AFRREV STECH

An International Journal of Science and Technology
Bahir Dar, Ethiopia
Vol. 2 (2) July, 2013: 67-98
ISSN 2225-8612 (Print) ISSN 2227-5444 (Online)

Structural Properties of Dwelling and Thermal Comfort in Tropical Cities: Evidence from Warri, Nigeria

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Abstract

The aim of this study is to determine if structural properties of dwelling lead to thermal comfort of the occupant. The research design adopted is the explanatory field Ex post facto design. Primary climatic data for a period of four months (June-September, 2010) were *generated. In addition, secondary data on daily air temperature, relative humidity, wind speed and solar radiation for six years (2005-2010) were collected from the archival records of the Nigeria Meteorological Agency (NIMET) Warri. The structural properties of dwelling units, in particular "window types" in 1, 250 apartments and their indoor temperature levels were collected. One hypothesis was formulated: (HO) There is no significant variation in effective temperature index and thus thermal comfort between dwellings built with wooden windows and those with slide-glass windows. The data were analyzed using the One-way ANOVA and the paired t-test. Finding shows that dwellings with wooden windows are more thermally comfortable than those with slide-glass windows in the absence of artificial means of ventilation. Strategies proffered for the development of liveable dwellings include: The need for the input of climatologist in dwelling designs and construction couple with the need to initiate policies that make it difficult for residential glass firms to thrive among others.*

Key words: Structural properties, dwelling, thermal comfort, tropical cities, Warri, Nigeria.

Introduction

Thermal comfort is the air temperature experienced in an area when one has no desire to increase the air temperature or decrease it either because of coldness or excessive heat in that environment (Ayoade, 2008; Ojeh, 2011). Thermal comfort is essential for occupants' well-being, productivity and efficiency. It can be achieved with good dwelling design.

One of the main functions of a building is to protect the occupants against harsh outdoor climate and to provide a comfortable and healthy environment for them that would impact positively on their productive performance (Sangowawa, Adebamowo and Godwin, 2008). However, in this era of climate change and global warming, providing comfort for the occupants of a building is quite challenging and very fundamental. This is as a result of growing ranges of challenges now facing designers to provide buildings that will be fit and comfortable for the 21st century (Akande and Adebamowo, 2010). The study of thermal comfort is very important because it is correlated not only with occupants' comfort, but also with energy consumption (Ye, Zhang, Pang and Zhao, 2006) in an energy deficit world.

In modern buildings, thermal comfort is accomplished with the help of mechanical cooling or heating while in ancient designs the buildings had many characteristics which led to thermal comfort, i.e., the shape of the building and different parts of the building, (For example, indoor spaces, doors and windows are located and oriented to take maximum advantage of the climate. The role of vegetation and water around the building in determining the thermal comfort is well documented (Hajat et al., 2002). With the advent of energy crisis there has been a renewed interest in those aspects of architecture which contributed to thermal comfort in a building without (or with minimum) expenditure of energy.

Since Warri Metropolis and environs have been areas of high population attraction due to the presence of some oil companies and will still continue to attract population in the future while the land area is static, consequently increasing the heat emissions from the companies, vehicular movements and humans themselves, there is the need to examine ways in which residential buildings should be designed and oriented with setbacks to ensure thermal comfort.

For optimum bodily comfort and efficiency, it is necessary to maintain a suitable indoor climate within buildings. This can be done by artificial heating or cooling or by proper design that will ensure adequate ventilation and through wise choice of building materials. Since artificial heating or cooling is expensive both in terms of capital costs and maintenance, emphasis in the tropics should be on climate conditioning within buildings through proper design and choice of building materials (Loomans, 1998). This will obviate the need for expensive artificial cooling.

Climate conditioning is concerned with landscaping and the placement of other buildings as well as the design of the building itself (Roonak and Kamaruzzaman, 2009). The aim of climate conditioning is to create a suitable climate in and around the building. In site selection for a building, air flow and drainage should be carefully considered. As mentioned earlier, the wind produces direct effect on a building by exerting pressure on it. Air flow also helps to modify temperature and humidity conditions. This is particularly important in warm, humid environment where there is need to lessen the effect of excessive humidity and high temperatures. The local relief is the most important factor that determines the wind condition at a given site. Windward slopes, summits and plains are usually well aerated (Roonak and Kamaruzzaman, 2009).

Apart from suitable sitting of buildings, good design and wise choice of building materials can enhance good indoor climate in a building, the orientation of the building in relation to the prevailing wind direction and position of the sun is of utmost importance (Cheng, Ng and Givoni, 2005). Recent studies (Environmental Issues, 2008) show that almost eight in ten dwellings across Australia are artificially heated. There has also been a substantial increase in the number of households with air conditioners. The condition is not much different in most urban environments in Nigeria.

This study on structural properties of dwelling and thermal comfort in tropical cities is borne out of a common challenge of overheated building interior as a consequence of solar penetration through the building envelope and windows and lack of ventilation in dwelling places found in cities in the tropical regions of the world. This has been observed in Malaysia (Rajapaksha *et al.*, 2003); Kuala Lumpur (Nasibeh *et al.*, 2007) and Warri, Nigeria (Ojeh, 2011). However, in a bid to conquer this problem posed by the natural environment, scarce energy resources are utilized (increase demand for air conditioners) which has given rise to high energy demand and usage. This has led to the corresponding increase in the production of green-house gases (GHG) energy related problems in cities of developing countries where there is virtually poor generation and high consumption of energy with limited affordability for usage in residential buildings and industries. Moreover, due to the limited open land spaces and high density of the building blocks and crowded dwellings in tropical cities, a large number of buildings do not fulfill the requirements for thermally comfortable design in the face of a changing climatic environment thus compromising sustainable development in the housing sector.

More worrisome is the recent trend of using environmentally unfriendly materials that compromise thermal comfort in dwelling design and none existence of planning policies from stake holders to discourage such act. The role of dwelling design in aiding thermal comfort has been given relatively little attention by scholars because thermal comfort can also be achieved mechanically. This places the poor masses at the disadvantaged position in terms of providing the needed energy to power mechanical cooling/heating systems

Literature and Conceptual Issues

The study of urban design on outdoor thermal comfort in Colombo, Sri Lanka by Johansson and Emmanuel (2006) showed that the outdoor environment is deteriorating in many tropical cities due to rapid urbanization. This leads to a number of problems related to health and well-being of humans and also negatively affects social and commercial outdoor activities. The environmental parameters affecting thermal comfort, viz. air temperature, humidity, wind speed, and solar radiation, were measured, and the thermal comfort was estimated by calculating the physiologically equivalent temperature (PET). The thermal comfort is far above the assumed comfort zone due to the combination of intense solar radiation, high temperatures, and low wind speeds, especially on clear days. The worst conditions were found in wide streets with low-rise buildings and no shade trees. The most comfortable conditions were found in narrow streets with tall buildings, especially if shade trees were present, as well as in areas near the coast where the sea breeze had a positive effect. In order to improve the outdoor comfort in Colombo, it is suggested to allow a more compact urban form with deeper street canyons and to provide additional shade through the use of trees, covered walkways, pedestrian arcades, etc. The opening up of the city's coastal strip would allow the sea breeze to penetrate further into the city. Johansson and Emmanuel (2006) concluded that the creation of thermally comfortable microclimates in urban environments is therefore very important.

In Hong Kong, Cheng , Ng, Chan and Givoni (2012) carried out a longitudinal study on outdoor thermal comfort of sub-tropical climates using predicted mean vote (PMV) and physiological equivalent temperature (PET). The result of their study shows according to the formulas, that for a person in light clothing sitting under shade on a typical summer day in Hong Kong where the air temperature is about 28°C and relative humidity about 80%, a wind speed of about 1.6 m/s is needed to achieve neutral thermal sensation. However, according to Uzuegbunam , Chukwuali and Mba (2012), design strategies have not been properly scrutinized, categorized or scientifically indexed for appropriate evaluation. This they posited, have demonstrated that, the knowledge on the above issues is not yet complete, and that the critical problems, have not been solved. People in buildings experience poor ventilation discomfort. This is in no way a minor issue for the occupants of the buildings or for those interested in productivity. The economic consequences of having dissatisfied group of people can be deleterious (Uzuegbunam , Chukwuali and Mba, 2012).

Methodology of Study

The study area is located between latitude $5^0 30`$ N and $5^0 35`$ N, and Longitude $5^0 29`$ E and $5^0 48`$ E. Warri is situated within the Niger Delta region of Nigeria. It is bounded on the North by Okpe and Sapele Local Government Areas on the South by Warri South West Local Government Area and the Atlantic Ocean. The area is bounded on the East by Ughelli South Local Government Area and on the West by Warri North Local Government Area, as shown in Fig 1.2. Warri Metropolis is made up of Warri South, Udu and Uvwie Local Government Areas as shown in Fig 1.3.

The location of Warri affects the thermal comfort attributes experienced by her people. The area expansion of Warri during the past two decades has been remarkable. From a small river settlement, Warri has grown to engulf the surrounding towns of Effurun, Ekpan, Enerhen, Edjeba, Ogunu, Jakpa, Ovwian-Aladja and Udu (Efe, 2002). The area is characterised by tropical equatorial climate with mean annual temperature of 28^0C and rainfall amount of 3000mm (Efe, 2002). Rainfall period ranges from January — December, with the minimum value of 20.4mm in January and over 499.1mm in September. However, double rain maxima between the months of July and September are observed. There is a little dry spell in the month of August called “August break”. Convectional type of rainfall is predominant in the city. The predominant Air Mass System in Warri Metropolis and environs is the Tropical Maritime Air Mass (mT). This air mass is humid, moist and brings rainfall into this environment and popularly called the SW Monsoon Wind. The influence of the Tropical Continental (cT) air mass is minimal and it brings harmattan into the area between December and February and referred to as the NE Trade Wind. This climatic mix accounts for the natural thermal characteristics of the area. Thus, the geography of Warri and environs influence the thermal environment condition of the area (Ojeh, 2011).

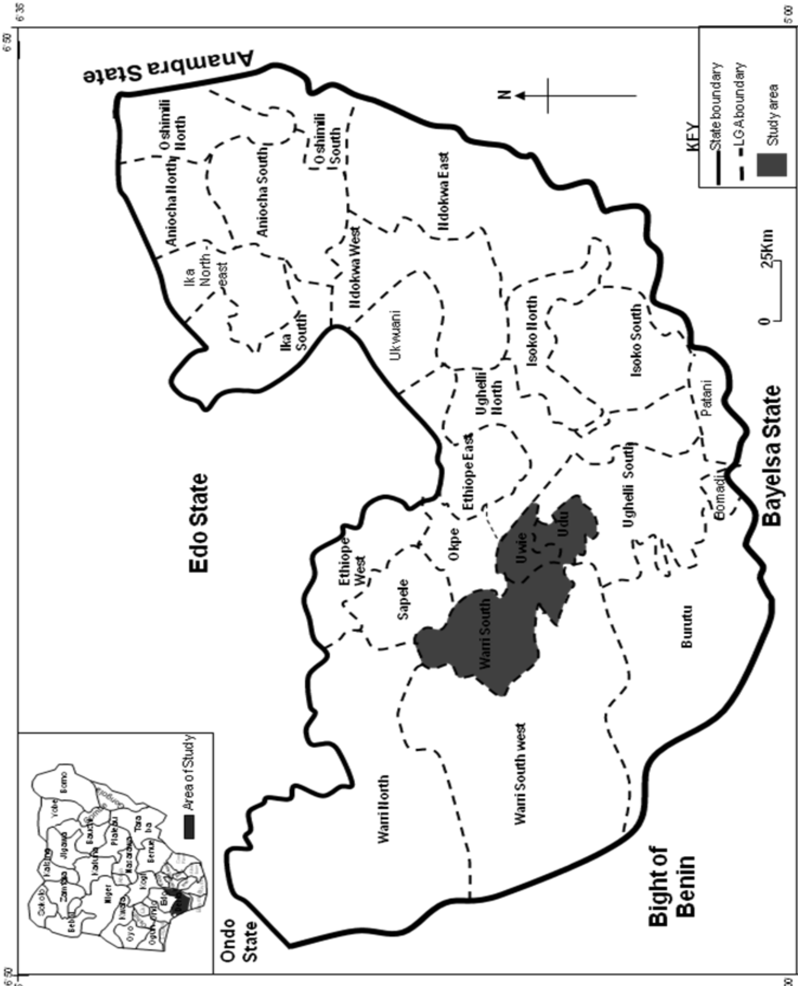

Fig. 1.1 Map of Delta State Showing Study Area

Source: Modified after Ministry of Lands, Survey and Urban Development Asaba, 2008

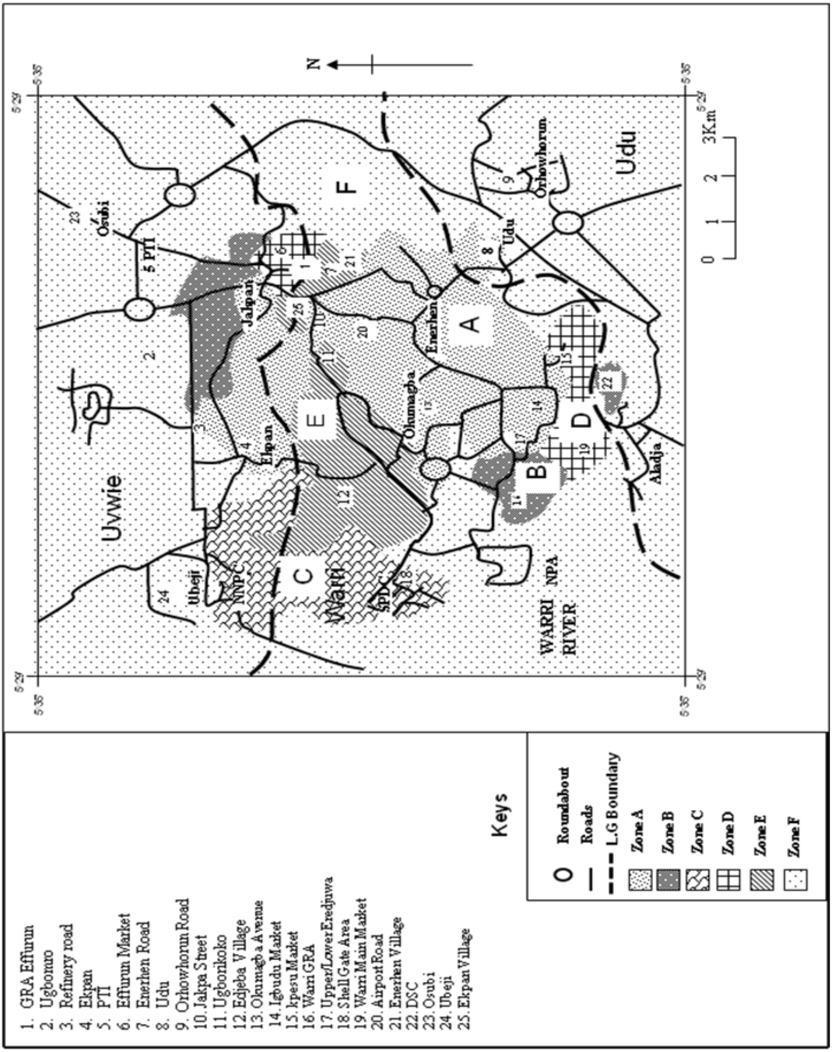

Fig 2: Street Map of Warri and Environs showing study site

Two types of data were used. They are primary and secondary data. The primary data include those data generated from the daily reading of the wet bulb and dry bulb thermometer and air temperature that was installed indoors in the living rooms as well as measurement of outdoor humidity and air temperature of sample points in the study area.

The secondary data used were the wind speed, solar radiation, temperature and relative humidity data for Warri which was collected from the archival records of the Nigeria Meteorological Agency (NIMET) located in Lagos and Warri. Decadal temperature for 102 years (1907-2009) was collected from the Archival records of NIMET, in Lagos while six years mean monthly records of temperature, wind speed, solar radiation and relative humidity were collected from NIMET, in Warri because it was adequate to access the thermal comfort characteristics of the urban environment (Efe, 2009). Previously, Ayoade (1978) used archival data collected from meteorological stations for 13 hours over Nigeria.

The study was based on stratified sampling method where the study area was stratified into 6 zones based on the land use types. Thus, the study area was zoned using the alphabetical notations (A–F). The zones are:

(A) High-density residential areas (Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road etc.).

(B) Low density residential areas (Delta Steel Town, G.R.A at Warri & Effurun, PTI Road).

(C) Industrial areas (Nigerian National Petroleum Corporation Refinery, Petrochemical (NNPC), Ogunu, DBS express Road etc.

(D) Commercial zones (Effurun, Pessu, Igbudu and Warri main Market).

(E) Traditional residential areas (Edjeba, Ugborikoko, Enerhen Villages .etc).

(F) Fringe areas (Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro) which serve as control stations.

The use of letters A – F for the zones was based on convenience. The rationale for these zones was to ensure adequate spread. Oriero (1998) and Efe (2005) have used some of these zones too in their studies in Warri metropolis and they achieved a significant result.

In all, a total of 25 neighbourhoods out of the 46 neighbourhoods were randomly selected and used for the study (Table 1). Within each neighbourhood, all existing streets were given identification numbers. Using systematic random sampling technique, every 3rd street was selected for detailed survey. Furthermore, along each selected street, the researcher used the systematic random sampling technique to select houses for administration of questionnaires. The researcher used an interval of five (5) houses to select the dwelling units where records were collected and questionnaires were distributed. Where there were more than one (1) household in a compound, the simple random sampling technique was further employed to select the households where data were generation and for the administration of questionnaires.

For the daily reading of the wet bulb and dry bulb thermometers, the living rooms were the sample point. Thermometers were mounted at 5 ft (1.5m) above the floor before readings are taking for uniformity.

The dwelling units were divided into those that have air conditioning systems (AC) and naturally ventilated buildings (with or without fans). This classification was necessitated by the researcher's description of these buildings and their environmental control systems. The primary distinction between the building types was that the non-ventilated buildings have no mechanical air-conditioning. Thus, natural ventilation occurs through operable windows and doors that are directly controlled by dwellers.

Three types of housing units: namely, houses with louvre windows, houses with aluminium windows and houses with wooden windows were selected from each zone (A-F) based on availability and population of households. The dwelling units in each area shared a common denominator – they had the same number of households, roof types and with, at least, a passive cooling system such as fan or air conditioner.

The instruments used in this study were the hygrometer (dry bulb and wet bulb thermometer), the maximum and minimum thermometer. While the dry and wet bulb thermometer measures the humidity- the traditional way to measure humidity is a two-step process: both wet bulb and dry bulb temperatures are obtained, and then converted to relative humidity using a psychometric chart. The maximum and minimum thermometer measures the air temperature. The measurement techniques involved mounting the thermometers at 5 feet (1.5m) above the floor level on the north facing wall of living rooms in all the sampling areas. Before the reading of the hygrometer and the maximum and minimum thermometer was done in all the sample points, the instruments were made to stay for 5 minutes, a time-frame within which the instruments will adapt to the climatic condition(s) of the particular sample point. This condition is known as the process of standardization of the instrument. This process has been applied by Olaniran (2004) and Efe (2006) and was effective. The outdoor temperature reading was taken outside the dwelling premises with the same instrument used for taking the indoor readings also observing the standardization process to get accurate records without any direct contact with the radiation of the sun. The measurement of weather parameters for both indoor and outdoor records were done in the six sampling zones with the help of 20 field research assistants who were duly trained in such act by the researcher.

Observations were made and recorded at intermediate standard observatory hours of 06.00hr-12.00hrs, 12.00hrs-18.00hr, 18.00hrs-00.00hr and 00.00hrs-06.00hrs as recommended by the World Meteorological Organisation (1969). Olaniran (2004) used mean monthly data collected on a 3-hourly basis interval and achieved significant results. City traverse method of using mobile thermometers to collect data within the city and its environs within one hour was adopted in all sampling zones between the 0600hr and 2100hr while the research assistants took three hourly records between 0000hr and 0300hr (GMT) in their residences. The researchers that have used this method of field assistants include Oguntoyinbo (1973; 1981; 1986), Efe and Awaritefe (2004). Oguntoyinbo (1981) applied this method in his study of aspect of urban microclimate of Ibadan, Nigeria. Efe and Awaritefe (2004) carried out a study on urbanization and its influence on the microclimate of Warri metropolis using this method and achieved a significant result.

The primary climate data was collected for a period of four consecutive months from June 1, 2010 to September 30, 2010 after which the secondary data on daily air temperature, relative humidity, wind speed, solar radiation for six years (January 2005 – September 2010) were collected from the archival records of the Nigeria Meteorological Agency located in Warri based on record consistency. In presenting the data, tables, statistical diagrams were employed. Subsequently, comparative analysis was done based on the data. The data were analysed using the One-way ANOVA test and the paired t-test. The One- way ANOVA was used to test the stated hypotheses one and two while the paired t-test was used to test hypothesis three. The data were entered in Statistical Package for Social Sciences (SPSS) version 17 and double checked before analysis. In other words, the test would show if there is variation between or within the samples from the different building based on window type in the dwelling unit and also the differences between indoor and outdoor temperature characteristics

The effective temperature index (ET) was used to determine the comfort level of the living rooms. This study employed the use of effective temperature index (ET) because it appears to be the most widely used measure of thermal comfort and is highly empirical and favoured by heating and ventilation engineers and requires that comfort limits be established for the location. Hence an ET value of 18.9^{o}C or below indicates an uncomfortable condition arising from cold stress, while an ET value of above 25.6^{0}C will indicate heat stress (Thom, 1959; Ayoade, 1978; 1993; 2008). The effective temperature was employed for this study because it is used to establish thermal sensation by equating prevailing conditions with a set standard as shown above.

Spatial variations were observed in the air temperature distribution in the study area. The spatial air temperature trend has remained generally on the increase since 1907 (See Fig.3). The mean temperature in Warri and environs between 1907 and 2009 was 26.7^{o}C. The increase was gradual between 1907 and the mid 1940s. A slight drop in temperature was experienced between the late 1951 and 1953. Thereafter, the gradual increase continued until the late 1957. A sharp rise in air temperature became evident as from the early 2000 which continued till 2009 (Fig 3). The sharp rise in temperature observed in Warri and environs in Nigeria since the early 1970s is in agreement with the global trend (IPCC, 2007).

In the 1907-1935 climatic periods, the mean air temperature was 26.1°C. By 1936–1970, the air temperature slightly increased to 26.7°C while it rose to 27.1^{o}C between the periods of 1971-2009. This implies that temperature increase between 1907-1935 and 1936-1970 was only 0.6°C while it was 1.3°C between 1935-1970 and 1971-2009. Within the study period 1907-2009 (102 years), temperature increase in Warri and environs was 1.3°C. Global temperatures on the earth's surface have increased by 0.4 - 0.8°C with a mean of 0.74°C as recorded since 1860 when actual scientific temperature measurement started (Spore, 2008; IPCC, 2007). With an increase of 1.3^{o}C in Warri and environs as this study found out, this implies that there has been climate change in Warri and if the increase continues unabated, Warri and environs may experience between 1.4^{o}C to 4.26^{o}C increase in temperature by 2015.

Findings and Discussion

Outdoor and indoor temperature characteristics

From Table 3, this study shows that there was a general high indoor ET in the study area irrespective of the time of the day when compared with the critical threshold of 25.6^{0}C. The mean indoor ET between the hours of 6am-12noon was 28.2^{0}C, 28.7^{0}C between the hours of 12noon-6pm and 26.9^{0}C between the hours of 6pm-12am. It was observed that the night hours through the early hours of the morning (6pm-12am) were cooler than the remaining hours. The hours of 12noon-6pm recorded the highest indoor ET of 28.9^{0}C during the period of study (See Fig 4). Temperatures in the city starts rising from the morning hours (6am-12noon) up to 6pm as result of the effect of the building and its occupants emitting their own heat as well as reduced cross ventilation due to the urban congestion of buildings because little or no building setbacks are maintained in the area during the construction stages to allow natural ventilation. The study shows that the hours of 6pm-12am was more thermally comfortable than the other hours of the day.

Indoor and Outdoor Physiological Temperatures in Warri

Table 4 shows the monthly mean indoor and outdoor effective temperature values in the study area for different kinds of windows used. It reveals that in the month of June, between the hours of 6am-12noon (0500-1100hrs GMT), the highest outdoor ET value of 25.6^{0}C was recorded for the month in both the high density residential areas of Jakpa road, Okumagba layout, Airport road, Upper/Lower Erejuwa, Enerhen/Udu road and the commercial areas (Effurun market, Warri main market, Pessu market). In the traditional areas of Edjeba, Ugborikoko, Enerhen and Ekpan villages, outdoor ET value of 25.5^{0}C was recorded. 25.4^{0}C outdoor ET value was recorded in the low density residential areas of Delta steel town, GRA at Warri and Effurun, 25.3^{0}C in the industrial areas of NNPC, Ogunu, DBS express road and 25.2^{0}C in the fringe areas of Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro. From this result, the study confirms that the four zones with values of 25.5^{0}C, 25.4^{0}C, 25.3^{0}C and 25.2^{0}C were thermally comfortable while the two areas with 25.6^{0}C are at the critical threshold level. The fringe areas of Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro with ET value of 25.2^{0}C is the most comfortable outdoor environment in the month of June during the study period. This is attributed to the spacing level between buildings in these areas as well as the number of occupants per dwelling unit.

In the same month of June, the study reveals that the following indoor ET values occurred in the six zones based on the window types in use; 26.5^{0}C, 25.8^{0}C, 27.9^{0}C in buildings louvres, wooden and slide glass windows respectively in the Jakpa road, Okumagba layout, Airport road, Upper/ Lower Erejuwa, Enerhen /Udu Road areas. These results shows that buildings with wooden windows were more thermally comfortable followed by those of louvres and slide glass windows. In the low density residential areas of Delta Steel Town, G.R.A at Warri and Effurun, indoor ET values of 26.2^{0}C, 25.5^{0}C and 27.5 were recorded in buildings with louvres, wooden and slide glass windows respectively. By this result, the buildings with slide glass windows were the most thermally uncomfortable dwelling units. Table 4.5 shows that the trend explained above was observed in the remaining four zones; buildings with wooden windows recorded the lowest ET values and adjudged more thermally comfortable.

From Table 4, the hours of 12noon-6pm (1100-1700hrs GMT) in the same month of June recorded highest indoor ET values. At this time of the day, the sun is directly overhead causing direct heating up of the buildings through the contributory effects from all paved surfaces in the built-up areas. In the high density residential areas of Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road, indoor ET values of 28.8^{0}C (louvre window buildings), 26.6^{0}C (wooden window buildings) and 28.9^{0}C (slide glass window buildings) were recorded. This confirms that buildings with slide glass windows were hotter while those of wooden windows were less hotter. These periods of the day were thermally not comfortable because even buildings with wooden windows recorded high ET value

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that was above the critical threshold. This scenario was general observed as the ET trend in the remaining five zones during this period. Buildings with slide glass windows were more thermally uncomfortable for the dwellers.

For the night period of 6pm-12midnight in the month of June, Table 4 shows that the highest indoor ET values of 26.6^{0}C, 26.3^{0}C, 26.4^{0}C, 26.6^{0}C, 26.4^{0}C and 26^{0}C were recorded in buildings with slide glass windows from the high density residential areas to the fringe areas while it was 25.5^{0}C, 25.4^{0}C, 25.5^{0}C, 25.3^{0}C, 25.2^{0}C and 25.1^{0}C respectively in buildings with wooden windows. This result also implicates the buildings with slide glass windows as less thermally comfortable than those of louvres and wooden windows.

In the month of July, Table 4 shows that between the hours of 6am-12noon (0500-1100hrs GMT), indoor ET values of 26.2^{0}C (buildings with louvre windows), 25.9^{0}C (buildings with wooden windows) and 27.8^{0}C (buildings with slide glass windows) were recorded in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road areas. In the commercial areas of Effurun Market, Warri Main Market, Pessu Market areas, indoor ET values were 26.3^{0}C (buildings with louvre windows), 26^{0}C (buildings with wooden windows) and 28.3^{0}C (buildings with slide glass windows) while it was 26^{0}C (buildings with louvre windows), 25.6^{0}C (buildings with wooden windows) and 28.6^{0}C (buildings with slide glass windows) in the fringe zones of Osubi, Ubeji, Aladja, Orhowhorun and Ugbomro area. This result shows that the fringe areas were more thermally comfortable than the high density residential areas while in each area buildings with wooden windows were more thermally comfortable than those of the slide glass windows. This is attributed to the spacing units between buildings in these areas, the number of occupants per dwelling unit as well as the moderating effect of vegetation found in the area.

In the same month of July, between the hours of 12noon-6pm (1100-1700hrs GMT), the highest indoor ET values of 28.7^{0}C (louvre windows), 27.4^{0}C (wooden windows) and 28.4^{0}C (slide glass windows) were recorded in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road areas while it was 28.1^{0}C, 27^{0}C and 28^{0}C in the Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro. This result indicates that the buildings with slide glass and louvre window had higher ET values than the wooden windows, thus, less thermally comfortable for this period of time. The reason for this is that both slide glass and louvre windows have higher emissivity of heat than the wooden windows.

The hours of 12midnight to 6am in the same month of July recorded the highest outdoor ET values of 23.9^{0}C in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road as well as in the Effurun Market, Warri Main Market, Pessu Market areas while outdoor ET value of 23.6^{0}C was recorded in Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro areas which shows that the fringe areas were more thermally comfortable.

For the month of August, Table 4 shows that the outdoor ET were 25.4^{0}C at Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road areas, 25.2^{0}C at Delta Steel Town, G.R.A at Warri and Effurun, Nigerian National Petroleum Corporation Refinery (NNPC), Ogunu, DBS express Road and at Edjeba, Ugborikoko, Enerhen and Ekpan villages while it was 25.3^{0}C at the areas of Effurun Market, Warri Main Market, Pessu Market and 25^{0}C at the fringe areas of Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro between the hours of 6am-12noon (0500-1100hrs GMT). With this result, the fringe areas were more thermally comfortable. This is attributed to the spacing between buildings in these areas as well as the number of occupants per dwelling unit.

Table 4 also shows that between the hours of 12noon-6pm (1100-1700hrs GMT), the highest outdoor ET value of 28.6^{0}C was recorded in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road areas as well as in the Effurun Market, Warri Main Market, Pessu Market areas while the Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro area in the fringe zone recorded ET values of 28.3^0C. This means this period is generally hotter than other periods of the day in the area as a result of enormous industrial and other socioeconomic activities going on at this time of the day as well as the solar radiation effects on the paved surfaces found in the area. The hours of 12 midnight-6am (2300-0500hrs GMT) in the same month of August recorded highest outdoor ET values of 23.9^0C in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road as well as in the Effurun Market, Warri Main Market, Pessu Market areas while outdoor ET value of 23.5^0C was recorded in Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro areas.

Table 4 shows that the highest indoor ET value of 28.5^0C (slide glass windows), 27.4^0C (Wooden windows) and 28.4^0C (Louvre's windows) were recorded in the Effurun Market, Warri Main Market, Pessu Market areas and in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road in the month of August. This is as result of heavy concentration of people, vehicular traffic and goods found in these areas on a daily basis. On the other hand, in Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro areas lower indoor ET values of 26.2^0C were recorded in buildings with slide glass windows, 25.1^0C in buildings with wooden windows and 25.2^0C in buildings with louvre windows. This indicates that buildings built with slide glass windows have less thermal comfort while those built with wooden windows have more thermal comfort.

In the month of September, Table 4 shows that between the hours of 6am-12noon (0500-1100hrs GMT), outdoor ET value of 25.3^0C was recorded in the commercial areas of Effurun Market, Warri Main Market, Pessu Market areas as well as in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road. The low density residential areas recorded outdoor ET values of 25.3^0C while in Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro, ET value of 25^0C was recorded and was within the acceptable physiological comfort threshold indicating that these zones are thermally comfortable. The Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro areas with outdoor ET value of 25^0C was the most comfortable outdoor environment. From the hours of 12noon-6pm (1100-1700hrs GMT), the highest outdoor ET value of 28.3^0C was recorded in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road areas while the Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro area in the fringe zone recorded ET values of 28^0C. This result means none of the areas were thermally comfortable at these hours of the day.

The hours of 6pm-12midnight (1700-2300hrs GMT) in the same month of September recorded highest outdoor ET values of 23.8^0C was recorded in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road as well as in the Effurun Market, Warri Main Market, Pessu Market areas while outdoor ET value of 23.5^0C was recorded in Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro areas.

Table 4 shows that between the hours of 12noon and 6pm, the highest indoor ET value of 28.9^0C were recorded in buildings with slide glass windows while 27.3^0C were recorded in buildings with wooden windows and 28.9^0C were recorded in buildings with louvre windows in Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road areas as well as in the Effurun Market, Warri Main Market, Pessu Market areas in the month of September. This could have been accounted for by the high concentration of people, vehicular traffic and congested buildings found in these areas. On the other hand, in Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro areas lower indoor ET values of 26.2^0C in buildings with slide glass windows, 25^0C in buildings within wooden windows and 25.2^0C in buildings with louvre windows were recorded. This indicates that buildings built with slide glass windows have less thermal comfort than those built with wooden windows which have more thermal comfort.

Testing of Hypothesis I

One way ANOVA analysis on the variation of indoor physiological temperature in Warri and environs

Table 5 shows that the calculated F (158.5) is greater than the critical 't' (3.11) at P<0.05. Therefore, we reject the null hypothesis and accept the alternate hypothesis which states that there is a significant variation in the indoor physiological temperatures of Warri and environs. This finding corroborates Adebamowo (2007) in Lagos and Ogbonna and Harris (2008) in Jos.

Testing of Hypothesis II

Paired T-test analysis on the variation of indoor physiological temperature in building structures in Warri and environs

Table 6 shows that the calculated 't' (37.558) is greater than the critical 't' (2.02) at P<0.05. Therefore, the null hypothesis was rejected and the alternate hypothesis which states that there is a significant variation in effective temperature index and thus thermal comfort between buildings built with wooden windows and those with slide glass windows was accepted. A structure built with wooden windows absorbs less heat from the surrounding environment and thus more comfortable than those built with slide glass windows even though it has more aesthetic form.

Physical Planning Implications of the Study

The study has been able to point out that the cause of thermal discomfort in Warri and environs are the results of poor building designs that are not climate responsive. It also showed that an increase in temperature regime coupled with wrong urban structural designs and orientations leads to corresponding increase in indoor and outdoor thermal stress in Warri and environs.

Firstly, that there should be a clear role for applied urban climatology in the development of sustainable settlements in Warri and environs. Secondly, from an overarching climatic point of view, while increasing vegetation cover (urban greening) is an obvious solution because vegetation does help reduce heat storage and hence night time UHI intensity. Incorporating these ideas into new and existing legislative frameworks will be a challenge and require the concepts, processes and conclusions presented in this study to be embraced by those involved in planning and designing built environments to provide a more integrated policy and planning response. This means all practitioners involved in urban planning should take a climate sensitive design approach (considering the micro, local and regional scale) in erecting new buildings in Warri and environs. Thirdly, barriers that constrain the inclusion of climate knowledge within the urban planning processes must be eliminated if sustainable settlements are to be achieved for an ever increasing urban population. Once the potential for improved climates through building and infrastructure planning and design is realised, initiatives can be incorporated into existing legislative frameworks. Many initiatives, such as increasing vegetation cover, can result in significant cooling and energy reductions, which can result in large economic savings from reduced energy consumption. In addition, such measures provide urban scale cooling available to all urban dwellers, not just those that can afford air conditioning.

Depending on the size of the plot of land, it is further recommended that in the low density areas, buildings should occupy 25%-30% of the plot, 45% for the medium density areas while in the high density areas, buildings should occupy about 60% of the plot. Meanwhile, minimum setback of three metres (3m) from the building to the fence should be maintained. These measures will help the building in maintaining good ventilation across it such that high physiological temperatures as recorded in this study are minimised in the future.

Conclusion

The study examined the problem of thermal discomfort in Warri and environs in Delta state, Nigeria. The study revealed that Warri and environs is not thermally comfortable in both the indoor and outdoor environment. This varied from the urban core areas to the fringe areas of the study area irrespective of the kind of windows in use in the building. This was predicated on poor orientation of buildings, high urban albedo caused by developmental effort, lack/neglect of climatic parameters by building engineers at the design stage of the buildings. Thus, drastic steps should be taken to save our tomorrow today in order to ensure sustainability. This will help in improving thermal comfort and ensure energy efficient and sustainable dwelling units in Warri and environs now and in the future.

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APPENDIX 1

Table 1: Selected Areas used for the study

Zones	Areas
A	Jakpa road, Okumagba layout, Airport Road, Upper/Lower Erejuwa, Enerhen /Udu Road
B	Delta Steel Town, G.R.A at Warri & Effurun
C	Nigerian National Petroleum Corporation Refinery (NNPC), Ogunu, DBS express Road
D	Effurun Market, Warri Main Market, Pessu Market.
E	Edjeba, Ugborikoko and Enerhen Village, Ekpan Villages.
F	Osubi, Ubeji, Aladja, Orhuwhorun and Ugbomro

Source: Oriero (1998), Efe (2005)

Table 2: Mean decadal outdoor temperature in Warri and environs from 1907 to 2009

Years	Temperature (^oC)
1907	26.5
1910	26.6
1920	26.6
1930	27.0
1940	26.5
1950	26.8
1960	26.7
1970	26.5
1980	26.5
1990	26.8
2000	27.3
2009	32.6
Mean	26.7

Source: Nigeria Meteorological Station (NIMET) Lagos

Table 3: Mean temporal indoor ET in Warri and environs

	June	July	August	September	Mean
6am-12noon	27.9	28.3	28.2	28.4	28.2
12 noon -6pm	28.9	28.3	28.5	28.9	28.7
6pm-12am	26.9	26.8	26.8	26.9	26.9

Source: Field work, 2010

Table 4: Monthly mean indoor and outdoor effective temperature

Months	**Time**	**Zones**	**Outdoor (°C)**	**Indoor Temp. in the various housing window types**		
				Louvre's (°C)	**Wooden (°C)**	**Slide Glass (°C)**
June	6am-12noon 0500-1100hrsGMT	A	25.6	26.5	25.8	27.9
		B	25.4	26.2	25.5	27.5
		C	25.3	26.3	25.4	27.6
		D	25.6	26.5	25.8	27.9
		E	25.5	26.4	25.5	27.5
		F	25.2	26.2	25.3	27.3
	12noon-6pm 1100-1700hrsGMT	A	28.2	28.2	26.6	28.9
		B	27.9	28.1	26.3	28.6
		C	28.0	28.2	26.4	28.7
		D	28.1	28.3	26.8	28.9
		E	28.0	28.2	26.3	28.5
		F	27.8	28.0	26.2	28.2
	6pm-12midnight 1700-2300hrsGMT	A	23.9	25.6	25.5	26.6
		B	23.8	25.5	25.4	26.3
		C	23.9	25.6	25.5	26.4
		D	24.0	25.6	25.3	26.6
		E	23.9	25.5	25.2	26.4
		F	23.5	25.2	25.1	26.0
July	6am-12noon 0500-1100hrsGMT	A	25.4	26.2	25.9	27.8
		B	25.3	26.0	25.7	28.2
		C	25.3	26.1	26.1	27.7
		D	25.4	26.3	26.0	28.3
		E	25.3	26.2	25.8	27.7
		F	25.0	26.0	25.6	28.6
		A	28.3	28.7	27.4	28.4

	12noon-6pm 1100-1700hrsGMT	B	28.2	28.4	27.2	28.5
		C	28.2	28.5	27.2	28.6
		D	28.3	28.7	27.4	28.6
		E	28.1	28.2	27.1	28.3
		F	27.9	28.1	27.0	28.0
	6pm-12midnight 1700-2300hrsGMT	A	23.9	25.6	25.4	26.8
		B	23.8	25.4	25.2	26.4
		C	23.7	25.5	25.4	26.5
		D	23.9	25.6	25.3	26.8
		E	23.7	25.5	25.5	26.4
		F	23.6	25.2	25.1	26.2
August	6am-12noon 0500-1100hrsGMT	A	25.4	26.5	25.9	28.2
		B	25.2	26.4	25.5	27.9
		C	25.2	26.3	25.6	28.0
		D	25.3	26.4	25.9	28.2
		E	25.2	26.3	25.6	28.1
		F	25.0	26.1	25.2	27.5
	12noon-6pm 1100-1700hrsGMT	A	28.6	28.4	27.4	28.5
		B	28.5	28.2	27.3	28.3
		C	28.5	28.3	27.2	28.3
		D	28.6	28.3	27.4	28.5
		E	28.5	28.2	27.3	28.4
		F	28.3	28.1	27.2	28.2
	6pm-12midnight 1700-2300hrsGMT	A	23.9	25.8	25.6	26.8
		B	23.7	25.4	25.3	26.6
		C	23.8	25.5	25.3	26.5
		D	23.9	25.8	25.4	26.7
		E	23.8	25.4	25.2	26.4
		F	23.5	25.2	25.1	26.2
September	6am-12noon 0500-1100hrsGMT	A	25.3	26.3	26.0	28.4
		B	25.2	26.2	25.9	28.3
		C	25.3	26.1	25.9	28.2
		D	25.3	26.2	26.1	28.4
		E	25.2	26.1	26.0	28.3
		F	25.0	26.0	25.6	28.1
	12noon-6pm 1100-1700hrsGMT	A	28.3	28.9	27.3	28.9
		B	28.2	28.6	27.4	28.6
		C	28.2	28.5	27.2	28.5
		D	28.3	28.9	27.3	28.9

		E	28.2	28.4	27.2	28.5
		F	28.0	28.2	27.0	28.3
	6pm-12midnight 1700-2300hrsGMT	A	23.8	25.5	25.3	26.9
		B	23.7	25.4	25.2	26.6
		C	23.6	25.3	25.2	26.5
		D	23.8	25.4	25.2	26.9
		E	23.7	25.3	25.2	26.4
		F	23.5	25.2	25.0	26.2

Source: Field Work, 2011

Table 5 One way ANOVA

	Sum of Squares	**Df**	**Mean square**	**F**	**P**
Between groups	14.5478	5	7.2739	158.5	0.00
Within groups	0.52833	12	0.03522		
Between subjects	0.6944	2	0.013888		
Total	15.0761	17			

Table 6: Paired Sample Test

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Dev	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 Wooden_Windows - Slide_glass_Windows	-1.60000	.10435	.04260	-1.70951	-1.49049	-37.558	5	.000

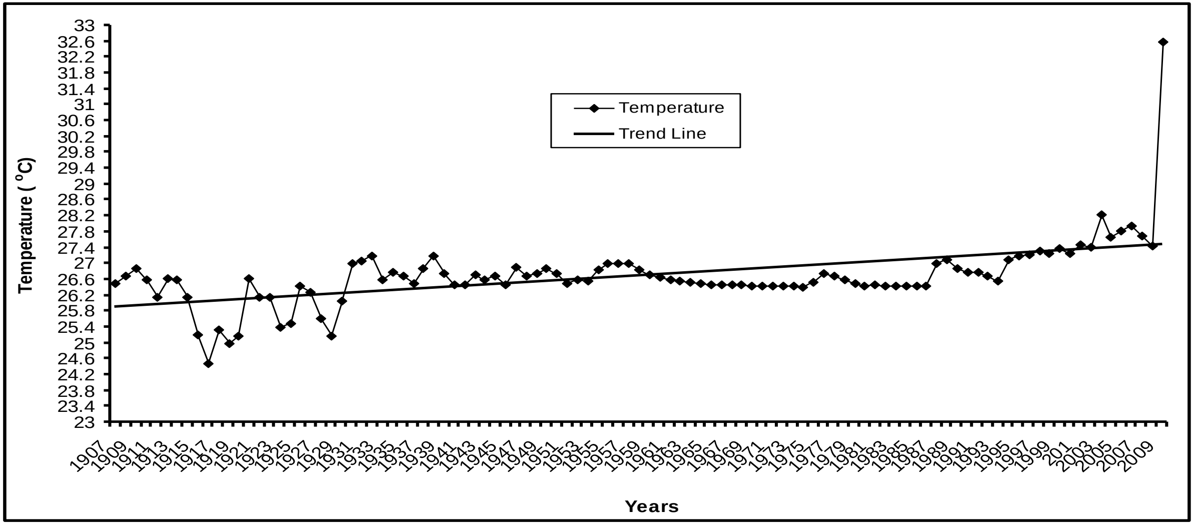

Fig 3: Temperature variation in Warri from 1907-2009

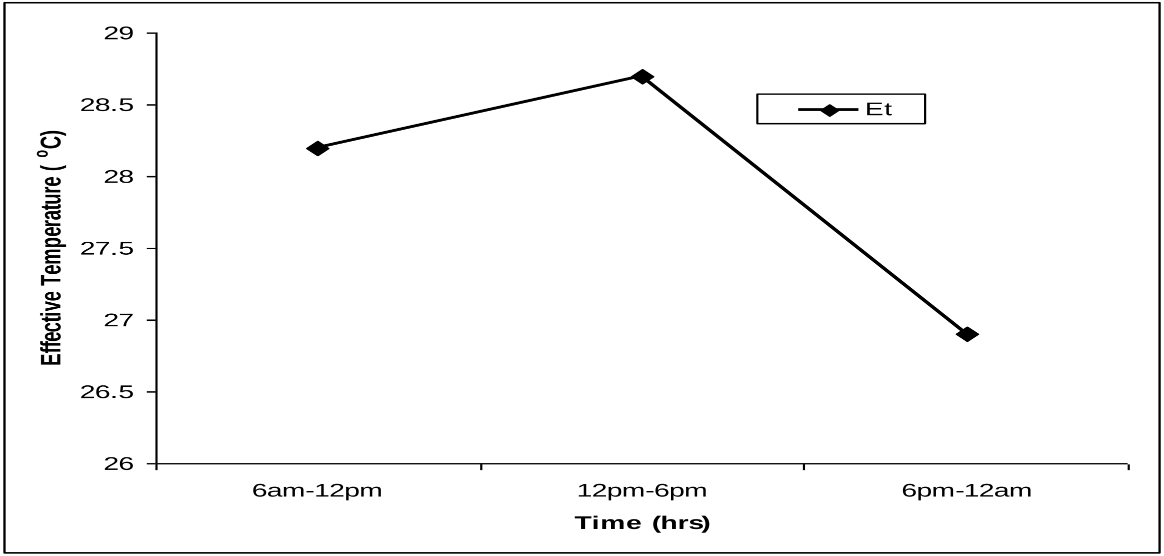

Fig 4: Temporal variation of indoor effective temperature in Warri and environs