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VENTILATION FOR COMFORT IN PASSIVE RESIDENTIAL LIVING SPACES IN A WARM-HUMID URBAN ENVIRONMENT

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ABSTRACT: *The natural ventilation provision for comfort in selected residential estate buildings in Ibadan, Nigeria was assessed in this paper. This was with a view to assessing the indoor air movement for comfort and sustainability of passively operated urban living spaces within a warm-humid climatic environment. Systematic sampling was used to select 91 buildings from the 273 in the estate. The ventilation analysis indicated that the living-room spaces in the buildings had adequate comfort ventilation with the average indoor wind speed obtained ranging from 0.21m/s to 0.24m/s. In the comfort survey it was found that 82% of the total votes of the respondents were within the comfort zone and 72% of the respondents preferred their naturally ventilated spaces to air-conditioned spaces. The buildings were adjudged to be comfortable and sustainable since they operate passively and are maintained at no extra cost to the users.*

KEYWORDS: Adaptive comfort, naturally ventilated spaces, Sustainability, Ventilation, Warm-humid

INTRODUCTION

The local climate greatly affects the environmental conditions of any location. The challenge of climate however has prompted technological advancement in space heating and air-conditioning. With the industrial revolution many urban buildings were designed to function with active energy systems for indoor comfort. This has proved financially burdensome. This design approach has also been revealed to consume too much energy than what the world energy resources can accommodate on the long run. In the tropics generally, there is constant exposure of buildings to solar radiation and this leads to overheating of interiors. Most of the countries in this part of the world are not as rich as the developed countries. Air-conditioning of building spaces in these countries has not been practicable on large scale especially in the residential units. Also, buildings which depend on air-conditioning have always encountered maintenance problems. Thus the active energy system has not proved to be the most appropriate means of attaining indoor thermal comfort.

Economical and energy efficient methods are required. Barozzi et al (1992) stressed that there is need for passive cooling strategies in developing countries where hot annual temperatures are predominant. Holmes and Hacker (2006) advocated the use of low-energy strategies for attainment of energy efficiency and sustainability in buildings. There is also the inadequacy of infrastructure for power supply in Nigeria. Sambo (2008) observed that electricity demand in Nigeria far outstrips the supply which is epileptic in nature and reported that electricity generation went down from the

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installed capacity of 5600MW to about 1750MW as compared to a load demand of 6000MW in 2001. Pathetically, the power supply kept on declining in the face of increased urbanization and population growth.

One potential solution to the sustainability and energy requirements for tropical buildings is the passive design of buildings utilizing natural ventilation for the spaces. According to Szokolay (1990), provision of adequate cross-ventilation was considered as the only passive control method with some promise of success in tropical warm-humid climates. This study is concerned with the ventilation provision for comfort within the living spaces of naturally ventilated residential buildings in the warm-humid climate of Ibadan, a Nigerian city. The concept of comfort provision through natural means needs to be assessed to determine the viability of residential buildings constructed to be naturally ventilated in the warm-humid climate. Provision of comfortable, energy-efficient building spaces are highly desirable for building sustainability. An assessment of the level of ventilation within the passive living spaces and the comfort experience of the occupants would indicate the acceptability or non-acceptability of these free-running buildings both in terms of sustainability and user-satisfaction.

LITERATURE REVIEW

One of the potent measures to reduce the impact of climate change is to reduce the emission of greenhouse and ozone-depleting gases into the atmosphere. The building sector has been a major contributor to the emission of such harmful gases like carbon dioxide and hydro fluorocarbons through the use of active energy for indoor comfort provision. Due to thermal discomfort, many buildings in tropical cities utilize air-conditioning with the energy demand increasing daily as well as the negative impact on the environment. Unfortunately, the use of air-conditioning has the disadvantage of high cost which the poor urban dwellers of developing countries which are mostly located in the tropics cannot afford. Additionally, power generators consuming substantial amounts of fossil fuels are used extensively in a country like Nigeria by both rich and poor alike because of incessant power outage. All these uncoordinated excessive energy use in buildings contribute to global environmental problems like climate change through the release of greenhouse and ozone-depleting gases into the atmosphere.

Presently, energy conservation is entrenched in most energy policies worldwide. The building sector is also being expected to reduce as far as possible the dependence on active energy. Bragança and Pinheiro (2007) stressed the need for low-energy building and presented low-energy solutions that could facilitate and promote the adoption of policies, methods and tools to accelerate the movement towards a global sustainable built environment. For a sustainable environment, it will be helpful if active energy is not relied upon solely for the provision of comfort within buildings. It should be the designer's aim to ensure the required indoor conditions with little or no use of energy, other than from ambient or renewable sources (Szokolay and Brisbin 2004).

The environmental need in a developing country like Nigeria is the improvement of urban living standards at minimal costs without destroying the natural environment.

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This is in agreement with the principles of sustainable development as discussed in Edwards (1999). However, urban growth and development can be partly sustainable if the occupants of residential buildings are not over–burdened by the running and maintenance costs of their apartments and their environment. Sustainability of the built environment can be enhanced through the attainment of indoor thermal comfort at little or no cost to the building user. This however is a challenge in urban buildings within the warm-humid climate because of the influence of climatic elements and the pollutions generated in the urban environment. The cost of building and maintaining urban residential buildings need to be evaluated to ensure that the economic strengths of users and developers are adequate. Apart from the initial cost of building, developers of urban residential buildings take cognizance of running and maintenance costs. This is also of importance to both owner-occupiers and tenants. The issue of environmental quality both indoor and outdoor features within the running and maintenance costs of a building. A major aspect of the environmental quality is the thermal comfort within the building spaces. The cost of providing and maintaining indoor comfort can be overbearing if not considered properly with appropriate introduction of adequate measures.

All environmental challenges notwithstanding, indoor thermal comfort is considered a primary functional requirement of a building. It can be asserted that thermal comfort within residential living spaces cannot be discountenanced when considering building performance. Buildings are meant to provide the requisite thermal environment indoors so that human activities may be carried out conveniently. According to Nicol and Humphreys (2002), people have a natural tendency to adapt to changing conditions in their environment which is expressed in the adaptive approach to thermal comfort. People do this by taking actions to suit the environment to their liking or by changing themselves to suit the environment. Markus and Morris (1980) pointed out that buildings act as barriers and as responsive filters concerning the environmental conditions. The occupants can only be satisfied if they are thermally comfortable. Thus the thermal comfort of occupants of residential buildings is of utmost importance.

STUDY AREA

The study area, Ibadan is an urban centre located on longitude $7^{0}22'$N and latitude $3^{0}58'$E in the South-Western part of Nigeria. The city is in the warm-humid climatic zone. This is the climatic context for this study. According to Hyde (2000), the warm-humid climate is found close to the Equator and extends to 15° latitude, North and South. The dominant feature is lack of seasonal variations in temperature. It is characterized by high humidity and high temperatures. The seasonal pattern is dominated by periods of high rainfall, fairly evenly distributed. There is small diurnal and annual variations of temperature and little seasonal variations. There are light winds and long periods of still air (Hyde 2000). There are two broad seasonal patterns in Ibadan, namely the dry season (November to April) and the rainy season (May to October). The weather conditions in Ibadan, as well as in other places in Nigeria and other West African countries during the course of a given year actually depends on the location of the place in relation to the fluctuating surface position of the Inter-Tropical Discontinuity (ITD) in the region (Ojo, 1977).

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The residential buildings used for this study were within the Olubadan Housing Estate in Ibadan. The estate is located along New Ife Road opposite the New Gbagi Market. The six typologies in the estate were designed to be naturally ventilated.

METHOD OF STUDY

Relevant climatic data for Ibadan, the study area was obtained from the meteorological station at the International Institute of Tropical Agriculture, Ibadan for bioclimatic analysis. Simulation technique was used to deduce the internal environmental conditions of the building spaces using the climatic data and the thermo-spatial properties of the buildings as applied in Koenigsberger et al(1973) and Egan(1975). Spatial analysis was done for the living room spaces of the different typologies on the Olubadan Estate using the architectural drawings for the buildings. The type, number and percentage area of openings in each space were used in the Ventilation analysis. Use was made of a mathematical model as applied by Givoni(1976) and adapted by Butera (1987), to obtain the average indoor wind speed in the living rooms of the different typologies.

$$V_1 = 0.45\,(1-e^{-3.84x})V_0$$

where V_1 = Average indoor wind velocity , V_0 = Average outdoor wind velocity,
x = window/wall area ratio.

The standard set by Borda-Daiz et al (1989), was that the indoor wind speed should be between 0.15 – 1.5m/s for acceptable indoor thermal comfort in the warm-humid climate. The window/wall area and window/floor area ratios were determined for each living room space. According to Chand (1976), it was recommended that openings should be within 30 – 50% of the exposed wall area and 20 – 30% of the floor area of the space.

Field survey was adopted to determine the residents' assessment of the level of thermal comfort within the residential buildings in the estate. Systematic sampling technique was adopted. 91 buildings were selected from the 273 within the estate. Questionnaires were administered to the occupants and they were interviewed to record their responses to the thermal environment in their living spaces. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) scale of warmth (slightly modified) was used in the thermal assessment. The results of the survey were subjected to statistical analysis. Subjective estimates of warmth were obtained by means of the rating scales and Actual Mean Comfort Votes (AMV) were determined. The level of comfort within the buildings was determined to infer the level of their sustainability.

RESULTS AND DISCUSSION

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The results of the ventilation analysis for the living rooms are shown in Tables 1 and 2. Table 1 shows the computed values of the indoor wind speed taking the average outdoor wind speed of 0.87m/s from the climate data for the reference month.

Table 1 : Indoor wind speed in the living room spaces.

Typology	**2BRLC**	**3BRLC**	**3BRMC**	**4 BRLC**	**4BRMC**	**4BRHC**
Reference Window Area (m^2)	2.16	2.16	4.32	2.88	2.88	2.88
Reference Wall Area (m^2)	9.72	9.72	17.82	11.34	12.42	14.31
Window/wall ratio	0.222	0.222	0.242	0.254	0.232	0.201
V_1 (m/s)	0.2246	0.2246	0.2369	0.2439	0.2309	0.2106

Source: Author's Analysis of Field work

Legend
2BRLC-2BedroomLowCost 3BRLC-3BedroomLowCost 3BRMC-3BedroomMediumCost
4BRLC-4BedroomLowCost 4BRMC-4BedroomMediumCost 4BRHC-4BedroomHighCost

The average indoor wind speed obtained ranged from 0.21m/s to 0.24m/s. This values were assessed as adequate going by the standard set by Borda-Daiz *et al* (1989) that the indoor wind speed should be between 0.15 – 1.5m/s for indoor thermal comfort in the warm-humid climate. Table 2 shows the calculated values of these ratios for the six living room types.
Using Chand's recommendations based on the window/wall area ratio, it can be seen that none of the spaces attained the required 30 – 50%.The values were however close to the minimum value of 30%. Taking the total window/floor area ratio, however, all the living spaces attained the required value of between 20 – 30%. The spaces are approximately in the same category for these ratios. It is therefore inferred that the living spaces would all enjoy appreciably adequate air movement. The ventilation has been assessed to be adequate and sustainable for the purpose of indoor comfort. The inference is that the spaces are acceptable in terms of comfort ventilation. based on the theoretical analysis.

Table 2 : Window/floor area ratio and window/wall area ratio for the living room spaces.

Typology	**2BR L.C**	**3BR L.C**	**3BR M.C**	**4BR L.C**	**4BR M.C**	**4BR H.C**
Total window area	5.04	5.40	7.56	6.12	5.4	5.4
Floor area	20.34	20.70	39.60	24.15	23.92	24.12
Window/floor area ratio %	24.78	26.09	19.09	25.34	22.57	22.39
One side window area (m^2)	2.16	2.16	4.32	2.88	2.88	2.88
Floor area (m^2)	20.34	20.70	39.60	24.15	23.92	24.12
One-sided window/ floor area ratio %	10.62	10.43	10.91	11.93	12.04	11.94
Wall area (m^2)	9.72	9.72	17.82	11.34	12.42	14.31
Window/wall area ratio %	22.2	22.2	24.2	25.4	23.2	20.1

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Source: Author's Analysis of Fieldwork

The mean responses of subjects to the thermal sensation experienced within the living room spaces were obtained from the questionnaires. Table 3 gives the thermal assessments with respect to the seven-point thermal comfort scale used in the study. Fig. 1 gives a representation of the results for the different periods of the day showing the variations in the mean thermal feelings of respondents and their frequencies.

Table 3: Numbers of respondents with corresponding mean thermal assessments for their living rooms at different periods of the day.

Mean Thermal feeling	**Morning**	**Respondents Afternoon**	**Evening**	**Night**
1 Very hot	1	4	2	-
2 Hot	2	22	5	4
3 Warm	11	29	16	8
4 Neutral	27	27	18	8
5 Cool	44	11	46	56
6 Cold	6	-	4	13
7 Very cold	1	-	1	4

Source: Author's Analysis of Fieldwork

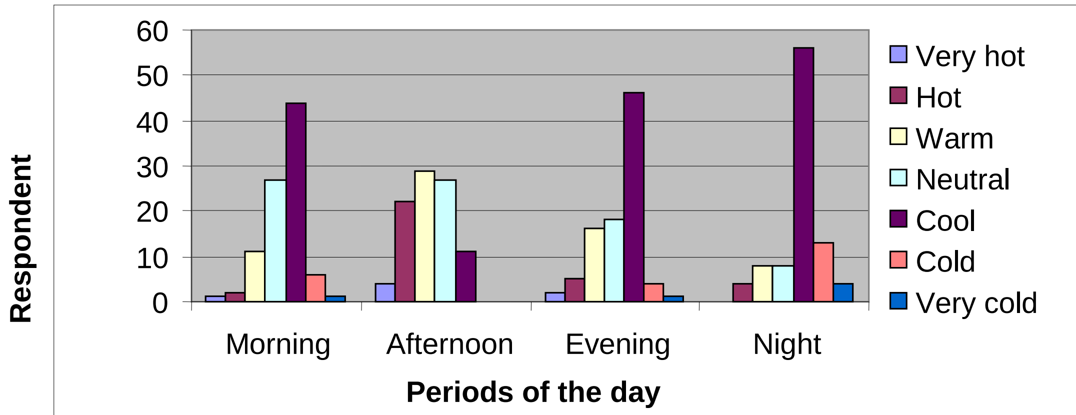

Fig. 1 : Thermal response of occupants in the living room at different times of the day

In the morning, 89.1% of the respondents were in the comfort range of warm, neutral and cool while 77.1% were in the comfort range of neutral and cool. Results for the afternoon indicated that 72.0% were in the comfort range of warm, neutral and cool while 40.8% were in the comfort range of neutral and cool. For the evening, 86.1% of the respondents were in the comfort range of warm, neutral and cool while 68.9% were in the comfort range of neutral and cool. Considering the night, 77.4% of the respondents were in the comfort range of warm, neutral and cool while 68.8% were in the comfort range of neutral and cool.

The respondents' total thermal assessments considered by their categories in percentages are presented in Table 4. 82% of the total votes of respondents were in the comfort zone.

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Table 4: Percentage of Total Votes of respondents in the different thermal categories

Thermal Category	% of Total Assessment
Hot discomfort	10.6
Warm	17.39
Neutral	21.74
Cool	42.66
Cold discomfort	7.61

Source: Author's Analysis of Fieldwork

The mean indoor air temperature experienced in all the living spaces was calculated to be 23.8^{0}C.The Actual Mean Comfort Vote (AMV) that corresponded to this was 4.2 which was taken as cool or comfortably cool because it was within the comfort range of neutral and cool. The thermal experiences of the occupants were therefore assessed averagely as comfortably cool based on the AMV and the mean indoor air temperature.

When asked about their choice between their naturally ventilated living space and an air-conditioned space, 72% of the respondents voted in favour of their naturally ventilated spaces. The majority therefore expressed satisfaction with the level of comfort within the buildings. The result of the survey agrees with the submission of Szokolay (1990). Provision of adequate cross-ventilation was considered by Szokolay (1990) as the only passive control method with some promise of success in tropical warm-humid climates after the application of the Control Potential Zone (CPZ) technique.

It can be inferred that a lot of energy would be conserved in these buildings. According to Nicol and Humphrey (2002), naturally ventilated buildings typically use about half the energy of those which are air-conditioned. Appropriate design of naturally ventilated building spaces would certainly give high level of cost-effectiveness.

ADAPTIVE COMFORT

The adaptive aspect of thermal comfort study has been emphasized in recent literature (Humphreys and Nicol 2002, Merghani 2004, Lin et al 2010, Indraganti 2010, Ai et al 2011). The adaptive approach investigates the dynamic relation between people and their everyday environments. People make adaptations to their clothing and their thermal environment to secure comfort. As stated by Humphreys et al (2007), the concept is that thermal comfort is self-regulating whereby people take actions to attain comfort. Buratti and Ricciardi (2009) reported that numerous studies are on to support adaptive models in indoor thermal comfort evaluation and to establish quantitative indices to allow the subject to optimize his/her thermal comfort conditions.

A number of adaptive measures taken by the respondents in this study were found relevant in the determination and sustenance of their thermal comfort. The adaptive opportunities of note in this study were choice of clothing, drawing of curtains, opening of windows, putting on of fan and putting on the light. The respondents wearing lighter clothing expressed more feeling of comfort in the different periods of the day. The reason for this was the heat loss from the body through the low thermal resistance of light clothing. A greater proportion of respondents (83%) wore lighter clothing and this

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helped to maintain their comfort. The Chi-square test was employed to ascertain the possibility of a relationship between the feelings of the occupants about the thermal environment and the adaptive opportunities (Table 5). The result indicated the following variables as highly relevant in the determination of indoor thermal feelings of the respondents in this study: curtain drawing in the morning, window opening in evening, putting on fan in evening and putting on light in evening. To confirm the relationship between two variables the value of computed Pearson Chi-Square must be greater than the value obtained from the table of Percentage points of the Chi-Square Distribution (χ^2).

Table 5: Chi-Square Tests to Determine relationship between thermal feeling of respondents and adaptive opportunities

	Value	**df**	**Asymp. Sig. (2-sided)**	χ^2
Pearson Chi-Square(case1)	29.485[a]	18	.043	28.869
Pearson Chi-Square(case2)	47.171[a]	28	.013	41.337
Pearson Chi-Square(case3)	86.218[a]	35	.000	50.999
Pearson Chi-Square(case4)	59.947[a]	28	.000	41.337

case1- Feeling in the morning and curtain drawing in the morning.
case2 - Feeling in the evening and window opening in the evening
case3 - Feeling in the evening and putting on fan in the evening
case4 - Feeling in the evening and putting on light in the evening
Source: Author's Analysis

CONCLUSION

Building sustainability has a lot to do with energy efficiency and cost-effectiveness in comfort provision within living spaces. For residential buildings the major energy requirement is for comfort and lighting .To make such buildings sustainable the cost of maintaining appropriate comfort level must be minimized. Thermal comfort is demanded for building functionality and environmental quality. However, care must be taken not to expend much energy and finances in the pursuit of indoor thermal comfort. In this study of passively designed residential buildings, the findings indicated that the building spaces were comfortable at no extra cost to the users. There was no use of active energy for attainment of comfort. The natural ventilation provision was adequate enough and the adaptive measures employed by the residents were effective in maintaining comfort within the living spaces. Sustainability was therefore afforded by the passively operated building spaces considered.

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