International Journal of Architecture, Arts and Applications
2023; 9(1): 14-19
http://www.sciencepublishinggroup.com/j/ijaaa
doi: 10.11648/j.ijaaa.20230901.13
ISSN: 2472-1107 (Print); ISSN: 2472-1131 (Online)

Investigation of Airflow for Natural Ventilation in the Typical Medium-Rise Housing Cluster in South-Eastern Nigeria

Akubue Jideofor Anselm

Department of Architecture, Baze University, Abuja, Nigeria

Email address:
akjideofor@yahoo.com

To cite this article:
Akubue Jideofor Anselm. Investigation of Airflow for Natural Ventilation in the Typical Medium-Rise Housing Cluster in South-Eastern Nigeria. *International Journal of Architecture, Arts and Applications*. Vol. 9, No. 1, 2023, pp. 14-19. doi: 10.11648/j.ijaaa.20230901.13

Received: January 26, 2023; **Accepted**: February 23, 2023; **Published**: March 3, 2023

Abstract: Wind driven natural ventilation dependents on the microclimate conditions of its environment to thrive. In urban streets, it is influenced by the wind velocity and air temperatures factors. In this study, field experiments were carried out in selected streets of a typical medium rise housing cluster in southeastern Nigeria. The aim of the study was to understand the characteristics of air flow within this housing category, and to better examine the potentials of wind driven ventilation in this class of settlement. Wind speed and directions in the middle of selected streets were measured. Respectively, the undisturbed climatic conditions above the street canyon were recorded as well. The overall conclusion at the end of the study is that inside the streets, the potential of natural ventilation for both the single type 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 attributed to the internal interferences and reduction of the 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 the microclimates of urban surroundings. Study indicates that this condition is influenced by ambient wind flows, ambient air temperatures and solar radiation. In recent years, several studies on air circulations 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 lower levels, the urban-space structure is mostly responsible for the microclimate difference [1-5]. Those responsible for the design of urban/city spaces are often unversed with the challenges of thermal comfort that originate mainly from the distinctive connections between the urban structure and local climate conditions [6]. Consequently, it is observed that many urban settlements do not often respond to their relative climatic conditions. The general practice for urban and building designers involves the use of universal meteorological data. However, these data often originate from weather stations located in areas of the city which are unobstructed by city structures like isolated fields (such as airports and farms). Studies show that the use of inappropriate temperature and wind data/information in the production of designs of urban buildings often result in inaccuracies in the airflow performances in urban buildings [7]. Investigation into urban air flow identified the structure of urban wind-fields as characterized by the generation of a two layered vertical structure. The process of airflow from the rural areas to the urban centers requires adjustments to the boundary conditions defined by the cities. This process results in the development of what is referred to as the urban canopy sub-layer (obstructed sub-layer), which is often extended from the ground levels upwards to the topmost levels of the buildings, while the urban boundary layer (referred to as the free-surface layer) is extended over the roof tops of buildings. This canopy sub-layer possesses its own flow characteristics that is mostly driven or regulated through interactions of flow fields above the building layers and the local factors like the building geometry, street patterns, urban traffic, natural topography and other street elements such as the presence of trees and landscaping structures. Generally, it is observed that wind velocity in the canopy layer of urban fabrics is seriously decreased compared to the normal wind speed. Due to this reduction of wind velocity in the urban street structure, there are often substantial limitations to the degree of which natural ventilation can be adopted in densely structured urban environments [8]. Therefore, comprehending the flow systems and the wind speeds in urban/city street structure is essential for evaluating the natural ventilation potentials required for building designs in cities.

Due to the effects of urbanization, conditions like the heat island phenomena in cities together with global warming has contributed to the surges in the general peak cooling/electricity loads required for building indoor cooling purposes. Due to these factors, it is significant to improve building and urban space designs with regards to energy demands that consider 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 temperatures within the street levels in urban spaces often impacts on the energy load of the building's environment, therefore determining the cooling potential of available natural and hybrid ventilation systems. Concurrent thermal conditions as well as recurring vortices that are often formed at street corners frequently dominate the airflow patterns inside streets of settlements. Likewise, as solar heating of building exterior facade systems produce surface temperature variations which also influences the air temperature conditions found within the streets of settlements, such air temperature systems eventually generate local upwind along the warmer sides of building facade and form downward flows on the opposite sides [9]. Furthermore, when wind velocities are minimal, thermal effects are activated within the surrounding environment. When this occurs, buildings present warmer conditions than the surrounding air, and depending on the thermal intensity, it is either the approach winds dominate the environment or the thermal convection dominates. The degree of the resulting thermal change is dependent on several factors which may include the anthropogenic heat flux within the streets layers, sky view factor, and the albedo of the present building surfaces [10-13]. Also, the air temperatures distribution at the top of the buildings as well as on different floors of buildings inside the streets of urban settlements indicated that temperatures above the street are often higher during the day time than the corresponding temperatures recorded within the streets. Lower air temperatures within the streets were observed as the penetration of solar radiation is limited owing the depth of the street blocks. The lower temperature may be attributed to the blending phenomena formed inside the street tunnels that tend to regulate the air temperature [14]. This shows that the air temperatures in the streets of urban building settlements are mostly controlled by certain complex factors than the normal ambient surface temperatures despite the fore bearing effects of the 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 [1]. Eddy vortex are formed in front due to flow down the windward face, while behind is generated a lee eddy 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.

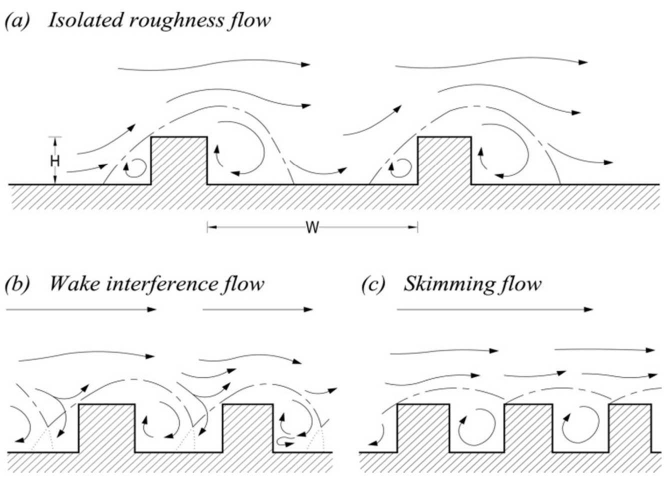


Figure 1. The different airflow systems in urban streets within and over the buildings.

The Street configurations in cities are often designed to serve the basic functions of accessibility, routing and circulation. The significant configurations of the local streets in the study area are well-defined by urban planning classification [15]. These classifications are embedded in the structure of the high density districts, 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 [16]. Enugu city's climate is categorized as tropical rain-forest with a resulting savannah. The city is located on an altitude of about 304.7 meters above sea-level, with a climate that is characteristically humid in nature. This distinctive humidity is generally oppressive between the months of March and November as indicated in figure 2 and 3 [17]. The city's mean maximum temperature is recorded as 34.9°C and its mean low temperature is 22.3°C. The yearly mean temperature is recorded as 26.7°C. The rainy and dry seasons are the only weather periods in Enugu, which is a typical condition prevalent in West Africa. Over the course of a year, the average hourly wind speed in Enugu experiences major seasonal variations. While the windier part of the year lasts for a period of 7 months (between the months of March to September), with average wind speed of 5.5m/s, the month of August is noted to be the windiest month of the year (with an average wind speed of 7.1m/s). Also a significant feature of the climate lies in the wind direction, which comes relatively from the west for a period of 10 months (monsoon season), ranging from January to November, with a peak directional percentage of 75% in the month July. Additionally the wind direction originates from the north for 2 months (Harmattan season) through the months of November to January, with a directional peak percentage of 41% in the month of January. The wind data used in this study were gotten from the Nigerian Meteorological Agency, 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 has an effect on the street microclimate [1]; 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.

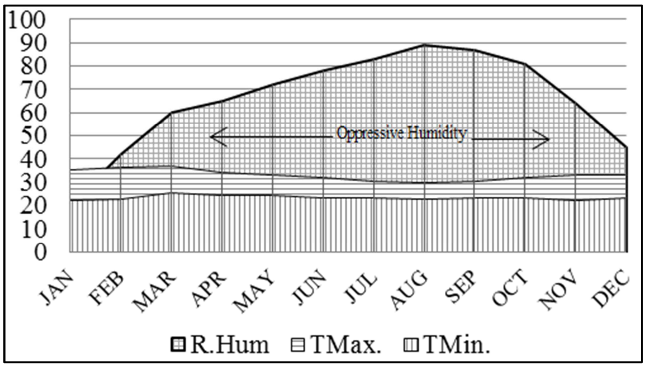


Figure 2. *Average climatic data of Enugu city.*

The district considered for the study is characterized with 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).

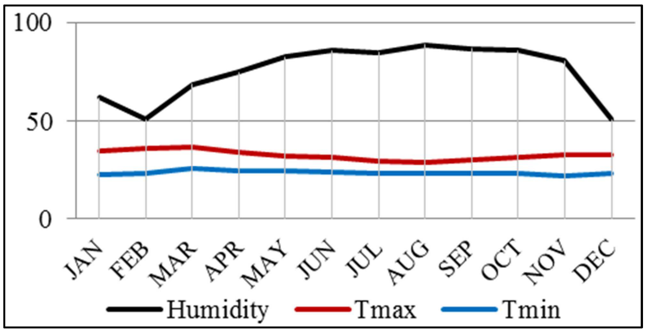


Figure 3. *Average monthly temperature and relative humidity of Enugu city during the year of study.*

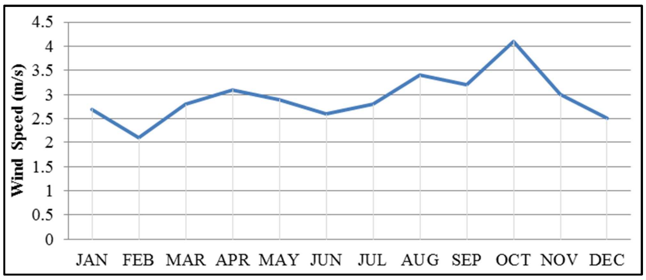


Figure 4. *Average monthly wind speed of Enugu city during the year of study.*

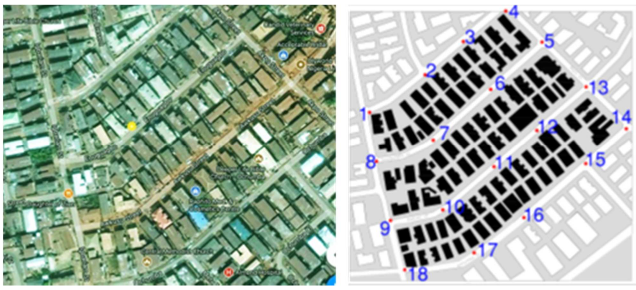
(a) (b)

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

For the purpose of this study, 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, hand held equipment were utilized, which were operated by 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, the awareness and methods of recording and documenting microclimatic elements was 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 was 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.

2.3. Field Investigations



(a) (b)

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

The measurements for this study were performed on 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 characteristic climate month and for 6 hours of the selected non-rainy day. Due to security preference the daylight hours of a working week day (8:00, 10:00, 12:00, 14:00, 16:00, 18:00) was used for the measurements. Wind velocity, air temperature and wind direction were measured using portable Digital Anemometer with sensor (LCD Digital CFM, CMM Airflow Gauge Meter, accuracy = + 3%+0.2m/s, with response time of 1 second) fixed on the selected points (at 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 study.

3. Results and Analysis

For designers of buildings, it is essential to evaluate the micro climatic impacts at the initial stages of a design process of metropolitan areas before construction. For humid tropical regions, the cooling and soothing effect provided by air-flow across the streets is essential in mitigating the effects of urban heat islands. Thus, the importance of airflow formation within street tunnels is vital for human health conditions and the general energy efficiency of buildings, hence a pleasant urban microclimate [18, 19]. In Urban streets, airflow systems are often defined by the interface between imminent winds within the cities. On the other hand, the existing regional wind-flow pattern is frequently altered as it flows across the streets of our built environment [20]. For the purpose of this work, the streets in the study area are categorized according to the openness of its tunnels for receiving re-circulated wind flow as seen in figure 7. The following characteristics are identified:

1) Arterial Street with multiple branches (intersections) as seen in streets A&B (figures 7 and 8).
2) Arterial Street with single branch as seen in streets C&F (figures 7 and 8).
3) Continuous Street with no branches or intersections as seen in streets D&E (figures 7 and 8).

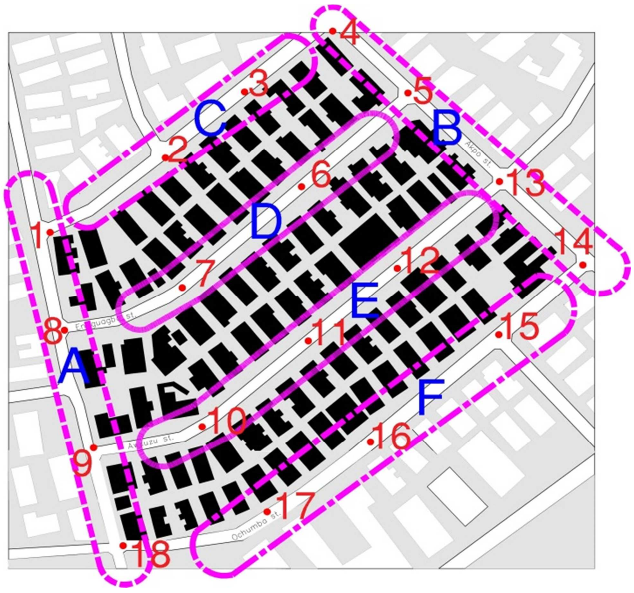


Figure 7. *The six streets (A, B, C, D, E, F) used for the study, showing the measuring points 1-18.*

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

TIME	POINT 1			POINT 2			POINT 3			POINT 4			POINT 5			POINT 6		
	H	V	Dir	H	V	Dir	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	80.1	0.8	SE	74.5	1.6	SE
10:00 AM	73.4	1.1	NE	72.3	0.6	NE	71.5	0.8	SE	70.3	1.4	NE	68.7	0.7	NW	69.4	1.1	NW
12:00 AM	67.1	1.2	SW	65.1	0.8	SW	64.2	1.3	SW	64.4	0.4	NW	63.1	2.3	NW	64.4	1.9	NW
14:00 AM	62.2	1.0	NE	62.1	0.7	SW	63.2	0.6	SE	63.5	0.8	NE	62.8	1.3	NW	66.6	1.8	NW
16:00 AM	72.0	0.6	SE	69.8	1.1	NE	70.1	1.3	SE	72.4	1.0	SE	70.0	1.2	SE	72.3	1.5	SW
18:00 AM	76.4	1.6	SW	74.3	1.3	SE	72.9	1.0	SW	73.0	1.4	NE	72.7	1.0	SE	72.0	0.8	SW

TIME	POINT 7			POINT 8			POINT 9			POINT 10			POINT 11			POINT 12		
	H	V	Dir	H	V	Dir	H	V	Dir	H	V	Dir	H	V	Dir	H	V	Dir
8:00 AM	74.7	0.8	WW	72.0	0.9	SE	74.1	0.8	SE	74.6	1.6	SE	72.8	1.2	SW	75.1	0.8	SE
10:00 AM	69.2	0.5	SW	66.4	0.5	SE	65.7	0.8	SE	65.1	2.2	SW	68.4	1.8	SW	67.2	1.1	SW
12:00 AM	66.2	1.6	WW	65.6	2.0	WW	65.7	1.2	NE	61.4	1.3	NW	61.0	1.6	NE	61.9	2.1	SS
14:00 AM	64.3	1.4	WW	62.6	2.1	WW	75.1	1.2	NE	66.6	1.2	NW	70.2	1.4	SW	72.0	1.7	SE
16:00 AM	72.9	1.1	SW	73.0	1.4	SE	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	0.6	SW	74.8	1.1	SE	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			POINT 17			POINT 18		
	H	V	Dir	H	V	Dir	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	75.5	1.7	SE	74.6	0.8	SW
10:00 AM	68.0	0.6	SW	66.9	1.1	SW	69.3	0.5	SW	69.2	1.4	SW	71.3	1.3	SW	66.8	0.8	SW
12:00 AM	60.9	1.5	SW	61.1	1.4	SW	64.3	1.2	SW	60.5	0.5	SW	65.3	1.4	SW	62.9	1.1	NW
14:00 AM	60.5	1.4	SW	64.6	1.9	SW	64.9	1.1	NW	62.3	1.0	NW	66.6	1.6	SW	62.1	1.3	NW
16:00 AM	68.0	0.8	SW	68.0	1.3	SW	70.1	0.8	SE	71.9	1.1	SE	60.5	1.2	NW	62.6	0.7	NW
18:00 AM	71.2	1.1	WW	71.8	1.0	SW	72.5	0.9	SW	73.1	0.5	SW	70.2	1.3	SW	73.0	0.8	SW

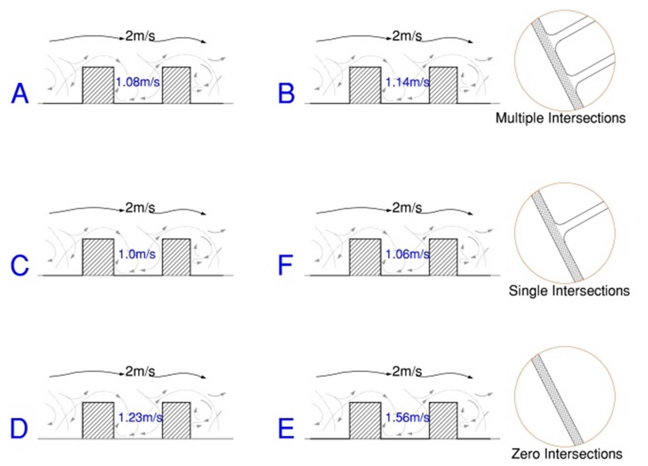


__Figure 8.__ Section of the streets showing the average monthly wind speed for the month under study (as 2m/s) and the average wind velocity obtained in each street (A, B, C, D, E, F) during the study day.

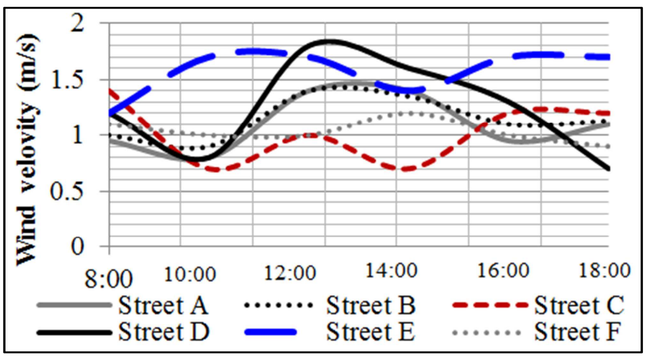


__Figure 9.__ Graphical comparison of the wind velocity across the six streets (A, B, C, D, E, F).

While streets A, B, C & F had a number of branches/intersections across its canyon, 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 are also affected by the presence of the intermittent inter-sections. Also, from the values in Table 1, whereby 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.

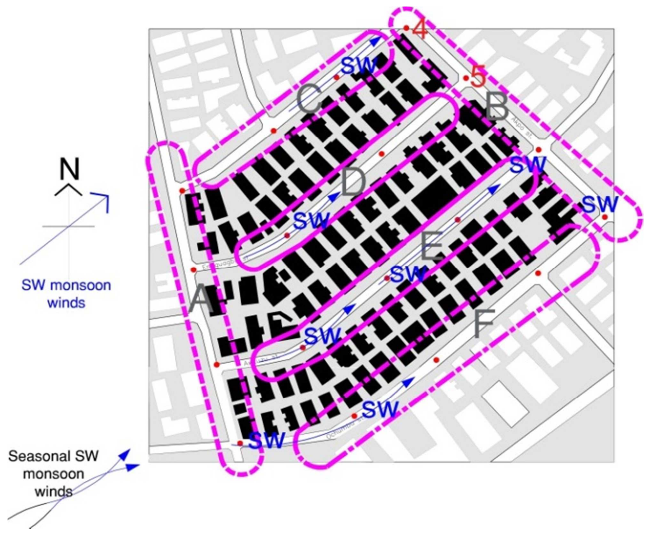


__Figure 10.__ The Southwesterly Monsoon seasonal wind effect in the streets during the period of study.

4. Conclusion

Study of natural ventilation in urban streets identifies significant impact by the microclimate conditions comprising of the ambient airflow systems, relative humidity and air temperatures. In this study, the potential of natural wind driven ventilation in a medium rise housing cluster was investigated with the aim of identifying its performance relative to street/building orientation, street configurations and seasonal wind flow patterns. It was discovered that continuous street configurations have higher potential for wind driven ventilation than the streets with multiple intersections. This lower performance of the non-continuous street configuration was as a result of the interferences brought about by the intersection (outlets), thereby causing decrease of the wind speeds within the street canyons.

In order to improve wind driven ventilation in such cluster settlements, understanding the patterns of airflow and other microclimatic features within urban streets is paramount for creating settlements that will possess energy saving properties for improving human comfort conditions. It is evident that the rises in urbanization which result in city expansions contribute immensely in creating huge areas of increased drag, with rough systems and thermal loads that may significantly affect the airflow systems. Therefore, it is vital to propose appraisal systems with accurate depictions of air-flow, natural ventilation and relative thermal conditions in tropical regions, in collaboration with meteorological schemes that will enable forecasts of air-flow patterns on a larger urban scale.

Also, with its characteristic climatic conditions that are made up of predominantly high temperatures and humidity, cities in tropical regions like the southeastern Nigeria, should focus on reducing street objects that pose as barriers against airflow for natural ventilation. Furthermore, the significant knowledge of the wind field elements like wind velocity, wind direction, and 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 needed for cooling and indoor air quality purposes in dense cluster housing schemes.

References

[1] Oke, T. R. (1988). Street design and urban canopy layer climate. Energy and Buildings, 11, 103–113.

[2] Nakamura, Y; Oke T. R. (1988). Wind, temperature and stability conditions in an east-west oriented urban canyon. Atmospheric Environment, 22, 2691–2700.

[3] Bourbia, F.; Boucheriba, F. (2010). Impact of street design on urban microclimate for semi-arid climate (Constantine). Renewable Energy, 35, 343-347.

[4] Andreou, E.; Axarli, K. (2012). Investigation of urban canyon microclimate in traditional and contemporary environment. Experi-mental investigation and parametric analysis. Renewable Energy, 43, 354-363.

[5] Yoshida A.; Tominaga K.; Watani S. (1991). Field measurements on energy balance of an urban canyon in the summer season. Energy and Buildings, 15&16, 417–23.

[6] Gomez, F.; Perez, A., Valcuende, M., Matzarakis, A. (2013). Research on ecological design to enhance comfort in open spaces of a city (Valencia, Spain). Utility of the physiological equivalent temperature (PET), 57, 27-39.

[7] Geros, V., Santamouris, M., Tsangrassoulis, A., Guarracino, G. (1999). Experimental evaluation of night ventilation phenomena, Energy and Buildings, 29, 141–154.

[8] Santamouris, M. (2001). Energy and climate in the urban environment. James and James Science Publishers, London, pp. 412.

[9] Georgakis, C., Santamouris, M. (2006). Experimental investigation of air flow and temperature distribution in deep urban canyons for natural ventilation purposes. Energy and Buildings, 38, 367-376.

[10] Oke, T. R. (1987). Boundary Layer Climates. Routledge, vol. 2, Chapt. 8, 262–303.

[11] Tseng, Y. H.; Meneveau, C. (2006). Parlange, M. B. Modeling flow around bluff bodies and urban dispersion using large eddy simulation. Environmental Science Technology, 40, 2653–2662.

[12] Kim, J. J., Baik, J. J. (1999). A numerical study of thermal effects on flow and pollution dispersion in urban street canyons. Journal of Applied Meteorology, 38, 1249–1261.

[13] Fernando, H. J. S. (2010). Fluid mechanics of urban atmospheres in complex terrain. Annual Review. Fluid Mechanics, 42, 365–389.

[14] Sakakibara, Y. (1996). A numerical study of the effect of urban geometry upon the surface energy budget. Atmospheric Environment, 30, 487–496.

[15] Akubue, J. A. (2019). Effects of Street Geometry on Airflow Regimes for Natural Ventilation in Three Different Street Configurations in Enugu City. Strategies of Housing Design, Intechopen, 2, 11-26.

[16] Ofomata, G E. (2002). A Survey of Igbo Nations. Africana first publishers, Onitsha Nigeria, pp. xxiv-703.

[17] Reifsnyder, W., Darnhofer, T. (1989). Meteorology and agroforestry. World Agroforestry Centre. Nairobi, pp. 544.

[18] Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N. (2003). Outdoor comfort research issues. Energy and Building, 35, 77-86.

[19] Memon, R. A., Leung, D. Y. C. (2010). Impacts of environmental factors on urban heating. Journal of Environmental Sciences China, 22 (12), 1903-1909.

[20] Al-Sallal A., Al-Rais L. (2012). Outdoor airflow analysis and potential for passive cooling in the modern urban context of Dubai. Renewable Energy, 38, 40-49.