International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 25 No. 1 Dec. 2018, pp. 337-346

http://www.ijias.issr-journals.org/

AN EXAMINATION OF SEASONAL VARIATION IN THE LEVELS OF OUTDOOR THERMAL COMFORT IN MAKURDI METROPOLIS, NIGERIA

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ABSTRACT: The study investigated seasonal variation in outdoor thermal comfort in Makurdi from 1971-2010. Daily air temperature (^{0}C) and relative humidity (%) of the study area were obtained from Nigerian Meteorological Agency Operational Headquarters, Oshodi, Lagos. Daily thermal comfort levels were computed from the obtained data using the temperature humidity index (THI). The THI values were then summed into monthly, seasonal and annual comfort values. Correlation analysis was used to determine trend in the level of thermal comfort from 1971 to 2010. The monthly variation of THI showed the highest THI of 27.2 in April and the lowest THI of 24.7 in January. The seasonal variation of THI indicated highest THI of 26.5 during the hot dry season and the lowest THI of 25.1 during the cool dry season. The annual variation of THI showed an increasing trend from 1971-2010 with a positive correlation coefficient (R^2) of 0.018. The result suggest that human discomfort is common in April while January is thermally comfortable Seasonally, the hot dry season was associated with human discomfort whereas the cool dry season is relatively comfortable. The positive annual trend of THI suggested a progressive change from human comfort to discomfort in the study area. The study concluded that measures of ameliorating human thermal discomfort should be focused principally in the months of March and April which coincides with the hot dry season to minimize the negative effects of outdoor thermal discomfort on the socio-economic development in Makurdi.

KEYWORDS: Seasonal Variation, Human Comfort, Temperature, Humidity Index, Climate.

1 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Cities are growing towards mega cities with higher population densities, narrower urban corridors and more high-rise urban structures. This urban transformation causes day-time and night-time Urban Heat Island (UHI) which leads to declining of urban environmental quality (Wong, Steve, Rosita, Anseina and Marcel, 2011).

Urban structures absorb solar heat during day-time and release it during night-time. Densely built area tends to trap the heat when it is released from urban structures into urban environment, increases urban air temperature compared to surrounding rural areas and causes urban heat island effect, which in turn affects street level thermal comfort, health, environment quality and may cause increase of urban energy demand. Mayer, Holst and Imbery (2009) also were of the view that urban building structures and urban processes modify the atmospheric background conditions by a positive or negative change which can be regarded as a function depending on different factors like weather, time of day and year, urban land use, street design and type of building structure. By this modification, a specific urban climate consisting of different urban microclimates within the urban canopy layer is formed.

The phenomenon of the rapid urbanization in cities has also become one of the important studies in climatology, urban planning and sustainable development. This is as a result of the negative environmental impact on rapid urbanization which includes urban microclimate modification. Furthermore, the rapid urbanization with limited landscape negatively affects human health due to increased pollution (Harlan, Brazel, Prashad, Stefanov and Larsen, 2006).

According to Lafini, Grifoni and Tascini (2010), there is a strong public interest in creating pleasant open spaces and this sense, thermal comfort is as important as acoustic or visual comfort. The liking and use of open spaces are influenced by the microclimatic conditions provided. Whereas, microclimate and thermal perception definitely depend on urban design and show a high temporal and spatial variation. The outdoor thermal environment infact, is impacted by the built environment through anthropogenic heat (Ichinose, Shimodozno and Hanaki, 1999), ground surface covering (Lin, Ho and Huang, 2007), evaporation and evapotranspiration of plants (Robitu, Musy, Inard and Groleau, 2006) and shading by trees or constructed objects (Lin, Matzarakis and Hwang, 2010).

A given urban density can result from independent design features that affect urban microclimate in different ways, such as fraction of urban land covered by buildings, distances between buildings and average height of buildings (Givoni, 1998). These parameters affect the urban microclimate in terms of air and surface temperatures, solar radiation, solar reflection, relative humidity wind speed and direction.

Urban planning regulations on the other hand, guide the development in cities at certain periods. These regulations include the instruction that lead to the development in terms of building construction, urban spaces, parks, streets (Yahia, 2012). Furthermore, the urban form is strongly influenced by urban planning regulations such as zoning ordinances which govern spaces between buildings, building heights, building footprints etc. Consequently, these regulations have great impact on the microclimate in urban areas (Johansson and Yahia, 2010).

Urban microclimate and outdoor thermal comfort are generally given little consideration in urban design and planning processes (Elliason, 2000; Johansson, 2006a). However, in order to reduce the negative climatic impacts in cities the urban developers, planners and designers must begin to incorporate climatic knowledge in the planning strategies and also create links between microclimate thermal comfort, design and urban planning regulations.

Al-Hemaidi (2001) and Eben Saleh (2001) reported that current urban design in Saudi Arabia has led to an undesirable microclimate around buildings. They explain this with the prescription of an extremely dispersed urban design where the provision of shade is totally lacking. The current urban form is characterized by gridiron plans with wide streets where the detached, low-rise “villa” is the most common type of house.

Thermal comfort is very difficult to define because one needs to take into account a range of environmental and personal factors when deciding what will make people feel comfortable. These factors make up what is known as ‘the human thermal environment’ (Fanger, 1970). Human thermal comfort however is defined by ASHRAE (1966), Fanger (1973), Parson (2003) and ISO7730 (2005) as that condition of the mind which expresses satisfaction with the thermal environment. Outdoor thermal comfort therefore refers to the condition of the mind which expresses satisfaction with the thermal environment outside a building or in the open air.

The study of outdoor thermal comfort is of great significance in cities. This is because, the aggravated increase in human activities leads to high temperature. The prevalence of human activities decreases natural surfaces which reduce surface and air atmospheric temperatures thereby increasing surface and air temperatures at the local and regional levels. The increase in population and socio-economic activities emanate the phenomenon referred to as the urban heat island (UHI). These coupled with the global increase in temperature has great effect on urban outdoor thermal comfort. Makurdi, an urban centre is not exceptional. Since such a study is yet to be conducted within Makurdi town, this study seeks to assess the outdoor thermal comfort in Makurdi.

1.2 STUDY AREA

1.2.1 LOCATION

Makurdi is the capital of Benue state. Benue state is one of the states located in the middle belt region in Nigeria. Makurdi is bounded by Tarka to the East, Guma to the North, Gwer-West to the West and Gwer to the South.

Makurdi town lies between Latitude $7^0 44^I$N and $7^0 52^I$N of the equator and longitude $8^0 24^I$E and $8^0 38^I$E of the Greenwich meridian (figure 1). River Benue from which the State name is derived flows through the town thereby dividing the town into south and north banks respectively. The major areas defined as Makurdi town are enclosed within North Bank, Wadata, Modern Market, High Level, Kanshio and Gaadi.

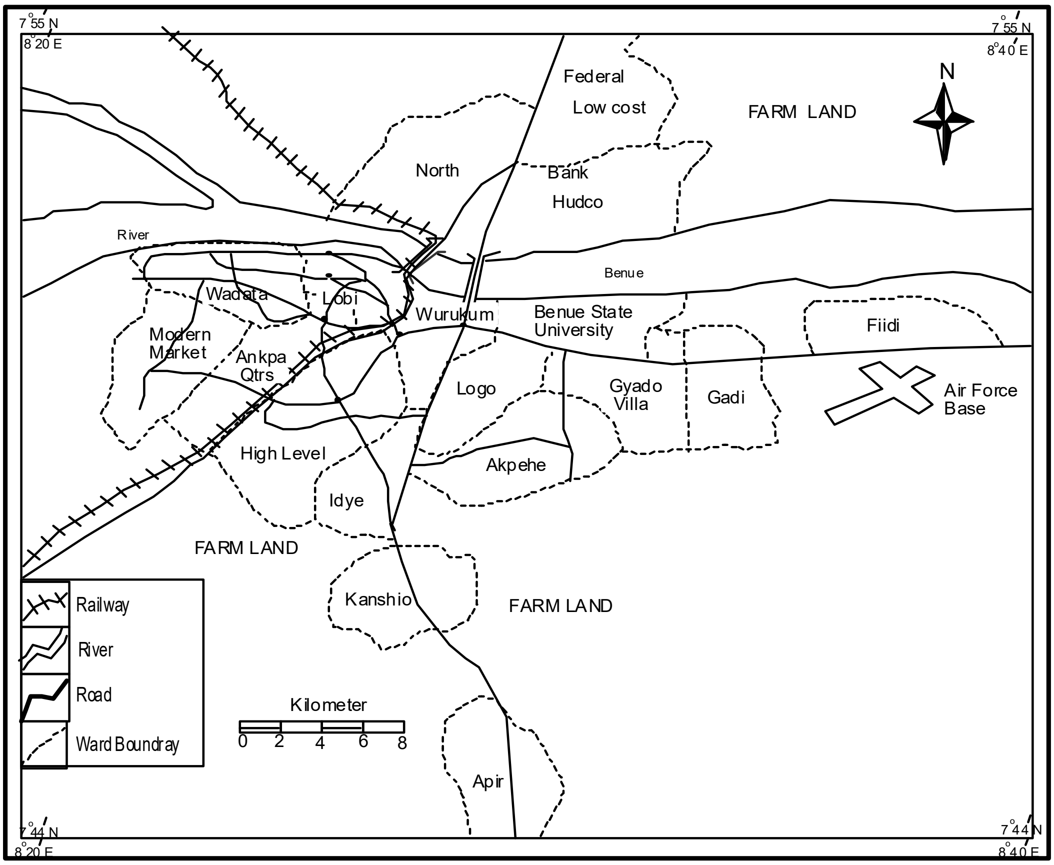

Fig. 1. Map of Makurdi town

Source: *Ministry of Lands and Survey*

1.2.2 Relief and Drainage

Makurdi town lies in the plains, except towards north bank area where there is slight elevation. River Benue drains the minor streams or channels during wet season. Rainwater infiltrates into the soil thereby percolating into the water table. The sandy nature of the topsoil makes penetrations easy.

1.2.3 Climate and Vegetation

The climate of Makurdi town is the tropical Aw type with alternating wet and dry seasons which are also hot and cool. The rainfall periods are from April to October, with rainfall amount ranging from 900mm to 1500mm with the heaviest rains in June and September which decline with increasing latitude (Tyubee, 2004). The dry seasons begin in November and end in April. Temperatures are generally high, with a mean annual temperature of 32.5^{0}C. The hottest months are February to April and the coldest, December to January. The three temperature periods experienced in the study area as investigated by Tyubee (2004 and 2005) are:

1. The cool-dry season at the period of low sun (November to January).
2. The hot-dry season just preceding the rains (February to April).
3. The cool-wet seasons during the rains (May to October). This is graphically shown in Figure 2.

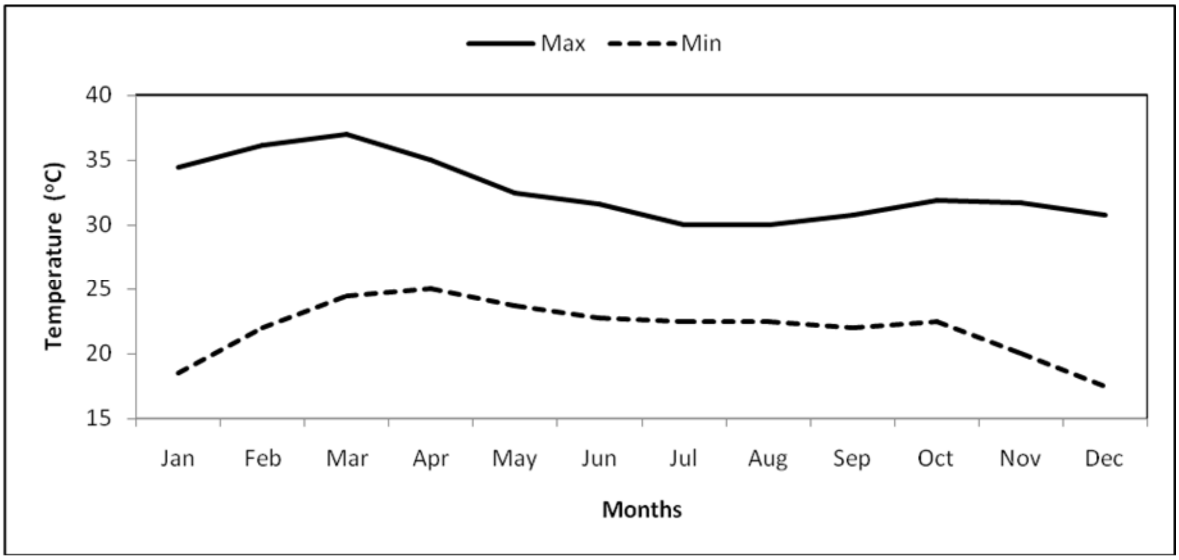

Fig. 2. Monthly temperature distribution graph in Makurdi

Source: *Tyubee (2004)*

The vegetation in the area is characterized by a mixture of trees and grasses of the guinea savanna specie. The trees include fruit trees such as cashew, citrus and mango along side other economic trees like mahogany, obeche, gmelina and iroko. The grasses are of a mixture of shrubs and herbs which are useful for animal grazing and medication respectively.

1.2.4 POPULATION

Makurdi town being the capital of Benue state is the most urbanized and populated town in the state. It has a population of 300,173 people at a growth rate of 3.0 (2006 National Population Census). The town's population makes up 7.01% of the State's population. It has area coverage of over 380 persons/km^2. The population shows a slight imbalance in favour of the males (156,384 males and 143,789 females). The population is rapidly growing faster than other urban centres in the State because; it is the capital of the State and the headquarters of Makurdi Local Government Area.

1.2.5 SOCIO-ECONOMIC ACTIVITIES

Several socio-economic activities are carried out in Makurdi town, these include trading due to the presence of markets, teaching due to several primary, post primary and tertiary institutions, administration due to the presence of Local, State and Federal Secretariat and headquarters of private and government establishments. Farming is also practiced as a result of fertile lands for cultivation and rich shrouds for grazing.

The crops produced include cereals (zea mays, sesamum indicum and oryza sativa spp) and vegetables. Fishing activities also takes place due to the presence of river Benue. Hospitality and recreational activities are not left out due to the presence of several rest homes and sporting centers.

2 RESEARCH METHODOLOGY

2.1 DATA NEED AND SOURCE

In order to achieve the aim of this study, daily air temperature (°C) and daily air relative humidity (%) of Makurdi was obtained from Nigerian Meteorological Agency Operational Headquarters, Oshodi, Lagos for a period of forty years (1971 – 2010). The needed data was obtained because Ayoade (2004) explains that a standard weather station serve an area coverage of 10,000km^2. Hence, the obtained data is to be greatly considered since the area coverage of Makurdi urban from the weather station measures 8,000km^2

The daily air temperature (°C) and daily air relative humidity (%) obtained from the meteorological Agency were summed up by each month of the years in order to obtain the mean monthly air temperature and relative humidity. These monthly means were further computed into seasonal means to derive the means of both air humidity and the temperature in the three seasons (cool dry, hot dry and cool wet). In the case of the annual means the monthly means were summed and divided by the number of months for each year.

These mean temperatures and mean relative humidity obtained were used in calculating the comfort levels based on the temperature humidity index and the humidex indices. The monthly variation in the levels of comfort was derived from the monthly means, the seasonal variation from the seasonal means and the annual variation from the annual means of the two climatic elements used.

2.2 HUMAN COMFORT INDICES

There are several indices used to assess outdoor human thermal comfort levels. These are physiological equivalent temperature (PET), the temperature humidity index (THI), the psychometric chart, the humidex rating, the wet bulb globe temperature (WBGT) and the standard effective temperature (SET).

These indices use some climatic elements in determining the comfort levels. There are variations in the elements used based on the index chosen. These are temperature, humidity and windspeed (PET). temperature and humidity (THI), air temperature, humidity, windspeed and radiation (psychometric chart), air temperature and humidity (humidex rating), air temperature, humidity, windspeed (WBGI) and temperature, solar radiation, windspeed and relative humidity, visible and infrared radiation (SET).

Even though thermal comfort deals with condition of the mind which expresses satisfaction with the thermal environment, there are standardized indices that have been obtained which are applicable to the assessment of thermal environment in the different regions of the world. As a result of this, studies such as that of Johansson (2006a) conducted in the hot dry climate in Fez, Morocco; Pearlmutter et al (2007) carried out within urban canopy; Ahmed et al (2010) conducted within the hot-humid tropical city of Akure, Nigeria; and that of Okpara, Kolawole, Gbuyiro and Okwara (2002) done in Akure, established the thermal conditions of the studied areas based on the various climatic parameters needed in determining comfort levels from the different comfort indices derived. Hence, this study also addressed thermal conditions in Makurdi town on this basis.

This study however used the temperature humidity index (THI) which makes use of two parameters; air temperature and relative humidity. The THI index was chosen because the two climatic elements used in determining comfort levels are the major climatic elements that influence outdoor comfort in the tropics (Okpara et al 2002). The tropics generally experienced weak wind velocity and variations in solar radiation. Thus both parameters have insignificant effect on human comfort compared to temperature and humidity. The humidex rating which uses the same climatic parameters was used to validate the THI result.

2.3 THE TEMPERATURE HUMIDITY INDEX (THI)

This index of human comfort was proposed by Thom (1959) to determine the comfort levels. The THI equation is given as:

$$THI = T - (0.55 - 0.0055Rh)(T - 14.5) \quad (1)$$

The index used seven comfort classes ranging from THI value of >17.0 to <28.0 in determining human comfort levels. When the THI ranges from 19.0-26.9, the thermal condition shows a comfort zone when people feel relatively comfortable. The THI from <18.9 to >27.0 gives discomfort cold and hot respectively.

Table 1. Thermal comfort levels based on the THI

Range	Comfort levels
> 28.0	High discomfort
27.0 – 28.0	Discomfort
25.0 – 26.9	Transitional (warm)
22.0 – 24.9	Comfort
19.0 – 21.9	Transitional (cool)
17.0 – 18.9	Discomfort
< 17.0	High discomfort

Source: *Thom (1959)*

2.4 THE HUMIDEX RATING

This is a measure of how hot we feel. It is an equivalent scale intended for the general public to express the combined effect of temperature and humidity. It provides a number that describes how hot people feel, much in the same way, the equivalent chill temperature or 'wind-chill factor' describes how cold people feel. The number expression table of the humidex is shown in table 2 (Canadian centre for Occupational Health and Safety, 2011).

The index used five comfort classes ranging from humidex value of 20 to >54 in determining human comfort levels. When the humidex is from 30 to>54, the thermal condition shows some discomfort to heat stroke imminent. When the thermal condition is comfortable for humans, the humidex ranges from 20-29.

Table 2. Humidex rating

Humidex range	Degree of comfort
> 54	Heat stroke imminent
46 – 54	Dangerous
39 – 45	Great discomfort; avoid exertion
30 – 38	Some discomfort
20 – 29	Comfort

Source: *Canadian Centre for Occupational Health and Safety (2011)*

When the air temperature and relative humidity are known the comfort level can be derived from the humidex chart (see Appendix A)

2.5 DATA ANALYSIS

The descriptive statistics such as the mean, tabulation and graphing were used to analyse the data. The inter-annual variation in temperature and humidity was analyzed using the summation of the obtained data in the twelve months and dividing the result by twelve. This was done for each year for the forty year period under study.

The monthly variation in the level of outdoor thermal comfort was however analysed by summing the derived mean in each month for the forty year period.

To analyse the seasonal variation in the levels of outdoor thermal comfort, three thermal seasons in the area were adopted. These include the cool dry, the hot dry and the cool wet seasons (Tyubee, 2004). The cool dry season covers November to January, the hot dry season is experienced between February to April and the cool wet season ranges from May to October. According to Tyubee (2004) these thermal seasons have mean temperatures of 28.0ºC, 38.5ºC and 30.0ºC respectively.

The annual variation in the levels of outdoor thermal comfort was analyzed by using the summation of the twelve months and dividing the result by twelve. This was done for the forty year period obtained data.

The Spearman 2-tail correlation coefficient was used in determining the fluctuation trend in thermal discomfort from 1971-2010.

3 DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

3.1 MONTHLY VARIATION IN THE LEVELS OF OUTDOOR THERMAL COMFORT

The result of monthly variation in the levels of outdoor thermal comfort in Makurdi is presented in Table 3 and Figure 3.

Table 3. Monthly variation of thermal comfort levels in Makurdi (1971 – 2010)

Month	THI	Humidex
January	24.7	33
February	25.8	37
March	27.0	40
April	27.2	40
May	26.3	35
June	26.4	39
July	26.0	39
August	26.1	39
September	26.2	38
October	26.0	38
November	25.9	36
December	24.9	34

Source: Fieldwork (2013)

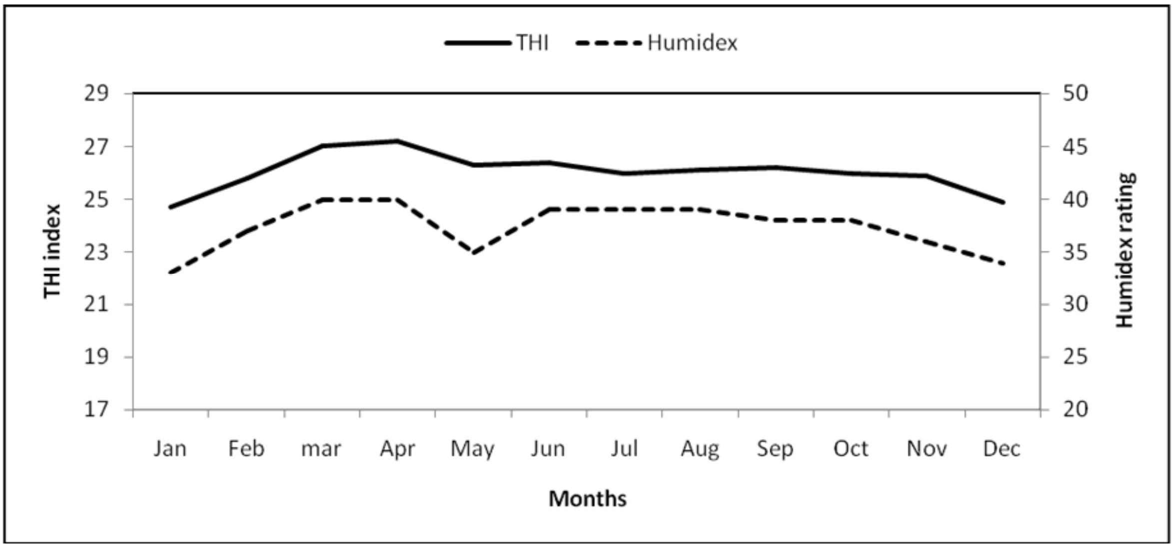

Fig. 3. Monthly variation in the levels of outdoor thermal comfort

Source: Fieldwork (2013)

THI index recorded the highest comfort levels of 27.2. The lowest comfort level however was recorded in January at 24.7. The highest THI record was obtained in the discomfort class. The lowest comfort level on the other hand was recorded at a comfortable class. This conforms to the humidex result obtained.

There is a decrease in the mean December and January temperatures. This could be attributed to the continental air which prevails over most of Nigeria during the season thereby influencing increases with distance from the coast. In addition, the cloudless condition characterized by continental air results in rapid heat loss during the night hence, reduction in air temperature. The January pattern takes a reversed pattern from February to April where highest mean monthly temperatures records range to about 40°C. This agrees with the study conducted by Ojo (1977).

The result suggests that the most discomfort months in Makurdi are from March to May. These months of high discomfort will have negative economic health and social life consequences. The increased and intensified discomfort could result in billions of dollars in economic damage annually. This was also observed by Patz Campbell-Lendrum and Foley (2005) in Europe in 2003 when an abnormal and extreme heat wave was experienced which killed more than 35,000 people thereby causing an estimated $135 billion in economic damage. This period as a result, could discourage investors into Makurdi since it is not a relative favourable period of living within the area.

Exposure to heat stress can cause physical problems which impair workers' efficiency in mental tasks and may cause adverse health effects such as increased irritability, loss of concentration, fatigue and threat of exhaustion which are mental, psycho-physiological and physiological problems. This was also observed by Kenny (2011) and Tyubee (2004) confirms that about 80% of respondents experienced heat-related disorders such as insomania, heat rashes, irritation and exhaustions during April 2004 in Makurdi. Vanos, Warland, Gillespie and Kenny (2010) adds that exposure to such thermal condition results to chronic heat exhaustion, sleep disturbances and susceptibility to minor injuries and sickness. Tyubee (2005) further reports that communal conflicts in Tivland, Benue State are also related to high temperatures.

3.2 SEASONAL VARIATION IN LEVELS OF OUTDOOR THERMAL COMFORT

The result of seasonal variation in outdoor comfort in Makurdi is presented in figure 4.

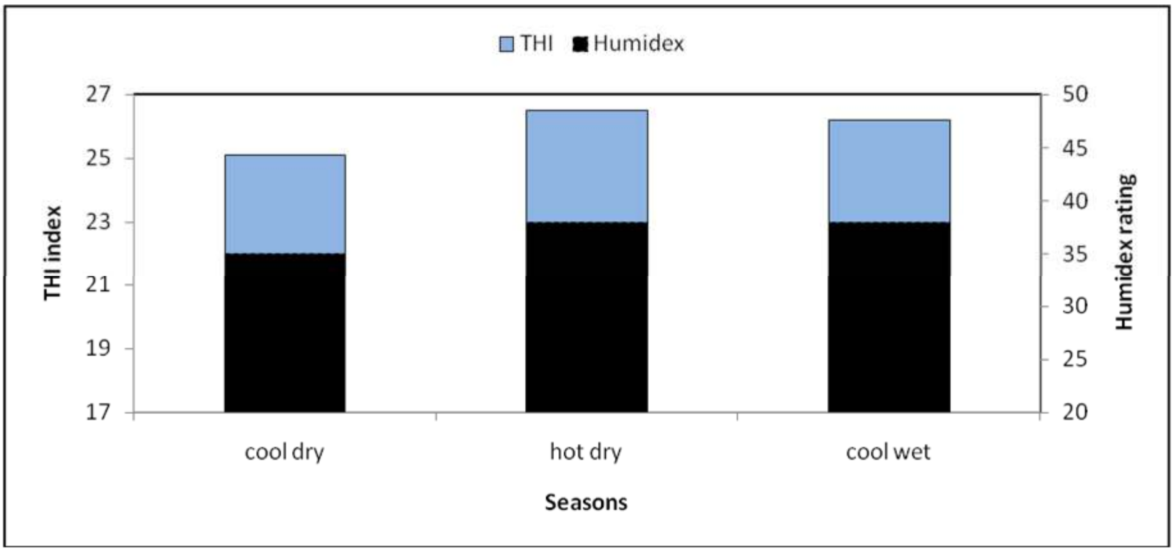

Fig. 4. Seasonal variation in levels of outdoor thermal comfort (1970 – 2010)

Source: Fieldwork (2013)

The highest THI level of 26.5 at transitional warm was recorded during the hot dry season. The lowest comfort range of 25.1 was shown during the cool dry season. The lowest comfort range was at a transitional warm level. Even though there are slight variations in the three seasons, the two indices show a transitional warm condition which agrees with the humidex result.

The seasonal variation in outdoor thermal comfort in Makurdi is related to seasonal variation in weather condition. The hot dry season is characterized by lack of cloud cover, low humidity, lack or little rainfall which increases solar radiation receipt and high temperature. Lower temperatures however occur at the peak of the rainy season (August) because of the dense cloudcover and high albedo experienced during the period. The relative higher discomfort level experienced in the cool wet season as compared to the cool dry is as a result of the energy cycle (Ojo, 1977). The low temperatures as a result of dense cloud cover during the cool wet season obstruct incidence radiation. The energy received by the earth has little or no reflective ability thereby continuously cycling within the atmospheric earth as rainfall. As a result giving rise to a warm thermal environment even with the presence of the rains. The clear skies experienced during the cool dry season permits high incidence rays and complete energy loss through reflection.

The result reveals that all the three prevailing seasons in Makurdi record some discomfort (transitional warm) in the levels of thermal comfort. This agrees with Okpara, Kolawole, Gbuyiro and Okwara (2002) study conducted in Akure which was conducted partly in the cool wet and partly cool dry seasons. Patz et, al (2005) explains that a constantly discomfort environment of this nature plays a large role in the derivation of human health due to physical inactivity. This leads to higher rates of illness, heart disease, obesity and heat related casualties.

4 Conclusion

Based on findings of this research, the following conclusions were drawn:

The least mean annual temperature of 27.3°C, was recorded in 2007 while 29.6 °C the highest was obtained in 2010. Humidity however, recorded 46.5% as the least in 1989 and 79.6% in 1974 as the highest annual records.

Highest thermal discomfort in Makurdi occurred in the month of April. Relatively, the most comfortable month is January. Makurdi generally experience some discomfort through out the year.

Though there is variation in the annual thermal comfort levels, 1971 – 1989 period was generally comfortable compared to other periods. There is however an increasing trend in thermal discomfort from 1990 – 2010 in Makurdi.

5 Recommendations

Based on the research findings, the following recommendations were made to control the increasing level of thermal discomfort in Makurdi.

Vegetation has positive influence on the thermal environment hence, should be greatly encouraged and adopted within the town. This could be in form of flowers, lawns, gardens and trees. Tree planting should be encouraged particularly; artificial parks should be given priority in order to curb the dangers associated with thermal discomfort.

Urban structures should be well sited hence, proper urban planning done. The use of building and construction materials which greatly absorb heat but have less reflective ability should be discouraged and modern technology in high reflective building materials which control high heat absorption and have high reflective capacity be introduced

Landscaping should be controlled. This is because landscaped surfaces have high heat absorption capacity. Also, a long term urban integrated programme based climate change adaptation and implication to disaster risk reduction is required, taking into cognizance the assessment planning implementation, training and capacity building with particular action research.

Detail study on the effect of climate variability should be conducted on outdoor thermal comfort within the study area to ascertain the actual effect on the thermal environment.

Also, the dress code should be greatly considered. This is because when the environment is thermally discomfort but light clothings are worn, the discomfort is relatively mitigated thereby making the people within such an environment feel relatively comfortable.

Acknowledgements

My greatest appreciation goes to the Almighty Father for bringing me thus far in life and leading me through this programme.

My profound appreciation goes to my supervisor Dr. Bernard T. Tyubee for thoroughly guiding and directing the research. I am grateful to Dr. S.A. Iorkua, the Departmental Postgraduate Coordinator and Dr. D.S. Ortserga, the Head of Department and all lecturers and staff of the Department of Geography for their wonderful contributions to the research work.

I am grateful to Mr A.K Danjuma, Mr B Umaru, Mr B.D Angyu and Mrs V.C Chuma for their great contributions to the realization of this research work.

I am indebted to my loving parents Mr. and Mrs. Titus T. Akera and my entire family for their financial and moral support. You have firmly placed this ladder I have climbed to this height in life.

I thank Mr. Angwe Martins for ensuring that I get the needed articles for the review of literature and Mr. Fave Jacob for putting me through the graphing of this piece. I can not leave out Mr. Kyonev Morris Terhemba for his immense financial and moral support for actualization of this research work. God in His infinite mercy shall reward you all abundantly.

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