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# Performance of Wind Flow for Activating Natural Ventilation on different Hostel Building Forms in Nigeria

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***Abstract*** – Most regions in Nigeria are notable for the hot and humid environments. This is attributed to the major weather factors which in turn influences the indoor thermal comfort of occupants. Owing to the economic constraints in the country, the choice of active air conditioning is often not realizable in public university halls of residence. This leaves designers in this region with the only other option of passive cooling applications in hostel building designs. Study identified that natural ventilation processes is mostly dependent on regional windflow systems for wind driven ventilation. This paper examines the impact of windflow systems around different building configurations adopted in the design of hostel buildings in most Nigerian public universities. The atypical behavior of air movement which is necessary for activating passive ventilation within these building forms is studied and the results justified the effectiveness of building orientation for functional indoor ventilation.

*Keywords – Passive Ventilation, Hostel Designs, Nigerian University Hostels, Natural Ventilation, Wind Flow Systems.*

## I. INTRODUCTION

Study of previous analyses of Nigerian climate identify that most of the analyses were for agricultural use or weather prediction purposes. They have little or no application for building design. Buildings in the tropical area of the world are constantly exposed to solar radiation almost daily. As a result, building design should aim at minimizing heat gain indoors and maximizing evaporative cooling so that users of these spaces can have adequate thermal comfort. To achieve this objective, buildings in this part of the world should have shapes and forms which should be responsive to this objective, be properly oriented, and the fabric of the buildings should be specified to prevent or minimize heat gain. Also buildings in this area should respond to passive energy and have minimal use of active energy for economic viability [1]. According to Simmonds [2], it is desirable to select these parameters such that the difference between the space condition and the outside environment is minimized. In particular this is significant with respect to the design space temperature and relative humidity. The selection of space operating parameter, such as air and radiant temperatures, relative humidity and air velocity impacts both occupant comfort and building energy consumption. In Nigeria, study reveals that most of the above criteria have not been strictly adhered to. Most traditional buildings in Nigeria have laid too much emphasis on socio-cultural and economic factors [3]. The result of this is easily felt in the poor attention given to the climate and its parameters in the built environment across Nigerian cities and also of its building design approaches both in the past and present. On the other hand, the vast majority of well built Nigerian contemporary buildings have depended on imported building materials. Various problems have emanated from this present design approaches and philosophy. First, most buildings seem to be replicas of buildings in European countries in shape and form despite marked differences in climatic conditions. Secondly, despite observed climatic differences in various cities within the country, forms and shapes of buildings tend to look alike. Thirdly, windows of buildings have not been properly oriented to maximize air movement for space cooling indoors. Window sizes and openings have not responded to physiological comfort [4]. Finally, material specification for buildings in the housing sector has followed the same pattern despite the difference in climate within the country.

### A. *Overview of student's hostels in Nigeria*

It is common knowledge that about 80% of Nigerian University Students live in Hostels which are either privately owned or by the Institutions. A student hostel building amongst other functions must also be a home for the students to live, interact and study. To ideally function as a home, the building must also satisfy other basic human comfort needs. A comparison 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 living. Crucial among these essential amenities is the quality of indoor thermal comfort elements. In the hot humid environment today (as is the case in the institution selected for this study; the University of Nigeria Enugu campus), the major challenge to indoor thermal comfort conditions is the factor of ventilation of enclosed spaces. The obvious poor conditions of air ventilation in the student hostels in Nigeria has raised doubts and fear 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 problem has led to a number of mandatory measures by the National Universities Commission 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.

The Nigeria National Universities Commission (NUC) [5] has the following guide lines for Student Hostel designs:

1. It proposed the design of hostels to be based on a module of 100 rooms in a block of two or three floors.
2. It defines a Bed space as a reasonable ample space for a standard 1.8m x 0.75m bed, desk space for studying and a personal computer, bookshelves and 0.537m wide 2.850m high built-in wardrobe for each student.
3. Maximum of four people in a room with a minimum of 5-7m² per person and a maximum of six hundred people in a building.

From investigations, any Student Hostel 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.

### B. *Climate classifications in Nigeria and their effects on building design*

A climatic classification useful for architectural building design must have a combined effect of temperature, relative humidity, (MRT) mean radiation temperature and wind velocity. Most classifications are based on one or two of the above items. Notable among these are Budyko [6], Tergung [7] and Fagbenle [8], who used the rational index of dryness for the classification, and thus only took care of mean radiant temperature. Oliver's [9] classification is based on air mass movement and as a result can only account for movement.

The tropical areas of the world are generally referred to as the overheated regions [10]. For building design purposes, overheated regions of the world are classified into three categories namely:

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

The characteristics and the corresponding design strategies for each of these categories are well discussed in Bowen's study [10]. Based on Bowen's latitudinal classification, Nigeria located on 4° and 14° N strictly falls within the area labeled as a warm–humid region. Ojo [11] on the other hand observed that the general climate, like those of other countries in sub-Saharan West Africa, is controlled by two main factors 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.

As a result of this, there are two well-marked seasons in Nigeria, the dry season lasting from November to March and the rainy season lasting from April to October. Ideriah and Suleman [12] also observed that there is variation of climate as one moves from the coast to the northern parts of the country and the climate of a particular location varies with the time of the year, latitude of the location and landscape. There is however a lack of climate data for building designs in most cities. Many researchers, both foreign and local, have attempted to classify the climate of West Africa. Most of the early classifications have been based on temperature and precipitation only. Among these are Fagbemi and Okulaja [13] who applied Thornthwaite's (1948) and Papadaki's (1961) systems of classification to the Nigerian climate. Figure 1 below shows the major climate classes in Nigeria with the southeastern location falling into the zone-4 class (hot-humid).

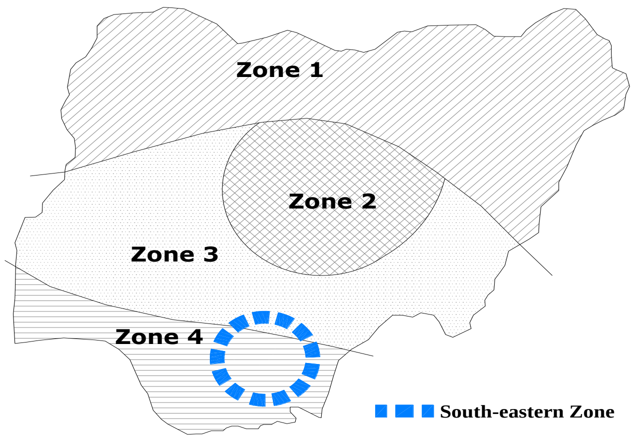



Fig. 1 Example Map of Nigeria showing the major climate zones

The major characteristics of a typical hot-humid climate are:

1. Two distinct seasons, the dry and the wet. While the dry is characterized by hot dry days with little rainfall, the wet produces torrential downpours filling the atmosphere with moisture generating a hot and humid environment.
2. Relatively high temperatures throughout the year with average annual maximum temperature as 31ºC.
3. Minimum seasonal temperature variation.
4. Low diurnal (day/night) temperature range.

C. *Defining thermal indexes*

The climatic conditions mentioned above strongly affect the indoor thermal environment within the southeastern region. However, given these climatic conditions, the need for effective control of the climate elements must be considered when designing energy-efficient buildings in this region. Architectural design with climate aims at keeping microclimatic conditions in dwellings within the comfort limits, irrespective of the external conditions. A thermal index measures the stress imposed by external climate conditions and predicts the optimal environment needed for comfort within buildings. This provides architects a scientific chance of evaluating comfort. The knowledge of the thermal stress is necessary for the design of walls, roofs and shading devices however, the choice of the most appropriate index is difficult. The selection falls between over 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 the 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. Assessment of the climatic compatibility of architectural design usually involves computer models [14], thus it should be possible to build a computer model of the index.

The climate index for determining comfort in dwellings can be 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 some 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. The way the minor factors listed above affect comfort is not well understood. However, Fanger et.al [15] among claims that the effects of ethnic grouping, color of a space enclosure and noise are negligible. 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, about 70% of the population will be comfortable. Knowledge of the way 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 should reasonably accurately predict the consequences of any combination of the six major factors affecting comfort. It should be applicable both indoors and outdoors and it should be capable of indicating the degree of discomfort.

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

In this paper it is important to delineate how outdoor temperature, air movement and humidity affect the comfort temperature of building occupants in the hot-humid climates. The following analysis looks at the analytical and experimental predictions and then tests them against results from field surveys.

### A. *Outdoor temperature*

The linear relationship which Humphreys [16] derived between comfort temperature and mean outdoor temperature for free-running buildings is:

$$T_c = 0.534T_o + 12.9 \quad (1)$$

where $T_c$ is the comfort temperature and $T_o$ is the mean outdoor temperature.

This relationship provides building professionals the possibility to predict the temperature which will be comfortable in free-running buildings by calculation from the monthly mean outdoor temperature given by meteorological records. The results for Enugu state (southeastern Nigeria) using data from [17] are shown in Fig. 2. The figure shows the comfort temperature overlaid on the outdoor temperature to indicate the temperature differential which the building must achieve to remain comfortable indoors.

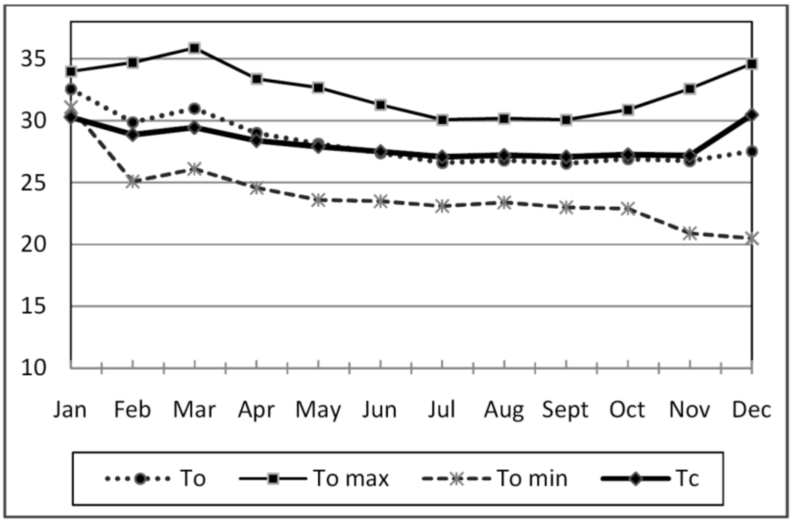



Fig. 2. Comfort temperature Tc for Enugu (southeastern Nigeria) calculated from the outdoor temperature To using Eq. (1). To is calculated as the mean of the monthly mean maximum (To max) and minimum (To min).

### B. *Air movement*

In tropical climates air movement is considered an important factor in determining comfort. A theoretical analysis [18] suggests that where the air velocity is above 0.1 m/s and fairly constant, this allowance can be equivalent to raising the comfort temperature by:

$$7 - \frac{50}{4 + 10v^{0.5}}\,^{\circ}\mathrm{C} \quad (2)$$

There are assumptions built in to 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 is require is a simple set of rules which can be used to modify the predicted comfort temperature to account for air movement and high humidity enabling building designers to provide a comfortable environment. In developing the relationship in Eq. (1) Humphreys [19] attempted, where possible to give the relationship where air movement can be assumed to be small (≤0.1 m/s) and relative humidity (RH) standardized at 50%. Numerous studies of the effects of temperature, humidity and air movement on the human body in hot climates [20] have been undertaken. Much of this work in this area was to determine the relative effects of these factors on people's subjective response to heat. The effect of air movement and humidity are particularly important in hot climates where the heat lost by evaporation predominates. The comfort limits of naturally ventilated spaces in the tropics have been estimated at between 26 - 31 degrees centigrade with wind speed of 1.0m/s [21]. Higher wind speeds may be desirable to maintain thermal comfort at higher temperatures, obtainable in the hot humid climatic zones [22]. Natural ventilation can be induced by wind pressure, temperature difference (Sack-effect), humidity difference (cool-tower effect) or a combination of any or all of the three [23].

The fact that buildings in urban areas are closely spaced makes air flow through the interior difficult to be achieved [24]. Houses on the upper floor have more possibility for air flow, particularly if there is cross ventilation. Also observed is the influence of window protection materials in obstruction of airflow into the buildings. The use of burglary grills and insect netting greatly reduces the scope of air flow indoors even if there is air flow outside. The only reliable 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.

### C. *Humidity*

It is more difficult to account for the effect of humidity. Whilst humidity has been investigated in a number of field surveys in hot climates, and found to have a significant effect on comfort temperature, the size of the effect is generally small in most cases. The first problem for the analysis of the effects of humidity 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. RH is a relative measure and is therefore highly dependent on air temperature, especially at high temperatures.

## III. EVALUATION OF MAJOR THERMAL COMFORT ELEMENTS OF HOSTEL ROOM SPACES IN THE HOT-HUMID SOUTHEASTERN NIGERIAN REGION.

Air movement has always been known to improve significantly the human thermal comfort sensation. However in the passively controlled environments, natural-ventilation induced airflow is a main feature of thermal comfort control. To fundamentally evaluate the indoor comfort conditions and its influencing factors in the tropical 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 southeastern region presented significant consistency in the patterns over the years. According to meteorological data of 2009 (summary shown in table 1), 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. The significance of this is basically to identify the factors that may be responsible for the significant indoor discomfort within this season in the university hostels.

Table1. Enugu (Southeastern Nigeria) Climate analysis for the year 2009

| **Climate elements (2009)** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Temperature (ºC)** | 34 | 34.7 | 35.9 | 33.4 | 32.7 | 31.3 | 30.1 | 30.2 | 30.1 | 30.9 | 32.6 | 34.6 |
| **Humidity (%)** | 75 | 76 | 70 | 75 | 83 | 83 | 84 | 82 | 88 | 85 | 65 | 48 |
| **Wind speed Knots (m/s)** | 2.5 | 3 | 2.9 | 2.85 | 2.35 | 2.5 | 3 | 3.5 | 2.5 | 2.5 | 2.4 | 2.6 |
| Source: Nigerian Meteorological Agency, Abuja [26] | | | | | | | | | | | | |

A. *Outline of field study*

This study focuses on the University of Nigeria Enugu campus hostel buildings. There exists two major typologies for the graduate and post graduate students (see fig.3). A typical typology of a 'Z' winged building for the PG (post graduate students) and a typical 'Courtyard' typology for the UG (undergraduate students).

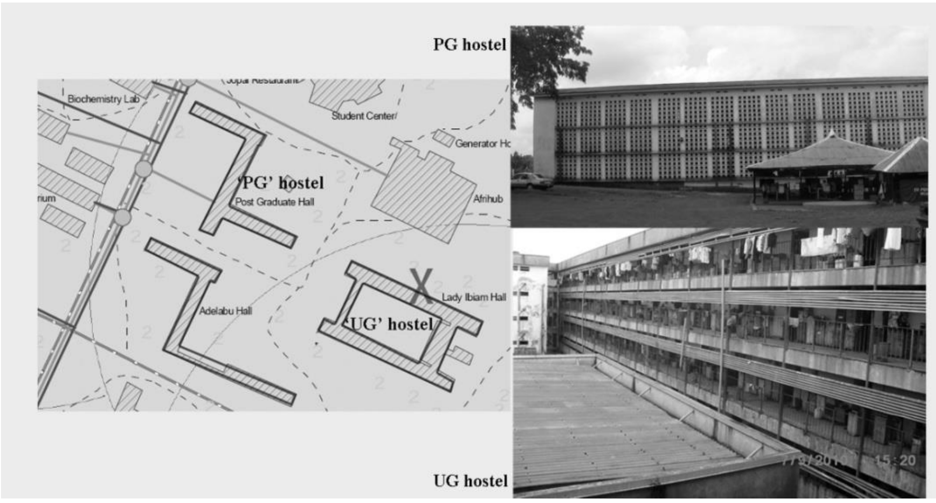



Fig.3. The two main hostel types in the University of Nigeria

The 'Z' winged hostel building (fig. 4a) 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' type hostel (fig. 4b) was selected in order to compare the conditions obtainable in the two typologies with regards to natural wind flow paths and building orientation.

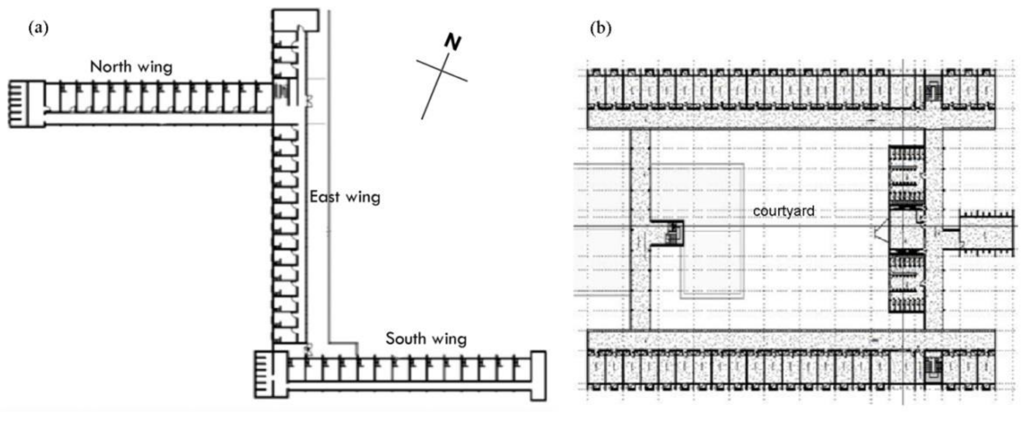



Fig.4 Typical floor plans of the two main hostel typologies

From study of the two typologies, the major design philosophy that defined the method of passive control applied in the buildings for effective thermal comfort could be found mainly in the use of the courtyard design for the UG hostels and the application of screen walling for sun shading and ventilation in the PG hostels. Also observed in the PG hostel building as shown in figure 5, was the use of overhead passive vent pipes which was placed above the door heights to function as outlets for the extraction of hot air within the rooms. Based on the chimney effect principle, these passive vents were placed on the opposite exteriors walls of the rooms as to achieve passive ventilation.

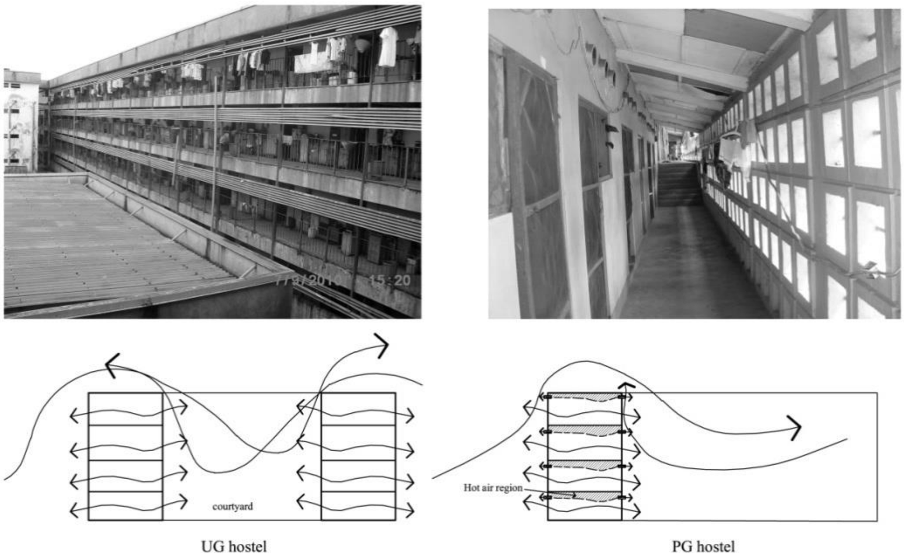



Fig.5. Strategy for passive control and natural ventilation in the hostel buildings

B. *Outline of field experiment and evaluation of the hostel room conditions*

The main purpose of this experiment is to compare the thermal and natural ventilation conditions in the different hostel typologies. The months of July to October as seen in table 1 presented the highest humidity levels with significant wind flow pattern. For this purpose, the field experiments were carried out to investigate the quantity of wind flow that is available in each typology and the extent of its effect felt in the hostel room during the days selected for the measurements. Measurements for indoor thermal environment were taken in the central rooms on the 1st floor of each of the hostel buildings and in each of the wings in the 'Z' type PG hostel. 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, humidity and air velocity | |
| 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 | Wane anemometer |
| | Duration | 6.00am – 8.00pm | |

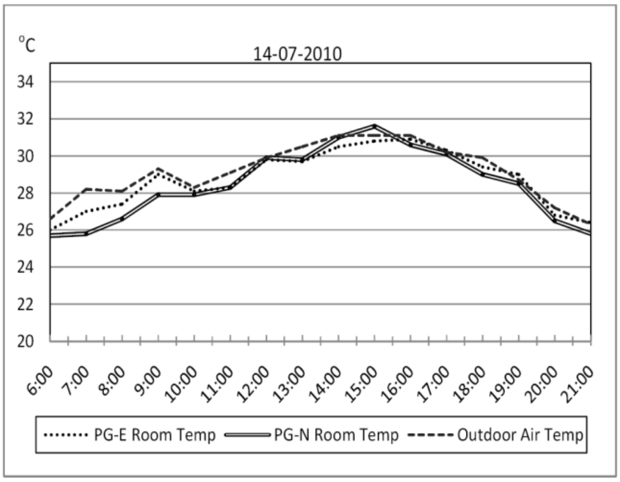
### C. *Results and discussion*

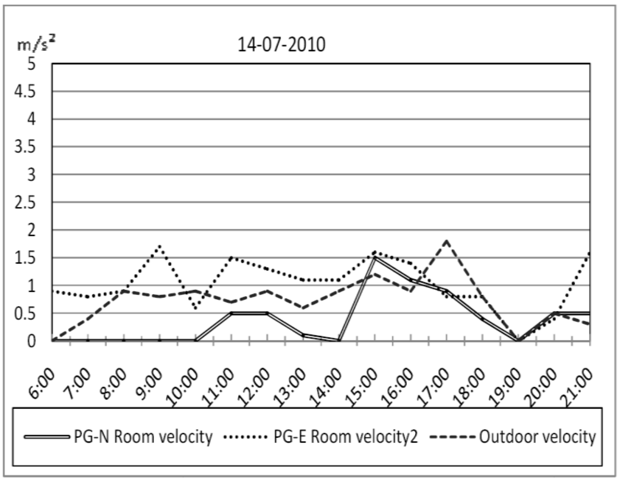
*Air temperature and air movement*

With all natural indoor conditions observed, it is observed that the indoor air temperatures increase with air movement in the two months under evaluation but only for certain values. Looking at figure 6, it could be 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 (see table 3). This condition goes against most of the season wind-path principles which were initially utilized in the building orientation.

*Humidity*

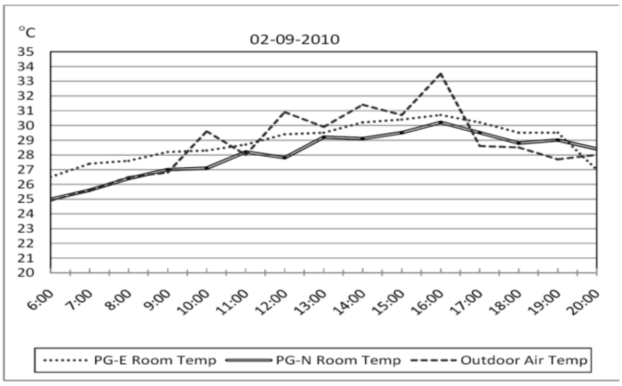
The humidity values in the eastern wing were mostly lower than that of the north facing wing all through the period tested. This demonstrates the effectiveness of the airflow in the eastern façade which seem to have better natural ventilation support unlike the northern wing. These results clearly indicate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

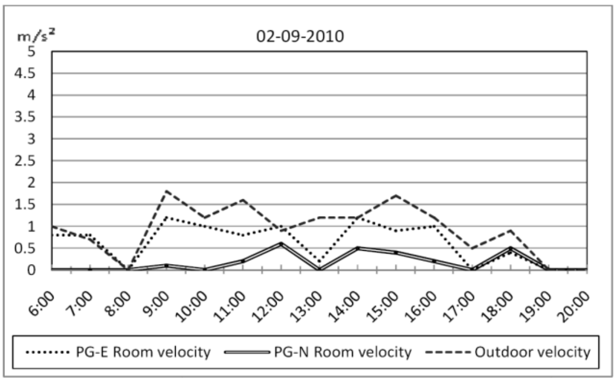



Air temperature

Air velocity

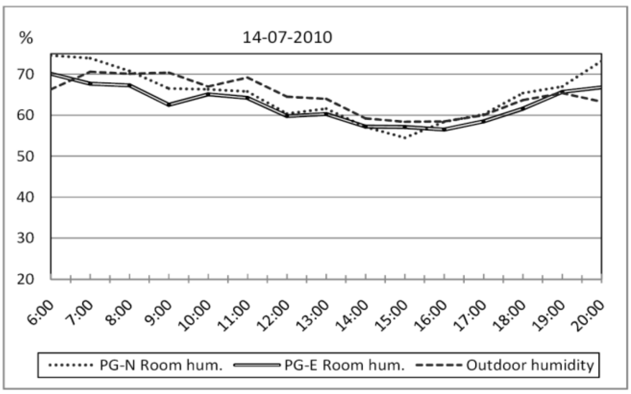


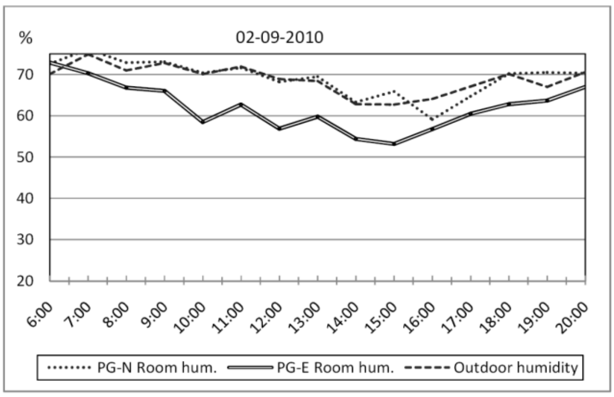




Air temperature

Air velocity

Relative humidity




July

September

Fig.6. Indoor temperatures, velocities and humidity readings in the rooms on the Northern and Eastern wings

*Comparing the ‘Z’ typology with the courtyard typology*

In the courtyard typology however, the July investigation recorded zero air movement all through 15 hour. The same marginal situation also repeated in september. This marginal air movement scenario in which natural ventilation may be restrained is an indication that the usual seasonal southwesterly (SW) wind movement was not present. This significant changes 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 microclimates, since the courtyard does not admit any airflow from its sky opening but acts as an “Upwind funnel” to discharge the indoor airflow into the sky.

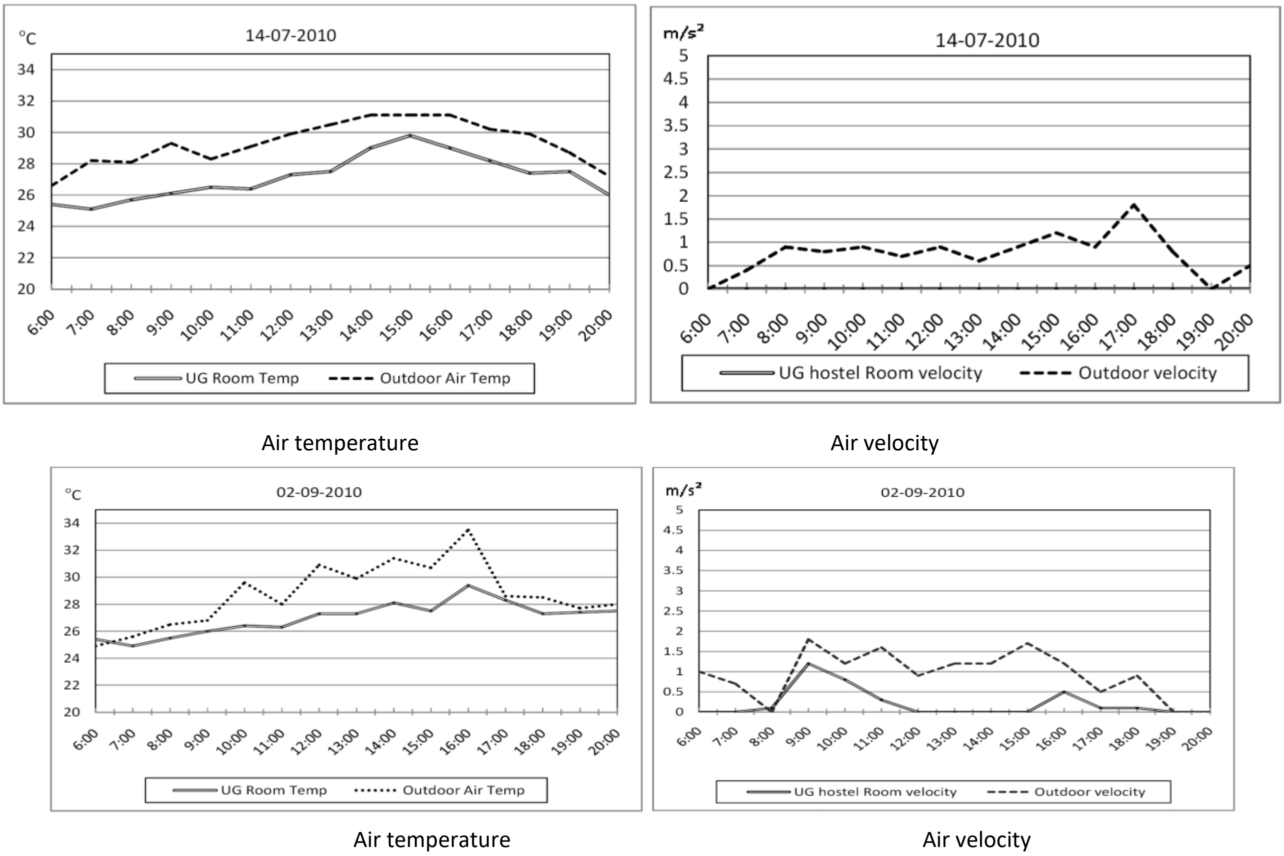



Fig.7. Indoor temperatures and velocities readings in the rooms of the courtyard type (undergraduate) hostel building

D. *Results and discussion of the computational analysis*

A computer simulation was performed using computational fluid dynamic (CFD) as a tool to evaluate the nature of the wind movement within the environment around the hostel buildings and to ascertain the wind behaviour around the building. 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 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 July and September days of the experiment.

Previous literature on the climatic classifications of Nigeria classify the Nigeria wind pattern into the northwards (SW) moist air and the southward (NE) dry air coming from the north [25].

Table 3 Measured wind speed and direction in the university campus

| **Time** | **14 July 2010** | | **2 September 2010** | |
|---|---|---|---|---|
| | **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 |

This information has been the background for all passive design solutions and building orientation for Nigerian professionals. Measuring at the height of 12.6m, the wind paths recorded presented a different pattern. This pattern which may probably occur due to deflection of wind direction by terrain, vegetation, building cluster, climate change and other environmental factors contribute greatly to the problem of effective harvesting of the natural airflow. Further research is required to further investigate the influence of climate change and other factors on the wind patterns in our environments. This will assist in providing adequate and accurate information for the building professionals. The CFD simulation performed using the wind path information in table 3 produced the actual behavior of the air movement around the hostel buildings in Enugu as shown in figure 8.

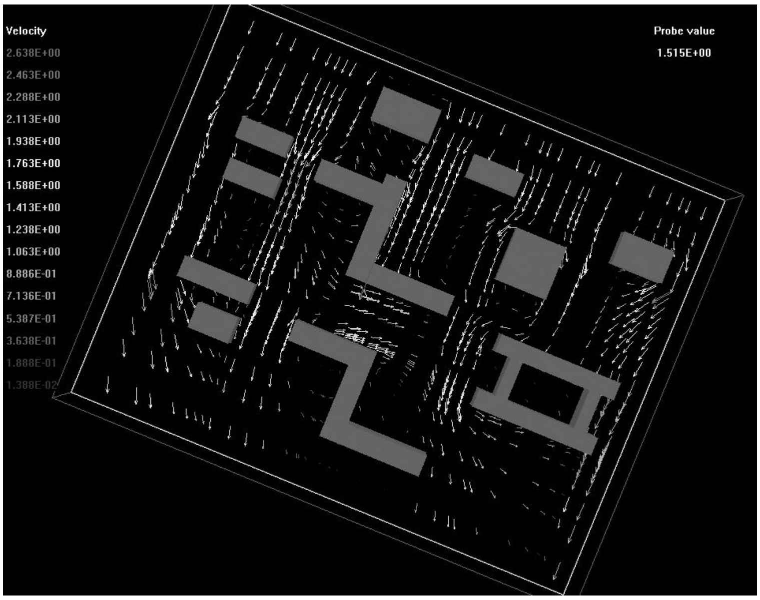



Fig.8. Wind velocity distribution at 2m height for north-east leading wind condition

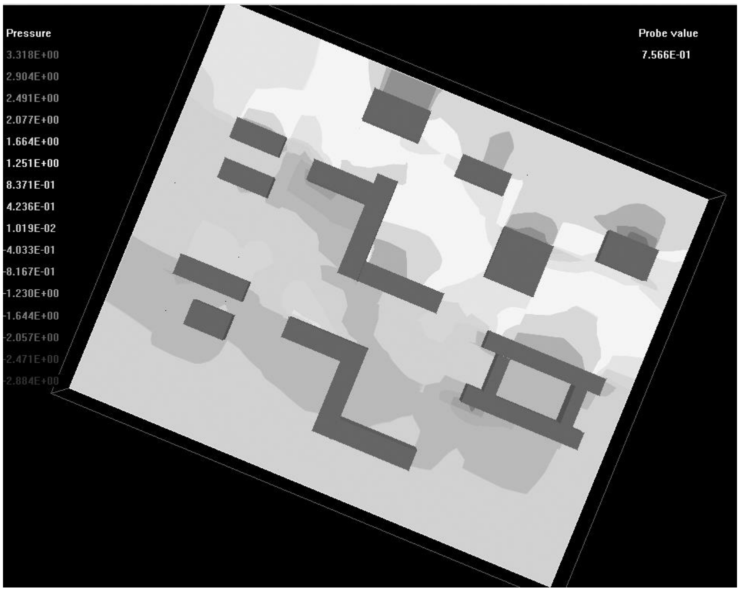



Fig.9. Pressure distribution at 2m height for north-east leading wind condition

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 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.

## IV. STRATEGIES FOR IMPROVING THE PASSIVE CONTROL OF COMFORT ELEMENTS IN THE TROPICAL HOT-HUMID HOSTEL BUILDINGS.

Having earlier noted the issue of economic constraint which may impede the application of mechanical thermal comfort control solutions in the Nigerian student's hostel buildings, it is thus critical for building designers to evolve suitable passive control techniques for improving thermal comfort conditions in the students dwelling place. In the case of the tropical environment, air movement is a vital instrument for improving significantly the human thermal comfort sensation. In this case, passively controlled environments or natural-ventilation induced airflow is a main feature of thermal comfort control. Various types of ventilating systems can be attempted either as single application or in a combined scheme. Since ventilation can occur as naturally ventilated, artificially ventilated or micro-ventilated, combination of these techniques can be adopted where the air-flow is regulated such that minimum heat is transferred to or from the building interior and exterior. A good example of this is the use of naturally occurring wind pressures, and/or the buoyancy force generated by external and internal heat sources to drive an air flow, thereby avoiding the use of mechanical energy. One of such methods is the use of advance natural ventilation or the stack effect. Stack effect utilizes the effect of air warmed by internal sources of heat to drive the air flow without necessarily depending on wind pressure. With this technique, airflow can be assured at all time when there is internal warmth within the building including during the nights. Since stack effect is most efficient at higher floor buildings, hostel buildings in this region should employ the use of multi-stories in design. With a five floor design initiative for instance, vent shafts (inlets and outlets) well located along corridors and connected to exhaust dampers can ventilate passively or connected with rooftop mechanical vents for effective flow. Ventilation by stack effect works on the principle of temperature difference between the air inside and the air outside a building with appropriate inlets and outlet. The rate of ventilation achieved by stack effect is directly proportional to the area of the inlet, and the square root of the difference in height between the inlet and outlet [26]. This relationship is given by the formula,

$$V = K.A1. (h.dt)^{0.5} \ m^3 s^{-1} \qquad (3)$$

Where V = rate of ventilation in $m^3 s^{-1}$
K = Correction factor, which varies with the ratio of outlet to inlet areas.
A1 = area of inlet
h = difference in height between inlet and outlet
dt = temperature difference

## V. CONCLUSION

This study investigated the performance of the student hostels in the southeastern 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 a challenge in the choice of passive control measures that may be employed in order to achieve effective natural ventilation of the room spaces. The application of more advanced natural ventilation principles in hostel building designs therefore becomes essential.

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