Climate Responsive Approach to Building Design for Comfort in Warm-Humid Climate

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ABSTRACT

Most of the previous analyses of the climate of Nigeria have been based on zones and vegetations. This paper examines the climate of Southwestern Nigeria warm humid climate with respect to building design parameters like temperature, relative humidity, air velocity, vapour pressure and solar radiation in order to provide climate responsive design recommendations towards the achievement of physiological comfort. After assessing previous methods of climate analysis for building designs, it develops bioclimatic charts for various cities for Southwestern Nigeria. Finally, design recommendations are then suggested for typical cities in the Southwestern Nigeria.

Keywords: Bioclimatic Chart, Control Potential Zone (CPZ), Design Strategies.

1. INTRODUCTION

A building is essentially a modifier of the microclimate; a space isolated from climate temperature and humidity fluctuations sheltered from prevailing winds and precipitation and with enhancement of natural light (Olanipekun, 2002). Heat radiation from sun penetrates the indoor space of the buildings through openings in walls, fabrics and roofs leading to overheated indoor space and discomfort.

Effect of extreme climate condition which is discomfort could be reduced through introduction of climate responsive design parameters (Lawal, 2008). Climate responsive design parameters are based on the way a building form and structure moderate the climate for human good and well-being. Ways of moderating the indoor climate in building includes sitting of buildings, shape, size, cross ventilation, penetration, orientation, ventilation and choice of appropriate materials to prevent and minimize heat gain. Buildings in this area should respond to passive energy and have minimal use of active energy for economic viability (Ajibola, 2001). To meet the above requirements, the building should be bioclimatic responsive.

Buildings are always exposed to solar radiation everyday in the tropically area of the world. Despite this, most buildings space designs do not aim at reducing heat gain indoors and increasing evaporative cooling. Occupants of these spaces cannot enjoy adequate thermal and visual comfort because of lack of adequate cross ventilation and spatial organization and consequently need more active energy (Akinbami, 2002). They have shape and forms that are not responding to passive energy, not properly oriented and appropriate fabrics are not specified to prevent or minimize solar heat gain into the building. Most traditional buildings in southwestern Nigeria have laid too much emphasis in socio-cultural and economical factors (Costa, 2000).

Windows sizes, types and location had not responded to physiological comfort thereby necessitating the use of mechanical devices for increased air movement and illumination while most buildings are not well treated with appropriate landscape (vegetation) that will provide adequate shade and still allow adequate ventilation for cooling the indoor spaces.

2. STUDY AREA

Southwestern Nigeria lies within longitude 2⁰ 48’ – 6⁰ 0’ E and latitude 5⁰5’ – 9⁰ 12’N. Southwestern Nigeria is located in the south western part of Nigeria and shares land borders with the Republic of Benin in the west, Kogi and Edo States in the east, and Kwara State in the north. Its coast in the south lies on the Gulf of Guinea on the Atlantic Ocean. The largest and most influential ethnic group in Southwestern Nigeria is Yoruba. In terms of religion Southwestern Nigeria is roughly split half and half between Muslims and Christians with a very small minority who practice traditional religion. Southwestern Nigeria is divided into six states namely Oyo, Ogun, Osun, Ekiti, Ondo and Lagos state. Southwestern Nigeria's largest city is Lagos. Lagos has grown from 300,000 in 1950 to an estimated 15 million today, and the Nigerian government estimates that city will have expanded to 25 million residents by 2015.
3. ANALYSIS OF SOUTH WESTERN NIGERIAN CLIMATE

The tropical areas of the world are generally referred to as the overheated regions (Bowen, 1975). Based on his latitudinal classification, Southwestern part of Nigeria lies within longitude 2°48’ – 6°0’E and latitude 5° 5’-9° 12’N and strictly falls within the area labeled as a warm humid region. Ojo (1967) as stated in Ajibola (2001) observed that general climate is controlled by two main factors which are the daily heating and cooling at the land mass of the Sahara desert and the heating and cooling of the large body of water in the Atlantic Ocean. There are two well-marked seasons in southwestern Nigeria namely the dry season lasting from November to March and the rainy season lasting from April to October. Variation of climate was also observed as one move from the coast to the northern part and the climate at a particular location varies with the year. (Ideriah and Suleiman, 1989).

Fagbenle and Okunlaja (1992) applied Thornwante’s (1948) climate classification based on temperature and precipitation. Cranier (1967) used frequency distribution of weather zones to delineate zones in Nigeria. Komolafe and Agarwal (1987) and Odeleye (1989) have four zones while Ogunsote (1991) had six zones. These classification are used for building design are over lapping in these zones. Szokolay (1986, 1992) in Ojo (1967) has earlier classified Nigeria into four climate zones while Ogunsote (1991) classified Nigeria into six climatic zones. The variations observed shows that since climate are dynamic; design solution cannot be static with climate classification but rather dynamic.

Figures 1-6 show the graph of annual maximum and minimum temperature superimposed on the comfort chart of each of the cities representing each state on the Psychometric charts. Each chart also contains various passive cooling strategies. For each chart, the optimum cooling strategies or a combination of strategies can be chosen for design purposes. Observation of figures 1-6 shows that there is variation in the values of outdoor temperature To, thermal neutrality temperature Tn, and the positions of the comfort zones on the psychometric charts from one side to the other. It is also observed that the monthly temperatures and humidity for most of the cities are fully outside the comfort zones and are not restricted to any particular state. This indicates that a single control potential technique strategy may not be realistic all the year round in these cities. A combination of strategies might be the best option. Further analyses are shown in table 1. This table shows the values of the annual outdoor temperature To, thermal neutrality temperature Tn, length of overheated lo, length of underheatedLu, length of overheateddry Lod, and length of overhumidLoh. The overheated fraction Fot and overhumid fraction Foh for each of the cities were also calculated and presented in the table. Observation from table 1 also shows the relationship between annual mean temperature To and thermal neutrality temperature Tn as obtained by Auclien (1981) is an earlier analysis. All the 6 cities had To >Tn with Lo > Lu which means that overheated periods are dominant. Szolakay (1992) suggested that the humidity and aridity of a particular locality can be determined by observing the value of Lod and Loh. The 6 cities had Loh>Lod which means that humidity dominates in all the cities. Also 4 of the cities
and Foh=1. These cities fall under what Szolakay (1992) described as the most difficult tropical climates as cited in Ajibola (2001).

6. SOUTHWESTERN NIGERIA CLIMATE AND IMPLICATION ON THERMAL COMFORT

Relevant climatic data were obtained from Nigerian Meteorological Agency at Oshodi, Lagos state. These included rainfall, evaporation, wind speed, solar radiation, minimum temperature, maximum temperature, minimum relative humidity, maximum relative humidity, and sunshine hour for Southwestern Nigeria for the referenced year of the study 2005 and the data were used for climate analysis.

7. CLIMATE ANALYSIS OF SOUTHWESTERN NIGERIA USING PSYCHROMETRIC CHARTS

Climate can be assessed at the pre-design analysis stage. The extent and magnitude of the (outdoor) under heated and overheated period must be compared, establish the thermal comfort zone, thermal control task and select the appropriate passive control potential technique. The psychrometric chart is used as a basis to describe the range of outdoor atmospheric conditions within which indoor comfort could be achieved by the various passive control potential techniques leading to active energy conservation in buildings. Szokolay (1985) stated that existing climate classifications are too general and therefore not useful for building design purposes. Observations from the analysis show that it is difficult to classify Southwestern Nigeria climate with any reasonable precision. This is because location of Southwestern Nigeria has a variety of weather zones. Ojo (1977) in Ajibola (2001) observed that weather zones in Nigeria depend on the location and movement of the inter tropical Divergent zone (ITDZ) between moist and dry air and on the resulting temperature, atmospheric humidity, rainfall and sunshine distribution. Ojo (1977) had also shown variations of humidity and aridity in various areas in Nigeria.

The observed variations can be explained by the simple fact that climate is dynamic rather than a static phenomenon. The above discussion confirmed Szokolay’s (1985) assertion that climate classification is not terribly useful for building design. The graph of maximum and minimum temperatures plotted along with value of minimum and maximum relative humidity respectively were superimposed on the comfort zones on the psychrometric charts for Ibadan, Osogbo, Ado-Ekiti, Ondo, Abeokuta and Lagos respectively representing Oyo, Osun, Ekiti, Ondo, Ogun and Lagos States. On the psychrometric charts were also plotted the various passive-cooling strategies applicable for each of the towns mentioned above based on the control potential zone technique (Szokolay, 1986). Table 1 shows the summaries of recommendations from psychrometric charts towards achieving passive building designs.

Psychrometric chart for Ibadan in Figure 1 shows that all the monthly climatic plots fell outside the comfort zone meaning that there is the need to apply control potential techniques to buildings in Ibadan (Oyo state) to bring about natural thermal comfort and reduce active energy consumption. Using this analysis the thermal neutrality temperature (Tn) for Ibadan was determined to be 26.9°C. The length of overheated (Lo=380) was greater than the length of under heated (Lu=100); this has implications on thermal stress of Ibadan with overheating as been predominant.

The length of over humid (Loh=380) was greater than the length of overheated dry (Lod=0). This brought the conclusion that humidity dominates in Ibadan. Fraction of overheated temperature (Fot) was 0.79, overhumid fraction (Foh) was 1 for Ibadan indicating that humidity is the problem of all the overheated times. The smaller the value of the over-humid fraction Foh, the lesser the humidity problems.

The psychrometric chart shows that “Thermal Inertia” control potential (zone) technique could solve the thermal comfort problems in Ibadan only in the months of February and March because part of the plotted monthly climatic lines for these months fell inside the zone. It also shows that most of the climatic plotting for all the months fell within “Air Movement Effect” control potential zone. It therefore implied that “Air Movement Effect” control potential technique would take care of thermal comfort condition in buildings in Ibadan (Oyo state) if properly applied.

Psychrometric chart for Osogbo in Figure 2 shows that part of climatic plotting for January, February and December fell within the comfort zone. This implied that control potential techniques must be applied to buildings in Osogbo (Osun state) to achieve natural comfort for most of the months and reduce active energy consumption. The thermal neutrality temperature (Tn) for Osogbo was 26.28°C. The length of the overheated (Lo=301) was greater than the length of under heated (Lu=147). This revealed that overheating was dominant in Osogbo throughout the year. The length of over humid (Loh=215mm) was greater than the length of overheated dry (Lod=86mm). This revealed that humid condition dominated in Osogbo. Fraction of overheated temperature (Fot) was 0.67 and overhumid fraction (Foh) was 0.71. This revealed that humidity was the problem at all the overheated times. The smaller the value of over humid fraction (Foh) the lesser the humidity problems. Five of the monthly climatic plotting fell within “Mass Effect” control potential zone, meaning that thermal inertia (control potential techniques) of the fabric is required to
provide natural comfort within the building for the months of January, February, October, November and December. Climatic plotting for all the months fell within “Air Movement Effect” control potential zone; it means that this control potential technique will help to provide natural thermal comfort conditions in buildings in Osogbo (Osun state) if properly applied.

Psychrometric chart in Figure 3 for Ado-Ekiti shows that all the monthly climatic plots fell outside the comfort zone except November meaning that there is the need to apply control potential techniques to buildings in Ado-Ekiti (Ekiti state) to bring about natural thermal comfort and reduce active energy consumption.

The thermal neutrality temperature (Tn) for Ado-Ekiti was 25.88°C. The length of the overheated (Lo=342) was greater than the length of underheated (Lu=162). This revealed that overheating was dominant in Ado-Ekiti throughout the year. The length of over humid (Loh=328) was greater than the length of overhated dry (Lod=14). This revealed that humid condition dominated in Ado-Ekiti. Fraction of overheated temperature (Fot) was 0.68 and over humid fraction (Foh) was 0.96. This revealed that humidity was the problem at all the overheated times. The smaller the value of over humid fraction (Foh) the lesser the humidity problems. The psychrometric chart revealed that “Thermal Inertia” control potential (zone) technique could solve the thermal comfort problems in Ado-Ekiti only in the months of January, February and November because the plotted monthly climatic lines for these months fell inside the zone. Climatic plottings for all the months fell within “Air Movement Effect” control potential zone; this means that this control potential technique will provide natural thermal comfort conditions in buildings in Ado-Ekiti (Ekiti state) if properly applied.

Psychrometric chart for Ondo in Figure 4 shows that none of the monthly climate lines plotted fell within the comfort zone meaning that there is the need to apply control potential techniques to buildings in Ondo (Ondo state) to bring about natural thermal comfort and reduce active energy consumption. The thermal neutrality temperature (Tn) for Ondo was 26.44°C. The length of overheated (Lo=369) was greater than the length of underheated (Lu=91). This revealed that overheating was dominant in Ondo throughout the year. The length of over humid (Loh=369) was greater than the length of overhated dry (Loh=0). This revealed that humid condition dominated in Ondo. Fraction of overheated temperature (Fot) was 0.80 and over humid fraction (Foh) was 1.0. This revealed that humidity was the problem at all the overheated times. The smaller the value of over humid fraction Foh, the lesser the humidity problems. None of the climatic plots fell within the “Mass Effect” control potential zone, revealing that thermal inertia control potential technique cannot solve the thermal Comfort problem in the buildings. All the climatic plotting for the months fell within the “Air Movement Effect” control potential zone. It therefore means that “Air Movement Effect” control potential technique will take care of thermal comfort condition in buildings in Ondo (Ondo state) if properly applied.

Psychrometric chart for Abeokuta in Figure 5 shows that all the monthly climatic plots fell outside the comfort zone, meaning that there is the need to apply control potential techniques to buildings in Abeokuta (Ogun state) to bring about natural thermal comfort and reduce active energy consumption. The thermal neutrality temperature (Tn) for Abeokuta was 26.79°C. The length of overheated (Lo=370) was greater than the length of under heated (Lu=39). This revealed that overheating was dominant in Abeokuta throughout the year. The length of over humid (Loh=370) was greater than the length of overhated dry (Lod=0). This revealed that humid condition dominated in Abeokuta. Fraction of overheated temperature (Fot) was 0.91 and over humid fraction (Foh) was 1.0. This revealed that humidity was the problem at all the overheated times. The smaller the value of over humed fraction (Foh), the lesser the humidity problems. None of the climatic plots fell within the “Mass Effect” control potential zone. This means that thermal inertia control potential technique cannot solve the thermal comfort problem in the buildings but since all the climatic plots fell within the “Air Movement Effect” control potential zone, it therefore means that “Air Movement Effect” control potential technique will take care of thermal comfort condition in buildings in Abeokuta (Ogun state) if properly applied.

Psychrometric chart for Lagos in Figure 6 shows that all the monthly climatic plots fell outside the comfort zone meaning that there is the need to apply control potential techniques to buildings in Lagos (Lagos state) to bring about natural thermal comfort and reduce active energy consumption. Using this analysis the thermal neutrality temperature (Tn) for Lagos was determined to be 27.18°C. The length of overheated (Lo=523) was greater than the length of under heated (Lu=43); this had implications on thermal stress of Lagos. Also the length of over humid (Loh=523) was greater than the length of overhated dry (Lod=0). These brought the conclusion that humidity dominates Lagos. From the chart, it is clearly shown that all the climatic plotting for the months fell within the “Air Movement Effect” control potential zone. It therefore means that “Air Movement Effect” control potential technique will take care of thermal comfort condition in buildings in Lagos (Lagos state) if properly applied.

8. CONCLUSION

Based on the analysis, it is obvious that the climate in Southwestern Nigeria is not strictly homogeneously warm humid although it lies within longitude 2° 48’ – 6° 0’ E
and latitude 5°5’ – 9° 12’N. The analysis of the climatic data closely related to the design environment will lead to more adequate and precise design decisions in terms of adequate orientations of the buildings, spatial organization, prevention of heat gain into indoor spaces, cross ventilation, better choice of building materials and vegetation. The control potential zone (CPZ) technique of climate analysis directly shows the optim design strategy on the bioclimatic chart. The design strategies for each of the cities under study can be seen in figures 1-6.

RECOMMENDATIONS

1. The variations in the location characteristics of climate variables in every geographical part of the Southwestern Nigeria should be simulated into the design principles of buildings.

2. There is need to continually carry out climatic observations and specific data collection of the parameters that may affect reaction of building envelopes to weather variables, and

3. The updates of these data should be used as basis on how to conceptualize the design of the openings and made of spatial distribution in buildings in order to ensure attainment of comfortable internal environment.

Table 1: Summaries of Recommendations from Psychrometric Chart

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<th>Ibadan (Oyo State)</th>
<th>Osogbo (Osun State)</th>
<th>Ado-Ekiti (Ekiti State)</th>
<th>Ondo (Ondo State)</th>
<th>Abeokuta (Ogun State)</th>
<th>Lagos (Lagos State)</th>
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<td>7° 20’ – 7°</td>
<td>7° 30’ – 7°</td>
<td>7° 10’ – 7°</td>
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<td>Tn</td>
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<td>26.28°C</td>
<td>25.88°C</td>
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<td>Lu</td>
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<td>162mm</td>
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<td>Lod</td>
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<td>Loh</td>
<td>380mm</td>
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<td>328mm</td>
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<tr>
<td>Fot</td>
<td>0.79</td>
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<td>0.68</td>
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Source: Authors Analysis of Field Work (2005)

Key

To = Monthly Mean Outdoor Temperature
Loh = Length of Over humid

Tn = Thermal Neutrality Temperature
Fot = Fraction of Over heated Temperature

Lo = Length of Overheated
Foh = Over humid Fraction

Lu = Length of Underheated
T I = Thermal Innertia

Lod = Length of Overheated dry
AME = Air Movement Effect
Figure 1: Psychrometric Chart for Ibadan (Oyo State)

Figure 2: Psychrometric Chart for Osogbo (Osun State)
Figure 3: Psychrometric Chart for Ado-Ekiti (Ekiti State)

Figure 4: Psychrometric Chart for Ondo (Ondo State)
Figure 5: Psychrometric Chart for Abeokuta (Ogun State)

Figure 6: Psychrometric Chart for Lagos (Lagos State)
REFERENCES


