© 2023 IJNRD | Volume 8, Issue 5 May 2023 | ISSN: 2456-4184 | IJNRD.ORG

IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

A study of effects of wind flow on different building forms for hostel designs in tropical Nigerian climate

[1]Akubue Jideofor Anselm

[1]Associate Professor
[1]Architecture Department
[1]Baze university Abuja, Nigeria

Abstract : In the tropical Nigerian environment, the major weather influence that poses a problem to indoor thermal comfort is the hot and humid climate. As the prevalent economic conditions of the country may not allow for full energy-active air conditioning that is necessary to maintain appropriate indoor thermal environments during the day and night times in all public Universities and colleges, the only other option applicable in hostel designs is the use of natural and passive methods. Natural or passive ventilation is highly dependent on the regional wind flow systems. A study was thus initiated to investigate the influence of different configurations of building forms typically utilized in the design of hostel buildings in the hot and humid climate of Nigeria. This paper presents the results of the study of two typical building typologies using data from field measurements. The values will also be used to simulate the wind flow pattern and thermal conditions in these building forms using PHOENICS-VR simulation software in order to view the atypical behaviour of air movement for passive ventilation in these buildings. The wind movement around the selected building typologies indicated a significant behaviour which concludes that building orientation is essential for the effective adoption of wind driven natural ventilation.

***Keywords* - Hostel design, natural ventilation, passive ventilation, tropical designs, airflow simulation**

1. INTRODUCTION

Buildings in tropical climates of the world are constantly exposed to solar radiation, high temperatures and humidity almost daily. Owing to the impacts of modern development, these conditions are amplified by the heat island effects in cities, which have contributed to the increase of the peak cooling loads and electricity load necessary for building space cooling purposes. The consequence is that buildings and built environment designers must optimize building and urban space designs in terms of sustainable options that consider local microclimates. In terms of natural ventilation for the built environment, it is noteworthy that wind pressures significantly affect ventilation performance [1]. However, due to the abundance of urban structures, the wind pressures are often reduced as it reaches the urban street levels. Because of this reduction of the wind pressure in urban street structure, there is significant limitation to the degree of which natural ventilation can be applied in urban environments [2]. Natural ventilation on the other hand, is hugely dependent on micro climate conditions of urban surroundings. Study shows that this condition is affected by the ambient wind flows, solar radiation and surrounding air temperatures. Following these conditions, building designers are tasked with aiming to minimize heat gain indoors and maximizing evaporative cooling, for the thermal comfort benefits of occupants. In order to achieve this objective, buildings in this part of the world depend on sustainable design ideas focused on adopting appropriate shapes and forms that would be responsive to its microclimate conditions, coupled with proper orientation for adopting passive ventilation. This also entails the creation of buildings intended for passive energy utilization with minimal use of active energy for economic viability [3]. In doing this, it is necessary to adopt parameters such that the differences between the indoor space condition and the outside environment are minimized [4]. The selection of built space operating parameter, such as relative humidity, air and radiant temperatures and air velocity impacts both occupant comfort and building energy consumption. However, in most buildings in Nigeria, too much emphasis is often laid on socio-cultural and economic factors compared to the emphasis given to the above mentioned criteria [5]. This is easily felt in the deprived attention given to the building forms and the microclimate created by the influence of these forms in building design approaches adopted in the country. On the other hand, the vast majority of well built Nigerian contemporary buildings are dependent on active energy for mechanized cooling and ventilation. Such design philosophies impacted on building forms and typologies, as most buildings seem to be replicas of houses seen in European countries both in their shapes, forms and materials used, despite discernable differences in climatic conditions. Moreover, despite significant climatic differences in various cities within the country, typologies, forms and shapes of buildings yet still tend to look alike. The result being that these significant features coupled with inappropriate orientation end up minimizing the air movement for passive ventilation and indoor space cooling targeted towards improving the physiological comfort of occupants [6].

2. Background of Study

2.1 Overview of student's hostel conditions in Nigeria

It is evident that about 80% of Nigerian university students live in hostels which are either privately owned or provided by the Institutions. A student hostel building is typically set as a home for the students to live, interact and study amongst other functions. For these hostels to ideally function as a home, the building must also satisfy other basic human comfort needs. An evaluation of the standards of living and quality of the physical environments in the case of Nigerian college hostels, reveal extreme shortage of essential amenities for modern living. Crucial among these is the quality of indoor thermal comfort elements. In the hot humid environment today, the major challenge to indoor thermal comfort conditions is the factor of ventilation of enclosed spaces. Thus the obvious poor conditions of environmentally conducive living in the student hostels in many Nigerian schools has raised doubts and fears as to the possibility of adequately providing a design that will charter for such needs in a tropical environment without resorting to the use of mechanical equipments. This situation led to a number of mandatory measures instituted by the National Universities Commission (NUC) aimed at not only reducing the problem caused by poor ventilation, but also at improving thermal conditions due to the ineffective passive control systems applied [7].

The NUC has the following guidelines for university and college students' hostel designs:

1. Proposed the design of hostels to be based on a module of 100 rooms in a block of two or three floors.
2. Restrictions to occupants, with provision for maximum of four people in a room with a minimum of 5-7m² per person and a maximum of six hundred people housed at same time in a building.
3. Definition of a Bed space to be an ample space for a standard 1.8m x 0.75m bed, with a desk space for studying and a personal computer, bookshelves and 0.537m wide 2.850m high built-in wardrobe provided for each student.

From investigations around the nearby campuses, student hostels hinged on the NUC standards was found to be very reasonable in cost as regards to investment returns, however post occupancy investigations of most of the college hostels still present the challenges of thermal comfort.

2.2 Climate classifications in Nigeria and their effects on building design

Climatic classifications necessary for building design must have combined values of temperature, relative humidity, solar radiation temperature and wind velocity. Most classifications are based on one or two of the above mentioned [8,9,10,11]. This suggests that building designers requires a greater awareness of the effect of the above mentioned conditions to produce effective building designs that are climate responsive. Naturally, the tropical areas of the world are generally referred to as the overheated regions [12]. For the purposes of building designs, the overheated regions of the world are classified into three major categories namely:

- Hot/warm and arid/semi arid regions,
- Warm and humid regions, and
- Temperate, arid and humid regions.

Nigeria located on 4° and 14° N strictly falls within the area labeled as a warm–humid region. The climate warm-humid climate of Nigeria, just like those of other countries in sub-Saharan West Africa, is controlled by two main factors [13], being:

1. The daily heating and cooling of the land mass of the Sahara Desert, and
2. The heating and cooling of the large body of water in the Atlantic Ocean.

Owing to these, there are two distinctive seasons in Nigeria, the dry season that lasts from November to March and the rainy season lasting from April to October. The variation of climate as one move from the coast parts to the northern parts of the country and the climate of a specific location varies with the time of the year, latitude of the location and landscape [14]. There is however a lack of significant climatic data for building designs in most cities of Nigeria and researchers both foreign and local, has attempted to classify the climate of West Africa. Most of the early classifications have been based on temperature and precipitation only. The most notable being the Thornthwaite's and Papadaki's systems of classification of the Nigerian climate [15]. Figure 1 below shows the major climate classes in Nigeria with the south-eastern (field study area) location falling into the zone-4 class (hot-humid).

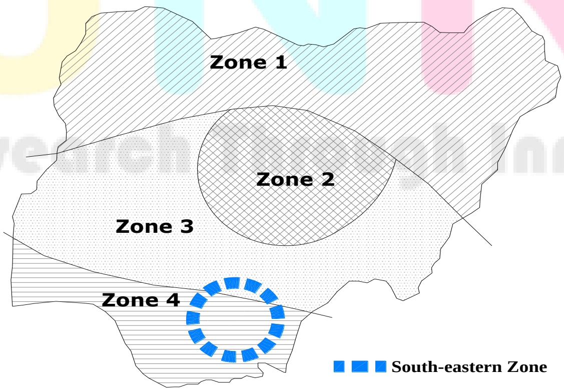


Figure1. Map of Nigeria showing the major climate zones

The major characteristics of typical hot-humid climate are:

1. Two distinctive seasons, which are the dry and the wet. While the dry is characterized by hot dry days with little rainfall, the wet on the other hand produces torrential rains filling the atmosphere with moisture generating a hot and humid environment.
2. Relatively high temperatures observed throughout the year with average annual maximum temperature in the ranges of 31ºC.

3. Minimum seasonal temperature variations.
4. Low diurnal (day/night) temperature ranges.

2.3 Defining thermal indices

All the climatic conditions mentioned above are believed to strongly affect the indoor thermal environment within the southeastern region. However, given these climatic conditions, the need for effective passive control of the climate elements must be considered when designing buildings in this region. Buildings designed with climate considerations naturally aim at keeping microclimatic conditions in dwellings within the comfort limits, irrespective of the external conditions.

Thermal index measures the stress imposed by external climate conditions on buildings and predicts the optimal environment needed for comfort within buildings. This provides architects with scientific premise for evaluating comfort. The knowledge of the thermal stress is necessary for the design of walls, roofs and shading devices on buildings, however the choice of the most appropriate index is often challenging. The selection criteria fall within the range of 30 indices that are valid only for certain conditions. What is then needed is not only a scientific selection, but also a validation of the thermal index most appropriate for a particular climate, in this case that of southeastern Nigeria. The most appropriate index should not only accurately measure and predict thermal stress but should also be based on easily available environmental data. [16].

The climate index for determining comfort in dwellings is dependent on six major factors. These are:

- Ambient air temperature
- Humidity (relative humidity or vapor pressure)
- Radiation (mean radiant temperature)
- Air movement (air velocity)
- Intrinsic clothing
- Level of activity.

Other minor factors that may have significant effect on thermal comfort are age, sex, body shape, state of health, ethnic grouping, diet, sleep, color of clothing, acclimatization, availability of fresh air, transients, color of a space enclosure and noise [17]. An indication of the relative importance of these other factors is the fact that when all the six major factors are within an acceptable and optimal range, then about 70% of the population will be comfortable. Understanding how these different variables affect thermal comfort has been used to formulate thermal indices or thermal scales that indicate the effects of combining the different variables on comfort. An ideal index may accurately predict the consequences of any combination of the six major factors affecting comfort as listed above. It should likewise be applicable both indoors and outdoors and be capable of indicating the degree of discomfort. The Universal thermal climate index (UTCI) records the values of stress in the following categories; above 46° (extreme heat stress), 38° to 46° (very strong heat stress), 32° to 38° (strong heat stress), 26° to 32° (moderate heat stress), 9° to 26° (no thermal stress), 9° to 0° (slight cold stress) 0° to -13° (moderate cold stress) -13° to -27° (strong cold stress), -27° to -40° (very strong cold stress) and below -40° (extreme cold stress) [18].

3. JUSTIFYING OUTDOOR TEMPERATURE, AIR MOVEMENT AND HUMIDITY IN DEFINING THERMAL CONDITIONS OF BUILDING OCCUPANTS

In this paper it is important to outline how outdoor temperature, air movement and humidity affect the thermal comfort of building occupants in the hot-humid climates. This is vital in determining the significance of the study of wind flow and its impacts on building ventilation and indoor cooling purposes.

3.1 Outdoor temperature

The linear relationship derived between comfort temperature and mean outdoor temperature for free-running buildings is:

$$T_c = 0.534T_o + 12.9 \qquad \text{(equation 1)}$$

where T_c is the comfort temperature and T_o is the mean outdoor temperature [19].

This relationship offers building designers the possibility to predict the temperature which will be comfortable in free-running buildings by calculation taken from the monthly mean outdoor temperature given by meteorological records. The results for Enugu state (southeastern Nigeria) using data from [20] is presented in Figure 2. The figure shows the comfort temperature placed over the outdoor temperature to indicate the temperature differential which the building must achieve to remain comfortable indoors.

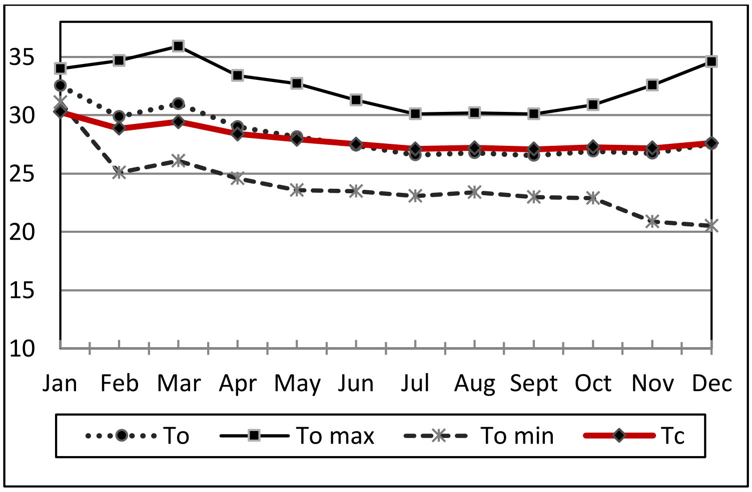


Figure 2. Comfort temperature Tc for Enugu (south eastern Nigeria) calculated from the outdoor temperature To using Eq. (1). To is calculated as the mean of the monthly mean maximum (To max) and minimum (To min).

3.2 Air movement

In tropical climates, the air movement values are considered as important factors in determining comfort. A theoretical analysis suggests that where the air velocity is above 0.1 m/s and fairly constant, this can be equivalent to raising the comfort temperature by:

$$7 - \frac{50}{4 + 10v^{0.5}}\,^{\circ}C \qquad \text{(equation 2)} \quad [19]$$

There are assumptions made for this this equation, but the result is not particularly sensitive to the accuracy of these assumptions. While considering comfort in hot-humid climates and because Eq. (1) is intended to give a target temperature, and not an instantaneous temperature, what may be required is a simple set of rules that can be used to modify the predicted comfort temperature to account for air movement and high humidity which enables architects and designers to provide a comfortable environment. In developing the relationship in Eq. (1) Humphreys [22] attempted to give the relationship where air movement can be assumed to be smaller (≤0.1 m/s) and relative humidity be standardized at 50%. However, numerous studies of the effects of temperature, humidity and air movement on the human body in hot climates exists and this was used to determine the relative effects of these factors on people's subjective response to heat [23]. The effect of air movement and relative humidity are particularly important in hot climates where the heat lost by evaporation often prevails. The comfort limits of naturally ventilated spaces in the tropics have been estimated at between 26° - 31°, with wind speed of 1.0m/s [24]. Higher wind speeds are often required to maintain thermal comfort at higher temperatures, obtainable in the hot humid climatic zones [25]. These Natural ventilation effects can be induced by wind pressure, temperature difference (Stack-effect), humidity difference (cool-tower effect) or a combination of any or all of these three [26].
Its noteworthy that buildings in urban areas are closely spaced, which makes air flow through the interior difficult to be achieved [27]. Usually, houses on upper floors have more possibility for air flow, particularly if there is cross ventilation than those on lower levels. Thus, the only reliable and cost effective means of air flow is in the use of the electric fan which has been seen to have a significant contribution to occupant comfort in the tropics.

3.3 Humidity

Whilst the impacts of humidity has been investigated in a number of field surveys in hot climates and found to have a significant effect on comfort temperature, the extents of the impact is generally small in most cases. The first problem for the analysis of the effects of humidity in the humid-tropical region is to decide how humidity should be measured. The relative humidity of the air is the best known measure and has been used in most studies of thermal comfort. Relative humidity is considered a relative measure and is therefore highly dependent on air temperature, especially at high temperatures.

3.4. Review of major thermal comfort elements in the hot-humid south eastern Nigerian region.

The three major climatic elements that influence thermal comfort comprise of temperature, humidity and air movement. Air movement has always been known to improve human thermal comfort sensations significantly. However in passively controlled environments, natural-ventilation induced airflow remains a major feature of thermal comfort control. To fundamentally examine the indoor comfort conditions and its influencing factors in the tropical Nigerian hot humid student's hostels, experiments were carried out within the most humid season of the year. A study of the annual temperature, humidity, wind flow patterns in the south-eastern region (Enugu city) presented significant consistency in the patterns over the years. According to meteorological data (summary shown in Figures 3, 4&5), the months of July to October presented the highest humidity levels with significant wind flow pattern. The experiment thus was to identify the extent of wind flow that is captured into the room spaces.

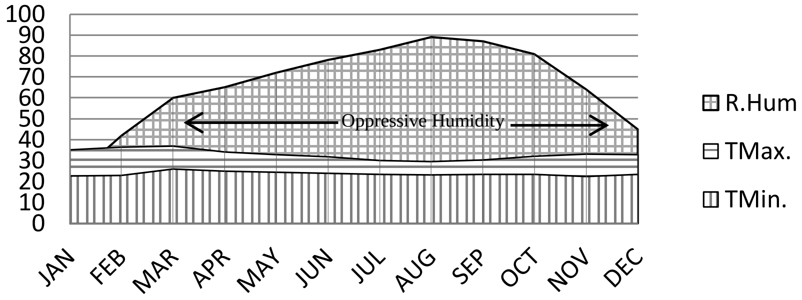


Figure 3. Average climatic data of Enugu city

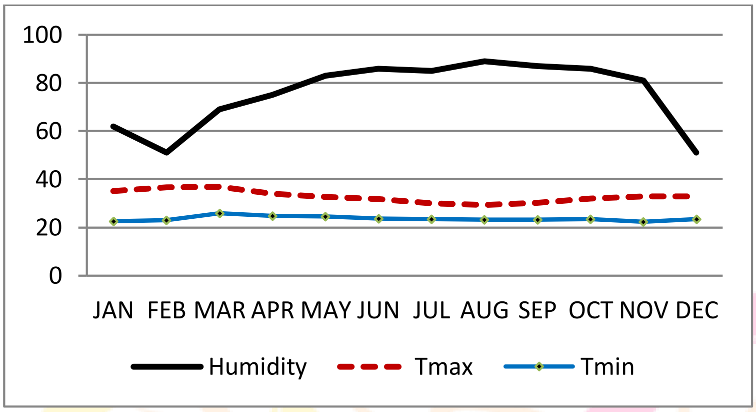


Figure 4. Average monthly temperature and relative humidity of Enugu city during the year of study

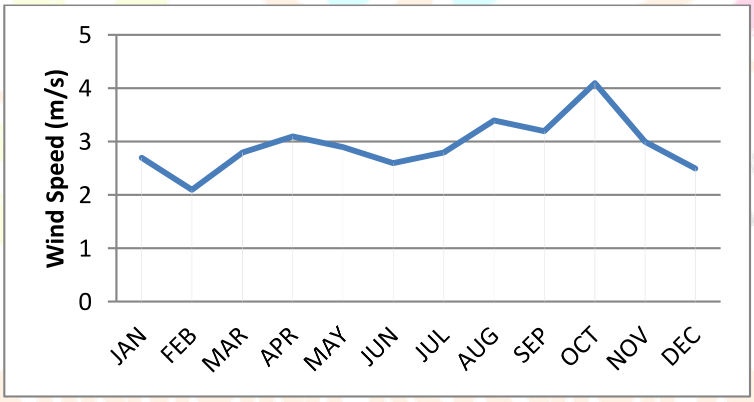


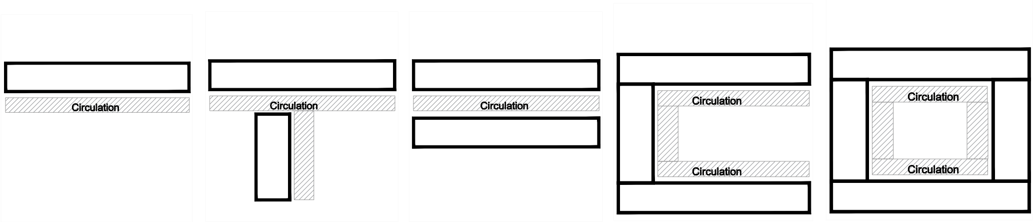
Figure 5. Average monthly wind speed of Enugu city during the year of study

4. Study Methodology

Having established the significance of the thermal comfort elements as stated above and for the purposes of this study, the conditions affecting wind driven natural ventilation for indoor use in mostly hostel building in a tropical environment is discussed. The significance is in identifying the behaviours of wind flow around buildings of different forms in order to ascertain the relationship between airflow and building forms for purposes of indoor ventilation. To ascertain the effects of wind flow on different building forms in the hostel buildings in Nigeria, an existing student residence which contained two distinct building forms was selected. The students' residential district of the University of Nigeria Enugu Campus was used for the study. Field investigation was conducted and measurements of air temperatures and air velocities were taken around these buildings at a height of 12.6m using Vane anemometer. The measurements were taken in order to record significant wind movement for the typical seasons of the Monsoon (SW wind direction) measured in the month of July and Harmattan (NE wind direction) measured in the month of September. Likewise, indoor airflow (air velocities) was measured at selected centrally located rooms in each building (at the height of 2m of the ground floor rooms) for the two hostel building typologies used for the study in order to identify the impact of the outdoor wind flow in the internal student room spaces for the different seasons. Furthermore, the data was used to run a CFD simulation to graphically show the wind behaviour around these building forms.

5. Evaluation of wind flow on existing hostel building typologies in the hot-humid South-eastern Nigerian region.

Studies across the colleges and university campuses across Nigeria identified the adoption of five major Hostel Building typologies. The adoption of these building types for students' hall of residences was attributed mostly to regional and cultural influences in communal accommodation. Most of the characteristics are attributed to the ease of assembly of the living units and accessibility to common shared facilities [28]. Figure 6 below enumerates the typical typologies for Student Hostel Designs in Nigeria.

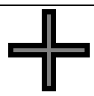
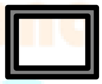
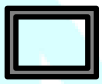


(a) (b) (c) (d) (e)

Figure 6. Typical Typologies of Hostel Buildings in Nigeria
(a) Linear type, (b) 'T-shaped' Polygonal type, (c) Double loaded Linear type, (d) 'U-shaped' Polygonal type, (e) Courtyard type

Hostel designers and developers in Nigeria often attach the value of the hostel shape and form to the element of population and housing capacity. While it is noteworthy that the level of technological development in the cities hinders the capability of producing higher rise buildings (for more accommodation purposes), the typical lower rise buildings (1-3 floors high) which can be operated without mechanized elevators are the preferred housing options. Owing to these, building types in the form of the larger Polygonal or Courtyard typologies are often preferred than the Single-Linear typologies. Table 1 below presents the significant preferential considerations for selection of each typology mentioned above.

Table 1. Design considerations for selection of major Hostel Building typology

Typology classification (as in Figure 6)	Configuration	Accommodation capacity	Development Preference
A		Lowest	Low preference
B		High	Moderate preference
C		Low	High preference
D		High	High preference
E		Highest	Highest preference

5.1 Review of wind flow pattern on buildings

Effective natural ventilation is dependent chiefly on the micro climate conditions of its location, as well as on the ambient wind flow, solar radiation and air temperatures of its environment. The building forms and geometry of existing elements within the environments is often regarded as the most significant parameter responsible for the microclimate variation at the micro level [29]. Airflow conditions occur due to vertical structure in two layers. On the one hand is the air coming from the less dense environments to the populated areas. When this happens, the wind flow naturally adopts existing boundary conditions created by these building forms and geometry of existing structures. The result is the formation of an obstructed sub layer, which extends from the natural ground surface to the buildings. The newly generated flow sub layer possesses specific characteristics which will be distinguished by the boundary between the air flow above building tops and the prevailing environmental conditions within the location such as building forms (figure 7). Owing to this phenomenon, the wind velocity in this layer of the environment is generally decreased compared to the natural and undisturbed wind flows, and this reduction of the wind speed is significant in determining the extent of natural ventilation that is available in dense urban environments [30]. The shapes and forms of different building geometry therefore affect the patterns and extents of wind flow around building, which in turn determines the extents of natural ventilation that may be achieved.

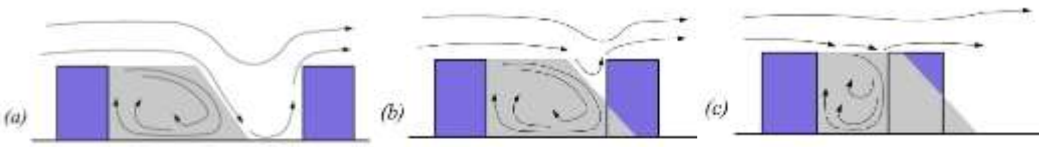


Figure 7. Schemes of airflow within buildings in urban environment layers. (a) isolated flow; (b) interference flow; (c) skimming flow [31].

5.2 Analysis of wind flow on the different building forms

Studies have further shown that airflow in dense urban settings can develop into two regions which are the recirculation region and the ventilated region as shown in figure 8. Studies also identified that the flows in these regions are dependent on building forms and geometry [31].

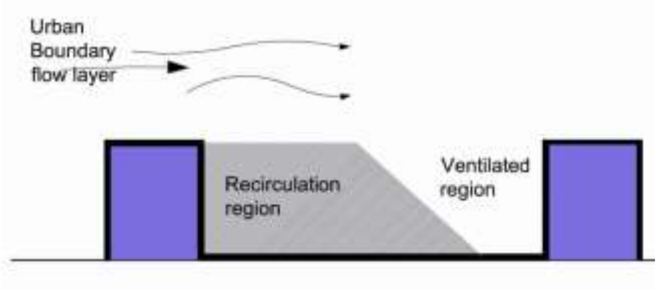


Figure 8. Regions of Airflow showing the Ventilated and Recirculation regions of flow

A further review of the typical building forms used in hostel designs in Nigeria, indicates various flow characteristics owing to the building forms. Taking into account the annual wind flow patterns, the building configuration and orientation often determines the extents of airflow available for ventilation purposes. As shown in Figure 9 below, while the linear typology (in appropriate orientation) provides a better configuration for capturing wind flow for effective ventilation, owing to its single line room arrangements (with only a single loaded corridor), the courtyard typology with four linear sides only provides one effective side at a time of the seasons to regional airflow. Despite its high potential for effective ventilation more than the other typologies, the Linear (Single loaded corridor) is often the lesser preference for designers of Hostel Buildings in Nigeria owing to the low accommodation capacity when adopting this option.

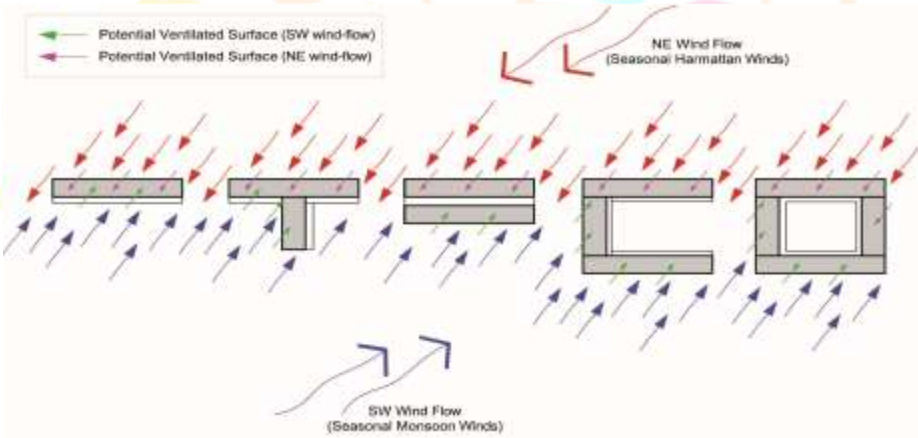


Figure 9. Performance of wind flow for activating natural ventilation around the five different building forms (Hostel typologies)

5.3 Analysis of wind flow on Existing Hostel building forms

This study identified five major building forms used in hostel developments in Nigeria. Having identified these typical typologies, this paper further examines the behaviour of wind flow for Natural ventilation around the existing building forms. The objective is to ascertain the ventilation potentials of different building geometry when impacted by regional airflow elements. Having selected the south-eastern region where both Monsoon winds and Harmattan winds are prevalent, the University of Nigeria Enugu campus Student's residence was found suitable for this study. This is because of the identification of two distinctive building forms within the same location (Figure 10), sharing same microclimatic environment that will be ideal for comparative assessment of the wind flow behaviours.

Figure 10. Google map showing typical hostel building typologies at the Student's Hostel district, University of Nigeria Enugu Campus (UNEC)

The two major typologies identified as shown in figure 10 are the graduate and post graduate students (see figure 11). They include a 'Z' winged building form for the PG residences (the Post graduate students' hall) and a typical 'Courtyard' typology for the UG residences (the Undergraduate students' hall).

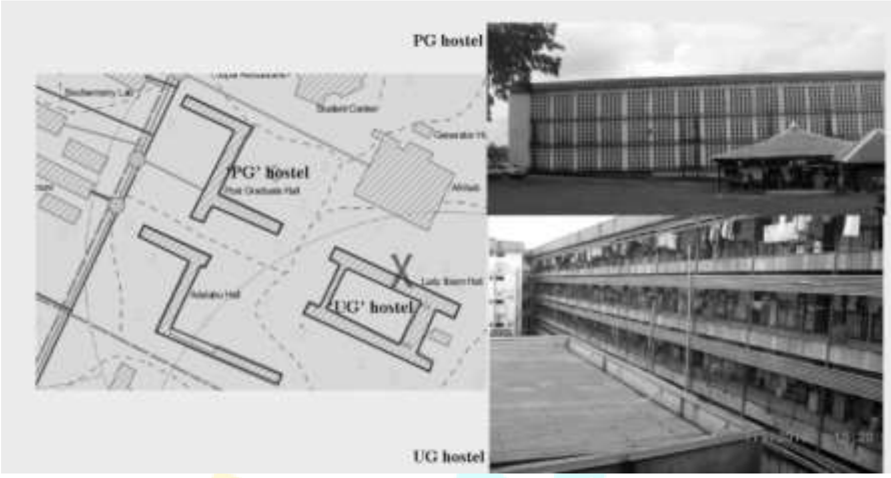


Figure 11. The two main hostel types in the University of Nigeria

The 'Z' winged hostel building form was selected because of its open north and eastern wing orientation, which displays a good premise for evaluating the natural ventilation course respect to the seasonal wing patterns on both the north facing and east facing wings. On the other hand, the 'Courtyard' building form was selected in order to compare the conditions obtainable in the two typologies with regards to natural wind flow paths and building orientation. The typical floor plans of the 3 floor buildings are shown in figure 12.

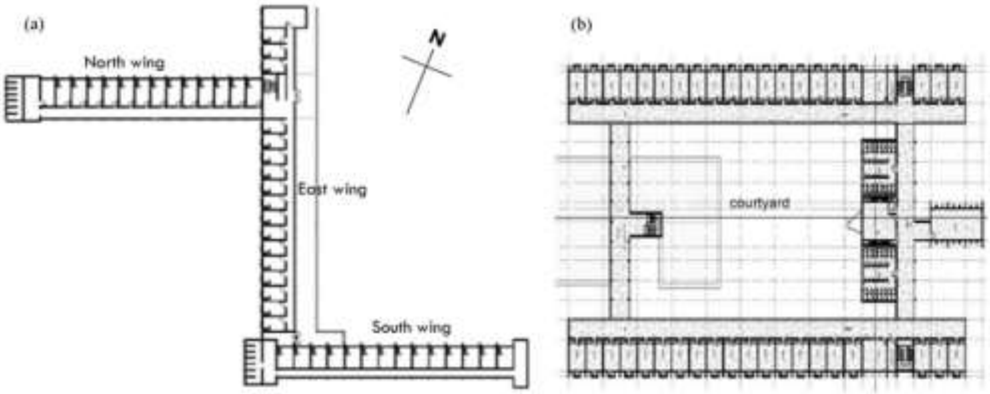


Figure 12. Typical floor plans of the two main hostel typologies
(a) PG residence. (b) UG residence

From study of the two typologies, the major design philosophy that defined the method of passive control applied by the designers for effective thermal comfort could be found mainly in the use of the courtyard design for the Undergraduate hostels and the application of screen walling for privacy of the circulation corridor, while allowing for natural ventilation in the Postgraduate hostels as seen in figure 13.

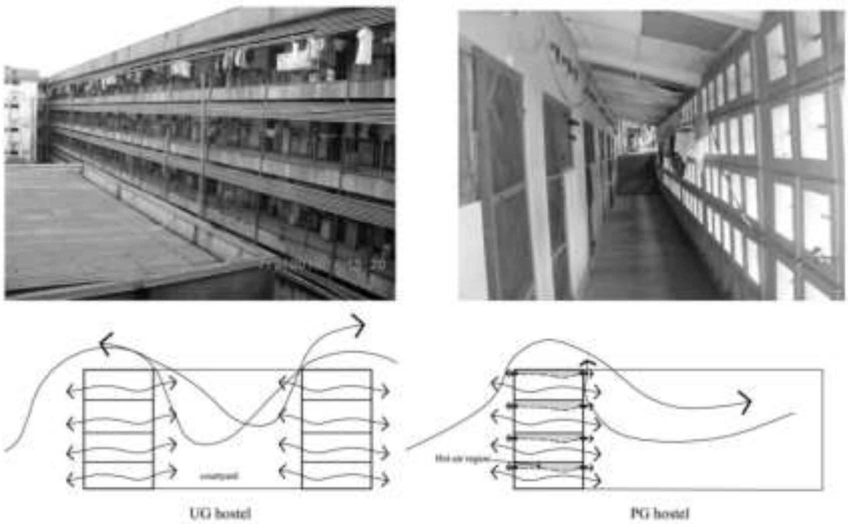


Figure 13. Strategy for passive control and natural ventilation applied by the designers in the different hostel buildings

To fundamentally examine these airflow behaviours and its influencing factors in the tropical Nigerian hot humid student's hostels, experiments were carried out within the most humid season of the year. A study of the annual temperature, humidity, wind flow patterns in the South-eastern region presented significant consistency in the patterns over the years. According to meteorological data (figure 3,4,5), the months of July to October presented the highest humidity levels with significant wind flow pattern. The experiment thus was to identify the extent of wind flow externally (around the buildings) as well as airflow captured into the room spaces of these distinctive building forms. Measurements for indoor conditions were taken in the central rooms on the 1st floor of each of the hostel buildings. The measuring points and measured parameters are summarized in the table 2 below. A one hour logging interval was used for all units. The parameters recorded include ambient temperature, air temperature, humidity, wind speed and direction.

Table 2. Measured parameters

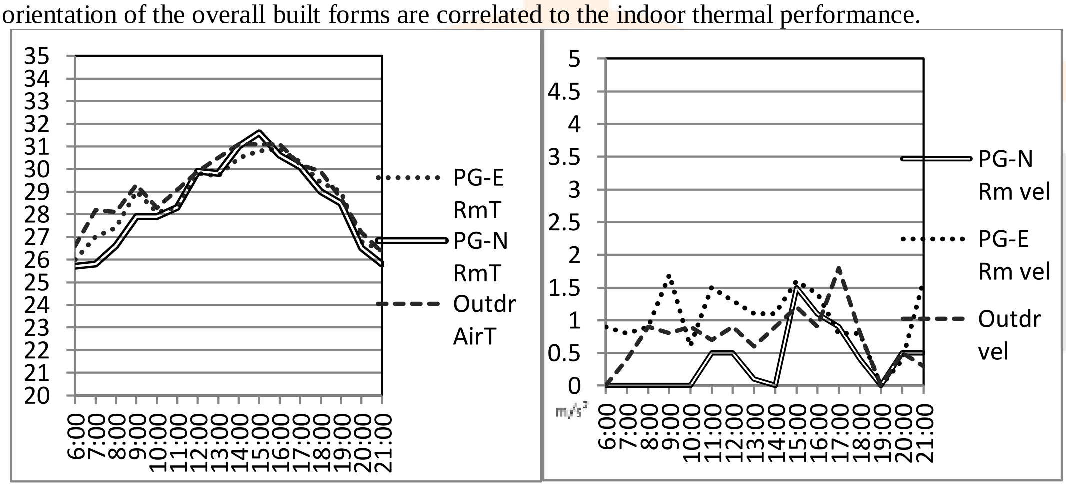
Measuring points (Height from floor in mm)	Measuring parameters		Measuring instrument
12600	Outdoor environment	Air temperature and air velocity	Vane anemometer
2000	Hostel room indoor thermal condition	Air temperature	IR Thermometer
1500	Hostel room humidity	Relative humidity	Hygro-thermometer
2000	Hostel room natural wind flow rate	Air velocity	Vane anemometer
	Duration	6.00am – 8.00pm	

5.4 Results and discussion

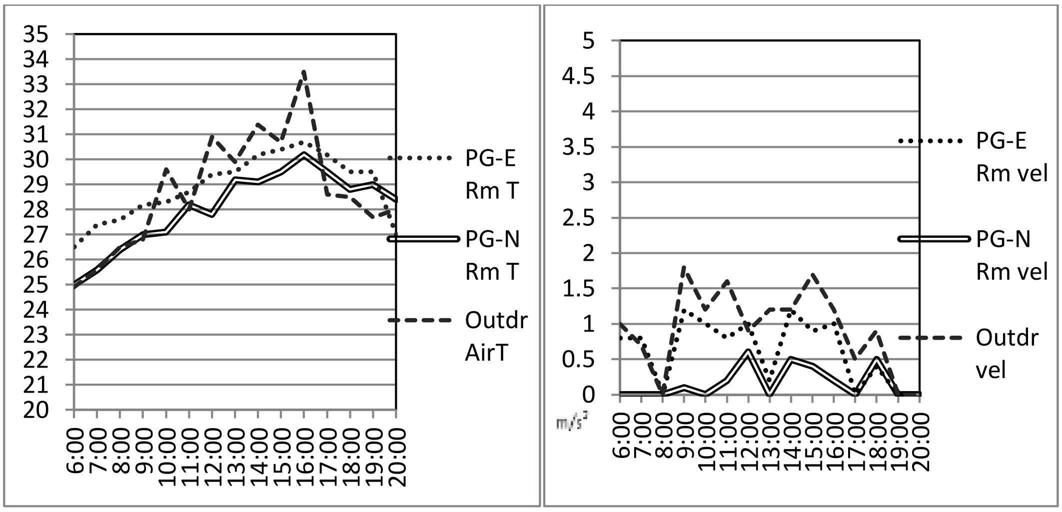
5.4.1 Analysis of the 'Z' building typology

With all natural indoor conditions observed, measurements taken in the 'Z' type building indicated that the indoor air temperatures increase with air movement within the period under evaluation for certain values. From figure 14 below, it is observed that the east facing wing had the most air movement within the room space more than that of the north facing wing which exhibited very minimal air movement throughout the period measured. This may be attributed to the fact that the wind direction was north-easterly (NE) most of the period under evaluation. This condition goes against most of the season wind-path principles which the designers may have initially utilized in the building orientation.

Also, the humidity values in the eastern wing of the 'Z' type building were mostly lower than that of the north facing wing all through the period tested. This demonstrates the effectiveness of the airflow in the eastern façade which seem to have better natural ventilation support unlike the northern wing. These results clearly indicate that the different airflow patterns and corresponding orientation of the overall built forms are correlated to the indoor thermal performance.



(a) Air temperature in July day (b) Air Velocity in July day

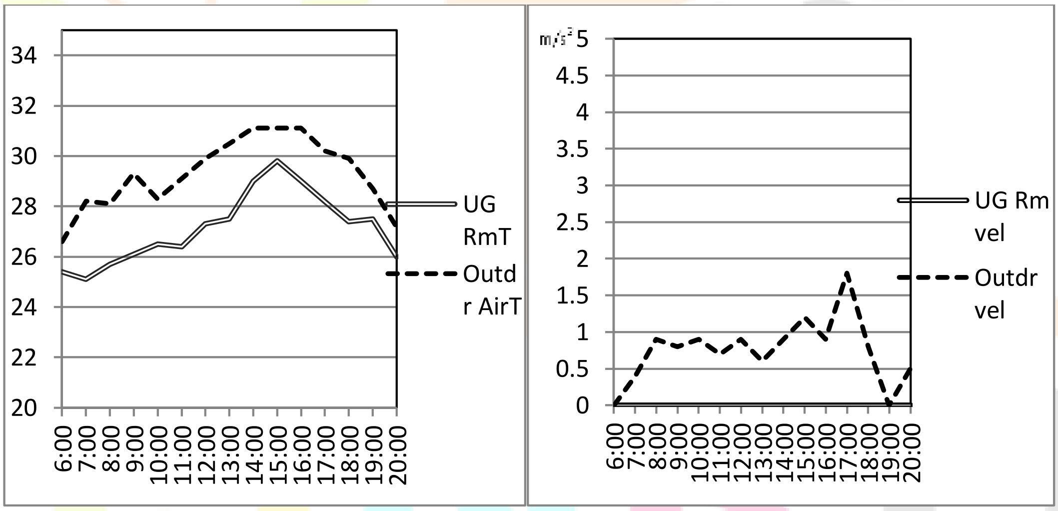


(c) Air temperature in September day (d) Air Velocity in September day

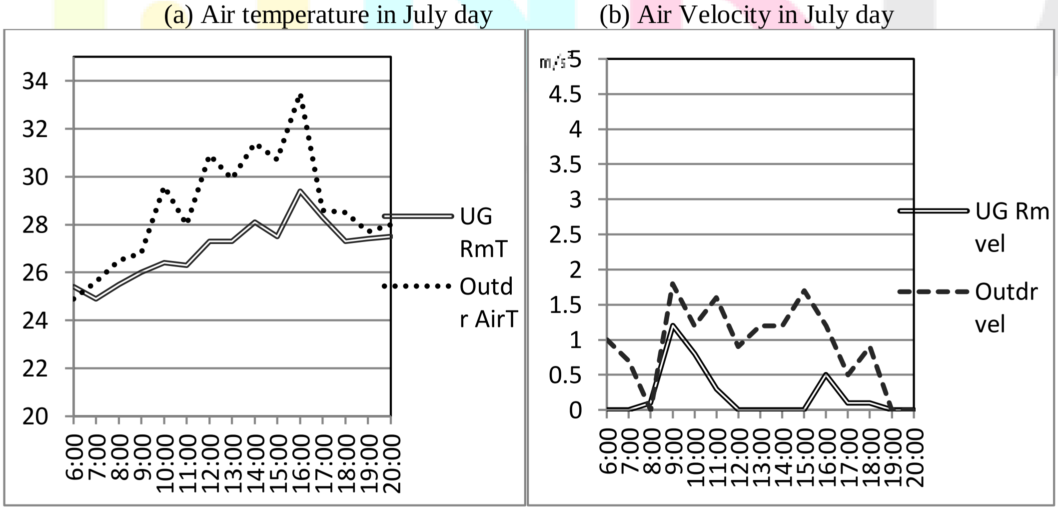
Figure 14. Indoor temperature and velocity readings in the rooms on the Northern and Eastern wings of the 'Z' type building (Postgraduate hostel)

5.4.2 Analysis of the courtyard typology

In the courtyard typology however, the July investigation recorded zero air movement all through the 14 hours of testing as seen in figure 15 (b). The same marginal situation also repeated in September (figure 15). This marginal air movement situation in which natural ventilation may have be restrained, is an indication that the usual seasonal south-westerly (SW) wind movement was not present. This significant change in wind direction against the usual case proves the relevance of microclimate studies in local environments before designs are carried out as the supposed wing pattern may not also occur as predicted seasonally due to deflection which can be cause by a variety of conditions. Secondly it presents the argument that the use of courtyard designs in the tropical environment may not always solve the problem of indoor cooling, since the courtyard does not admit any airflow from its sky opening but rather acts as an "Upwind funnel" to discharge the indoor airflow.



(a) Air temperature in July day (b) Air Velocity in July day



(c) Air temperature in September day (d) Air Velocity in September day

Figure 15. Indoor temperature and velocity readings in the rooms of the courtyard type building (Undergraduate hostel)

5.5 Results and discussion of wind flow computational analysis

A computer simulation was performed using computational fluid dynamic (CFD) as a tool to graphically evaluate the behaviour of the wind flow around the two types of hostel buildings. Computer simulation is necessary to predict the effect of wind movement on natural ventilation and to optimize the site planning criteria during design. For the purpose of this study, all iterations were observed for a basic airflow pattern within the environment. The wind movement data (as measured) in table 3 was considered in creating the necessary wind speed and wind direction for the (CFD) model. The table presents the outdoor wind speed and directions recorded at a height of 12.6m on the days of the study.

Table 3. Measured wind speed and direction in the university campus

Time	July day		September day	
	Wind direction	Wind speed m/s	Wind direction	Wind speed m/s
10:00am	NE	0.9	SW	1.2
12:00pm	NE	0.9	NE	0.9
03:00pm	SW	1.2	NE	1.7
05:00pm	NE	1.8	NE	0.5
06:00pm	SW	0.8	NE	0.9
08:00pm	NE	0.5		0.0

Measuring at the height of 12.6m, the wind paths recorded presented a different pattern from the assumed NE flow path. This pattern which may probably occur due to deflection of wind direction by geometry of elements in environment such as the terrain, vegetation, building cluster, street elements and other environmental factors contribute greatly to the problem of effective harvesting of natural airflow. The CFD simulation performed using the wind path information in table 3 produced the assumed behaviour of the air movement around the hostel buildings as shown in figure 16 and 17. Following the result from the CFD model, the poor airflow condition identified in the field measurements can be elucidated. From this investigation, a number of conclusions relating to the appropriateness of hostel designs and building orientation for purposes of harvesting wind flow for natural ventilation in this region can be drawn. It is therefore evident that the building orientation may be the major factor that is restraining passive ventilation from the outdoor flow.

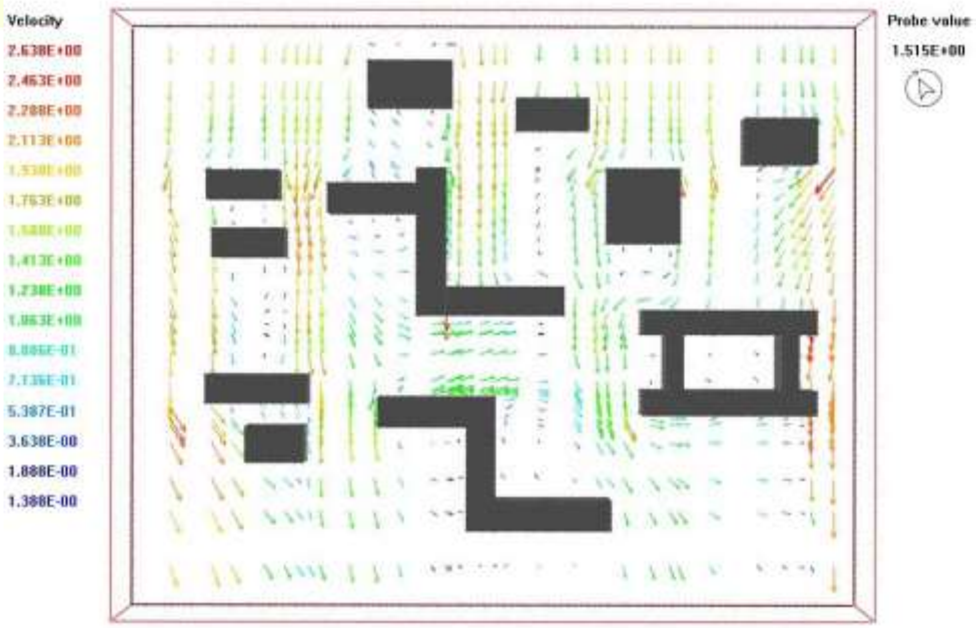


Fig. 16. Wind velocity distribution for north-east leading wind condition

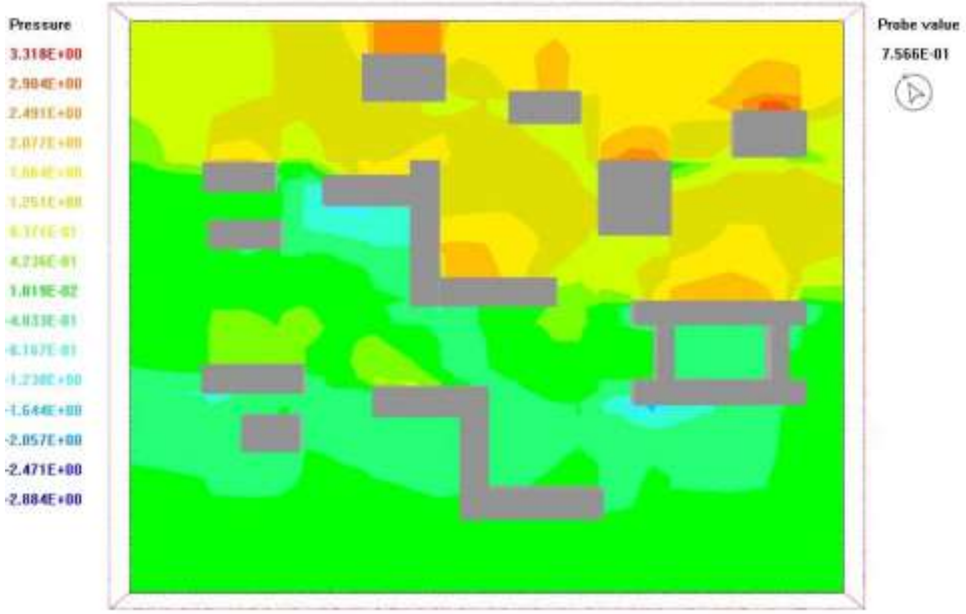


Fig. 17. Pressure distribution for north-east leading wind condition

6. Conclusion

This study investigated the behaviour of wind flow for natural ventilation in two distinct student hostel building typologies in the south-eastern Nigerian city of Enugu. The investigation identified peculiar conditions around the natural airflow pattern and passive ventilation of the room spaces. Through this study, it is evident that original wind path data used for the building orientation considered a north-easterly position of the buildings with the intention of utilizing the predominant south-westerly winds during the hot-and humid seasons. However, the inadequate airflow in and around the north facing façade of the hostel buildings presents the real situation that is often faced by designers when applying wind driven natural ventilation in building designs. The wind movement around the selected building typologies indicated a significant behaviour which concludes that building orientation is essential for the effective adoption of wind driven natural ventilation. Likewise, the courtyard Hostel building form demonstrated no significant advantage over other building forms. Conversely, the linear building typology presents a better option for effective harvesting of wind flow for natural ventilation and indoor cooling more than the courtyard building typology.

Reference

[1]. Vasileios, F., Kolarik, J., Smith, K. M. (2020). The Impact of Wind Pressure and Stack Effect on the Performance of Room Ventilation Units with Heat Recovery. Energy and Buildings, 234, 110689. https://doi.org/10.1016/j.enbuild.2020.110689

[2]. Akubue, A.J. (2019). Effects of street geometry on airfow regimes for natural ventilation in three different street configurations in Enugu City. Different Strategies of Housing Design. In: Ayşem Berrin Çakmakli, Intech Open, DOI: 10.5772/intechopen.84786.

[3]. Ajibola, K. (2001). Design for comfort in Nigeria: a bioclimatic approach. Renewable Energy, 23, 57-76.

[4]. Simmonds, P. (1993). Thermal comfort and optimal energy use. ASHRAE Transactions. Symposia, 1037-1048.

[5]. Costa R. (1989). Architecture in black Africa between development and tradition. J Solar Wind Energy, 6(4), 383–387.

[6]. Ajibola, K. (1997). Ventilation of spaces in a warm–humid climate: case study of some housing types. J Renewable Energy, 10(1), 61-70.

[7]. National University Commission (NUC) (2003). Private Sector Participation, in University Hostel Development and Management. National University Commission Lagos.

[8]. Budyko, M.I. (1956). The heat balance of earth surface gridrometeology. Leningrad. Washington, DC.

[9]. Tergung, W.H. (1970). Towards a climatic classification on net radiation. AAAG, 6(4), 140-144.

[10]. Fagbenle, R.O. (1992). Solar systems in Nigeria. RERIC Int Energy Journal, 14(2), 37–48.

[11]. Oliver, J.E. (1970). A genetic approach to climatic classification. AAAG 1970, 60(4), 615-637

[12]. Bowen A. Some historical indicators for building design under natural conditions in overheated region. Proceedings of the Annual Conference of the Afro-Asian Housing Organisation N.B.O. New Delhi, India: Nirva Bhavan. 1975.

[13]. Ojo, O. (1967). The climates of West Africa. London: Heinemann.

[14]. Ideriah, F.J.K., Suleman, S. O. (1989). Sky conditions of Ibadan during 1975-1980. Journal of Solar Energy, 43(6), 325-30.

[15]. Fagbemi, O.J., Okulaja, F.G. (1971). Space correlation fields of rainfall and homoclimates of Nigeria. Unpublished research paper. University of Lagos: Department of Computer Science.

[16]. Ogunsote, O. (1991). Computer Assessment of Architectural Design. Habitat International. London, 15 (4), 1-16.

[17]. Fanger, P.O., Breum, N.O., Jerking, E. (1975). Can colour and noise influence man's thermal comfort? Ergonomics (Technical University of Denmark).

[18]. Blazejczyk, K. Epstein, Y., Jendritzky G., Staiger, H., Tinz B. (2011). Comparison of UTCI to selected thermal indices. International Journal of Biometeorology, 56, 515–535.

[19]. Humphreys, M.A. (1978). Outdoor temperatures and comfort indoors, Building Research and Practice (J CIB), 6(2), 92-105.

[20]. Humphreys, M.A. (1970). A simple theoretical derivation of thermal comfort conditions. Journal of the Institute of Heating and Ventilating Engineers, 33, 95-98.

[21]. Kerslake, E.G., McK, D. (1972). Monographs of the Physiological Society, The stress of hot environments. Cambridge University Press.

[22]. Tantasavasdi, C., Srebric, J., Chen, Q. (2001). Natural Ventilation Design for Houses in Thailand. Thailand: Energy and Buildings, 33(8), 815-824.

[23]. Institution of Heating and Ventilation Engineers (IHVE). (1970). A Guide Book. London.

[24]. Boutet, T.S. (1987). Air Movement; A Manual for Architects Controlling and Builders. Mc-Graw Hill: New York.

[25]. Fuad, H.M. (1996). Thermal comfort and building design in the tropical climates. Energy and Buildings, 23, 161-167

[26]. Oyem, A.A, Igbafe, A.I. (2010). Analysis of the atmospheric aerosol loading over Nigeria. Environmental Research Journal, 4(1), 145-156

[27]. Amole, D. (2007). Typological Analysis of Students' Residences. International Journal of Architectural Research, 1, 76-87

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

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

[30]. Oke, T. R. (1987). Boundary Layer Climates. Routledge.