

## Chapter

# Spatial Distribution of the Nature of Indoor Environmental Quality in Hospital Ward Buildings in Nigeria

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## Abstract

This study seeks to ascertain the spatial distribution of IEQ in hospital wards based on the physical measurement of the hospital ward units with different architectural features. Field survey was undertaken in the medical and surgical wards units of two case study Hospitals both located in Jos, Nigeria. IEQ parameter variables were monitored and recorded, and compared against recommended international standards for hospital facilities. Results show that the measurements of the IEQ parameters conditions in the selected hospital ward buildings, differ substantially depending on the ward design configuration and orientation, and also the outdoor weather condition. The indoor environment in the hospital wards had different thermal conditions because of variations in orientations, window sizes and air inlet/outlet. Building orientation, also affected the indoor daylight quality in each of the hospital ward buildings within the period of measurements. The Teaching Hospital wards whose orientation (NW-SE) allows the fenestration façade to fall within the sun path, maximised it for daylighting within the wards. It is therefore recommended that, the design of hospital wards for improved IEQ conditions should be such that proper attention is given to the orientation, floor plan configuration and window design for natural ventilation and lighting.

**Keywords:** design configuration, orientation, spatial distribution, indoor environmental quality, hospital wards

## 1. Introduction

Indoor environmental quality (IEQ) has been defined as, the determination of the significant factors that have direct effect on a building occupant comfort and wellbeing [1]. IEQ is also seen as components responsible for an environment that appears to be psychosocially healthy for its inhabitants [2]. Buildings are designed and constructed generally for human habitation, as a result, the requirements for their usage is needed to be fulfilled as a precondition for their well-being [3]. Different studies on IEQ in buildings have shown that, achieving comfort in an

indoor environment should be based on the assessment of thermal, acoustic, lighting and the quality of the indoor air as parameters of importance [3–7].

Indoor environmental quality assessment in buildings have taken different dimensions based on building type and environmental setting. For example, it has been asserted that the assessments of the overall indoor environmental quality of office buildings do not follow any standard protocol [8]. This is also typical of hospital facilities where little has been done in assessing their indoor environmental quality, which has great impact on occupants' health, productivity as well as building energy demand [6, 9]. There is a need therefore, to have a standard measure for the overall indoor environmental quality of hospital buildings in order to prevent the negative impact of the environment on building occupants. The design of the hospital building environment should therefore be such that it has positive influence on occupants' health, comfort, and productivity.

The central theme surrounding any particular hospital is 'patient care'. Therefore, the design of a hospital building should be such that the patient as the main occupant experience comfort and protection from environmental elements. The hospital is seen as a therapeutic environment for caring for the sick and other related activities such as learning and research [10]. Neglecting the quality of a hospital environment will amount to issues that contradict the essence of a hospital as a healing environment.

The hospital which is generally seen as an environment for healing could possibly be harmful to both people and the environment [11]. Besides, occupants of hospital environment could contract some healthcare acquired infections that might even result into death. The adoption of sustainable design in healthcare facilities have been focusing on creating a facility that is supportive of an improved patient care, staff wellbeing and productivity, and environmental friendliness. Patient care, staff wellbeing and productivity, and environmental friendliness is referred to as the "Healthcare's Triumvirate [12] with respect to sustainable design in healthcare services. Different studies [11, 13, 14] have shown that promoting green hospital buildings could result into solving a wide range of sustainability issues which are challenging to the environment. Green building rating systems such as LEED, BREEAM and Australian Green Star (GBCA) have made some contributions towards promoting sustainable healthcare facilities planning, design, and construction [15].

Cross ventilation and building energy performance are among the main consideration in the design of hospital facilities. In as much as ventilation strategy is influenced by environmental settings, its long run cost implication is enormous. However, the running cost of providing proper ventilation using artificial system should not be deterrent in ventilating special hospital units such as Intensive Care Unit (ICU), Special Child Birth Unit (SCBU) and operating theatre among others. Air conditioning systems in a building allows for flexibility in form and space management [16, 17], while natural ventilation on the other hand requires use of courtyards for it to be achieved which takes much space. The provision of natural ventilation in hospital buildings would allow patients, and staff contact with nature [18], however, it has been attributed with infection spread.

Sustainable development and design processes in healthcare facilities is being driven by suppleness, cost minimization, innovation and healing environment [19]. Hospital design requires a careful consideration of the individual spaces to be provided and the incorporation of the requirement for optimum indoor environment, which is more challenging when compared to other building types. This study therefore seeks to ascertain the spatial distribution of IEQ in hospital wards based on the physical measurement of the hospital ward units with different architectural features (building orientation, design configuration and windows placement).

## 2. Methodology

The environmental conditions of different hospital settings might not be the same since they would have differences in certain architectural features, different management system and source of finance, and also, differences in the services they provide. Therefore, the need to study the indoor environment of different categories or settings of hospital facilities. To achieve the goals of this research, the rationality behind the concept and context in which the methods are employed needed to be explained, which will facilitate the evaluation of the research outcome [20].

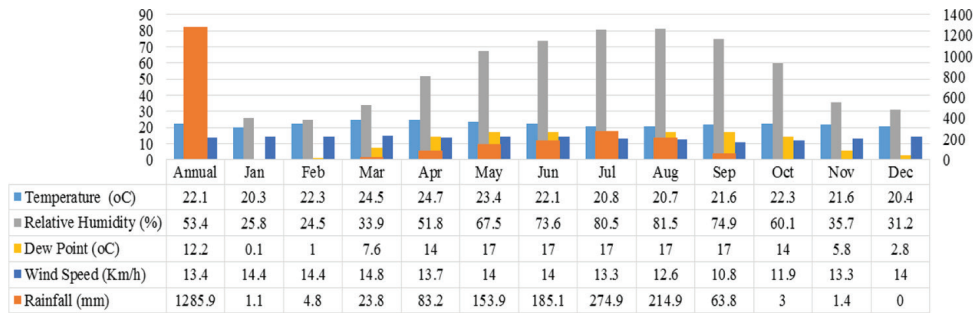
In Nigeria, there are three main categories of public healthcare settings namely: the primary, secondary and tertiary healthcare facility. For this study however, only two of the hospital categories were chosen (Tertiary—Teaching Hospital and Secondary—Specialist Hospital). The criteria used in the selection of the case study hospital wards is based on the differences in their orientation, spatial and physical conditions, and organisational settings. Field survey was only done in the medical and surgical wards units of the selected hospitals. Plateau Specialist Hospital and the Jos University Teaching Hospital both located in Jos, Nigeria were selected as case study. Both the Plateau Specialist Hospital and Jos University Teaching Hospital are government owned hospitals that were selected because of the ease of access and ease in eliciting the required information. The selection of these two different hospitals is in understanding the variations that might likely be found in the nature of the IEQ performance due to some of their architectural features (orientation and design configuration) and organisational differences. For simplification, the case study hospital wards are designated by their orientation as Teaching Hospital (NW-SE) and Specialist Hospital (NE-SW) orientations.

### 2.1 The study area

This study is carried out in Jos, Plateau State, which is the twelfth largest state in Nigeria. The State is located on latitude 9° 10' N and longitude 9° 45' E in central Nigeria. It has a total land area of 30,913 square kilometres and an estimated population of over 3 million people based on the 2006 population census, and having a population density of 100 per square of a kilometre [21]. Plateau State derived her name from the fascinating table top rock formation known as Plateau whose altitude ranged from 1200 to 1829 m above sea level. The climatic condition of the State could be referred to as temperate if compared with the other parts of Nigeria, even though it is situated within the tropical region of the world. The state records an annual mean temperature of between 18 and 22°C, with a mean annual rainfall of 1317.5 mm in the lower part of the Plateau and 1460 mm on the Plateau top.

The two case study hospitals are located in Jos the Plateau State capital city. Jos is located on latitude 9° 55' N and longitude 8° 53' E and at an altitude of about 1200 m above sea level [22]. Jos has an average monthly temperature that ranged from 20.3 to 24.7°C, with an average annual rainfall of about 1300 mm as shown in **Figure 1**. Jos experienced an average monthly relative humidity of 53.4%. This weather obtained from the web page of Nigerian Meteorological centre does not reflect the current weather situation in Jos, Nigeria as the outdoor field measurement results shown in **Table 1** is significantly at par with the sourced data.

The selection of the case study hospitals was based on their ward orientation and configurations. The ward buildings in Plateau Specialist Hospital faced the Northeast-Southwest orientation while those of Jos University hospital faced the Northwest-Southeast orientation.



**Figure 1.** Summary of monthly weather averages in Jos. Source: NiMet [22].

	10 am	11 am	12 pm	1 pm	2 pm	3 pm	Average
Temperature (°C)	27.4	28.6	29.5	30.0	30.7	30.9	29.5
Wind (m/s)	2.5	2.3	2.0	1.4	1.4	1.4	1.9
Humidity	71%	61%	47%	44%	43%	41%	51%

Source: Field data.

**Table 1.** Summary of daily hourly averages of outdoor weather in Jos (between 10 am and 3 pm, for 3 months period).

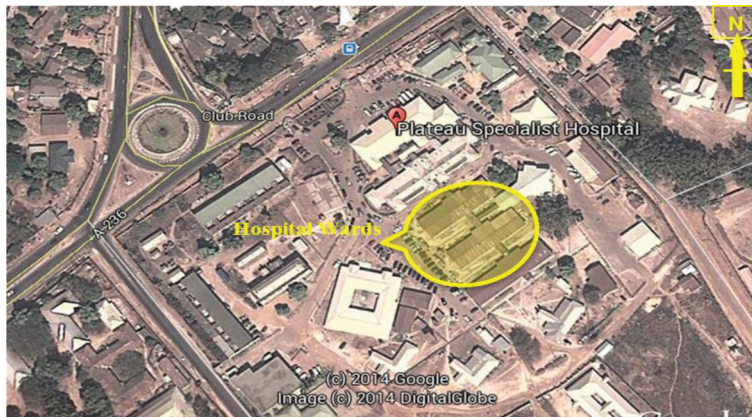
## 2.2 Plateau Specialist Hospital, Jos (NE-SW)

### 2.2.1 Hospital setting

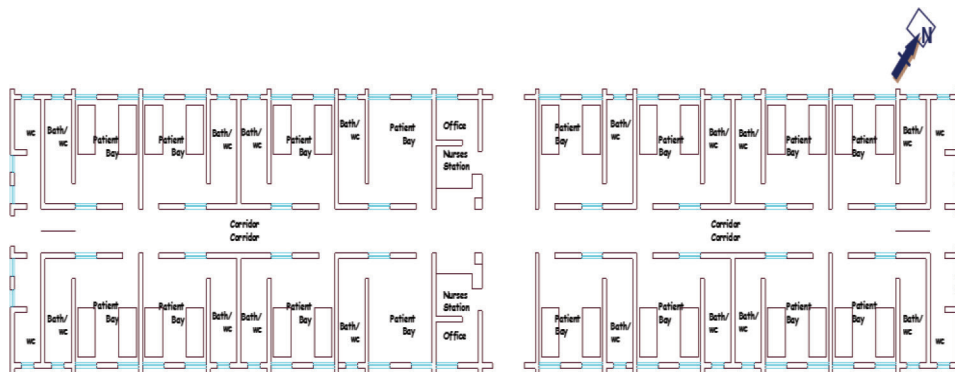
The Specialist Hospital which represents a secondary healthcare facility is named ‘Plateau Specialist Hospital’ and is located in Jos, the State capital city (Figures 2 and 5). Plateau Specialist Hospital provides general and specialised medical services, and is also an accredited healthcare institution for residency in family medicine and internship training. The hospital has a bed capacity of 176 (124 adult and 52 children) and staff strength of 633 personnel, with an average daily patient flow or visits of about 176 per day [23]. The ward buildings selected in this hospital have a total bed space capacity of 64 (32 bed spaces each). Each of the ward buildings are partitioned into 6 (8) single rooms each, which can accommodate a maximum of 2 (2) inpatients.

### 2.2.2 Architectural features

The Specialist Hospital is located on latitude 9° 53’42.9”N and longitude 8° 53’02.2”E, and within a densely populated are of the city-centre. The hospital wards building layout and orientation as shown in Figure 2 faces the Northeast-Southwest direction. The space organisation of the ward units is the corridor or continental form based on a description of hospital space types by James and Iatten-Brown [24]. The plan configuration of the hospital wards have 8 (16) units rooms of solid partitioned internal walls accommodating two bed-spaces each. The partitioned ward room units are access through a corridor (Figure 3) that separated them along two axis. Each of the ward room units is installed with two 1200 mm × 1200 mm Louvres glass windows on the same wall façade. The window to wall ratio (WWR) on the fenestration façade is 15%, which is less than the optimum recommended by Zain-Ahmed et al. [25]. The windows have curtains which were installed for shading.



**Figure 2.**  
*Site location of Specialist Hospital, Jos, Plateau State, Nigeria (Google Earth).*



**Figure 3.**  
*Typical floor plan of Specialist Hospital ward.*

The ward buildings are naturally ventilated with supplemental ceiling fans as artificial mechanical source. The mechanical source of ventilation (ceiling fans) powered by electricity are mostly not in use due to lack of power supply. A walkthrough observation of the hospital buildings revealed a lack of proper ventilation and lighting, and also, drain pipes leakages and fittings breakdown was observed. A typical floor plan and pictorial views of the Specialist Hospital is shown in **Figures 3–5**.

### **2.3 Jos University Teaching Hospital (NW-SE)**

#### *2.3.1 Hospital setting*

Jos University Teaching Hospital was established in 1981 by an act of Nigeria Parliament, and was operating at a temporary site until 2007. Work on the permanent site was completed and inaugurated in May 2007 after operating at the temporary site for over 20 years. The permanent facility constructed for Jos University Teaching Hospital has a 620 bed-space capacity that provides both inpatient and outpatient services, as well as medical personnel training and research. The focus of this hospital is in providing tertiary health services training, using modern technology and research in a conducive environment for both patients and staff. The hospital facility is a 2 (2) storey building complex that houses all





**Figure 4.** Specialist Hospital ward interior—(a) corridor, (b) typical ward room.



**Figure 5.** Exterior views of Specialist Hospital ward—(a) northeast view, (b) southeast view.

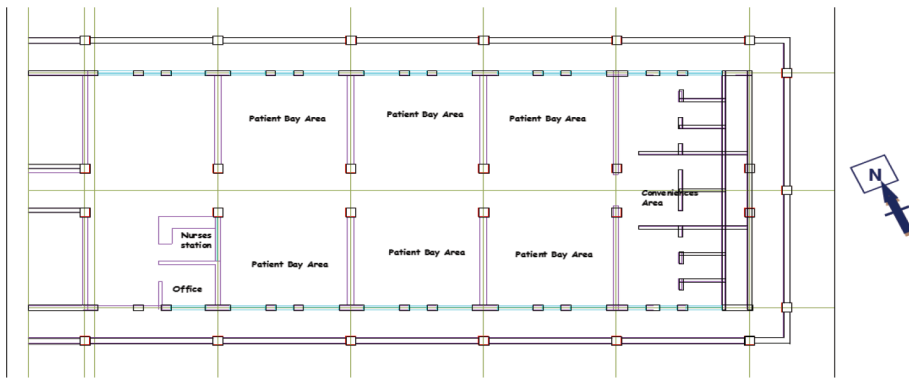
departments, offices, research laboratories, and instructional classrooms. The selected ward buildings in this hospital are located on the first and second floor of the complex (**Figures 6–9**).

### 2.3.2 Architectural features

The Teaching Hospital is located on latitude  $9^{\circ} 54'27.5''N$  and longitude  $8^{\circ} 57'37.5''E$ , in a sparsely populated area at the outskirts 14.3 Km away from the city-centre. The hospital complex was designed by Interstate Architects Limited in the late 1970s with an initial size of 320 beds. The hospital layout was designed to expand to a 1000 beds Teaching Hospital at the appropriate time in future. The first phase of construction work of the complex was completed in 2006. The ward buildings are both naturally and mechanically ventilated with ceiling fan, and also, with split-level air-conditioning system which is often not in use. This facility has three sources of power supply which enable uninterrupted electricity



**Figure 6.** Site location of Jos University Teaching Hospital, Jos, Plateau State, Nigeria.



**Figure 7.**  
*Typical floor plan of Teaching Hospital ward.*



**Figure 8.**  
*(a and b) Exterior views of Teaching Hospital complex.*



**Figure 9.**  
*(a and b) Interior space images of the Teaching Hospital.*

supply to the buildings. Artificial mechanical ventilation and lighting is readily available within the ward buildings. The building complex orientation is facing the Northwest and Southeast direction which allows for maximum utilisation of daylighting (**Figure 6**). The Teaching Hospital space organisation is the open or Nightingale type.

The Teaching Hospital wards spatial configurations are the multi-bed bays segmented into three. This provides the nurses with direct observation of patients but at the expense of patients' privacy. The facades and fenestration design of the wards were installed with glazed aluminium panelled windows on both axis facing Northeast and Southwest with a window to wall ratio (WWR) of about 50%. Also provided are top daylight windows for deeper penetration of light into the hospital ward. The glazing on the windows are double pane clear glass used on aluminium panels. **Figures 7** and **9** shows a sketch of the hospital ward floor plan, views and three dimensional elevations of the hospital wards building.

## 2.4 Measurement and evaluation

The assessment of IEQ performance is based on the measurement of its four-factor parameters in each of the selected ward buildings in the case study hospitals, which was carried out within 3 months period. The main objective of the physical measurement of IEQ is to investigate the thermal, acoustic, lighting and indoor air conditions in the hospital buildings in order to determine their comfort level. **Table 2** shows a list of IEQ parameters measurement variables. The objective physical measurement is used in cross-validating the IEQ parameters measures in comparison with certain international standards and guidelines. The specific objectives of physical measurement of IEQ parameters were:

- a. To measure the thermal condition (temperature and humidity) in the selected hospital wards in order to determine the thermal quality.
- b. To determine the acoustic quality by measuring sound level in dBA.
- c. To determine the lighting quality based on the measurement of lighting intensity.
- d. To measure carbon dioxide and carbon monoxide to determine the indoor air quality.

The procedure for the measurement of the indoor environmental variables is as described in BS EN ISO 28802 [36]. The variables measurement was conducted intermittently at a central location in-between patients' bed in the selected hospital wards. **Table 3** shows an overview of the field measurement of IEQ, and the IEQ variables were measured using the IEQ mobile measurement station as shown in **Figure 9b**. The measuring instrument was set to measure the variables continuously for a period of 2 hours at 5 minutes intervals. The variables were measured at a height of 900 mm above the floor level with the IEQ mobile measurement station positioned within ward building in a central location. The instruments that made up the IEQ mobile measurement station and the specific IEQ variable of measurement is described in detail in **Table 2**. The data logger, which is calibrated both before and after measurement, is set up 1 hour before the commencement of data acquisition on each day of data collection.

IEQ parameters measurements were taken in each of the selected ward buildings indoor environment for three consecutive times over a period of 3 months. This is

IEQ parameter	Measurement variables	Acceptable benchmark for hospitals
Thermal quality	Temperature (°C)	21–24°C [26] 23–26°C [27] 24–33°C Adaptive comfort. BS 15251 [28] 27–37°C [29]
		Relative humidity (%)
Acoustic quality	Sound intensity level (dBA)	<40 dBA [31] <60 dBA [32]
		Lighting quality
IAQ	Carbon dioxide (ppm)	<700 ppm [28], [35]
	Carbon monoxide (ppm)	<9 ppm [35]

**Table 2.**  
*Measurement variables for objective physical measurements of IEQ.*



IEQ field measurement	Selected case study hospitals	
	Plateau Specialist Hospital	Jos University Teaching Hospital
Building location	A236-Club Road, Jos. 9° 53'42.9"N and 8°53'02.2"E	Lamingo, Jos. 9° 54'27.5"N and 8° 57'37.5"E
Building unit type	Surgical and orthopaedic ward	Surgical and orthopaedic ward
Façade orientation	NW-SE	NE-SW
Design configuration reference [24]	Corridor or continental type	Open or nightingale type
Spatial layout	2-Bed space units of ward rooms	Open—plan multibed units
Measurement variables	Temperature, humidity, carbon dioxide, carbon monoxide, light Intensity, sound level	
Measurement executions	3 Months (April–June)	
Measurement times	2 Days per hospital wards per month (10 am–3 pm)	

**Table 3.**  
*An overview of objective field measurement.*

Measurements	Boundary conditions
Specialist Hospital (NE-SW) Teaching Hospital (NW-SE)	<ul style="list-style-type: none"> <li>• All windows open for ventilation within the period of measurement from 10 am to 3 pm.</li> <li>• Window blinds were rolled up to about 60%.</li> <li>• All external doors were closed throughout the period of measurement.                             <ul style="list-style-type: none"> <li>○ Artificial light off.</li> <li>○ Mechanical ceiling fan off.</li> </ul> </li> </ul>

**Table 4.**  
*Physical measurement boundary conditions.*

to ensure that any variation in the measured variables over time is being taken into consideration. The data collected from the different selected ward buildings of each hospital were average for statistical analysis. **Table 4** Shows the boundary conditions applied during the field measurements.

### 3. Results

This section discusses the relationship between IEQ and hospital wards having different building characteristic (orientation and spatial layout). The IEQ parameters variable data collected during the field measurements are, air temperature, relative humidity, sound intensity level, light intensity level (illuminance), carbon dioxide (CO<sub>2</sub>), and carbon monoxide (CO) as shown in **Table 2**. The results of the field measurements of physical indoor environmental variables in the different case study hospitals and taken in three different months is described below. The results of this empirical measurement of the IEQ variables is presented as a descriptive analysis summary for the two different hospitals ward buildings measured in three different months. **Table 5** shows a statistical summary of the monthly measured variables in the case study hospital wards.

Case study	Statistics	Temperature (°C)	Relative humidity (%)	Sound intensity (dBA)	Light intensity (lux)	CO <sub>2</sub> (ppm)	CO (ppm)
Specialist Hospital	Mean	30.89	55.91	71.57	248.01	463.28	6.17
	SD	2.11	5.08	6.88	62.08	58.67	4.01
	Minimum	26.20	43.00	54.10	173.60	400.00	3.00
	Maximum	35.00	63.20	83.80	342.60	608.00	14.00
Teaching Hospital	Mean	30.41	58.47	65.22	333.75	450.01	4.48
	SD	1.80	8.34	7.21	67.54	34.26	1.87
	Minimum	26.80	40.70	52.70	189.20	393.00	2.00
	Maximum	35.00	71.30	75.00	432.00	517.00	10.00

**Table 5.**  
Summary of objective empirical measurements in the hospital wards.

### 3.1 Thermal quality in hospital wards

The thermal quality in the selected hospital buildings is measured by indoor air temperature and relative humidity. A hospital environment is seen as being traumatic where excessive temperature could have great impact on the building occupants [37]. Temperature is a major determinant of thermal quality which also has relative humidity as its function. The two variables considered for thermal quality, temperature and relative humidity within the indoor spaces of the hospital ward buildings were measured consecutively within a period of 3 months. This section analyses the temperature and relative humidity in the selected hospital ward buildings according to the hospital wards orientations and period of measurement. The hourly average outdoor weather condition recorded within the period of measurement in each of the case study hospital ward is shown in **Table 6**.

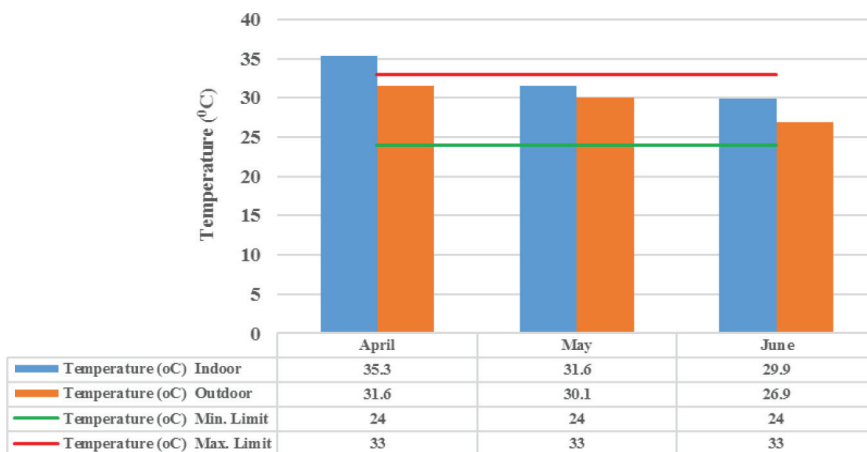
#### 3.1.1 Thermal quality in Specialist Hospital (NE-SW orientation)

The average mean outdoor temperatures for the period of measurement are shown in **Table 6**. The indoor and outdoor temperature difference in April and June is significantly different from the difference in May with about 1.5°C. The indoor and outdoor thermal variables measured showed a strong periodic trend. The mean monthly temperature measured in the Specialist Hospital is presented in **Figure 10**. The recorded mean temperature within the period of measurement ranged from 29.9 to 35.3°C. There was a relatively linear reduction in mean indoor temperature from April to May. A maximum temperature range of 33.2–36.2°C was recorded in April while a minimum temperature range of 29.0–31.9°C was recorded in June as presented in **Figure 11**. The variation in temperature increased with time in April while decreasing in May and June. The minimum temperature (30.8°C) was recorded in June at about 2.00 pm hours while the maximum temperature (36.2°C) was recorded at about 10.00 am in April (**Figure 11**). The acceptable limits of temperature shown in **Figures 11** and **12** are based on adaptive thermal comfort.

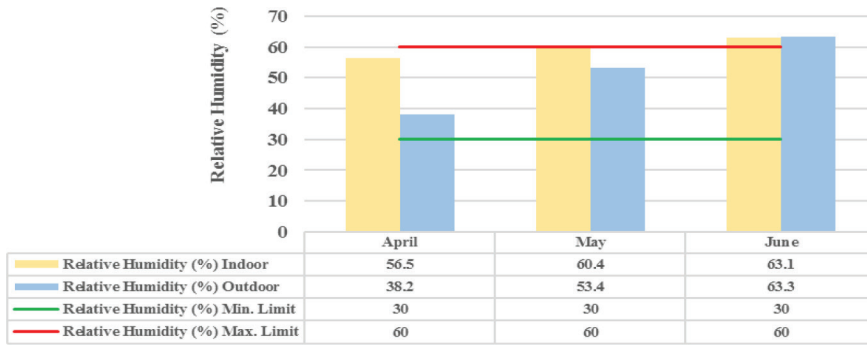
The relative humidity recorded showed an inverse variation to temperature within the period of measurement in this hospital buildings. The mean relative humidity recorded in April at 56.5% increased to 63.1% in June as a result of the significant effect of annual rainfall on the indoor air temperature. The minimum relative humidity

Period	Variable	10 am	11 am	12 pm	1 pm	2 pm	3 pm	Average
<b>Specialist Hospital</b>								
April	Temperature (°C)	28.9	29.8	31.7	32.8	33.1	33.3	31.6
	Wind (m/s)	2.2	2.2	1.8	0.9	0.9	0.9	1.5
	Humidity	52.0%	43.0%	36.0%	31.0%	34.3%	32.8%	38.2%
May	Temperature (°C)	27.3	28.9	30.4	31.0	31.3	31.5	30.1
	Wind (m/s)	2.9	2.3	2.3	2.3	2.4	2.4	2.5
	Humidity	74.9%	61.9%	51.8%	44.6%	41.8%	45.1%	53.4%
June	Temperature (°C)	24.6	26.0	26.9	27.9	27.9	28.3	26.9
	Wind (m/s)	3.1	2.5	2.5	2.5	2.6	2.6	2.6
	Humidity	90.0%	74.4%	62.3%	54.6%	50.2%	48.4%	63.3%
<b>Teaching Hospital</b>								
April	Temperature (°C)	29.4	30.6	31.7	32.2	32.2	32.2	31.4
	Wind (m/s)	2.8	2.2	2.2	2.2	2.3	2.3	2.3
	Humidity	51.0%	43.0%	34.0%	32.0%	30.0%	29.0%	36.5%
May	Temperature (°C)	27.8	28.9	29.9	30.5	30.5	30.5	29.7
	Wind (m/s)	2.3	2.4	1.9	0.9	0.9	0.9	1.6
	Humidity	73.4%	64.6%	49.0%	46.1%	45.7%	43.7%	53.7%
June	Temperature (°C)	25.0	26.5	26.9	27.4	29.5	30.1	27.6
	Wind (m/s)	2.5	2.5	2.0	1.0	1.0	1.0	1.7
	Humidity	88.2%	74.4%	58.8%	55.4%	51.9%	50.2%	63.1%

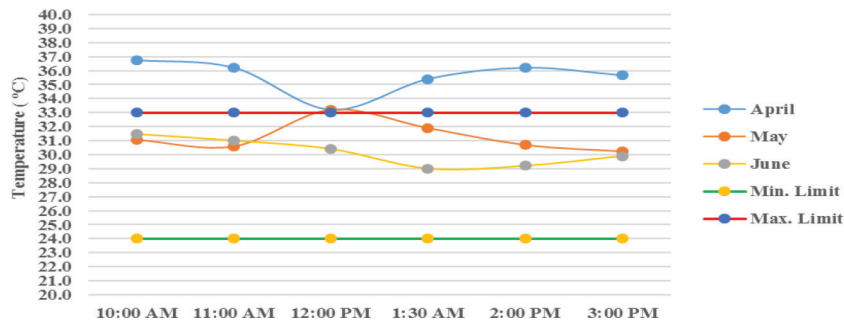
**Table 6.**  
 Field measurement of hourly average outdoor weather condition.



**Figure 10.**  
 Mean relative humidity in Specialist Hospital wards.



**Figure 11.**  
Variation in temperature in Specialist Hospital wards.



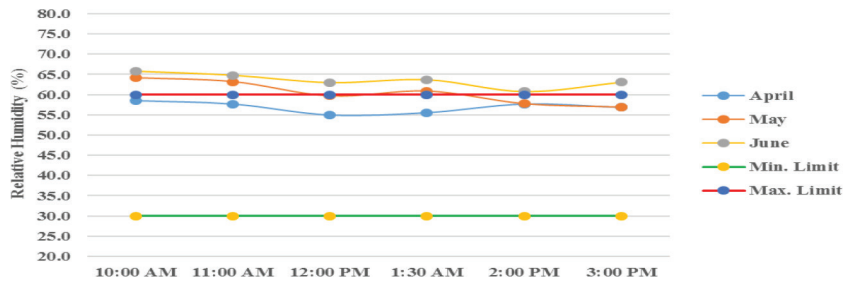
**Figure 12.**  
Mean temperature in Specialist Hospital wards.

recorded within the period of monitoring is between 54.9 and 57.7%, while the maximum is between 60.8 and 64.8%. The relative humidity are higher within the morning hour and lower in the afternoons. **Figure 13** shows variations in the relative humidity in the Specialist Hospital which is relatively uniform in May and June.

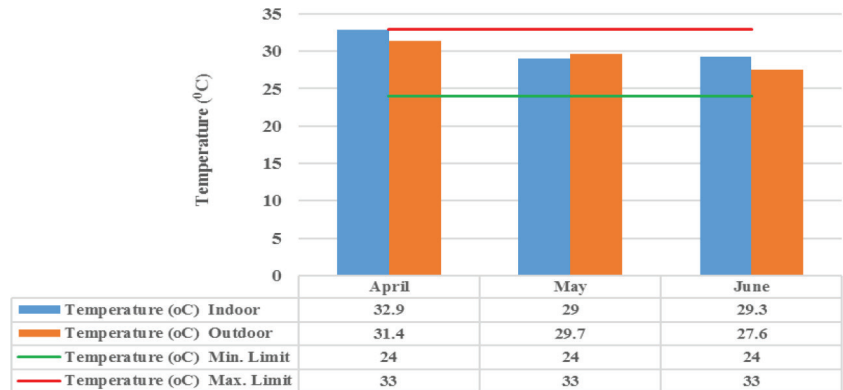
### 3.1.2 Thermal quality in the Teaching Hospital (NW-SE orientation)

The variation trend of temperature is the same as the other two case study hospitals, as there was also a temperature decrease recorded for May and June. The mean temperature and relative humidity recorded during the monitoring periods is shown in **Figures 14** and **15**. The mean temperature range recorded in each of the ward buildings is between 29.3°C recorded in May and 32.9°C recorded in April. The mean temperature in May and June which are almost invariable, are relatively lower than the mean temperature recorded in April. Temperature variation as shown in **Figure 16** decreases with about 4.0°C within an hour and increased again with the same magnitude within 30 minutes both in May and June. The temperature was steady in April with only a variation at about 12.00 noon where it recorded its highest temperature of 35.4°C.

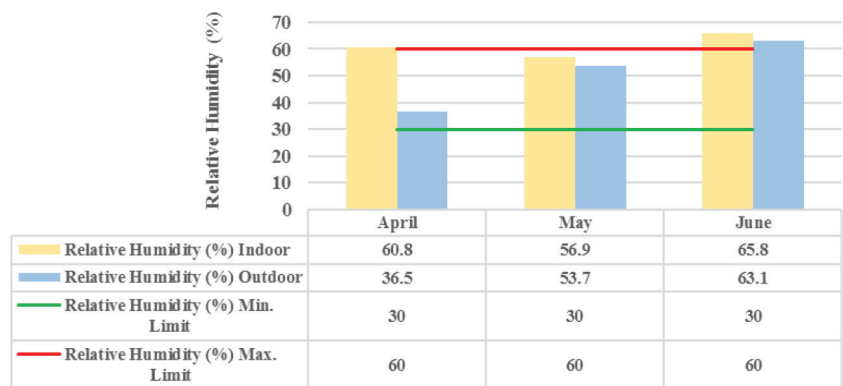
The mean relative humidity level ranged between 56.9 and 65.8% (**Figure 15**) as recorded in the ward buildings. There is no proportionality in the relationship between relative humidity and temperature in this hospital. As with the other hospital buildings, there are differences in the relative humidity measured at different periods. The variation of relative humidity as recorded at different periods is as shown in **Figure 17**. In April, the average relative humidity ranged from 53.1 to 69.2%, which was quite higher than the relative humidity recorded for May and June. The month of May recorded the least steady variation in relative humidity



**Figure 13.**  
 Variation in relative humidity in Specialist Hospital.



**Figure 14.**  
 Mean temperature in Teaching Hospital wards.



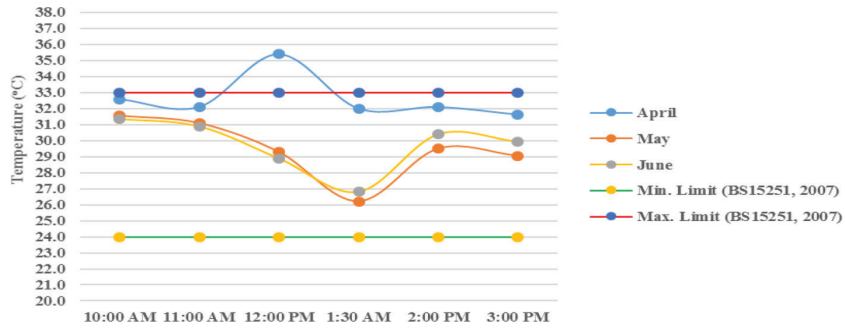
**Figure 15.**  
 Mean relative humidity in Teaching Hospital wards.

having a range difference 6.9% as compared to April and June having a range difference of 10 and 16.2% respectively.

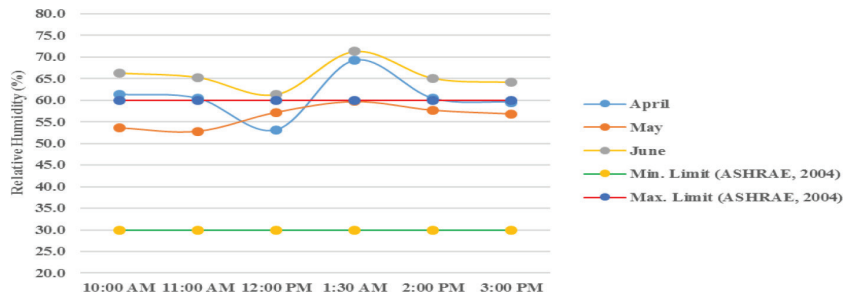
### 3.1.3 Thermal quality variations by hospital ward buildings

The monitoring of indoor temperature and relative humidity was carried out with the IEQ mobile measurement station data logger positioned within the ward buildings in each of the case study hospital wards. The thermal qualities in each of these hospital wards differ since their design, configurations and orientation also differs. The indoor temperature and relative humidity therefore varied according



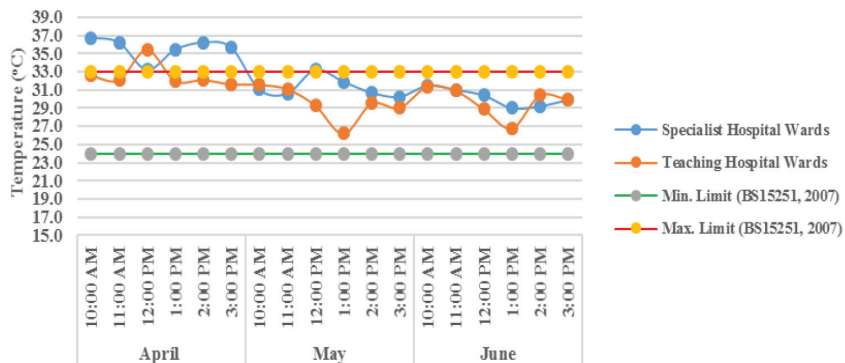


**Figure 16.**  
Variation in temperature in Teaching Hospital wards.



**Figure 17.**  
Variation in relative humidity in Teaching Hospital wards.

to the hospital ward orientation. The variation in temperature in each hospital measured within a given period is shown in **Figure 18** was highest (36.7°C) in the Specialist Hospital wards as measured in April while the lowest temperature (26.2°C) was recorded in May in the Teaching Hospital. The indoor temperature of both two hospitals changes with period of monitoring. The variations in the monthly temperatures in both hospital buildings can be said to be having the same trend. In April, the mean indoor temperature as measured in the hospital ward buildings ranged between 33.2 and 36.7°C in the Specialist Hospital, while the mean temperature ranged between 32.0 and 35.4°C in the Teaching Hospital. The same trend is evident in measurement for May and June for both hospitals; however, there was a drop in temperature of between 1.5 and 4.5°C in May and June respectively. There was no any particular trend in temperature variations at specific time



**Figure 18.**  
Monthly temperature variation in the hospital ward buildings.

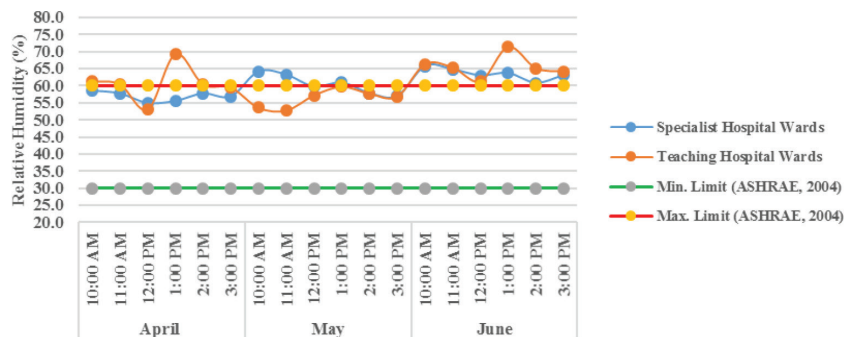
as measured in each hospital. Between the hours of 11.00 am and 12.00 noon in April, the temperatures increased from 32.1 to 35.4°C in the Teaching Hospital while decreasing from 36.2 to 33.2°C in the Specialist Hospital.

The indoor temperature levels in both hospital wards were influenced by incoming sunlight. The orientation of the Teaching Hospital wards is such that the façade windows are exposed to direct sunlight both at sunrise and sunset. However, the corridor provided on the Southwest façade provides shading against direct penetration of solar radiation. Due to heat gains from sunlight, the temperature in the Teaching Hospital wards were higher between the hours of 10.00 am and 12.00 noon than the hours between 1.00 pm and 3.00 pm. Temperatures in the Specialist Hospital wards were generally higher through the period of measurement as compared to temperatures in the Teaching Hospital wards.

The variation trend of temperature in both Specialist Hospital wards tend to reduce between the hours of 1.00 noon and 3.00 pm in May and June. As much as the Teaching Hospital has the minimum temperature range recorded within the periods of measurement, the fluctuations in the temperature within specific time of the day is highest. Also, the mean relative humidity recorded lowest and highest values both in the Teaching Hospital wards in the month of June (**Figure 19**). Relative humidity tends to increase from April to June as measured in the Specialist Hospital and Teaching Hospital. On an average, lower relative humidity was recorded at 12.00 noon in each monitoring day of the hospital wards.

The thermal quality of any building occupant depends more on temperature as the most important indoor environmental variable. Higher temperatures were recorded in the Specialist Hospital wards for the period of measurement as compared to the Teaching Hospital wards. The Specialist Hospital wards and Teaching Hospital wards are both located on the highland of Plateau. The average outdoor temperature difference between the locations of the two hospital ward buildings was below 1°C within the period of measurement. The mean temperatures as measured in the two hospital ward buildings ranged from 30.4 to 34.9°C. The relative humidity level on the other hand was from 55.9 to 58.5%. According to international standards and guidelines, the mean indoor temperature recorded in both case study hospital wards are above acceptable limits of 23–26°C for occupants’ comfort [28]. However, the temperature range recorded in the Teaching Hospital wards are within acceptable limits of adaptive comfort (24–33°C) stated in BS 15251 [28].

The Specialist Hospital wards whose average temperature recorded the highest (35.3°C) in the month of April still fall within the acceptable limit of 27–37°C as opined Nicol and Humphreys [29]. The average monthly indoor temperature pattern was relatively stable in the Teaching Hospital wards with open-plan configuration and windows that allows for cross ventilation than in the Specialist Hospital wards.



**Figure 19.** Monthly relative humidity variation in the hospital ward buildings.

The indoor relative humidity levels in both hospital ward buildings fall within acceptable range of (30–60%) as provided for in international standards [30]. The mean relative humidity level for April in all hospitals is lower, as April always mark the end of dry season. According to Environmental Protection Agency [38], high humidity level in buildings stimulates the breeding of micro-organisms which have adverse effect on building occupants especially in healthcare facilities. However based on [30] which recommended that relative humidity should not be greater than 65%, the mean relative humidity can said to be within acceptable range. The indoor humidity level in both hospital wards were not the same for the period of measurement. The Teaching Hospital wards recorded humidity levels which were significantly higher than the outdoor humidity as compared to the Specialist Hospital wards. This was strongly influenced by the wide windows provided on adjacent façade walls in response to variations in outdoor humidity.

The temperatures and relative humidity levels recorded in the hospitals are not uncommon for naturally ventilated buildings located in the tropical regions of the world. The high temperatures recorded in both hospital wards might be due to the exposure of their facades to direct solar radiation. The provision of appropriate shading through landscape elements could help in preventing overheating within the hospital wards. Hospital wards design in the tropics should there incorporate shading design principles either passive or active towards achieving thermal balance in the buildings. The design configuration of the Teaching Hospital wards having cross ventilation through the provision of wider windows allows for the free movement of air in and out of the wards. The free flow of air tends to cool the heated air within the wards thereby reducing the indoor temperature level. The Specialist Hospital wards on the other hand have closed-plan design configuration with the rooms not having proper ventilation that is required to provide thermal balance for the patients.

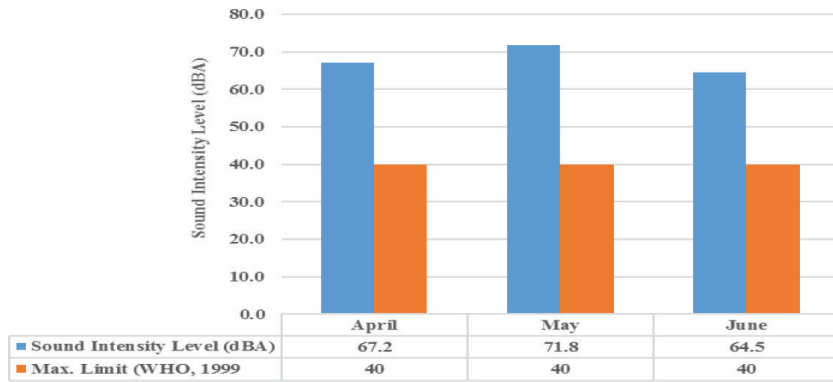
### **3.2 Acoustic quality in hospital wards**

#### *3.2.1 Acoustic quality in Specialist Hospital (NE-SW orientation)*

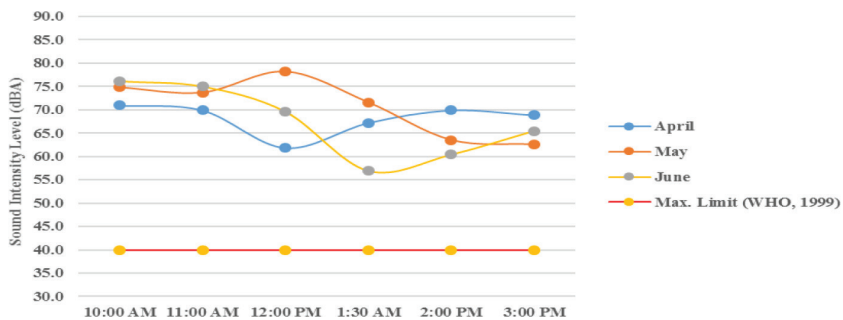
The measurement of background noise level within the hospital wards were carried out between the hours of 10.00 am and 3.00 pm. This have excluded the influence of sound level due to the activities of visitors whose permitted visiting hours is between 3.30 pm and 5.00 pm. The mean sound intensity levels in the Specialist Hospital is highest in May and lowest in June which range between 65.5 and 71.8 dBA. The mean difference in sound intensity level between May and June is higher than the mean difference between April and May. The mean sound intensity levels in the Specialist Hospital is presented in **Figure 20**. The variations in sound intensity levels tend to reduce in May and June while increasing in April from 12.00 noon to 2.00 pm as shown in **Figure 21**. The highest sound intensity level of about 78.2 dBA was recorded at 12.00 noon in May and the minimum of 56.9 dBA was recorded at 1.30 pm in June. The variation in sound intensity level within the period of monitoring was affected mainly by the noise level resulting from the number of visitors found within the ward buildings.

#### *3.2.2 Acoustic quality in Teaching Hospital (NW-SE orientation)*

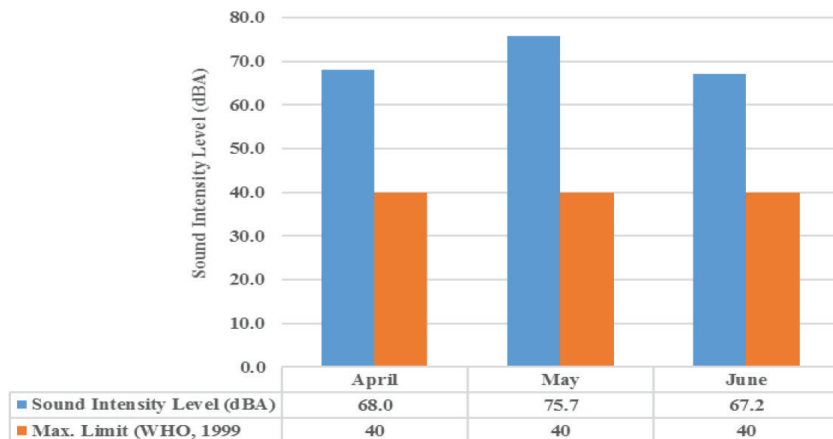
The mean difference in sound intensity level measured within the Teaching Hospital as shown in **Figure 22** is 8.6 dBA. Just like the Specialist Hospital, the highest sound intensity level was recorded in May and the lowest in June. The sound intensity level as measured within 2 hours were higher in May but lower in June.



**Figure 20.**  
 Mean sound intensity level in Specialist Hospital wards.

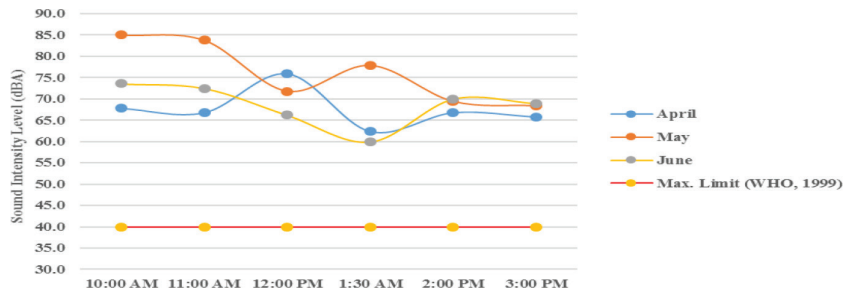


**Figure 21.**  
 Variation in sound intensity level in Specialist Hospital wards.



**Figure 22.**  
 Mean sound intensity level in Teaching Hospital wards.

The highest sound level was recorded at 10.00 am (85.1 dBA) in May while the lowest was recorded at 1.00 pm in June. There was no particular trend in the monthly variations of sound intensity level, as the sound level increased and decreased alternately in April but, reversed is the case in May. However in June, the sound intensity level decreased from 73.6 dBA at 10.00 am to 59.9 dBA at 1.00 pm. But there was an increase also to 70.0 dBA at 2.00 pm (**Figure 23**).



**Figure 23.**  
Variation in sound intensity level in Teaching Hospital wards.

### 3.2.3 Acoustic quality variations by hospital ward buildings

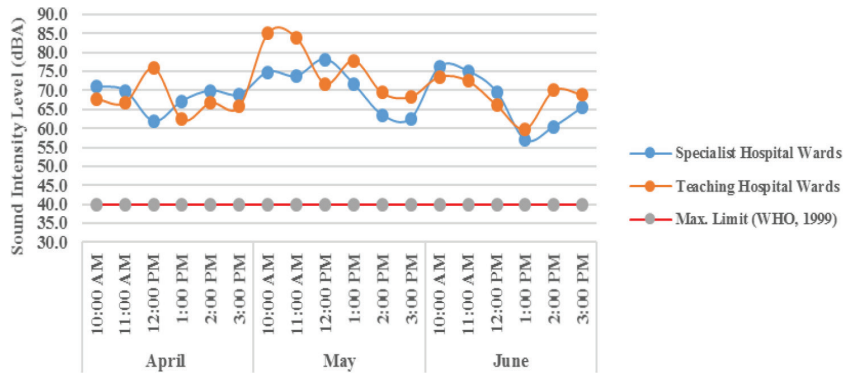
Acoustic quality is another important element that needs proper consideration in the design of hospital wards environment. Apart from the fact that it affects sleep, it also contribute significantly to patient's healing process. The world health organisation [31] have defined an acceptable maximum limit of sound intensity level range of 40 dBA. **Figure 24** shows the monthly variations in sound intensity levels in the two case study hospitals. The level of variations of sound intensity with time almost took the same pattern. The mean differences in sound intensity levels recorded ranged between 8.1 and 18.6 dBA in the Specialist Hospital, and 12.6 and 14.4 dBA in the Teaching Hospital. Both the minimum and maximum mean differences in sound intensity level were recorded in Specialist Hospital wards. This is an indication that, there was a wider variation in the sound intensity levels as measured in the Specialist Hospital wards than it was in Teaching Hospital wards. The highest sound intensity level (83.8 dBA) was recorded in the Teaching Hospital at 11.00 am in May while, the lowest (56.9 dBA) was recorded in the Specialist Hospital wards also at 1.00 pm but in June.

The variation in sound intensity levels is smaller in the Specialist Hospital wards with SD = 6.88 while the variation is more in the Teaching Hospital with SD = 7.21 (**Table 5**). The sound intensity level is highest in the Specialist Hospital (71.6 dBA) whose background noise is also influenced by vehicular traffic flow aside noise created by staff and visitors activities within the ward buildings. The location of the Specialist Hospital ward buildings are adjacent to a major road within the city centre with high vehicular traffic, while the locations of the Teaching Hospital is away from vehicular disturbances as the only is the vehicular access leading to the hospital.

The variations in sound intensity level in both hospitals ward buildings almost followed the same trend as seen in **Figure 24**. The average variation in sound intensity level is higher in the Teaching Hospital with a standard deviation of about 0.4 greater than the standard deviation for the Specialist Hospital. **Table 5** shows the mean sound intensity levels recorded in each hospital wards within the period of measurement. The sound intensity level can be said to be relatively the same in both two hospitals within the 3 months measurement periods having a maximum difference in intensity level of less than 4 dBA. The indoor sound levels in the hospitals are all above 40 dBA which is higher than the acceptable range of 30–40 dBA [31]. The highest sound intensity level for each of the hospitals is recorded in May which is slightly above 70 dBA.

A background noise level of up to 35 dBA is considered by the World Health Organisation (WHO) as acceptable in patient's wards during the day, and a sound level of not greater than 40 dBA at day and night peak to allow for patients' rest. Measures towards reducing background noise into the hospital wards is required





**Figure 24.** Monthly sound intensity level variation in the hospital ward buildings.

in both case study hospitals as sound intensity levels recorded within the period of measurement ranged from 56 to 85.1 dBA. This will go a long way in mitigating such impact as sleep loss and emotional exhaustion that could hamper the healing processes. The background noise affecting the Specialist Hospital wards might have been influenced also by vehicular traffic due to the location of the hospital in an area within the city centre, bounded by major roads. Other sources of sound that is typical includes; patients’ reaction to their health situation through groaning or crying, medical equipment and patient’s interaction with their caregivers. One major way of reducing such sound effect is by masking, which is beyond the control of the design team. The use of sound absorptive ceiling tiles having minimum NRC of between 0.90 and 0.95 [39] can be implemented in achieving high acoustics benefits in the patient wards. Where the acoustic condition of hospital wards is improved through design and selection of material components, it will improve on the patient healing process and reduce length of stay.

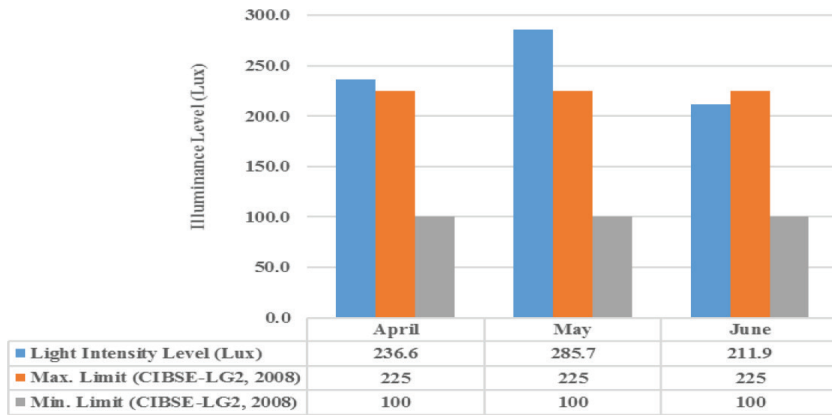
### 3.3 Lighting quality in hospital wards

#### 3.3.1 Lighting quality in Specialist Hospital (NE-SW orientation)

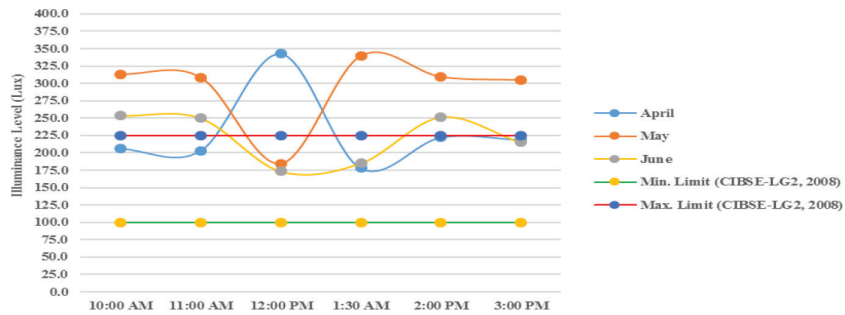
The mean illuminance level recorded in the Specialist Hospital fell above 100 lux as the minimum recommended for hospital wards [33, 34]. The mean difference in illuminance level between different periods of measurement ranged between 21.4 and 70.5 lux. **Figure 25** shows the mean illuminance levels recorded in the Specialist Hospital. The variation in light intensity level with time showed an increased in April but a decrease in both May and June from 12.00 am to 2.00 pm. Reverse is the case as from 2.00 pm to 12.30 pm (**Figure 26**). Higher illuminance level was recorded in April between the hours of 12.00 noon and 1.00 pm.

#### 3.3.2 Lighting quality in Teaching Hospital (NW-SE orientation)

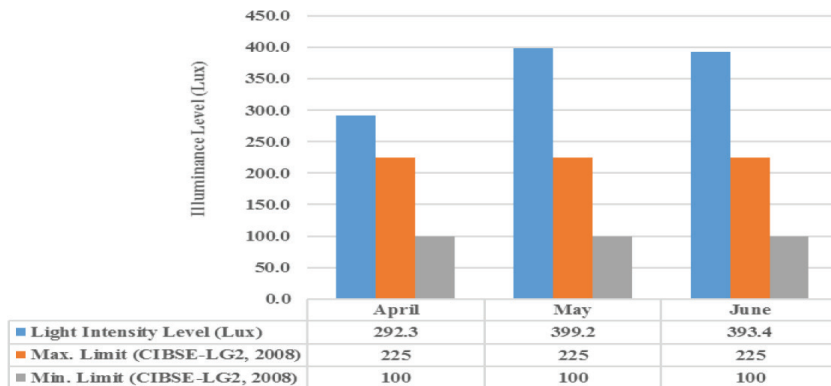
The mean illuminance levels recorded lower in May which was less than 200 lux. The mean illuminance levels in May and June are near equal in intensity and fall within the range of 184.6–339.6 lux. There was a mean difference in intensity level of about 101 lux between both May and June, and April. **Figure 27** shows the mean intensity level recorded for each measurement period. As also shown in **Figure 28**, the periodic increase and decrease in illuminance level pattern is almost similar, however, the change is higher in April than in May and June.



**Figure 25.**  
Mean light intensity level in Specialist Hospital wards.



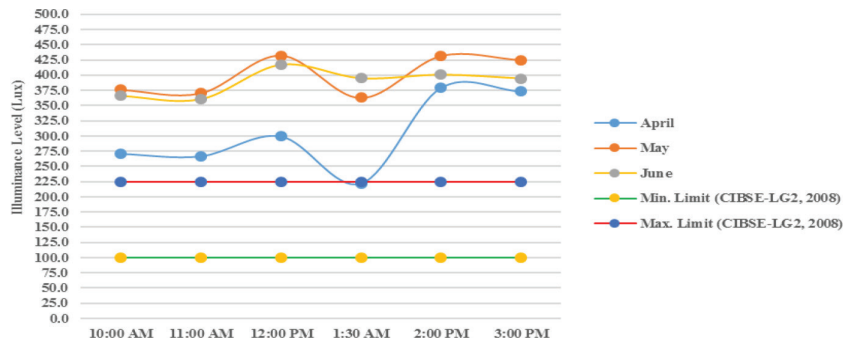
**Figure 26.**  
Variation in light intensity level in Specialist Hospital wards.



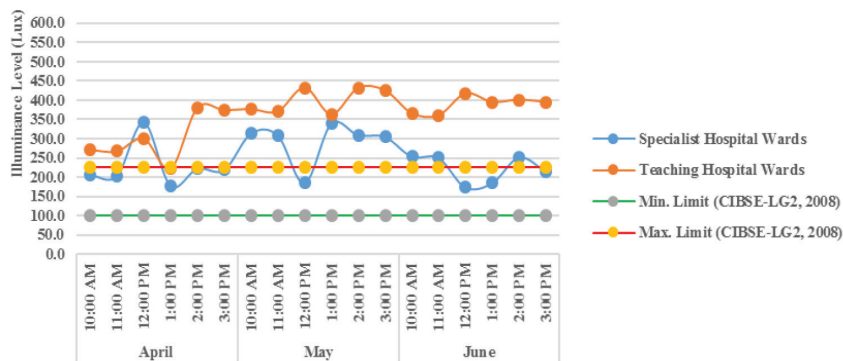
**Figure 27.**  
Mean light intensity level in Teaching Hospital wards.

### 3.3.3 Lighting quality variations by hospital ward buildings

The monthly variations in light intensity levels in the studied hospital buildings is shown in **Figure 29**. The illuminance levels recorded highest in April in the Specialist Hospital wards, while in May and June, it recorded highest in the Teaching Hospital. Generally, the lighting quality in the Specialist Hospital is poorer as compared with what was obtainable in the Teaching Hospital. The



**Figure 28.**  
 Variation in light intensity level in Teaching Hospital wards.



**Figure 29.**  
 Monthly light intensity level variation in the hospital ward buildings.

North-East and South-West window facing orientation of the Teaching Hospital allowed for optimum daylighting into the ward buildings. The orientation of the Specialist Hospital wards followed the North-West and South-East direction. Daylight penetration is only through one façade of the ward buildings in the Specialist Hospital where the light intensity level is influenced by sun path position.

The least light intensity level (173.6 lux) was recorded in the Teaching Hospital in the month of May which could have resulted from the effect of cloud cover at the time of measurement. The variation in the lighting quality with time in both hospital ward buildings can be said to be relatively equal as their differences in standard deviation is not more than 5.5. Their standard deviation values ranged between 62.1 and 67.5 whose difference cannot be said to be significant (Table 5).

The lighting intensity measured in both hospital ward buildings is an indication that the data were influenced by the variations in the sun direction. The light intensity in the Teaching Hospital wards was relatively higher because of the window size design which was quite large in size. The minimum average illuminance (292.3 lux) recorded in the Teaching Hospital wards was significantly higher than the acceptable limit of 225 lux recommended by CIBSE-LG2 [34]. These higher daylight illuminance level is a result of the hospital wards having window to wall ratio (WWR) of 55% which is even higher than the optimum (25%) recommended by Zain-Ahmed et al. [25] for passive design of windows for daylighting in the tropics.

### 3.4 Indoor air quality (IAQ) in hospital wards

#### 3.4.1 Indoor air quality (IAQ) in Specialist Hospital (NE-SW orientation)

The mean concentration level of CO<sub>2</sub> is higher in April as compared to the concentration levels in May and June (Figure 30). On the other hand, the CO concentration level is higher in June (Figure 31). The CO<sub>2</sub> concentration level which all fall within acceptable limits ranged between 439.3 and 608.0 ppm in April, between 399 and 442 ppm in May, and 393 and 455 ppm in June (Figure 32). Likewise, the CO concentration level ranged from 4 to 9 ppm in April, from 4 to 8 ppm in May and from 3 to 14.2 ppm in June. The CO concentration level for June as shown in Figure 33 indicated that only the recorded value at 1.00 pm fall within the acceptable limit that promotes occupants health and comfort.

#### 3.4.2 Indoor air quality (IAQ) in Teaching Hospital (NW-SE orientation)

The results of the measured CO<sub>2</sub> and CO concentration levels in the Teaching Hospital is shown in Figures 34 and 35. There was a small variation in the mean concentration levels of both CO<sub>2</sub> and CO in the Teaching Hospital, having a maximum mean difference of 30.3 and 2.3 ppm respectively. The concentration level of CO<sub>2</sub> ranged between 406.8 and 481.0 ppm in April, 410.0 and 492.0 ppm in May, and 394.0 and 457.8 ppm in June (Figure 36). There was quite stability in the concentration levels of CO<sub>2</sub> which were lower than the maximum acceptable range.

CO level ranged from 2 to 5 ppm, 3–10.2 ppm, and 3–6 ppm in April, May and June respectively as shown in Figure 37. The highest CO concentration level of 10 ppm was recorded at 10.00 am in May while the lowest concentration level of 2 ppm was recorded between 12.00 noon and 1.00 pm in April.

#### 3.4.3 Indoor air quality (IAQ) variation by hospital ward buildings

Figures 38 and 39 shows the variations in IAQ in the hospital buildings. There was no much variation in CO<sub>2</sub> concentration levels in the hospital buildings within the measurement periods. The CO<sub>2</sub> concentration levels in the Specialist Hospital wards ranged between 393 and 608 ppm, while in the Teaching Hospital wards ranged between 394.0 and 492.3 ppm. In April, the mean CO<sub>2</sub> concentration

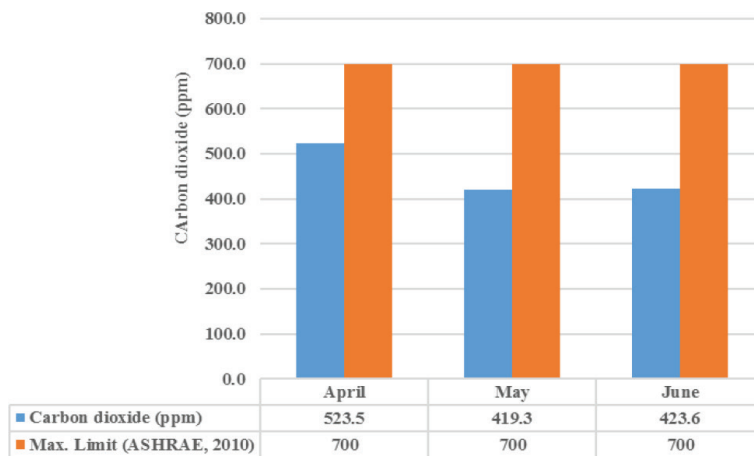
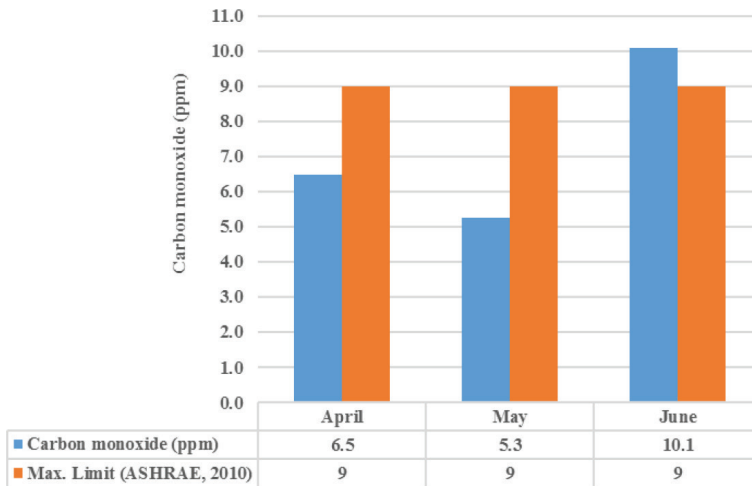
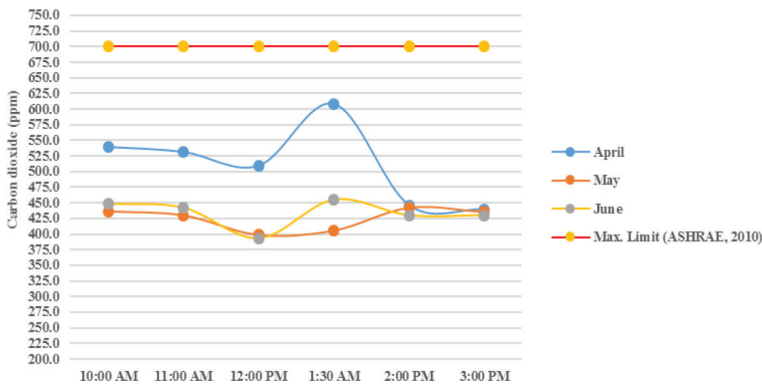


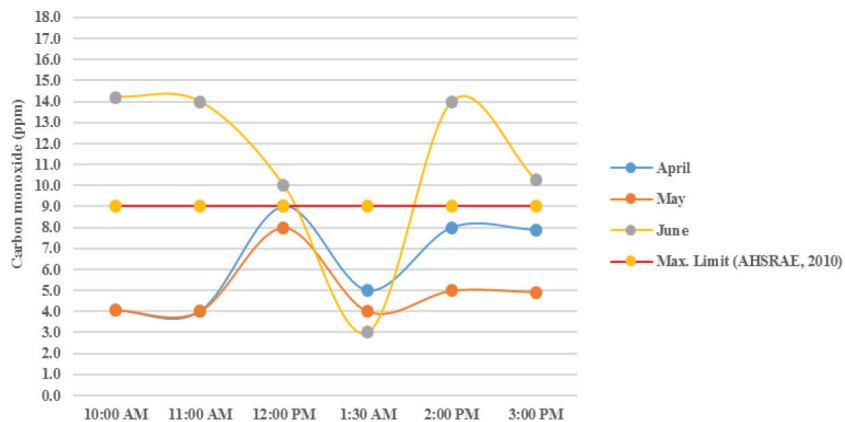
Figure 30. Mean carbon dioxide concentration level in Specialist Hospital wards.



**Figure 31.**  
 Mean carbon monoxide concentration level in Specialist Hospital wards.



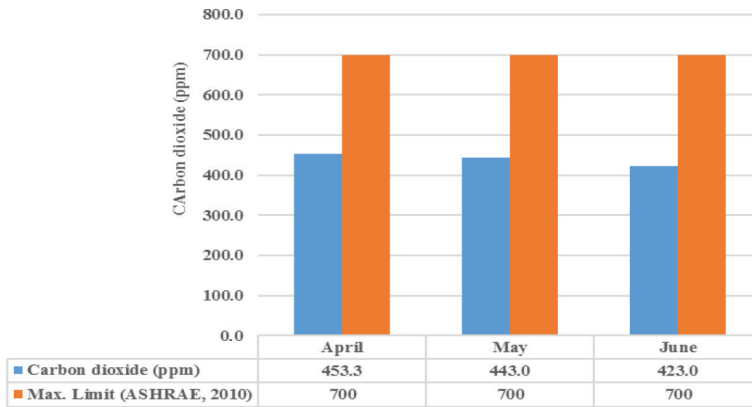
**Figure 32.**  
 Variation in carbon dioxide level in Specialist Hospital wards.



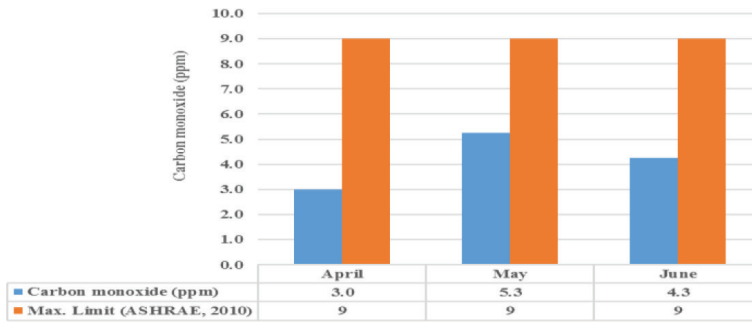
**Figure 33.**  
 Variation in carbon monoxide level in Specialist Hospital wards.

level was 408 ppm, 523.5 ppm, and 453.3 ppm for the Specialist and Teaching Hospitals respectively. The highest level of concentration of CO<sub>2</sub> (608 ppm) was recorded in April in the Specialist Hospital and the lowest concentration level

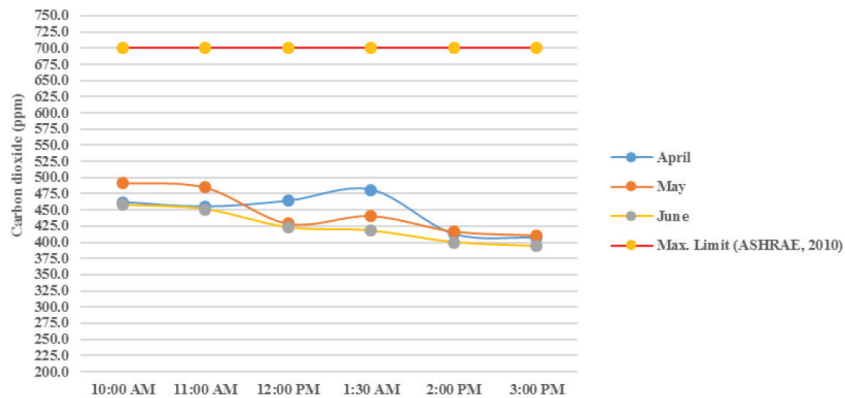




**Figure 34.**  
Mean carbon dioxide concentration level in Teaching Hospital wards.



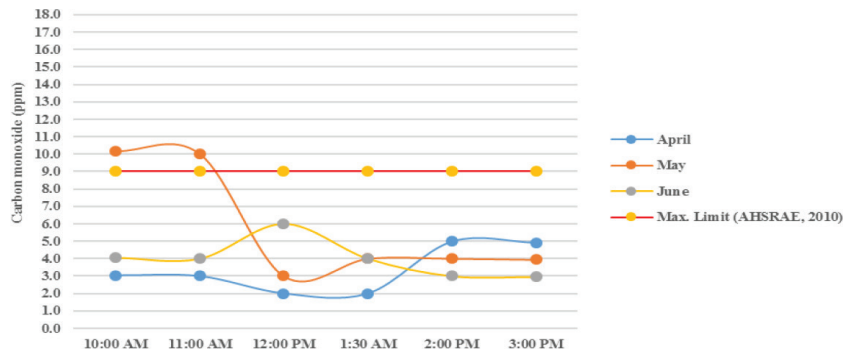
**Figure 35.**  
Mean carbon monoxide concentration level in Teaching Hospital wards.



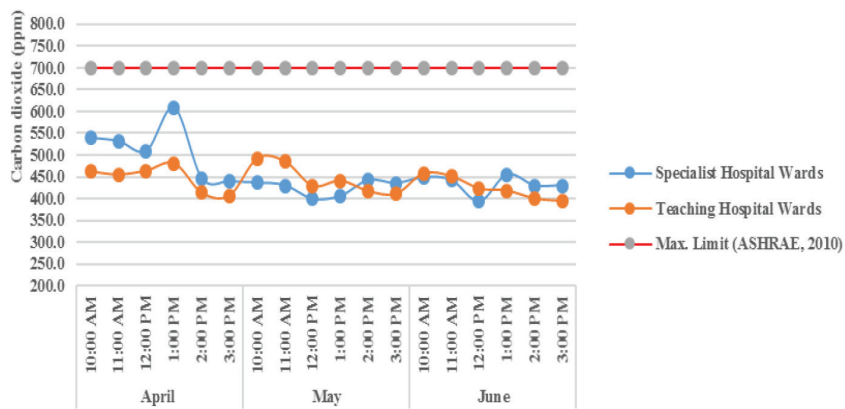
**Figure 36.**  
Variation in carbon dioxide level in Teaching Hospital wards.

(393 ppm) was also recorded in the Specialist Hospital but in June as seen in **Figure 38**. On a general note, the mean concentration levels of CO<sub>2</sub> in both case study hospital wards fall below the maximum recommended limit of 700 ppm [32, 40] within the periods of measurement.

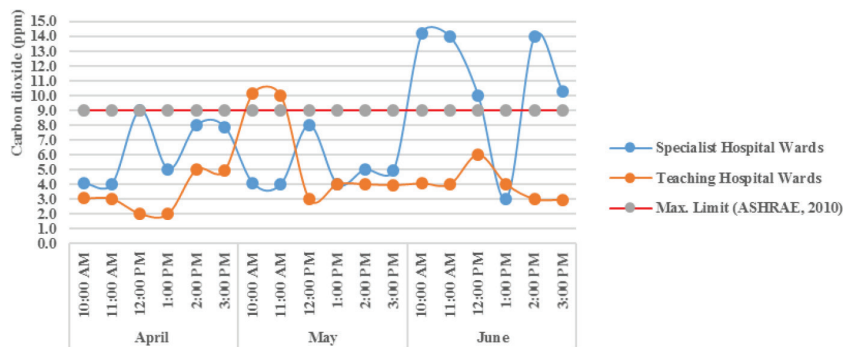
The IAQ in the Teaching Hospital wards is better compared to the Specialist Hospital wards because of its design and age which are contributing factors to the concentration levels of air pollutants. **Figure 39** shows the variations in CO levels



**Figure 37.**  
 Variation in carbon monoxide level in Teaching Hospital wards.



**Figure 38.**  
 Monthly carbon dioxide concentration level variation in the hospital ward buildings.



**Figure 39.**  
 Monthly carbon monoxide concentration level variation in the hospital ward buildings.

for both hospitals. The maximum recorded CO concentration level for the Specialist Hospital is 14.2 and 10.2 ppm in the Teaching Hospital. All the maximum recorded CO concentration levels are greater than the acceptable limit. The minimum CO concentration level was recorded in the Teaching Hospital. There was generally higher concentration of CO level in June than in April as recorded in both the two case study hospitals. This could be related to increase in humidity as a result of increased amount of rainfall.

The IAQ can be said to be much better in the Teaching Hospital whose design and configuration allowed for free flow of ventilation in and out of the hospital wards. The design of the Specialist Hospital provided no cross ventilation within the ward buildings which could have been the result of the higher level of CO concentration recorded. CO<sub>2</sub> concentration level based on mean estimates within the period of measurement is highest in the Specialist Hospital wards, having a difference in concentration as compared to the Teaching Hospital wards greater than 40 ppm respectively.

#### **4. Discussions**

The two hospital ward buildings are naturally ventilated through façade fenestrations with the exception of the Teaching Hospital whose ward buildings have supplemental split-level air-conditioning system. However, this air-conditioning system was not in operation within the periods of monitoring and data collection. The design of windows in the Teaching Hospital allows for proper cross ventilation and air circulation while the Specialist Hospital building design lacks cross ventilation. Based on the design guidelines and standards, the temperatures recorded for the two case study hospitals exceeded the recommended range of 23–26°C [28, 41], though, a temperature range of between 27 and 37°C can provide for occupants' comfort in a building based on human physiological adaptive mechanism [29]. On the contrary, BS EN 15251 [28] provided an acceptable temperature range of 24–33°C for adaptive comfort. The above findings suggests that the increase in the thermal level especially in the Teaching Hospital wards was a result of heat gains from sunlight. Both study hospital wards have no external shading to reduce the effect of heat gain through solar radiation.

The sound intensity level measured in the ward buildings of the two case study hospitals were all above 40 dBA which is above recommended ranges by the world health organisation WHO [31]. The sound intensity levels were high in the month of May than in April and June. Greater variations in sound level was recorded more in the Teaching Hospital wards which recorded higher sound intensity in each of the ward buildings than the Specialist Hospital wards. This might be as a result of more nursing activities related to patient care in the Teaching Hospital than the Specialist Hospital. Furthermore, both staff and caregiver activities in and around the ward buildings in the Teaching Hospital is higher. Sound has been ascertained to have much impact on work performance of building occupants [42] while in hospital environment, it can cause irritation, discomfort and retards patient's healing process [43]. Therefore, acoustic quality should be given much consideration in the design of buildings towards promoting occupants' performance and wellbeing.

One of the basic design indicators for green architecture in creating lighting quality in buildings is daylighting [44]. Natural daylight from the sun when effectively harnessed into a building design can provide a better environment for living and work. Daylighting quality in a building can be influenced by fenestration design, sun path, cloud cover and adjacent physical environmental elements. Building orientation also plays an important role in determining the amount of daylighting in a building as seen from this study. The mean daylight intensity in the Teaching Hospital wards is more than the intensity recorded in the Specialist Hospital wards. The Teaching Hospital ward buildings have their facades and fenestration facing North-east and South-west mostly within the Sun path position. On the other hand, the Specialist Hospital orientation is on North-west and South-east facing where its exposure to the Sun path direction is limited. The Specialist Hospital therefore, has shown the worst lighting quality within the indoor spaces. The mean illuminance

level in the Teaching Hospital wards ranged from 292.2 to 397.4 lux and are greater than the 150 lux as the minimum lighting required for hospital wards [33, 45].

For proper medication administration to patients and staff record keeping, it is required that the minimum light intensity level in a hospital ward building should range between 100 and 300 lux [46]. The daily variations in light intensity level in the Teaching Hospital is relatively smaller compared to the variations in the Specialist Hospital. The average light intensity level recorded in the two case study hospitals is an indication that, the application of daylighting features into the design of hospital ward buildings would lead to energy savings and environmental sustainability in healthcare facilities. The results of the measured illuminance level in the hospital wards have shown that ward building orientations have substantial influence in facilitating the use of natural daylighting in hospital buildings. The Teaching Hospital wards with Northwest-Southeast orientation recorded higher lighting intensity throughout the period of measurement than the illuminance level recorded in the Specialist Hospital wards with Northeast-Southwest orientation. However, the lack of shading on the windows and façade walls could pose some lighting challenges to the patients. Nevertheless, these challenges are not within the context of this study.

The maximum allowable threshold limit for CO<sub>2</sub> within an indoor environment given by different international standards is 700 ppm [28, 35, 47]. The concentration level of CO<sub>2</sub> in the ward buildings of the two hospital ward buildings was below 700 ppm within the period of measurement. The highest concentration of CO<sub>2</sub> was recorded in April in all two hospital wards with the Specialist Hospital having the highest. The month of April also recorded the highest temperature in both case study hospitals which indicated that, there is a relationship between CO<sub>2</sub> concentration and temperature. Consequently, there is a tendency of having higher concentration of CO<sub>2</sub> in a very hot environment. The carbon monoxide (CO) concentration level in the Teaching Hospital was lower than in the Specialist. The level of natural ventilation in the Teaching Hospital with wider window openings is higher which reduces the concentration of CO in the building spaces. On the whole, both hospitals have their CO concentration level within the 3 months period below the maximum threshold limit of 9 ppm.

From the measurements of the IEQ parameters conditions in the selected hospital ward buildings, it is evident that the quality of the indoor environment differs substantially depending on the ward design configuration and orientation, and also the outdoor weather condition. The indoor environment in the hospital wards had different thermal and lighting conditions because of variations in orientations, window sizes and air inlet/outlet. Heat gains from radiation rays of sunlight vary with the building orientation, also affected the indoor thermal quality in each of the hospital ward buildings within the period of measurements. The Teaching Hospital wards whose orientation (NW-SE) allows the fenestration façade to fall within the sun path, maximised it for daylighting within the wards. However, the wards attract more heat through their wide windows as compared to the Specialist Hospital wards. This results into increased indoor air temperature which is however, minimised through the influence of natural cross ventilation provided in the Teaching Hospital wards. The Specialist Hospital on the hand, with closed-plan design configuration are not provided with proper natural ventilation through passive means to allow for free air flow and exchange. This contributed to the higher level of temperatures recorded especially in April, which were above the acceptable limits as specified by BS 15251 [28]. This also contributed to the higher levels of Carbon dioxide (CO<sub>2</sub>) and Carbon monoxide (CO) concentration which affected the indoor air quality (IAQ). This result is in line with a study carried out by Altomonte et al. [48], which revealed that occupants in open-plan spatial layout buildings have a significantly higher level of satisfaction with their IEQ.

## 5. Conclusion

Indoor environmental quality (IEQ) problems in buildings are a result of certain decisions made during the building design processes and construction. As much as some of these problems can be solved through corrective measures such as retrofitting, it is essential to prevent and correct such deficiency at the building design stage, which is more economical and cost-effective. The outcome of this study would therefore serve as feedback to architects in the design process leading to improvement in sustainable hospital ward design.

The essence of a hospital as a healthcare facility is to provide an environment that promotes healing rather than the one that hinders it. The design and maintenance of hospital ward buildings should be such that the main building occupants (patients) would feel homely throughout their period of stay within the hospital environment. The objective measurement of IEQ in the selected hospital wards can be said to be substantially different according to the ward buildings orientation and design configurations. The hospital wards having Northwest-Southeast orientation and open-plan configuration had a better IEQ as seen from the results. The Teaching Hospital wards as expected has better IEQ since its design, configuration and orientation is more environmentally friendly as compared to the Specialist Hospital. The internal wards layout in the Specialist Hospital may have contributed to ventilation problem, which affected the thermal and air quality considerably. Hospital ward building orientation and design can therefore be harness towards reducing heat gain and providing natural ventilation, which can also reduce energy demand for cooling especially in tropical Nigeria. In conclusion, the design of hospital wards for improved IEQ conditions should be such that proper attention is given to the orientation, floor plan configuration and window design for natural ventilation and lighting.

### Abbreviations and symbols

ASHRAE	American Society of Heating, Refrigeration, and Air-conditioning Engineers
BS	British Standards
BREEAM	British Research Establishment Environmental Assessment Method
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CIBSE	The Chartered Institution of Building Services Engineers
dB	decibel
GBCA	Green Building Corporation of Australia
IAQ	indoor air quality
IEQ	indoor environmental quality
LEED	leadership in energy and environmental design
Lux	illuminance
Min	minimum
Max	maximum
NE-SW	Northeast-Southwest
NRC	noise reduction coefficient
NW-SE	Northwest-Southeast
PPM	parts per million
SD	standard deviation
WHO	World Health Organisation

WWR	window wall ratio
°C	degree Celsius
%	percentage

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