Environmental Arrangement, Building Openings and the Effectiveness of Natural Ventilation

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ABSTRACT

The study examined the environmental arrangement, building openings and the effectiveness of natural ventilation to achieve thermal comfort in middle residential houses in Uyo Metropolis, Akwa Ibom State. Descriptive survey research design was used for the study. The population for the study consisted all middle income housing in Uyo metropolis. The instruments used for data collection were liquid crystal thermometers, wet and dry bulb hygrometer, anemometer, questionnaire and the CBE Thermal Comfort Tool (a computer model programme). The instrument was face and content validated by expert from test, measurement and evaluation while Crombach Alpha technique was used to determine the reliability of the instrument at 0.84 coefficient. Data obtained were analysed using Pearson Product Moment analysis. The findings of the study revealed that there is significant relationship the environmental arrangement and building openings have with the effectiveness of natural ventilation and thermal comfort. It was recommended among others that environmental arrangement and building openings that allow for effective natural ventilation and thermal comfort should be used in buildings.

Key Words: Environmental Arrangement, Thermal comfort, building openings, ventilation

Introduction

Many housing facilities mostly in Africa have been built relying on natural climatic conditions for occupancy comfort throughout the year which has brought about discrepancies amongst users (Hazim, 2010.) Whilst natural ventilation can provide thermal comfort in some climates, a gap of thermal comfort improvement strategies in naturally ventilated buildings still exits to enhance suitable thermal condition in buildings thus avoiding occupant dissatisfaction, low productivity and overall building performance (Wang, 2006). Globally agreed, Fanger (1970) defines thermal comfort as the condition of the mind which expresses satisfaction with the thermal environment. Thermal comfort is said to be achieved in a building when the highest possible percentage of all occupants are thermally comfortable. The concept of natural ventilation doesn't seem to be complicated but it's a challenge to design naturally ventilated buildings due to the fact that natural ventilation is difficult to control since it is a medium of passage for solar latent loads from the external environment. Natural ventilation efficiency and building thermal comfort are affected by both internal and external factors (Cai and Wai, 2010). According to Hazim (2010), Natural Ventilation is where the airflow in a building is as a result of wind and buoyancy through openings or cracks within the building envelop. Therefore, as observed by Borgeson and Brager (2008), naturally ventilated buildings in some climates can operate for the entire cooling season within adaptive comfort constrains without mechanical cooling.

Objective of Study

The objective of the study is to examine the relationship the environmental arrangement and building openings have with the effectiveness of natural ventilation and thermal comfort.

Research Hypothesis

To achieve the objective of this study, the following hypotheses will be tested:

Ho: Environmental arrangement and building openings have no significant relationship with the effectiveness of natural ventilation and thermal comfort.

H_1: Environmental arrangement and building openings have significant relationship with effectiveness of natural ventilation and thermal comfort.

Research Problem

According to Chand (1976), the average typical temperature range of 25^oC to 36^oC and high relative humidity of 70% to 95% are common in most Nigerian towns. They are above recommended thermal comfort temperature of 30^oC and relative humidity of 75%. Reliance on air conditioning during the day appears to have become a must for most people who need thermal comfort in enclosed spaces (Uzuegbunam, Chukwuali and Mba, 2012). It is therefore on this proviso that this study is conducted to examine the relationship environmental arrangement and building openings have with the effectiveness of natural ventilation and thermal comfort.

Literature Review

Natural ventilation is considered a prerequisite for sustainable buildings and is therefore in line with current trends in the construction industry. The design of naturally ventilated buildings is more difficult and carries greater risk than those that are mechanically ventilated. A successful result relies increasingly on a good understanding of the abilities and limitations of the theoretical and experimental procedures that are used for design (Etheridge, 2011). There are two ways to naturally ventilate a building: wind driven ventilation and stack ventilation. The majority of buildings employing natural ventilation rely primarily on wind driven ventilation, but the most efficient design should implement both types.

Theories of Natural Ventilation

It is known that natural ventilation can be generated by two methods: by thermal force or buoyancy effect, and by wind pressure force or wind-driven effect. In general, wind-driven natural ventilation is easier to achieve because it only needs a low wind speed to create adequate indoor air velocities that help people's heat transfer by means of evaporation (Tantasavasdi, Jareemit, Suwanchaiskul and Naklada, 2007). In a study conducted by Tantasavasdi, Srebric and Chen (2001) on natural ventilation for houses in Thailand it was found that the buoyancy effect can create indoor air velocities only as high as 0.1 m/s because the height of a two-storied house is generally not enough to create a strong stack effect. On the other hand, the study finds that wind-driven effect can easily create higher indoor air velocities up to 0.4 m/s. In another study conducted by Uzuegbunam*et al.*(2012) on three different hostel buildings in University of Nigeria, Nsukka, it was discovered that a combination of wind and stack with roof aperture provided best and adequate ventilation level in one of the hostels than others which only depended on cross ventilation.

Achieving Ventilation

The main purpose of natural ventilation as a passive cooling strategy is to achieve high indoor air velocities with the air that has appropriate temperature and relative humidity. Factors that influence these parameters can generally be divided into two parts: outdoor environment and building component. It is known that landscape elements such as trees and water bodies can reduce the air temperature while hard-surface elements such as concrete grounds raise the air temperature (Tantasavasdi *et al*, 2007). According to Givoni, (1994), building components that affect natural ventilation include shape of the building, geometrical configuration, orientation of opening, window size and type, and subdivision of interior space.

Aynsley, (2007) classified these factors as:

1. the site and local landscaping features
2. the building form and building envelope design
3. the internal planning and room design.

Site and Landscaping Features: It is important to check on local wind conditions and factors that might influence local conditions when designing for a particular site. Ideally there should be some light winds in summer to provide sufficient internal air movement for thermal comfort during all but extreme conditions, and for night time cooling of the building.

Local wind speeds can be estimated from Bureau of Meteorology wind data, which is usually recorded 10 metres above the ground at local airports. This information has to be moderated according to local factors such as shelter belts and large buildings. The effects of shelter on wind speed can be estimated using Australian Standard AS 1170 Pt. 2-Wind Loads.

Wind speeds at 500 metres above ground level are fairly constant. Wind speeds below this level are slowed to varying degrees by the roughness at the ground surface. In areas without significant hills and valleys, knowing the mean wind speed at a nearby airport, one can estimate the wind speed at various heights in terrains of different roughness from Table 2.1. When there are substantial hills, corrections can be made to estimated mean wind speed by multiplying wind speeds by the appropriate factor from Table 2.2

Topographic features such as hills, ridges and escarpments can have a marked influence on local wind speeds. Winds can be accelerated by up to 54% on the windward side of a hill. Conversely on the leeward or sheltered side of the hill the wind speeds near the ground are usually reduced and the wind direction changed (and even reversed if a recirculation eddy is formed) (Ansley, 2007).

Table 2.1: Multipliers for Wind Speed Over Hills and Escarpments

Average Slope	Lower Third	Middle Third	Top Third	Over Top
≥1:10 <1:7.5	1.0	1.0	1.15	1.0
≥1:5 <1:7.5	1.0	1.0	1.25	1.0
≥ 1:3 < 1:5	1.0	1.15	1.4	1.15
≥ 1:3	1.0	1.25	1.55	1.25

Source: Ansley (2007)

Table 2.2: Reduction in Wind Speed Due to Roughness of Terrain

Height (metre) above ground	**Category 1** (Water) Log Law	**Category 2** (Airport) Log Law	**Category 3** (Suburb) Log Law	**Category 4** (Urban) Power Law
500				159%
400			159%	146%
300		159%	152%	132%
200	156%	152%	143%	114%
100	147%	140%	128%	89%
50	138%	128%	113%	69%
30	132%	119%	101%	58%
20	126%	112%	93%	50%
15	123%	107%	86%	45%
10	117%	100% Ref	77%	39%
9	116%	98%	75%	37%
8	115%	96%	72%	36%
7	113%	94%	94%	34%
6	111%	91%	66%	32%
5	109%	88%	62%	30%
4	106%	84%	57%	28%
3	102%	79%	51%	25%
2	97%	72%	42%	
1	88%	60%	27%	
0.5	84%	48%	11%	

Source: Tantsavasdi, *et al*. (2007)

Water Features and Vegetation: A water feature in or near a building can engender a sense of coolness. This psychological effect can be enhanced by 'sensible cooling' if, in medium to low humidity conditions, water which is significantly cooler than indoor air is used as a thin film cascade or fine fountain spray to maximize its surface area contact with the indoor air. Evaporative cooling uses the latent heat of evaporation to cool hot dry air as it passes over or through wetted surfaces. Provided the ambient air is hot and dry, the cooling effect can be significant. This process has been used for thousands of years in traditional buildings in desert regions (Koenigsberger *et al*, 1974). Similar cooling occurs by evaporation of moisture from the surface of soils and transpiration by plants – the evaporation of water via leaves into the air. The rate of evaporation from soil and transpiration from leaves increases with wind speed over the ground or leaves.

Vegetation can be used to modify the external wind direction so as to enhance ventilation, as well as cool incoming air. As a bonus, fragrant species can be used to perfume the air flowing through buildings. It is important, however, to keep dense shrubs and tree canopies clear of windows and other air inlets to the building. Grassed berms can also be used adjacent to buildings to direct the wind as required for natural ventilation (Tantasavasdi *et al,* 2007). Vegetation can be an effective means of moderating the temperature around a building and reducing the building's cooling requirement. Vegetation in the form of trees, climbers, high shrubs and pergolas, for example, can provide effective shading for the building's walls and windows. Ground cover by plants also reduces the reflected solar radiation and long-wave radiation emitted towards the building, thus reducing solar and long-wave heat gains. The evapo-transpiration process also cools the ambient air and nearby surfaces. Furthermore, climbers over the walls can reduce the wind speed next to the wall surfaces and provide thermal insulation when the exterior air temperature is greater than that of the walls (Chenvidyakarn, 2007).

Research Methodology

Design of the study

The study adopted a descriptive survey research method.

Study Area

The study area is Uyo, the Capital City of Akwa Ibom State.

Population of the Study

The population of the study consisted of all middle income housing in Uyo Metropolis.

Sample and Sampling Technique

The respondents in the study consisted of 200 household heads that are selected randomly from all the households in Uyo metropolis, using simple random sampling method. The sample size was determined using sample fraction from Ibanga (1992)

Instrumentation -validation of the instrument and reliability of the instrument

The following instrument were used to measure physical comfort variables, liquid crystal thermometers, Wet and dry bulb hygrometer, and anemometer for collecting data of the indoor thermal environment. The CBE Thermal Comfort Tool (a computer model programme) (Tyler *et* *al.,* 2013) and a structured questionnaire was used as tools to ascertain the prevalent comfort situation based on field measurements made.

Validity of Instrument

The instrument was face and contents validated done by one expert from test, measurement and evaluation.

Reliability of the Instrument

Crombach Alpha technique was used to determine the reliability of the questionnaire used in the study with a reliability coefficient of 0.84 to 0.94.

Sources of Data

The principal source of data used was from both the primary and secondary sources.

Methods of Analysis

Hypothesis was stated in the null form, and was tested using Pearson Product Moment Correlation analysis (PPMC) at significance level of 0.05

Case Study

CASE STUDY: 3- BEDROOM BUNGALOW AT PLOT A30, 1000 UNIT ESTATE, IDU URUAN

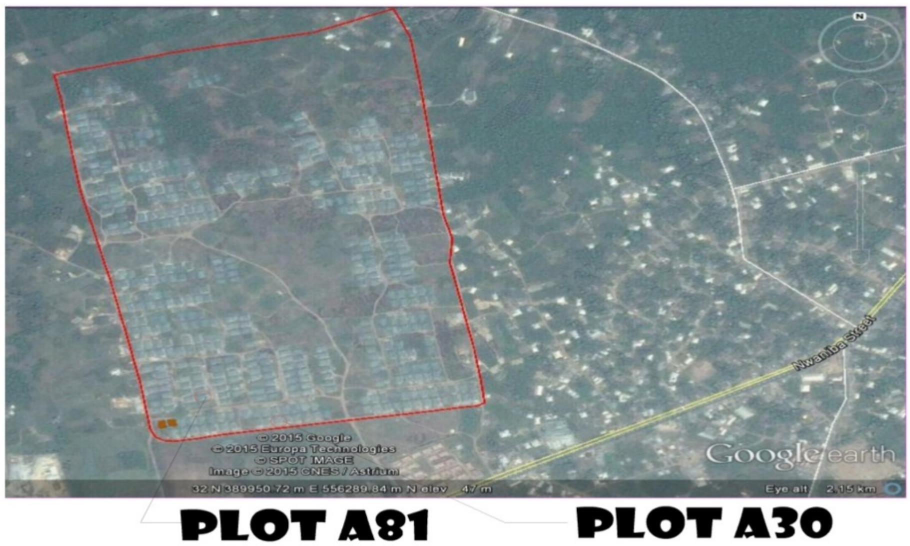
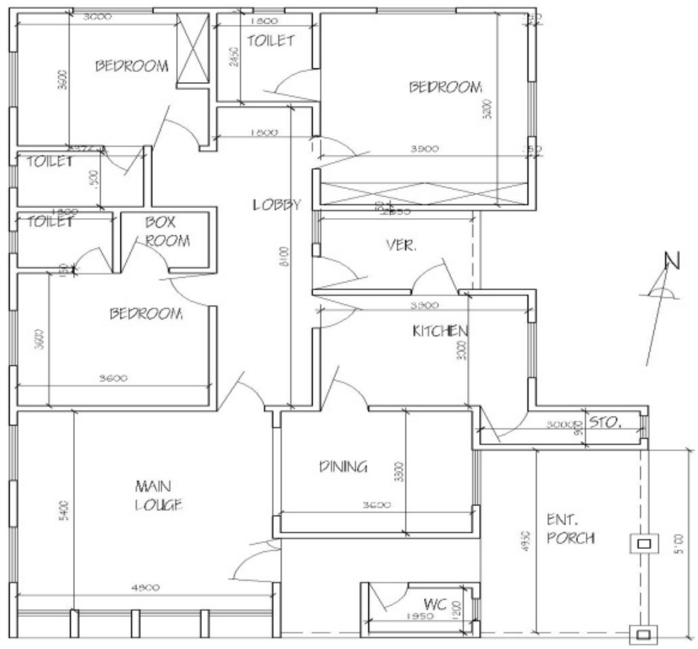


Plate III: Plot A30 and A81 on Google Earth map

Source: Author's Work (2015)



GROUND FLOOR PLAN

Plate IV: Front view of 3- Bedroom Detached Bungalow, Plot A30,
Source: Author’s Field Work (2015)

Data Presentation and Analysis

Hypothesis Testing

The null hypothesis states that environmental arrangement and building openings have no significant relationship with the effectiveness of natural ventilation and thermal comfort. In order to test the hypothesis, two variables were identified as follows:-

1. Environmental arrangement and building openings as the independent variable.
2. Effectiveness of natural ventilation and thermal comfort as the dependent variable.

Pearson Product Moment Correlation analysis was used to analyze the data, (see Table 1).

TABLE 1: Pearson Product Moment Correlation Analysis Result of the relationship between environmental arrangement with building openings and the effectiveness of natural ventilation with thermal comfort

Variable	$\sum x$ $\sum y$	$\sum x^2$ $\sum y^2$	$\sum xy$	R
Environmental arrangement (X1)	1560	17000	14160	-0.29*
Effectiveness of natural ventilation and thermal comfort (y)	1880	18280		
Building openings(X2)	2080	22800	19120	-0.51*
Effectiveness of natural ventilation and thermal comfort (y)	1880	18280		

***Significant at 0.05 level; df = 198; N = 200; Critical r-value = 0.139**

Source: Authors Field Work (2016)

Table 1 presents the obtained r-value of (-0.29) and (-0.51). These values were tested for significance by comparing them with the critical r-value (0.139) at 0.05 level with 198 degree of freedom. The obtained r-value (-0.29) and (-0.51) in their absolute forms was greater than the critical r –value (0.139). Hence, the result was significant. The result therefore means that environmental arrangement and building openings have significant relationship with the effectiveness of natural ventilation and thermal comfort in the reverse direction, meaning as far as the case study is concerned, that some level of environmental arrangement and position of building openings, can lower the level of natural ventilation and thermal comfort and vice versa.

Discussion of Major Findings

The result of the data analysis in table 1 was significant due to the fact that the obtained r-values (-0.29) and (-0.51) were greater than the critical r –value (0.139) at 0.05 level with 198 degree of freedom. The results imply that environmental arrangement and building openings have significant relationship with the effectiveness of natural ventilation and thermal comfort. The result is in agreement with the findings of Tantasavasdi *et al* (2007) and Chenvidyakarn

(2007). They discovered in their different works in houses in Bangkok that environment covered with large trees can give a higher average temperature drop in the buildings' interior spaces than small trees, grasses and hard surfaces. The significance of the result caused the null hypothesis to be rejected while the alternative one was accepted. This research work finds out that it is not every building opening that gives an efficient natural ventilation and thermal comfort, especially when the building is not properly orientated. In addition, the analysis in table 1 reveals that the environmental arrangement and building openings relationship with the effectiveness of natural ventilation and thermal comfort may be in a reverse direction.

Recommendations

1. Environmental arrangement and building openings that allows for effectiveness of natural ventilation and thermal comfort should be used in buildings.

2. The fenestration of common spaces in the buildings should be directly facing an open space in order to provide comfortable indoor air temperature and relative humidity.

3. Architectural features that promote thermal comfort should be used for building in order to make the occupants comfortable.

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