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Statistical Analysis of The Thermal Comfort In The Urban Climate of Ilorin-Nigeria: A Three Decade Event

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ABSTRACT

Objectives: Urban thermal comfort is higher than the rural due to massive anthropogenic activities. Hence a statistical and simulation analysis is required to estimate minute changes over the thirty decade. The uncontrolled injection of aerosols from industrial waste emission, decay of matter, biomass burning has its collective effect on the thermal comfort of the urban climate. **Methods**: The research site i.e. Ilorin, Nigeria is located in the middle of the Guinean zone coastline and Sudano-Sahelian zone. Thirty years (1981-2012) ground data from the Nigerian Meteorological Center was obtained for the study. Thermal comfort was statistically analyzed-using three key parameters i.e. surface temperature, relative humidity and hours of sunshine. **Results:** Two crucial factors were seen to affect the thermal comfort of the study site i.e. regional climate and aerosol emission volume. Four months i.e. November, December, January and February may be detrimental to people having respiratory or circulatory health challenges. This is because of the connection between thermoregulatory mechanisms and the circulatory/respiratory system. **Conclusion**: Thermal comfort has increased over thirty years. Hence, the health status of life forms is threatened. The geometrical transition of the thermal comfort between November to February shows that people with respiratory health challenges have low survival during the months of November, December, January, February and possibly March.

KEY WORDS: Aerosol, Thermal comfort, statistics, surface temperature, health effect

INTRODUCTION

Thermal comfort in the urban settings of the tropics is gradually becoming a significant challenge- largely due to increased anthropogenic activities (Emetere *et al*., 2013; Emetere, 2013). Its direct effect on thermal comfort is confirmed via the accumulation of atmospheric aerosol particles in the troposphere and stratosphere. Atmospheric aerosol particles have direct radiative forcing because of their ability to absorb or scatter solar and infrared radiation in the atmosphere. They reside in polluted regions (e.g. urban areas) and deplete direct solar radiation by an estimation of about 15%. Depleted direct solar radiation may be more in winter and less in summer. The variability of aerosols in the atmosphere makes it a herculean task to quantifying the aerosol radiative forcing which is believed to have either positive or negative climatic influence – depending on the aerosol size, life-time, complex refractive index, stoichiometry/composition and aerosol solubility. On the other hand, the aerosol indirect radiative forcing (especially in warm clouds) is traceable to two sources i.e. aerosol cloud condensation nuclei and change in precipitation efficiency. Observations of urban aerosol dynamics in coastal regions depends on convective outflow which are limited because of the sporadic nature of convection and aerosol pathway for ventilating pollutants from the planetary boundary layer (PBL) to the free troposphere and beyond. Hence, the global circulation system greatly influences the localization of aerosol in the troposphere and stratosphere. One of the major challenges facing scientist (about the aerosol) is the inability to adequately estimate – aerosol distribution, aerosol-cloud interactions, physical and chemical properties. The other effect is the longwave influence on the thermal comfort. Many researches (Emetere, 2014a,b; Uno *et al*., 2012a,b) have shown that the sensible heat flux from the earth is dangerous to life forms because it aids contagious diseases. Another noticeable effect on thermal comfort is the regional climate. The regional climate systems include inter-tropical discontinuity, subtropical anticyclones, atmospheric winds, Jet stream, monsoons,

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sea surface temperature (SST) anomalies etc. Ilorin, south-west Nigeria (ISWN), is characterized by monsoon characteristics like distinct seasonal shift in the prevailing winds, alternation between winter dry conditions and summer rainy conditions (Janicot *et al*., 2011). It experiences dry northeasterly winds coming from the Sahara Desert during the winter. This experience leads to drastic reduction in rainfall. During summer season, ISWN experiences low-level southwesterly winds and high rainfall rates (Hall *et al*., 2006). In the lower troposphere (LT) of ISWN, the wind flow is characterized by the south-westerly while the upper troposphere (UT) is characterized by the Tropical Easterly Jet (Peyrille *et al*., 2007). Thermal comfort is determine or estimated by the measurement of key climatic factors like relative humidity, surface temperature, sun shine duration, wind speed e.t.c. Recall we had discussed other influences –order than climatic. The impact of climate change on the human thermal comfort may lead to rise in heat related deaths per year. This idea is possible as high temperatures and humidity provides discomfort sensations and sometimes heat stress (Ahmed *et al*., 2014). The heat stress extends from the human skin contraction to the difficulty in breathing. Four known elements are used to analyzed thermal comfort i.e. temperature, humidity, wind and radiation (Bahman *et al*., 2014). From literatures, higher humidity and air temperature intensifies thermal sensation and reduces perspiration and evaporation of the body's capacity (Holm *et al*., 2005). However, It is not yet known how uncontrolled injection of aerosols from industrial waste emission, decay of matter and biomass burning can affect the thermal comfort of the urban climate.

Thermal comfort is also known as physiological equivalent temperature and could be defined as the equivalent effect of the degree of hotness or coldness on life forms. Here, we refer to the hotness noticed in the tropics. In this paper, we understudy thirty years (1981-2012) ground data of key thermal comfort parameters i.e. surface temperature, relative humidity and hours of sunshine. Significant study was performed for the average of each month to investigate the thermal comfort and the salient twist of both regional and global climate change.

Ilorin, Nigeria is located in the middle of the Guinean zone coastline and Sudano-Sahelian zone. Sudano-Sahelian zone is a region where average annual precipitation ranges from 500 to 900 mm. Guinean zone is a region where average annual precipitation exceeds 1100 mm. Hence, it is constantly between the influence of the tropical easterly and westerly Jet.

Methodology: The Statistical Tools:

The standard error (SE) of the mean was used (in this research) to estimate the population mean for each month of the year. SE technique used for this research captures the standard deviation of the monthly means over three decades sample. The standard error of the mean is expressed mathematically as

$$SE = \frac{\sigma}{\sqrt{n}}$$

Here $'s'$ is the population standard deviation and $'n'$ is the population size.

Standard error measures the uncertainty in each parameter (sunshine duration, relative humidity, surface temperature) and the deviations of the monthly mean from the thirty-years mean. Standard deviation (σ) measures the amount of visible dispersion from the monthly mean. Like the SE, a low magnitude standard deviation signifies that the monthly mean is closer to the thirty-year mean also called expected value. Also, a high magnitude standard deviation signifies how far monthly mean is from the thirty-year mean. Standard deviation is given as

$$\sigma = \sqrt{\frac{1}{N}\sum_{j=1}^{N}(y_i - \bar{y})^2}$$

Here y_i in the context of our research is the monthly-mean, $\bar{y}$ is the mean value of the thirty-year mean. The concept of variance is intrinsically connected with the effects of the difference between the monthly mean and the thirty-year mean on the performance of thermal comfort in our research area- Ilorin, Nigeria. The coefficient of variation is the measure of a normalized dispersion of probability distribution i.e. the thirty year mean for each parameter used. In statistics, coefficient of variation is referred to as relative standard deviation and expressed in percentage. Coefficient of variation is not used for few meteorological parameters because of the inconsistency of its interval scale. For example, coefficient of variation is appropriate for the Kelvin scale and inappropriate for the Celsius scale because its data has interval scale Therefore, we adopted the coefficient of variation because the scale used has interval scale and appropriate for comparison between data sets of widely different yearly or monthly means. Coefficient of variation can be represented mathematically as

$$CV = \frac{\sigma}{\mu}$$

Here σ is the standard deviation and μ is the monthly mean. Skewness, also known as skew(X) is a measure of the asymmetry of the probability distribution of the monthly mean about its thirty-year mean. For a normal distribution, the skewness is equivalent to zero. The skewness value can be positive , negative, or undefined.

When the skew is negative, it indicates that the mass of the distribution is concentrated on the right of the plotted graph i.e. left-skewed. When the skew is positive, the mass of the distribution is concentrated on the left of the plotted graph i.e. right-skewed. The Skew of a distribution can be written mathematically as

$$X = \frac{(\mu - \upsilon)}{E(|X - \upsilon|)}$$

Here υ is the median, E is the expectation error.

Kurtosis (β) is any measure of the flattening or "peakedness" of the probability distribution of the monthly mean for each month of the year. Like skewness, kurtosis is a descriptor of the shape of a probability distribution which can be interpreted as $\beta > 3$ (Leptokurtic distribution- high probability for extreme values), $\beta < 3$ (Platykurtic distribution- probability for extreme values is less than for a normal distribution) and $\beta = 3$ (Mesokurtic distribution - normal distribution). Kurtosis mathematically written as

$$\beta = \frac{\mu^4}{\sigma^4}$$

All parameters retain its usual meaning. The simulation was carried–out using Surfer analytical tool.

RESULTS AND DISCUSSION

The combined parameters- showing the thermal comfort in Ilorin are simulated as shown in figure (1-12). Figure (1) shows the distribution of sunshine, surface temperature and relative humidity in the mean January data for thirty years. To simply our description, we represent the mean January data for thirty years as bulk January data (BJD). The distribution of the thermal comfort for BJD is harsh -regardless of the duration of sunshine. Secondly, the rate of increase of relative humidity is negatively almost linear to the surface temperature. At higher relative humidity, the relation between the duration of sunshine and surface temperature transcends from positive linearity to varying positive-parabola. Also, at low relative humidity, the relation between the duration of sunshine and surface temperature transcends from varying positive-parabola to negative linearity. These occurrences show that beyond sunshine initiating other two processes (relative humidity and surface temperature), there are factors possibly at the lower atmospheric settings which retains heat to alter the normal relative humidity trend (Dudhia, 1989). We propose that the major factor is the volume of aerosol present in the atmosphere. Consequently, a varying relative humidity initiates an unpredictable evapotranspiration rates which determines the respiration-challenges of life-forms in January. Further on the BJD, we looked at the individual performance of the parameters. In Table 1, the duration of sunshine had the highest value of standard error, variance, standard deviation, coefficient of variation. This simply shows the high level of uncertainty in the thermal comfort on a yearly basis in the BJD. The sunshine has a Platykurtic distribution. However, its effect on other parameter are shown in see table 2 & 3. While surface temperature responds directly to the duration of sunshine i.e. having the same highest value of standard error, variance, standard deviation, coefficient of variation through-out the year, the relative humidity shows (see figure 2) the compendium of events during the day. High relative humidity shows the massive loss of longwave at night which is not uniform-looking at figure 1. The very unstable loss of longwave heat (in BDJ) that determines the increase in relative humidity gives further in-sight on the geological effect on the relative humidity. This idea simply explains why the hour of sunshine -duration would not replicate the same results in other regions. Furthermore, the negative kurtosis and a very low positive skew of the surface temperature indicate an uncertain or unpredictable thermal comfort in the years ahead.

In figure 2, the distribution of the mean February data for thirty years – referred to as bulk February data (BFD) is shown.

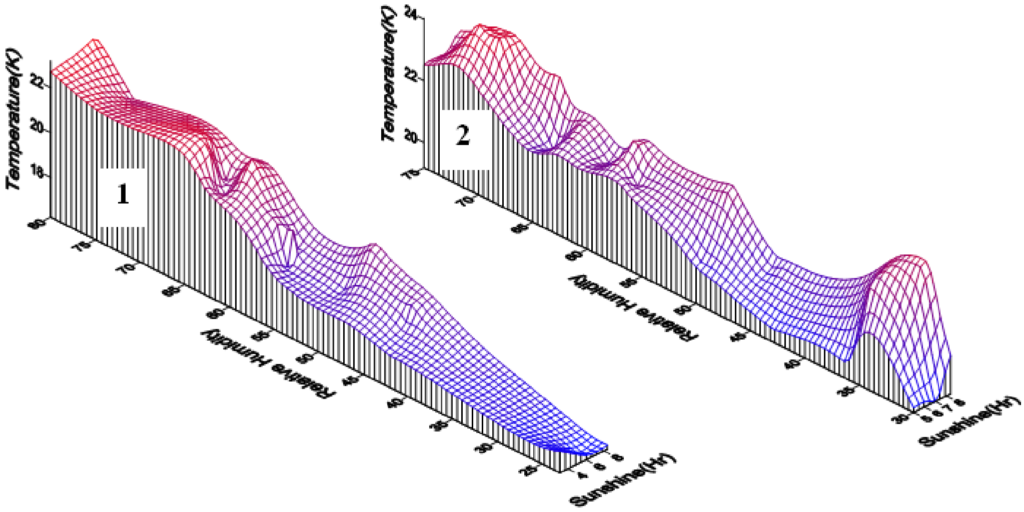

Fig. 1: Thermal Comfort for January (1981-2012); **Fig. 2:** Thermal Comfort for February (1981-2012)

Like BJD, the distribution of the thermal comfort for BFD shows more intense/harsh condition. At high relative humidity, the relation between the duration of sunshine and surface temperature transcends from positive parabola to varying negative-parabola and then to positive linearity. Also, at low relative humidity, the relation between the duration of sunshine and surface temperature transcends from varying positive-linearity to positive-parabola. Unlike BJD, the general performance of the surface temperature and sunshine duration showed a transition from positive parabola to positive linearity. On individual performance i.e. Table 1-3, BFD has the highest sunshine duration mean and throughout the year. Also it has a relative humidity which has the highest variance, standard deviation and lowest kurtosis throughout the year. This simply shows the degree of thermal comfort in February. Beyond the usual meaning, it shows the dual effect of an intersecting climatic zones (see figure 13) and aerosol volume in February. Furthermore, the negative kurtosis and skew of the surface temperature indicates sustainable thermal comfort (as explain above) in the years ahead.

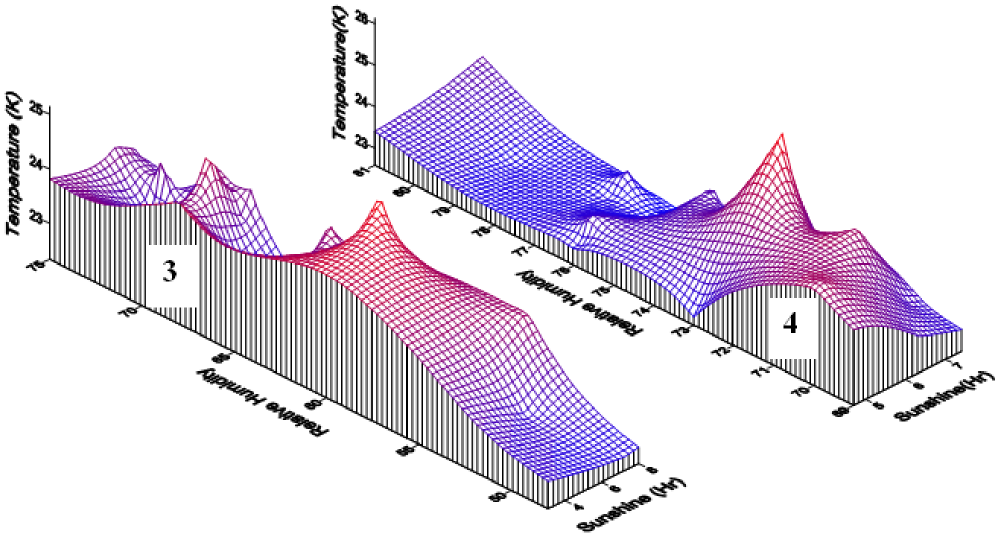

Fig. 3: Thermal Comfort for March (1981-2012); **Fig. 4:** Thermal Comfort for April (1981-2012)

In figure 3, the distribution of the mean March data for thirty years – referred to as bulk March data (BMD) is shown above. BMD had high surface temperature spread and unpredictable relative humidity. At high relative humidity, the relation between the duration of sunshine and surface temperature was unpredictable with multiple peaks. At lower humidity, a smooth negative curve was used to describe the relation between all parameters i.e. surface temperature relative humidity, and sunshine duration. Furthermore, the positive kurtosis and skew of the surface temperature indicates a sustained thermal comfort in the years ahead. However, its relative humidity and sunshine would be unpredictable via statistics shown in Tables 1-3. Figure 4, shows an inverse twist of instability compared to BMD. The bulk April data (BAD) showed a stable positive parabolic relation between surface temperature and sunshine duration at better part of April. Also the relation between surface temperature and relative humidity is explained via a negative parabola. The peak showed the level of inconsistency amidst the parameters. The frequency of peaks shows the inconsistency in the thermal comfort. This event spreads across the months of May, June and July (see figure 5-7). This may generally be due to the shift of the inter-tropical convergence zone (ITCZ) as shown in figure 13.

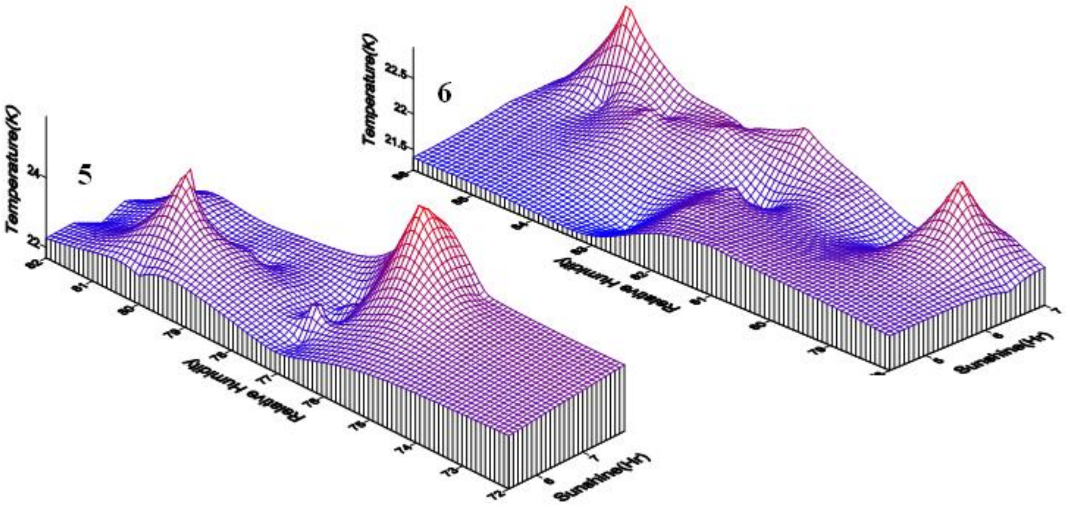

Fig. 5: Thermal Comfort for May (1981-2012); **Fig. 6:** Thermal Comfort for June (1981-2012)

Through the bulk August data (BAuD), the month of August is adjudged the most stable month with moderate thermal comfort. However, via tables 1-3, it can be seen via kurtosis and skew that the surface temperature would be unpredictable. The predictability of the relative humidity and the sunshine duration for the month of August is confirmed via kurtosis and skew analysis.

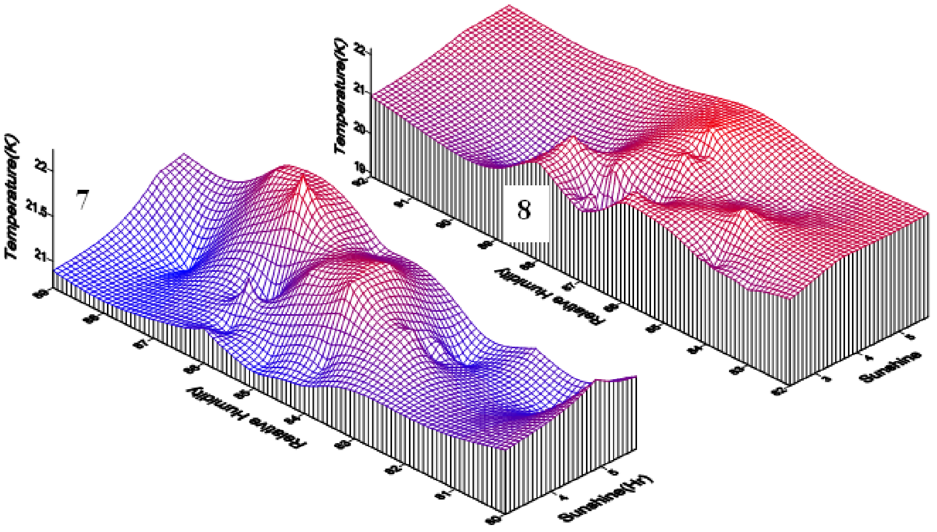

Fig. 7: Thermal Comfort for July (1981-2012); **Fig. 8:** Thermal Comfort for August (1981-2012)

The effect of the dwindling surface temperature shown in BAuD can be seen to affect the thermal comfort stability in the bulk September data (BSD) as shown in figure 9. The influence of the moist southwest wind gradually terminates via a turbulent shift in surface temperature (see figure 10). Thereafter the Ilorin-region experiences a perfect thermal comfort. In October, the dry northeast winds (see figure 13) introduces an instability which affects the relative humidity and surface temperature (see figure 11). As shown by the statistics in tables 1-3, the parameter predicts a sharp thermal comfort shift- very cold at night and very warm at day. This phenomenon spreads through December to January. Furthermore, figure 12, shows a positive parabolic relation between the surface temperature and the sunshine duration. The dwindling nature of the relative humidity further confirms that relative humidity in the lower atmospheric setting- depends on the lower cloud temperature amongst other factors.

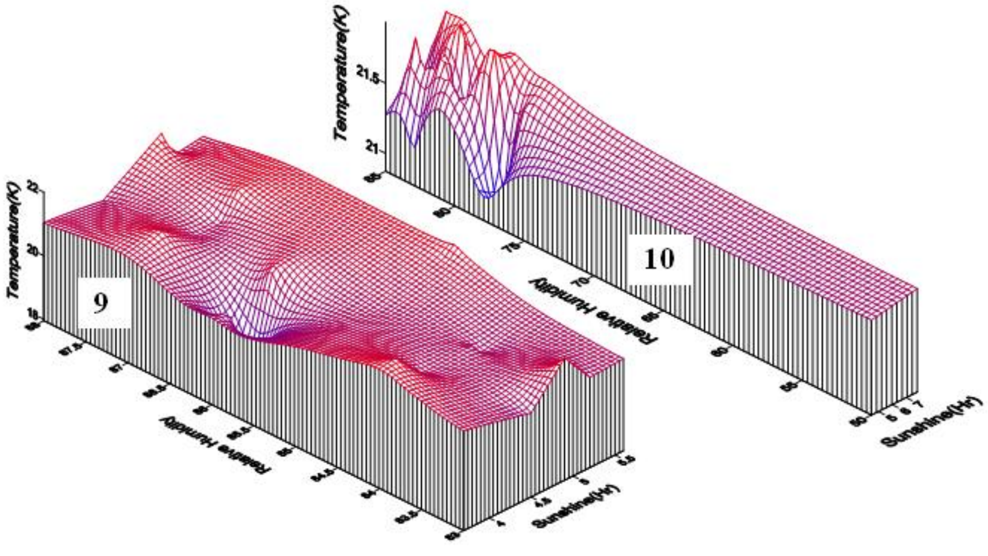

Fig. 9: Thermal Comfort for September (1981-2012); **Fig.10:** Thermal Comfort for October (1981-2012)

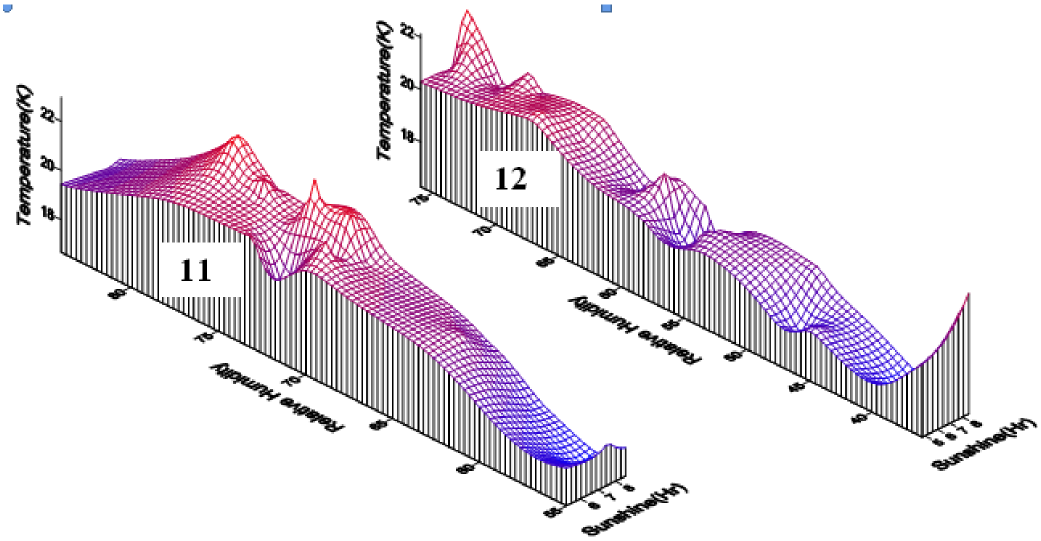

Fig. 11: Thermal Comfort for November (1981-2012); **Fig. 2:** Thermal Comfort for December (1981-2012)

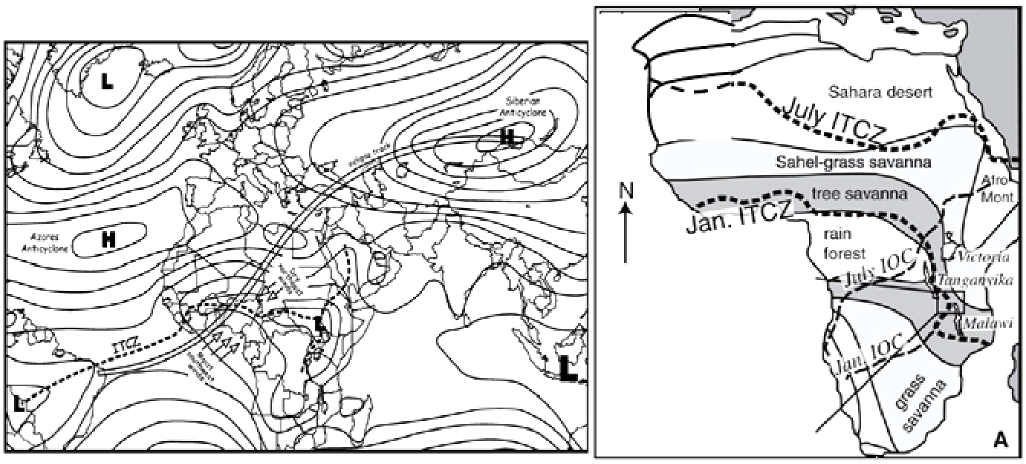

Fig. 13: Regional climatic influence (adapted from http://geology.gsapubs.org)

Other factors can be used to explain the interpretation of multiple troughs in figures 11 & 12. The topography of Ilorin cannot be over emphasized- especially the building layout between the traditional fabric and modern fabric of residential areas. Although in the case of this research, we are more interested in the lower atmospheric settings of the region. Our focus relates to the regional climatic influence (shown in figure 13) on the thermal comfort. By the kurtosis statistics, the regional climate enforces the Platykurtic distribution on the thermal comfort in Ilorin for the past thirty years. Therefore, the probability for obtaining extreme values is less compared with regions of normal distribution. This simply means that people with respiratory health challenges have low survival during the months of November, December, January, February and possibly March. This is because of the connection between thermoregulatory mechanisms and the circulatory/respiratory system**. S**cientists have reported that most people -during the above listed month surfer aches and pains in the joints (WMO, 1999). Figures 7, 9 & 11 shows the peculiar relation between the surface temperature and sunshine duration. Its geometrical characteristics confirmed the joint influence of the aerosol emission and ITCZ shift to thermal comfort.

Temperature (K) Data 1981-2012												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	18.3	20.8	22	21.4	19	21.1	20.3	20.6	20.6	21	21.4	20.2
Maximum	24.3	24.5	26.3	24.8	23.8	23.4	22.6	22.3	22.3	23.5	24	23.5
Mean	21.82	23.02	23.5	23.1	22.51	22.09	21.69	21.51	21.64	22.04	22.7	22.13
Variance	1.915	0.8037	0.7042	0.3687	0.6716	0.1903	0.2673	0.2118	0.2012	0.3477	0.5906	0.8791
Standard deviation	1.384	0.8965	0.8392	0.6072	0.8195	0.4362	0.517	0.4603	0.4486	0.5897	0.7685	0.9376
Coefficient of variation	0.06343	0.03894	0.03571	0.02628	0.03641	0.01974	0.02384	0.0214	0.02073	0.02675	0.03386	0.04236
Skew	-0.553	-0.413	1.203	-0.04	-2.566	0.56	-0.579	-0.081	-0.583	0.429	0.096	-0.508
Kurtosis	0.846	-0.062	3.253	2.397	10.309	1.624	1.179	-0.274	0.041	0.437	-1.344	-0.326
Kolmogorov-Smirnov stat	0.104	0.091	0.203	0.154	0.202	0.121	0.106	0.133	0.132	0.122	0.166	0.103

Relative Humidity Data 1981-2012												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	37	30	44	69	74	78	80	82	83	50	55	36
Maximum	80	76	75	81	82	86	92	92	89	88	84	76
Mean	55.3	58.3	66	74.4	79.4	83	85.8	86.7	86.2	81.2	72.1	59.1
Variance	138	204	68.4	9.8	5.43	5.45	6.42	7.4	2.79	50.6	57.8	147
Standard deviation	11.7	14.3	8.27	3.13	2.33	2.34	2.53	2.72	1.67	7.12	7.6	12.1
Coefficient of variation	0.21237	0.24494	0.12528	0.04206	0.02935	0.02814	0.02953	0.03138	0.01937	0.08761	0.10536	0.20506
Skew	0.185	-0.604	-1.346	-0.083	-0.852	-0.891	0.14	0.411	-0.365	-4.137	-1.075	-0.331
Kurtosis	-0.584	-0.731	1.49	-0.292	-0.12	-0.132	1.449	-0.304	-0.575	18.738	0.438	-0.742
Kolmogorov-Smirnov stat	0.157	0.141	0.164	0.119	0.19	0.239	0.255	0.108	0.154	0.334	0.232	0.12

Sunshine Data 1981-2012												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	3.1	5	3.1	4.7	5.4	4.4	3.1	2.4	3.7	4.5	5.2	4.8
Maximum	8.4	8.4	8	7.4	7.9	7	5.7	5.7	5.6	7.8	8.6	8.5
Mean	6.3	6.96	6.88	6.73	6.77	6.37	4.49	3.46	4.68	6.17	7.52	7.24
Variance	1.38	0.941	1.13	0.692	0.449	0.424	0.493	0.811	0.294	0.388	0.621	1.22
Standard deviation	1.18	0.97	1.06	0.832	0.67	0.651	0.702	0.9	0.543	0.623	0.788	1.11
Coefficient of variation	0.18648	0.13944	0.15454	0.12373	0.09893	0.10224	0.15632	0.26044	0.11596	0.10102	0.10477	0.15268
Skew	-0.732	-0.573	-2.116	-1.537	-0.277	-1.658	-0.102	0.864	-0.26	0.19	-1.207	-0.703
Kurtosis	1.66	-0.811	5.695	1.248	-0.351	2.622	-0.966	0.061	-1.087	2.224	1.671	-0.587
Kolmogorov-Smirnov stat	0.181	0.16	0.218	0.226	0.098	0.244	0.152	0.176	0.138	0.176	0.218	0.165

Statistical analysis of a thirty decade data of Ilorin shows salient features as seen in figures 1-12. Massive inconsistency are recorded with region multiple peaks like figures 4-7. The regional climate enforces the Platykurtic distribution on the thermal comfort. This signifies the challenges of modeling thermal comfort in this region-quantitatively. The trivial statistical tool like mean, standard error, variance, standard deviation and coefficient of variation gives the on-spot analysis of thermal analysis in an area. The kurtosis, skew and Kolmogorov gives a mathematical forecast of parameters. The geometrical transition of the thermal comfort between November to February shows that people with respiratory health challenges have low survival during the months of November, December, January, February and possibly March. This is because of the connection between thermoregulatory mechanisms and the circulatory/respiratory systems are more related to regional climate and atmospheric aerosol volume. Also, the relation between the thermal comfort parameters depends on the high atmospheric updraft and less downdraft. The strategic location of Ilorin gives it access to dry northeast wind and moist southwest wind which influences thermal comfort.

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Conflict of Interest:

This paper has no conflict of interest

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