ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE - Centre for Satellite Technology Development Special Issue:
Space Science and Technology for Sustainable Development
AZOJETE, June, 2019. Vol. 15(SP.i2):35-45
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

IMPACT OF CLIMATE CHANGE ON THE DESIGN PARAMETERS OF HEATING, VENTILATION AND AIR CONDITIONING SYSTEMS FOR MANNED SPACECRAFT

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ARTICLE INFORMATION

Submitted: 14/10/2018
Revised: 16/11/2018
Accepted: 18/03/2019

Keywords:
Air-Conditioning,
Dry-bulb Temperature,
Humidity,
Spacecraft,
Statistics,
Pressure.

ABSTRACT

Climatic design information has been published for several locations in the world by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) but there has not been data for Nigerian cities in these publications. Therefore, this study was embarked upon to bridge the gap in knowledge. The study of impact of climate change on the design parameters of Heating, Ventilation and Air Conditioning (HVAC) systems for spacecraft cabin environment is presented with particular focus on Ikeja-Lagos, Nigeria. Firstly, the characteristics climate parameters such as outdoor dry-bulb temperature, coincident wet-bulb temperature, relative humidity, pressures, air composition, among others as it affects manned spacecraft were discussed. The data for climatic parameters for Ikeja-Lagos, Nigeria, for a period of fifteen years (1995-2009) were obtained from Nigerian Meteorological Agency (NIMET), Oshodi-Lagos. Statistical data and Microsoft excel were used for evaluation of variation trends of the climate parameters for departure city. This is very important in determining thermal human comfort in spacecrafts on ascent. Results obtained from this study are hereby presented. The Ikeja-Lagos dry-bulb temperature average results obtained were 33.81°C, 32.98°C, 32.3°C, 22.1°C, 21.19°C, 20.43°C, 23.84°C and 31.65°C.at 0.4%, 1.0%, 2.0%, 97.5%, 99.0%, 99.6%, median of extreme lows and median of extreme highs, respectively. The Ikeja-Lagos relative humidity average results were 116.3, 112.65, 109.14, 99.83 and 49.42 at 0.4%, 1% and 2.0% occurrence as well as at median of extreme highs and median of extreme lows, respectively. Ikeja-Lagos had mean coincident dry bulb temperature of 33.81°C and 32.98°C at 0.4% and 1% percentile respectively. The dry bulb temperature for Ikeja-Lagos was determined to be an average range from 20.43°C to 22.1°C between January to December, in the period of 1995-2009, at 97.5% 99% and 99.6% percentile respectively. These results provide values of design parameters which are useful in the design of HVAC for space crafts with climate change adequately taken into consideration as it applies to Ikeja-Lagos, Nigeria

1.0 Introduction

There is robust evidence that extreme weather conditions are happening with greater frequency and intensity than what was experienced few decades ago. Mitigation measures needs to be put in place to avoid what can lead to decrease in performances of facilities in space technology due to dramatic increase in the frequency and intensity of these extreme weather conditions. In the aviation sector, infrastructures such as airports and aircrafts are designed with historical weather conditions. Often, these infrastructures like air ports and aircrafts will need retrofitted facilities to match changes in climatic conditions.

Therefore, aircraft and spacecraft designers will require a detailed and quantified information for specific regions and locations with a focus on maximum and minimum temperatures as well as associated humidity conditions. This then suggests a need for model-based climatic projections for future climate using historical climatic data to identify priorities in mitigation measures. Although the global environment is affected by climate change, this study is particularly concerned about the impact of climate change on the cabin environment in spacecraft. In this study the impact of climate change on design parameters of Heating, Ventilation and Air Conditioning (HVAC) systems were analyzed to determine the proper parameters to be used for design of the systems.

The HVAC systems are devices designed to control the climatic and environmental parameters to provide thermal comfort at acceptable indoor air quality in terms of air composition, temperature, humidity, pressure, wind speed and direction, amount of rainfall or water vapour in any area of application such as in manned spacecrafts. The payload includes the living things, air conditioners, fans, heaters and cargo carried by a spacecraft but excluding propulsion units.

The studies on effects of dry bulb temperature and relative humidity on performances of power electronics, gas turbines, compressors, among others have been documented as reported by Olorunmaiye and Awolola (2016). The load in a spacecraft can include gas turbines, compressors, refrigerators, amongst others, which are directly linked to climatic conditions.

Furthermore, the control of cabin environment in spacecrafts has been a challenge especially for flights across continents due to varying climate parameters. The relative humidity inside a spacecraft cabin is generally much lower than the minimum for thermal comfort recommended by ASHRAE (2013a), Wyon et al. (2006) and Uchiyama et al. (2007) for comfort standards. The temperature is the only variable which can be controlled to its optimal level, but this optimal control is only permitted in the cruise process, not during ascent and descent processes, as this can affect the performance of the engine. Therefore, in order to monitor the performance, reliability and control of HVAC systems in spacecrafts, the study of the climatic conditions of the departure city as recommended by ASHRAE in the design of HVAC systems is of key importance as reported by ASHRAE (2013a).

It is appropriate to determine the main climate input parameters in a location for when there is desire to launch and operate a space craft. Climatic design information had been published for several locations in the world but Nigeria did not feature as published by ASHRAE (2013a). Some West Africa countries such as Mali and Niger republic had climatic data stations at Bamako and Niamey, respectively, in which climate data had been recorded for over 15 years according to ASHRAE (2013a). In the design of comfort in space craft, complete knowledge of temperature, humidity, purity of air, motion of air and thermal load are required.

This study aimed to discuss climatic design parameters as it applied to Ikeja-Lagos, Nigeria. The objectives include data gathering and computation to provide information on dry bulb temperature and wet bulb temperature at several percentiles, median of extreme lows and median of extreme highs, as well as at mean daily temperature range essential in climatic design information for spacecraft technology.

2 Climatic Design Parameters for Human Comfort in Manned Spacecraft

2.1 Air Composition and Air velocity

The space craft cabin is a confined space with varying pressure from one atmospheric pressure to one-third atmospheric pressure in some extreme cases as reported by Liping et al. (2017). Similarly, air composition also varies between oxygen and nitrogen, with 20.95% oxygen like in the earth's environment or 40% oxygen and 60% nitrogen in some situations. When pressure in the cabin is high, oxygen has to be provided as well as disposal of cabin carbon-dioxide produced by human being. ASHRAE (2013a), Standard 62 recommends a certain volume of fresh air to be supplied to various areas in a space craft and is dependent on the number of people present and the nature of the activity taking place. Design condition for any habitable space is to guarantee an air flow of 10 litres/second (10 l/s) as reported by Ballaney (2003). Similarly, it is recommended that air supply speed should be within 2-5 m/s, to prevent air noise in built environment. ASHRAE (2013a) as well as Khurmi and Gupta (2003) reported that all spaces in spacecraft should receive minimum of air velocity of 0.3 m/s, that contains enough oxygen for breathing and also sweep away odours, microorganisms, and heat release.

2.2. Thermal Load

Radiations from warm surfaces of the load in spacecraft are important factor that can affect comfort reaction of human being. Radiations from occupants to room surfaces and structures as well as between occupants, has an important bearing on the feeling of warmth and can alter the optimum. The heat liberation from crew and passengers as well as heat liberation from machines and transformers in the spacecraft contributes to thermal load. Similarly, solar radiation around spacecraft and oxidation processes of materials of construction of spacecraft contributes to heat load. Air-conditioner is one of devices that contributes to human comfort in spacecraft. Some researchers reported that energy consumption for running air conditioning system depends on the climate of location along with the location solar radiation as reported by Olorunmaiye et al. (2012). The researchers also recommended use of economizers on air conditioner, orientation of buildings and planting of trees to positively influence climatic conditions to minimize global warming. Space technology is well suited to benefit from above particularly in location and environment of lunch of spacecraft and ascent.

2.3 Air Temperatures

Air temperatures in spacecrafts are evaluated based on dry-bulb temperature, wet-bulb temperature, and mean daily temperature ranges. The likelihood of temperature changes with height also affects design of spacecraft as stated in Liping et al. (2017). Spacecrafts are designed with temperatures that are not expected to exceed 27°C for wet bulb, 35°C for dry bulb while effective temperature, should not exceed 27°C, according to ASHRAE (2013a) Standard 55. In evaluation of climate changes, dry-bulb temperature is presented in percentile corresponding to 0.4%, 1.0%, and 2.0% cumulative frequency of occurrence and the mean coincident wet-bulb temperature, according to ASHRAE (2013a). Similarly, wet-bulb temperature is presented in percentile corresponding to 0.4%, 1.0%, and 2.0% cumulative frequency of occurrence and the

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mean coincident dry bulb temperature, according to procedures recommended for evaluation of climatic conditions in a location or region by ASHRAE (2013a). Dew-point temperature corresponding to 0.4%, 1.0%, and 2.0% annual cumulative frequency of occurrence, mean coincident dry-bulb temperature and humidity ratio are also parameters for climate study according to ASHRAE (2013a). The 0.4%, 1.0%, and 2.0% dry-bulb temperatures and mean coincident wet bulb temperatures indicates severity of conditions on hot, mostly sunny days as reported by ASHRAE (2013a). In summary, mean daily temperature range is mean of the difference between daily maximum and minimum dry-bulb temperatures for hottest months as reported by Anekwe and Onuchukwu (2017). Similarly, dry-bulb temperatures are calculated from extremes of the hourly temperature observations. It is important to note that dry and wet bulb temperatures is more convenient than the partial vapour pressure and temperatures in climatic characteristics evaluation of manned spacecraft.

2.4 Relative Humidity of Air

Human comfort demands relative humidity (RH) in the range of 50 to 70%, but this is not maintained aboard spacecraft to avoid condensation problems on cold walls and equipment, which tends to corrode metals and boost micro-organism growth as reported by Ballaney (2003) as well as Olorunmaiye and Awolola (2016). Therefore, relative humidity is kept in a low range of 10 to 20%, with some discomfort of evapotranspiration and electrostatic build up if human beings are among the payload in spacecraft as reported by Liping et al. (2017). At cruise altitudes there is practically no water vapor in the air, so it is natural to have dry cabin air. On ground and during ascent, the air conditioning system must dehumidify fresh air introduced into the cabin, particularly in tropical climates when doors are still open. Outside humidity is very small at high altitudes and is kept low inside spacecraft to minimize problems of condensation and frost on the cold structure. Some researchers undertook determination of energy requirements in a building with particular focus on provision of cooling by air conditioner, which is also relevant in provision of human comfort in spacecraft as reported by Ariyo and Olorunmaiye (2017a). Therefore, design values of relative humidity of departure city enable designers to size HVAC system to achieve an acceptable level of comfort. In some spacecrafts, cabin temperature can range between 18-24°C, while its relative humidity ranges between 50-70% as reported by Liping et al. (2017).

2.5 Minimum and Maximum Pressures

Climatic characteristics involves sum of all inlet pressures and pressure losses in the main lines and ducts as linked to air conditioners and fans in the manned spacecraft, called the system. The system constant is obtained at minimum and maximum pressures in relation to the air required delivery flow rate, which are in turn used to determine the system characteristics at minimum and maximum pressures. Worthy of note is effect of gravity compression of air in the spacecraft, that arose from the pressure difference at the surrounding surfaces and in the spacecraft on ascent and descend. The average of air pressures in different months of the year 2011 was determined for Calabar to have minimum of 1001.5 Pa and maximum of 1008.1 Pa, while Port Harcourt had minimum of 1003.5 Pa and maximum of 1012.0 Pa, according to some researchers such as Anekwe and Onuchukwu (2017). Researchers such as Liping et al. (2017) reported that spacecraft cabin pressure can range between 90-100 kPa.

3.0 Methodology

The hourly weather data for climatic design for Ikeja (Lagos, Nigeria), for a period of fifteen years (1995-2009) were obtained from Nigerian Meteorological Agency, Oshodi-Lagos (NIMET, 2011). The NIMET laboratories are equipped with facilities to obtain weather data. The NIMET procedures include hourly measurement of wet-bulb and dry-bulb temperatures at synchronized controls and stabilized power supply. The initial and final dry-bulb temperatures and wet-bulb temperatures, respectively, were recorded as well as the inlet and outlet of the forced air passage as well as the suction and discharge pressures including air velocity within the weather station (NIMET, 2011). Ikeja-Lagos, Nigeria, is located at latitude 6.59°N and longitude 3.34°E on an altitude of 9 m. Ikeja-Lagos, Nigeria, was hypothetically chosen to determine the climate parameters due to its heavy traffic of airplanes with large weather data generation.

This work involves use of statistical data and Microsoft Excel spreadsheet 2015 version with normal distribution table. The evaluation of variation trend of the climate parameters for departure cities, are very important in determining thermal comfort in spacecrafts on ascent. The high values of dry-bulb and wet-bulb temperatures were computed on criteria of 0.4%, 1.0% and 2.0% percentiles. Furthermore, the low values were also computed on percentiles of 97.5, 99.0% and 99.6% frequencies of occurrence for all twelve months of the year under consideration. The mean daily temperature range, median of extreme lows and highs for Ikeja-Lagos were computed.

4.0 Results and Discussion

This section presents results in Tables and Figures along with the discussion of them all.

4.1 Average Temperature of Ikeja-Lagos as at 1995 and 2015

The evidence of increase in temperature over the years can be observed as shown in Table 1. The average temperature for Ikeja-Lagos in 1995, was obtained from NIMET (2011) while average temperature for Ikeja-Lagos in 2015, was a weather forecast as predicted by Ojeh et al. (2016). In Table 1, the average temperature for the year 1995 in Ikeja-Lagos was 26.66°C while the average temperature for the year 2015 in Ikeja-Lagos was 26.81oC. The increase in average temperature in Ikeja-Lagos from 1995 to 2015 was 0.15°C, which agrees to convincing evidence to global warming. The temperature trends during the year 1995 and 2015 are as shown in Figure 1. Researchers have reported that there is gradual increase in average temperature of the earth surface which has been predicted to rise between 1.4°C and 5.8°C by year 2100 as reported by Trenberth, et al. (2007). The increase in average temperature in locations of spacecraft ascent and descent will have to be factor in during design stage to minimize retrofitting thermal comfort facilities.

Table 1: Average Temperature of Ikeja-Lagos as at 1995 and 2015

Year/Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Temperature, 1995	26.9	28.2	28.5	28.3	27.3	25.9	24.8	24.9	25.2	26.0	27.0	26.7
Temperature, 2015	27.3	28.5	28.5	28.0	27.1	25.6	25.3	25.1	25.5	26.4	27.2	27.2

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All these measurements are in degree Celsius (oC).

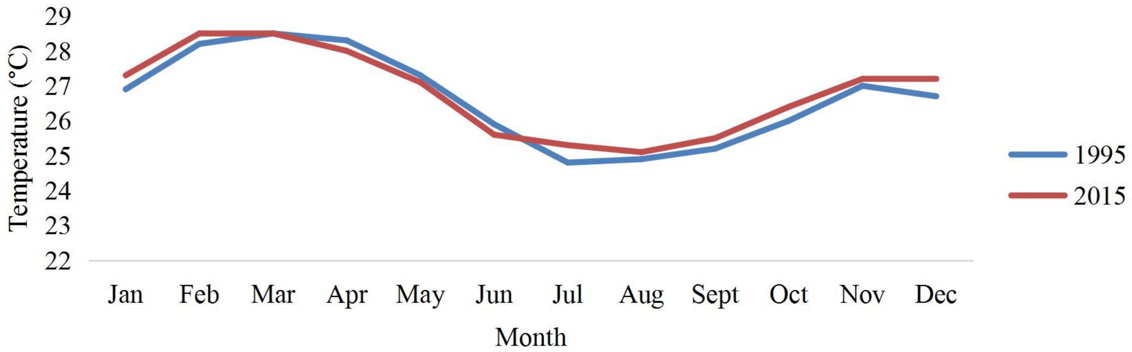

Figure 1: Average Temperature of Ikeja-Lagos as at 1995 and 2015

4.2 The Design Dry-Bulb Temperatures for Ikeja-Lagos from 1995-2009

The design dry bulb temperature for Ikeja-Lagos, are presented for all the months from 1995-2009 at various frequencies of occurrence obtained using normal statistical table is as shown in Table 2. Normal statistical estimates for average dry bulb temperature were made at 0.4%, 1.0% and 2.0% for Ikeja-Lagos. The corresponding highest mean maximum temperature occurs from February to May for years studied. These months of highest mean maximum temperature becomes the design month for consideration in planning and operation of spacecrafts. Furthermore, Figure 2, shows the mean coincident dry bulb temperature at 0.4% and 1% percentile and were computed as 33.8°C and 32.98°C for Ikeja-Lagos respectively. Similarly, the dry bulb temperature at 99% and 99.6% percentile respectively were at an average of 21.19°C and 20.43°C from January to December for Ikeja-Lagos, respectively, were as shown in Figure 3. These data are useful for cooling applications, especially air-conditioning in spacecraft technology.

The statistical values of median of extreme lows (MEL), median of extreme highs (MEH) and mean daily temperature range (MDTR) were also calculated as shown in Table 2 while Figure 4 illustrate the trends of mean daily temperature range for the period. The probability of occurrence of very extreme conditions can be required for the operational design of equipment to ensure continuous operation and serviceability as stated in ASHRAE (2013b). These values were calculated from extremes of the hourly temperature observations. The true maximum and minimum temperatures for any day generally occur between hourly readings. The 95.7%, 99.0% and 99.6% design conditions are often used in the sizing of heating equipment. Some sophisticated electronics need a particular dry bulb temperature and relative humidity for its proper design and operation as reported by Liping et al. (2017).

The design dry-bulb temperatures and mean daily dry bulb temperature for Ikeja can be employed to calculate heating and cooling degree-days, which is further used in energy estimation of HVAC systems as reported by Ariyo and Olorunmaiye (2017a). The design conditions based on wet-bulb temperature represent extremes of the total sensible plus latent heat of outdoor air, according to ASHRAE (2010). The dry and wet bulb temperatures together with other climatic characteristics are useful for cooling towers, evaporative coolers, and fresh air ventilation system design, which are adaptable for spacecraft technology. Generally, in design of

HVAC systems, it is not economical to choose either the maximum or minimum prevailing climate data of a location but highly recommended that the 0.4%,1%, 2%, 5%, 97.5%, 99.0%, and 99.6% values of occurrences be adhered to as suggested by some researchers such as Liping, et al. (2017). However, no one knows what exactly the future climate is going to be but statistical analysis of the climate of the past years can give a clue to the future as reported by Burdick (2011).

Table 2: The Design Dry-Bulb Temperatures for Ikeja-Lagos from 1995-2009

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average
0.4%	35.6	36.6	36.4	35.8	34.6	33.0	30.4	30.0	31	32.6	34.5	35.3	33.81
1.0%	34.6	35.6	35.5	34.9	33.7	32.1	29.8	29.5	30.3	31.8	33.6	34.4	32.98
2.0%	33.7	34.8	34.7	34.2	33.0	31.4	29.3	29	29.8	31.2	32.9	33.6	32.3
97.5%	21.3	22.7	23.4	23.0	22.6	21.2	21.9	21.7	21.6	21.8	22.2	21.8	22.1
99.0%	20.2	21.6	22.3	21.2	21.6	20.3	21.2	21.1	20.9	20.9	22.0	21.0	21.19
99.6%	19.2	20.6	21.4	21.0	20.8	19.4	20.6	20.5	20.2	20.1	21.3	20.1	20.43
MEL	23.7	25.5	25.6	25.3	24.5	23.6	23.2	23.3	23.5	23.5	24.4	20.0	23.84
MEH	32.5	33.8	33.5	33.0	31.8	29.9	29.0	28.3	29.2	30.5	32.0	36.3	31.65
MDTR	4.9	4.4	4.2	3.9	3.6	3.1	2.9	2.6	2.9	3.3	3.9	4.3	3.67

All these measurements are in degree Celsius (°C)

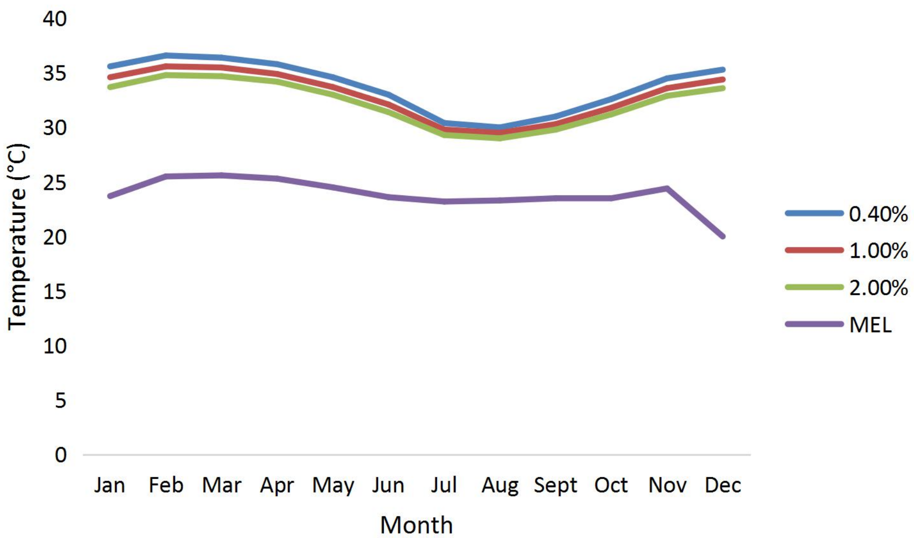

Figure 2: The Mean Coincident Dry-Bulb Temperatures for Ikeja-Lagos from 1995-2009

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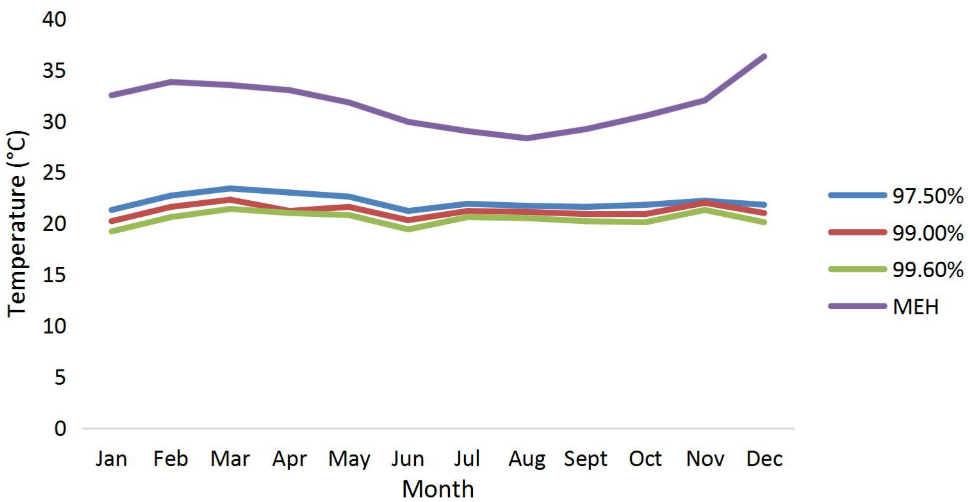

Figure 3: The Design Dry- Bulb Temperatures for Ikeja-Lagos from 1995-2009

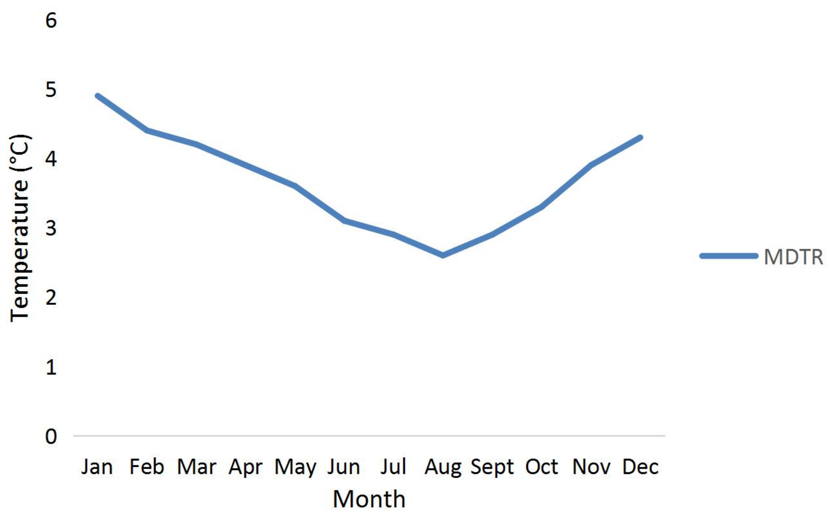

Figure 4: The Mean Daily Temperature Ranges for Ikeja-Lagos from 1995-2009

4.3 The Relative Humidity for Ikeja-Lagos from January-December of 1995-2009

The design relative humidity for Ikeja-Lagos from January to December of 1995-2009, is as shown in Table 3 and Figure 5. The normal statistical estimates for the design relative humidity were computed for 0.4%, 1.0% and 2.0%. The design relative humidity calculated for period exceeded 100% as shown in Table 3. Since the design relative humidity exceeded 100%, it implies that normal distribution statistical method cannot be used as stated by Ariyo and Olorunmaiye (2017b) as well as Erbs (1984). Erbs (1984) suggested Weibull distribution for design relative humidity to overcome defect of normal distribution statistical method. The statistical values of median of extreme lows (MEL) and median of extreme highs (MEH) were also calculated as shown in Table 3. Using the classification of ASHRAE (2013a), the relative humidity for Ikeja, Lagos were computed to be an average of 116.3 and 112.6 at 0.4% and 1.0% percentile, respectively, which is as shown in Table 3.

In the design and sizing simulation of HVAC systems for spacecrafts, design data based on dry bulb temperature represent peak occurrences of sensible component of ambient outdoor conditions. The design values based on wet-bulb temperature are related to enthalpy of the outdoor air while conditions based on dew point relates to peaks of the humidity ratio. The design data for dry bulb, wet bulb and humidity ratio are optimized to obtain the most reliable situation to adopt as stated in ASHRAE (2016). The foregone statement agrees to view on decisions of conditions and probability of occurrence of climatic conditions to the design of spacecraft as reported by Liping, et al. (2017).

Table 3: The Relative Humidity for Ikeja from January-December of 1995-2009.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
0.4%	127.4	125.7	116.4	113.6	114.2	112.9	111.6	111.7	112.6	113.2	115.5	121.3	116.3
1.0%	121.3	119.9	110.6	109.7	110.6	109.2	108.8	108.7	109.7	110.1	111.9	121.3	112.65
2.0%	116.6	115	108.1	106.5	107.6	107.5	106.4	106.2	107.3	107.4	108.7	112.4	109.14
MEH	100	99	99	100	100	100	100	100	100	100	100	100	99.83
MEL	23	21	44	53	56	62	63	60	64	61	56	30	49.42

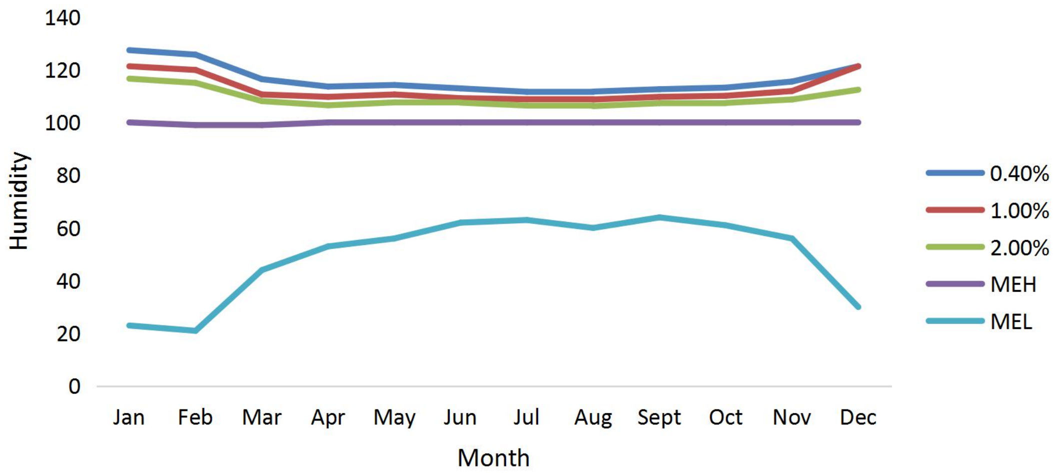

Figure 5: The Relative Humidity for Ikeja-Lagos from January-December in the Period of 1995-2009

5.0 Conclusion

In this study, an investigation of the impact of climate change on the design parameters of Heating, Ventilation and Air Conditioning (HVAC) systems for spacecraft was carried out. The climate parameters investigated were outdoor dry-bulb temperature, coincident wet-bulb temperature and relative humidity. These parameters are very important in determining thermal comfort of payload in space crafts on ascent. Furthermore, the city of Lagos was used as a base for potential launch of spacecraft. The values of climatic parameters were obtained with adequate consideration of climate change. From the investigations carried out, the conclusions drawn includes determination of mean coincident dry bulb temperature of 33.8oC and 32.98oC at 0.4% and 1% percentile respectively at Ikeja, Lagos, on altitude 39 m with coordinates of Latitude 6.59°N and longitude 3.34°E. The heat dry bulb temperature for Ikeja, Lagos, was determined to range from 20.43oC to 22.1oC from January to December, in the period of 1995-2009, at 97.5% 99% and 99.6% percentile respectively. The median of extreme lows (MEL) was at an average of 49.42% for the period. The median of extreme highs (MEH) was at an average of 99.83% for the period. The Lagos relative humidity average results were 116.3, 112.65, 109.14,

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99.83 and 49.42 at 0.4%, 1% and 2.0% occurrence as well as median of extreme highs and median of extreme lows, respectively.

Acknowledgement

The authors wish to thank the Director and Chief Executive, Center for Satellite Technology Development (CSTD) of the National Space Research and Development Agency (NASRDA), Abuja, Nigeria, and Editorial Committee of CSTD for consideration of our paper for publication earlier presented at 2017 CSTD conference.

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