weekday (8:00,

10:00, 12:00, 14:00, 16:00, 18:00) were used for the measurements. Wind velocity, air temperature, and wind direction were measured using a portable Digital Anemometer with a sensor (LCD Digital CFM, CMM Airflow Gauge Meter, accuracy = $\pm 3\% + 0.2\text{m/s}$, with a response time of 1 second) fixed on the selected points (at a height of 3m) and recorded simultaneously at exactly these hours of the measuring day of the study. Figure 6 shows the Google map of the study area as well as the designated points (points 1 to 18) where measurements were taken. Table 1 presents the summary of values recorded on the day of the study.

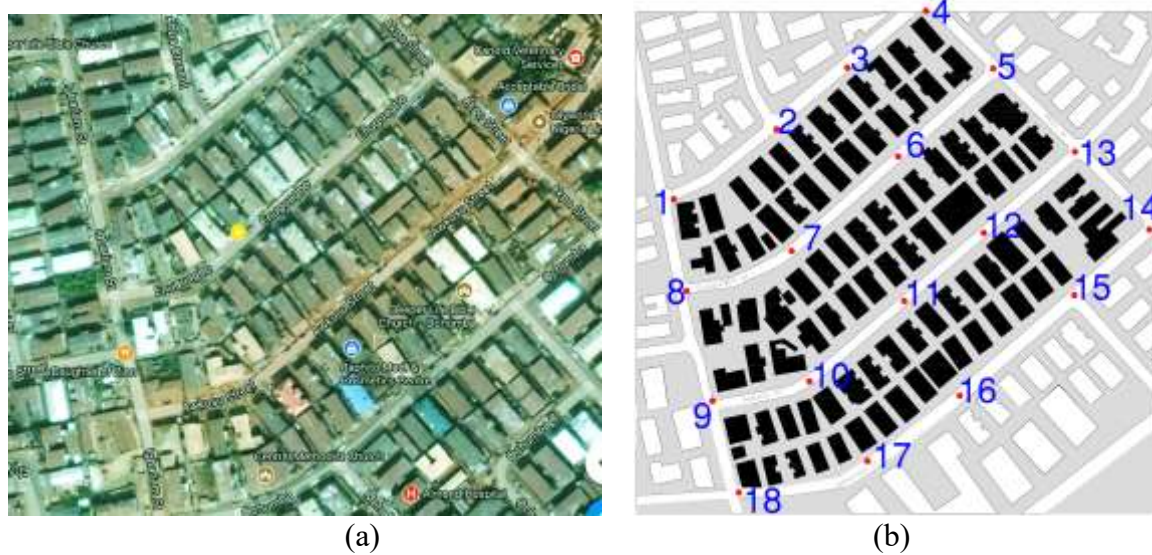


Figure 6. (a) Google aerial map of study area, (b) Aerial map showing the designated points for field measurements

Table 1. Showing the values of the measured points (H=humidity, V=air velocity, Dir=wind direction).

TIME	POINT 1			POINT 2			POINT 3			POINT 4		
	H	V	Dir	H	V	Dir	H	V	Dir	H	V	Dir
8:00 AM	80.7	1.3	SE	82.9	1.0	SE	80.0	1.8	SW	80.0	1.1	SE
10:00 AM	73.4	1.1	NE	72.3	0.6	NE	71.5	0.8	SE	70.3	1.4	NE
12:00 AM	67.1	1.2	SW	65.1	0.8	SW	64.2	1.3	SW	64.4	0.4	NW
14:00 AM	62.2	1.0	NE	62.1	0.7	SW	63.2	0.6	SE	63.5	0.8	NE
16:00 AM	72.0	0.6	SE	69.8	1.1	NE	70.1	1.3	SE	72.4	1.0	SE
18:00 AM	76.4	1.6	SW	74.3	1.3	SE	72.9	1.0	SW	73.0	1.4	NE
TIME	POINT 5			POINT 6			POINT 7			POINT 8		
	H	V	Dir	H	V	Dir	H	V	Dir	H	V	Dir
8:00 AM	80.1	0.8	SE	74.5	1.6	SE	74.7	0.8	WW	72.0	0.9	SE
10:00 AM	68.7	0.7	NW	69.4	1.1	NW	69.2	0.5	SW	66.4	0.5	SE
12:00 AM	63.1	2.3	NW	64.4	1.9	NW	66.2	1.6	WW	65.6	2.0	WW
14:00 AM	62.8	1.3	NW	66.6	1.8	NW	64.3	1.4	WW	62.6	2.1	WW
16:00 AM	70.0	1.2	SE	72.3	1.5	SW	72.9	1.1	SW	73.0	1.4	SE
18:00 AM	72.7	1.0	SE	72.0	0.8	SW	74.2	0.6	SW	74.8	1.1	SE
TIME	POINT 9			POINT 10			POINT 11			POINT 12		
	H	V	Dir	H	V	Dir	H	V	Dir	H	V	Dir
8:00 AM	74.1	0.8	SE	74.6	1.6	SE	72.8	1.2	SW	75.1	0.8	SE
10:00 AM	65.7	0.8	SE	65.1	2.2	SW	68.4	1.8	SW	67.2	1.1	SW
12:00 AM	65.7	1.2	NE	61.4	1.3	NW	61.0	1.6	NE	61.9	2.1	SS

14:00 AM	75.1	1.2	NE	66.6	1.2	NW	70.2	1.4	SW	72.0	1.7	SE
16:00 AM	76.1	1.1	NE	72.6	1.4	SW	69.8	1.8	NE	74.7	2.0	SE
18:00 AM	74.2	0.8	SE	73.0	1.8	SW	72.7	1.8	SW	73.1	1.4	SW
TIME	POINT 13			POINT 14			POINT 15			POINT 16		
	H	V	Dir	H	V	Dir	H	V	Dir	H	V	Dir
8:00 AM	72.7	1.3	SW	71.1	0.9	SW	75.2	1.4	SE	75.0	0.3	SE
10:00 AM	68.0	0.6	SW	66.9	1.1	SW	69.3	0.5	SW	69.2	1.4	SW
12:00 AM	60.9	1.5	SW	61.1	1.4	SW	64.3	1.2	SW	60.5	0.5	SW
14:00 AM	60.5	1.4	SW	64.6	1.9	SW	64.9	1.1	NW	62.3	1.0	NW
16:00 AM	68.0	0.8	SW	68.0	1.3	SW	70.1	0.8	SE	71.9	1.1	SE
18:00 AM	71.2	1.1	WW	71.8	1.0	SW	72.5	0.9	SW	73.1	0.5	SW
TIME	POINT 17			POINT 18								
	H	V	Dir	H	V	Dir						
8:00 AM	75.5	1.7	SE	74.6	0.8	SW						
10:00 AM	71.3	1.3	SW	66.8	0.8	SW						
12:00 AM	65.3	1.4	SW	62.9	1.1	NW						
14:00 AM	66.6	1.6	SW	62.1	1.3	NW						
16:00 AM	60.5	1.2	NW	62.6	0.7	NW						
18:00 AM	70.2	1.3	SW	73.0	0.8	SW						

4. Analysis and Results

For designers of buildings, it is important to forecast the microclimatic consequences at the early stages of the design process of urban development areas before construction. For humid tropical climates, the cooling effect provided by airflow across the streets could mitigate the effects of the urban heat island phenomenon. Thus, the significance of the formation of airflow within a street tunnel is essential for human health and the energy efficiency of buildings and, therefore, a pleasant urban microclimate (Givoni, 2003; Memon & Leung, 2010). In Urban streets, airflow patterns are determined by the interaction between approaching wind within the built environment. On the other hand, the pattern of an existing regional wind is changed when it flows through the streets of our built environment (Al-Sallal & Al-Rais, 2012). For this work, the streets in the study area are categorized according to the openness of its tunnels for receiving recirculated wind flow, as seen in Figure 7. The following characteristics are identified:

- Arterial Street with multiple branches (intersections) as seen in streets A&B (figure 7 and 8).
- Arterial Street with a single branch as seen in streets C&F (Figure 7 and 8).
- Continuous Street with no branches or intersections as seen in streets D&E (figure 7 and 8).



Figure 7. The six streets (A,B,C,D,E,F) used for the study, showing the measuring points 1-18

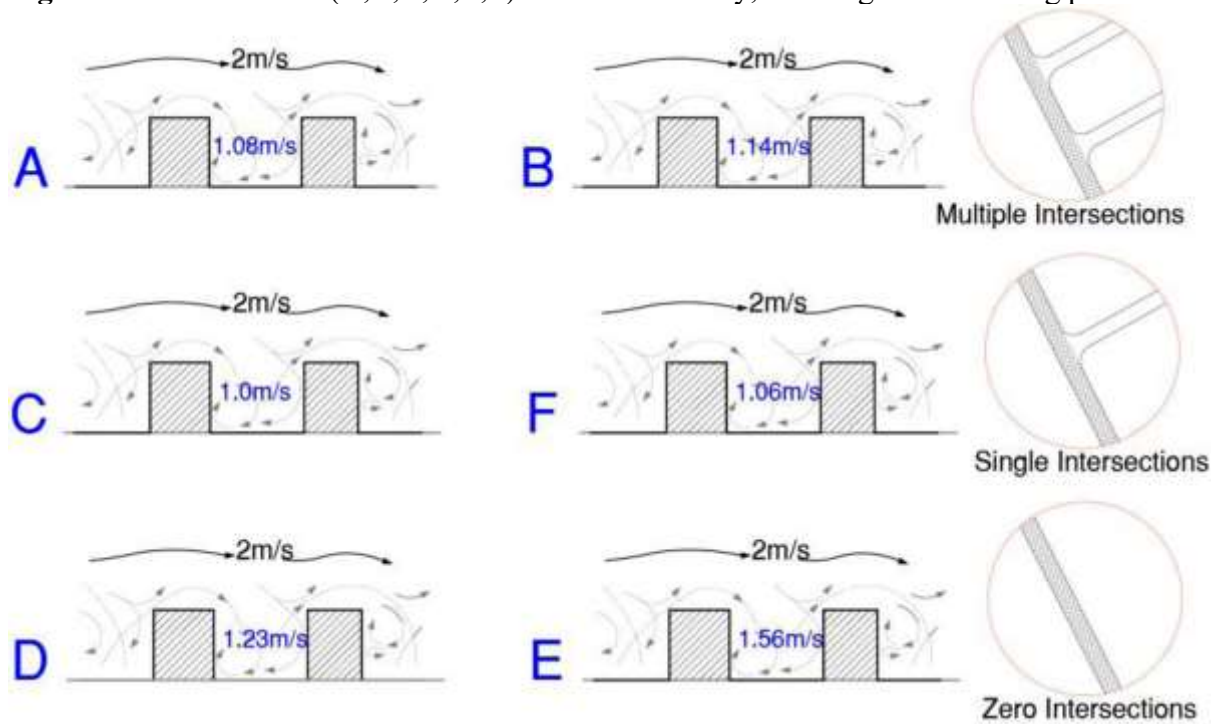


Figure 8. Section of the streets showing the average monthly wind speed for the month under study (at 2m/s) and the average wind velocity obtained in each street (A,B,C,D,E,F) during the study day.

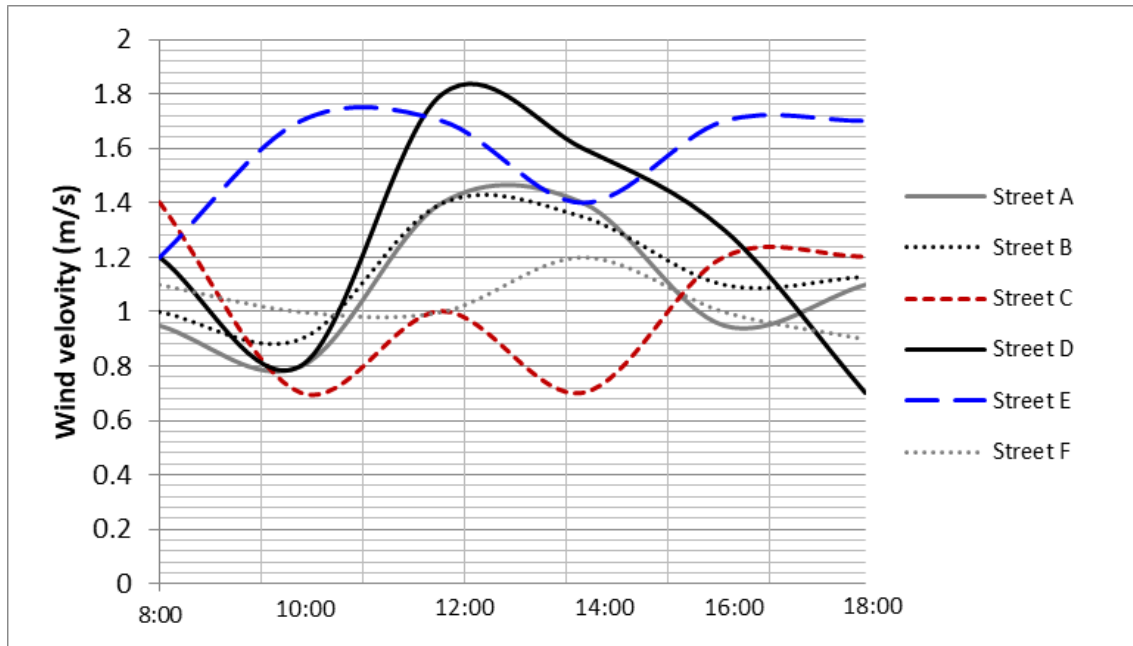


Figure 9. Graphical comparison of the wind velocity across the six streets (A,B,C,D,E,F).

While streets A, B, C, & F had several branches/intersections across their canyons, only streets D&E provided tunnels that can enable continuous airflow across the street lengths (end to end). The effects of the intersection can be seen from the recorded wind velocity values in Table 1. The continuous streets (D&E) presented higher wind speeds than the streets with branched intersections, as seen in the graph (Figure 9). This suggests that apart from the presence of street features like fence walls, trees, cars, etc., the speed of airflow within street tunnels is also affected by the presence of the intermittent intersections. Also, from the values in Table 1, summarized in Figure 10, the seasonal monsoon wind system experienced during the season was seen to be consistent with a SW flow in the continuous street patterns. Apart from apparent obstructions from street features, this result significantly suggests that the SW pattern for street orientation in this region is most effective for driving wind currents for operative ventilation not only during the Monsoon season as seen above, but also for the Harmattan season with Northeasterly flow in the same street orientation.



Figure 9. The Southwesterly Monsoon seasonal wind effect in the streets during the period of study

5. Discussion and Conclusion

As observed in the analysis of average monthly wind speeds in Figure 8, the wind velocity obtained in each street displayed significant performance of each of the street configurations studied. Whereas the streets A, B, C, and F, which were oriented against the prevailing wind directions (NE, SW), but possessed multiple branches and intersections across its canyon, recorded lower wind speeds, streets D and E, which had their tunnel orientation mostly along SW and NE axes, presented better wind speeds as their tunnels enable continuous airflow across the street lengths. This result agrees with studies by Kai & Cheuk (2026), which state that street orientation and configuration play major roles in the quality of wind flow that is available for wind-driven natural ventilation in this region. Based on these similar research findings by Ayça & Hakan (2020) and findings from this study, it is recommended that designers of residential districts within the region and across Nigeria, where natural ventilation is paramount, adopt the orientation of residential streets along prevailing wind directions as much as possible.

To improve wind-driven ventilation in such cluster settlements, understanding the airflow and other microclimatic characteristics within the streets is paramount for developing settlements that will possess energy-saving considerations and human comfort. The rapid expansion of cities creates huge areas of increased drag, with roughness and thermal forces that may significantly impact the airflow patterns. Therefore, it is vital to provide evaluation systems with an appropriate description of airflow, thermal conditions, and natural ventilation outlooks within tropical regions in collaboration with meteorological frameworks that will incorporate predictions of airflow patterns on urban scales.

Also, with its characteristic climatic conditions prevalent in high temperatures and humidity, tropical cities in regions like southeastern Nigeria should aim towards the reduction of barriers and elements that impede airflow for natural ventilation. Furthermore, the significant knowledge of the wind field elements like wind velocity and direction, as well as the temperature distribution within streets levels, will enable building and settlement designers make realistic assumptions in determining the street and block configurations, building orientation decisions and appropriate sizes of openings and fenestrations on building facades, which will boost the extent of airflow for cooling and air quality purposes in dense cluster housing schemes.

Informed Consent: Informed consent was obtained from each participant involved in this study

Conflicts of Interest: The authors declare that they have no conflict of interest.

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