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ASSESSMENT OF INDOOR AIR QUALITY IN HOSTEL ACCOMMODATION IN FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGERIA.

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Abstract
Indoor air pollution is placed among the top five environmental public health risks that cause morbidity and mortality globally. The majority of people spend more than 90% of their time indoors. Poor indoor air quality (IAQ) can cause varieties of adverse health effects on people. More also, the recent pandemic has necessitated the need for good indoor environmental quality. Students hostel have been found to be living overcrowded due to the limited accommodation facilities in tertiary institution across Nigeria. This therefore requires urgent need to have an empirical evidence on indoor air quality. Hence this paper is focused at assessing the impact of indoor air quality on the health status of the occupants in the hostel spaces, with a hypothesis placed that occupants' behaviour is the primary mechanism influencing indoor particulate concentrations. The monitor areas within the hostel were determined, an assessment of the monitor areas was conducted to determine the prevalent pollutants in the indoor spaces. Due to the need of empirical evidence, a quantitative research approach was used where a questionnaire survey was conducted and air samples were tested for pollutants using the air visual node. It was discovered from the monitor areas, the presence of biological pollutants such as mold and mildew, chemical pollutants such as CO, CO_2 and Particulate Matter ($PM_{2.5}$ and PM_{10}). Study rooms where students cook in their spaces had more quantity of CO_2. The highest concentrations of pollutants were recorded in spaces with more number of occupants as this influenced occupants behaviour. The impact of the indoor air on the occupants' health was shown through reported cases of respiratory symptoms and diseases. In conclusion, it was established that number of occupants and occupants' behaviour influences indoor air quality and particulate concentrations of air contaminants.

Keywords: *Indoor Environmental Quality (IEQ), Indoor Air Quality (IAQ), Occupants' health,*

INTRODUCTION
The National Health and Medical Research Council (NHMRC) Australia, defines indoor air as the air within a building occupied for at least one hour by people of varying states of health. This space can include the office, classroom, hostels, shopping centres,

hospitals and homes. The air within these spaces can be polluted. The presence of harmful substances such as gases, particulates or biological molecules in the Earth's atmosphere is known as air pollution (Loomis *et al.,* 2013). Human exposure to air pollution has serious implications for health: Short term exposure may exacerbate asthma and be responsible for hospital admissions (Zheng *et al.,* 2015), whilst long term exposure to ambient air pollution is repeatedly associated with a higher incidence of cardiovascular and respiratory diseases (Pope *et al.,* 2011; Atkinson et al., 2016), birth defects (Padula *et al.,* 2013) and neuro-degenerative disorders (Moulton and Yang, 2012).

Indoor air pollution is placed among the top five environmental public health risks that cause morbidity and mortality globally. The majority of people spend more than 90% of their time in indoor environments (Abraham and Li, 2016; Amaotey *et al.,* 2018), and health problems and diseases associated with poor indoor air quality (IAQ) can cause a variety of adverse health effects to them (Amaotey *et al.,* 2020; Koivisto *et al.,* 2019). The time spent indoors recently increased significantly in year 2020 due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic when people are advised to 'stay home stay safe' to protect health workers (Brittain *et al*., 2020; Kumar and Morawska, 2019).

Clean air should be everyone's right just as clean water (UNEP, 2019). Unfortunately, indoor air quality is often compromised because of air pollution, mould and many other factors (Marjo, 2021). Oxygen a component of air is needed for man to breathe and for the total running of his system and when polluted, it creates discomfort to man and can cause respiratory diseases and an eventual death. Indoor air quality is a factor for humans to live comfortably in any enclosed space and it is affected by factors which ranges from the factors in the enclosed space even to the factors of the environment.

Having stayed five (5) years in the male hostel, it was observed the poor state of indoor air quality arising from a load of factors which include; overcrowding of space, air pollutants generated from cooking indoors as well as the poorly maintained general toilets, improper waste disposal systems especially for rooms in the upper floors, clogged drainages in the courtyards, poorly landscaped outdoor environment which has generated air pollutants within the environment, polluting the air coming into the indoor environment. This generated a concern and need to assess the indoor air quality of the existing hostels generally. This paper therefore aims at assessing the impact of indoor air quality on the health status of the occupants in the hostel spaces.

LITERATURE REVIEW

Definition of Hostel

Kolawole and Boluwatife, (2016), identifies the hostel as an essential aspect of the tertiary institution as its availability is an attraction to a large number of students from different backgrounds to study in the tertiary institution. Nimako and Bondinuba, (2013), further stated that hostels in tertiary institutions are so important that its adequacy is highly needed in any tertiary institution to enable students make most use of the educational opportunity. This agrees with what (Muhammad *et al.,* 2014) said about hostel. Gichere et al. (2019), defines hostel as a place that a student lives while studying a particular programme at an institution which comprises of the immediate environment, health, economic, sporting and social activities that are sympathetic to academic work. Dabo *et al.* (2013) categorized students' accommodation into four, these include; Traditional on campus accommodation (TOC), Off campuses leased (OCL), On-campus school managed (OSM) and Off-campus private (OP). The type of hostel that is adopted in the Federal University of Technology (FUT) Minna is the traditional on campus accommodation. Irrespective of the type of accommodation adopted, the living conditions of the spaces must be conducive.

Environmental Health

The first line of thought when the phrase environmental health is mentioned is towards hygiene and sanitation. Lukkumanul (2019), explained vividly the term environmental health been broader than hygiene and sanitation as it comprises of hygiene, sanitation and every other environmental factor that influences health. The World Health Organization (WHO) defined environmental health as all the physical, chemical and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health. There exists both indoor environment and outdoor environment (Darçin and Balanli, 2020)

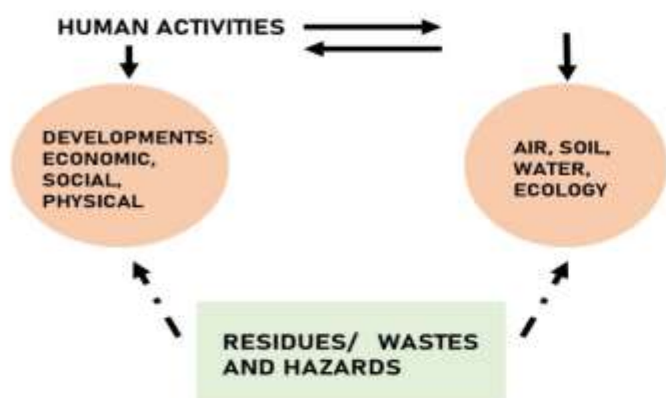

Figure 2.1: Human–environment interaction model. Source: (Lukkumanul, 2019)

The relationship between human activities and the ambient environment as shown in figure 2.1 above, iterates the need for the resources from the environment for development which generates wastes, residues and hazards (Lukkumanul, 2019). These hazards affect humans in various forms including pollution. The only way pollution affects any human is when an exposure to the pollutants occurs. These exposures exist at both the indoor and outdoor environments (Lauren *et al.,* 2020).

Air pollution

The presence of harmful substances such as gases, particulates or biological molecules in the Earth's atmosphere is known as air pollution (Loomis *et al.,* 2013). Human exposure to air pollution has serious implications for health: Short term exposure may exacerbate asthma and be responsible for hospital admissions (Zheng *et al.,* 2015). These exposures as earlier established by Lauren *et al.* (2020) is experienced at the outdoor and indoor level. For the purpose of this research, indoor exposure is critically examined. However, there exists a connection between the indoor air and outdoor air as the flow of air comes from outdoor to indoor as shown in figure 2.2.

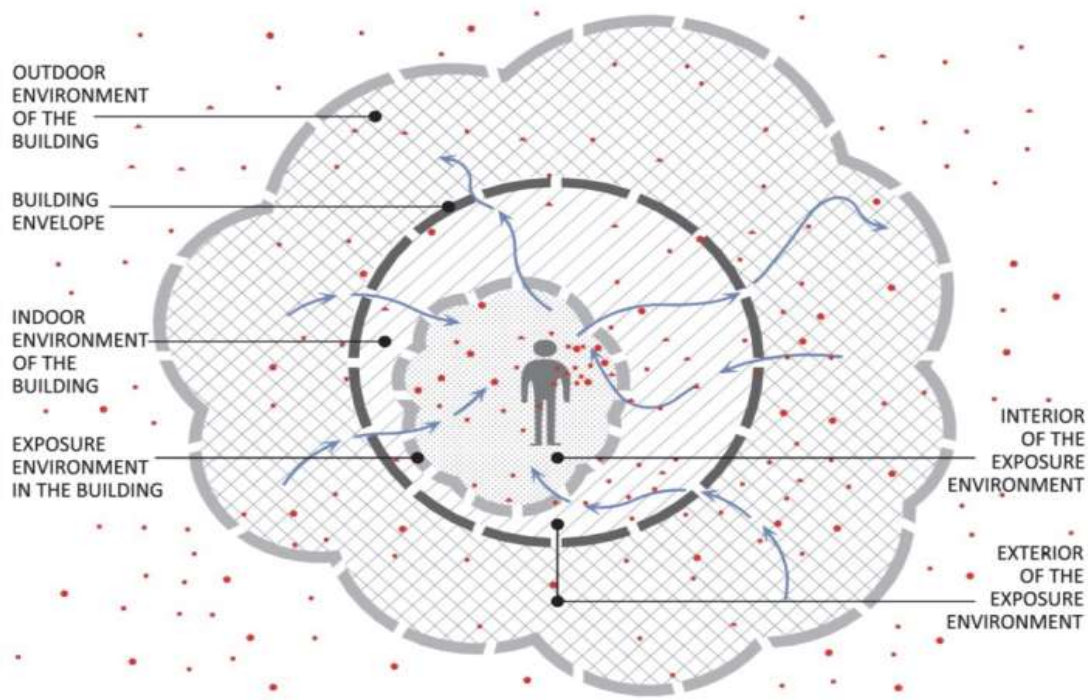

Figure 2.2: Building and its environments. Source: (Darçin and Balanli, 2020)

Indoor air pollution from outdoor sources may occur due to infiltration of pollution from anthropogenic activities, such as vehicular traffic, a common source of particulate matter (PM) and nitrogen dioxide (NO_2) (COMEAP, 2018), or natural sources, such as radon from radioactive decay in the ground (Turk *et al.,* 1990). The airtightness of the dwelling, the number of external façades and their exposure to wind, and window-opening behaviour by the occupants will impact the amount of pollution that passively enters (Hänninen *et al.,* 2003).

Indoor Environmental Quality (IEQ)

Indoor environmental quality (IEQ) as one of the features of green buildings and the sustainable environment has been drawing much attention, due to its high impact on the behaviour of the building users (Alfa and Öztürk, 2019). A growing body of knowledge recognizes the need for satisfactory indoor environmental quality (IEQ) in the built environment. According to Zuhaib *et al.* (2018) and Tang *et al.* (2020), acceptable IEQ is a vital factor in achieving a productive and healthy building environment, reduces sick building syndrome (SBS), and minimizes short-term absence.

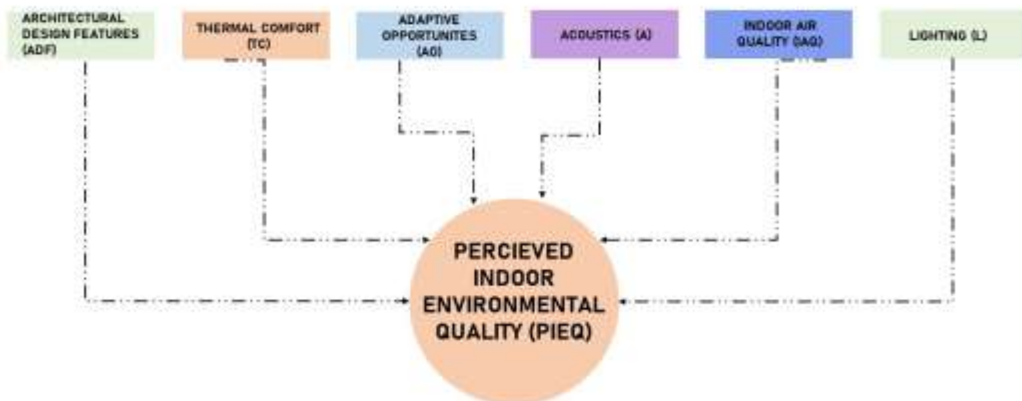

Figure 2.3: Various aspects of IEQ. Source: (Alfa and Öztürk, 2019)

The university's hall of residence is one of the most important facilities provided on any conventional university campus to serve students' housing needs (Valiyappurakkal, 2021). The hostel facilities accommodate students who would daily spend an average of 8–12 hours within the facility outside other learning facilities (Busch-Geertsema & Sahlin, 2007). A hostel facility that is well designed, must put into consideration the (IEQ) of the space. Figure 2.3 illustrates the various aspects of indoor environmental quality. For the purpose of this research, the aspect of indoor air quality will be further explained.

Indoor Air Quality (IAQ)

Buildings are becoming increasingly airtight in developed countries (Chan *et al.,* 2005), under moves designed to provide thermal comfort and to reduce energy consumption. Indoor environments are fundamental environmental factors capable of impacting health (Gocgeldi *et al.,* 2011). The quality of air in homes, offices, schools, day care centres, public buildings, health care facilities and other private and public buildings where people spend over 80% (Hoskins, 2007) of their time daily is crucial for healthy living and people's well-being (WHO, 2010). Air quality of indoor environments is one of the main factors affecting the health, well-being and productivity of people (Morakinyo *et al.,* 2015).

Poor indoor air quality has been linked with a wide range of effects on respiratory health such as asthma development and exacerbation, respiratory infections and upper respiratory tract symptoms. Emmanuel (2006), has reported that over 1.6 million lives have been lost with over 38.5 million disabled persons in the year 2000 due to IAQ problems. Hostels are part of public buildings in Nigeria, and so far, there are few studies that focused on the air quality in this complex environment. Recently, Nigeria Government has recognized the potential risk and problems related to indoor air pollution in public buildings and it's striving to establish IAQ guidelines for different types of indoor environments (Nnadozie *et al.,* 2017).

Factors affecting indoor air quality (IAQ) in buildings

The quality of indoor air can either be good or bad due to certain factors that play in the indoor and outdoor environment. However the quality of air in the enclosed space, there is an impact on the occupants of that space, either positive or negative impacts.

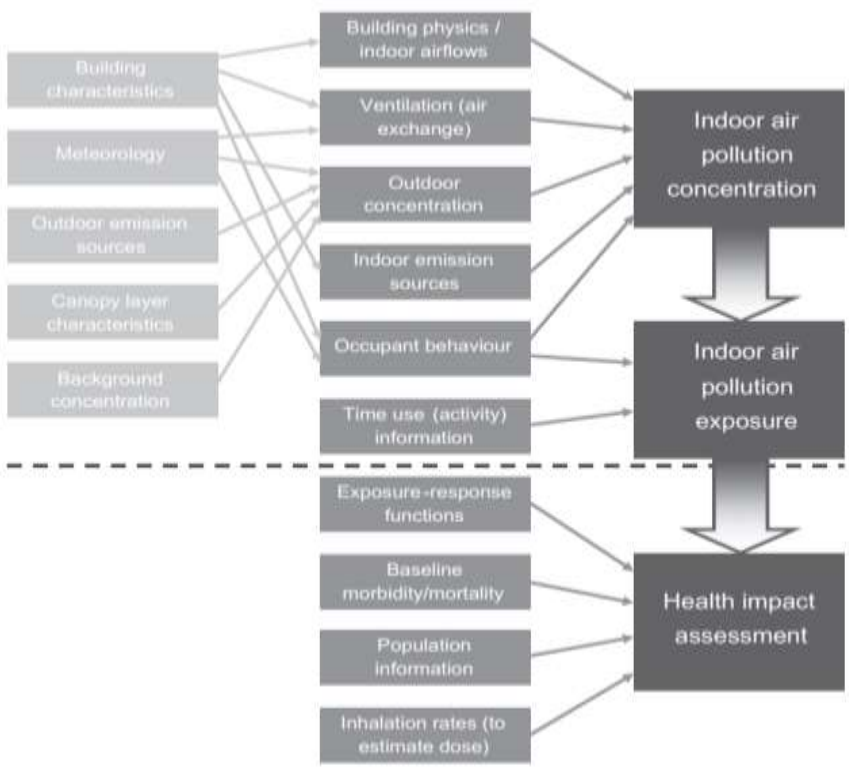

Figure 2.4: Factors affecting indoor air pollution concentrations and exposures (IAQ), and inputs to health impact assessment. Source: (Milner *et al.,* 2011).

Deductions from figure 2.4 categorizes factors affecting indoor air quality; these range from the factors in the enclosed spaces even to the factors of the environment. Enclosed factors include; space configuration and requirement, number of occupants in the space, ventilation, users' behavior, materials used and pollution level. The environmental factor includes; the building orientation, the outdoor air pollution level, vegetation and landscape design, air flow.

Building Characteristics and IAQ

Various building characteristics affect indoor air quality. The ones considered include space configuration, building materials, and ventilation. Ventilation is key factor as it affects the influx of air into the building and airflow dynamics. Ventilation are of various types namely cross ventilation, one-side ventilation and stack ventilation all of which are affected by the orientation of the building to the prevailing winds. According to Chand (1977), an angle between 90^o and 60^o to the face of the building is appropriate. Space configuration of the indoor space affects the quality of air as it relates to the space volume, layout and occupancy.

As the air pollutants emerge into the building, they disperse in the indoor air filling the volume of the closed space depending on their physical properties and air conditions to develop a certain level of concentration. Under proper circumstances, molecules of the pollutants in the gas / vapor state can homogeneously mix into indoor air (Kephalopoulos *et al.,* 2006) and reveal a constant concentration level throughout the space (Repace, 2007). Subsequently, the volume of the space is inversely proportional to concentration level of gas and vapor pollutants (Figure 2.5).

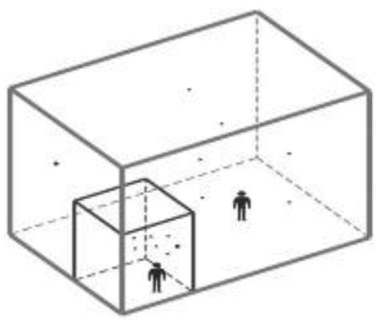

Figure 2.5: Relationship between Volume of the Space and Concentration Level. Source: (Darçin and Balanli, 2020)

Indoor air pollution and IAQ

The problems associated with the air we breathe indoors have become one of the greatest challenges we face in recent time (Ehsanul *et al.,* 2012). Air pollution in closed spaces of built environments is quite often a mixture of many different pollutants (Ferro and Hildemann, 2007) that may emerge from a vast number of sources and mostly prone to undergo, hard to predict transformations (Milner *et al.,* 2011). Hawaii's Pollution Prevention Information (HAPPI) stated that there are four major sources of indoor air pollution which are; combustion byproducts, such as smoke and carbon monoxide, building materials, including carpets, wood products, and paints, household products and chemicals, such as cleaning solvents, adhesives, and paint strippers and biological contaminants such as mildew, animal dander, and dust mites as shown in figure 2.3 below.

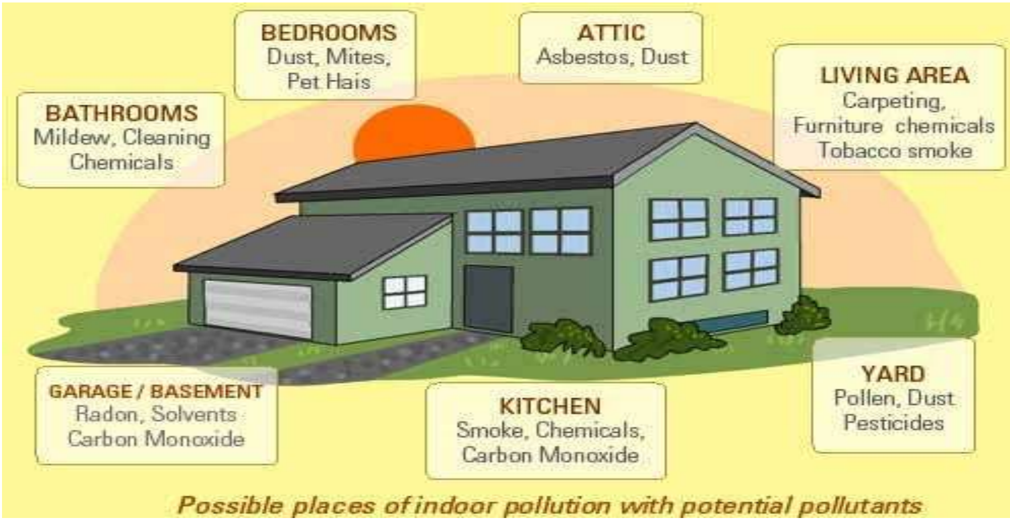

Figure 2.6: image showing common indoor pollutants and their sources. Source: Google images 2021

Occupants Behaviour and IAQ

Occupant behavior' is the primary mechanism determining indoor particulate concentrations. Various indoor human activities generate particulate matter. Human-building interactions, such as window opening behavior, change the number of outdoor particulate matter introduces to the building as seen in figure 2.7 (Chai *et al.,* 2022). The results of their research indicate that indoor air quality can be severely degraded by opening windows without considering the level of outdoor particle concentration.

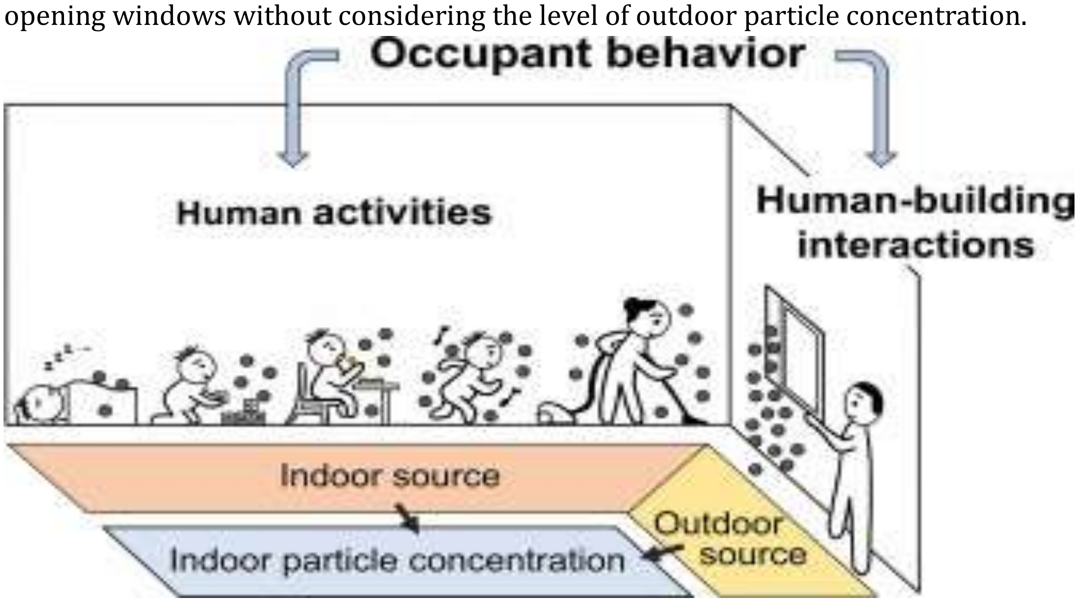

Figure 2.7: Image showing how occupants behaviour increases indoor particulate concentrations. Source: Chai et al. (2022).

Health Conditions Affiliated with Poor IAQ

Over the past decades, various symptoms and illnesses have been linked to diminished IAQ in buildings and houses. Indoor exposure to inorganic, organic, physical, and biological contaminants, though often at low levels, is common, ubiquitous, and sustained (Tran *et al.,* 2020). Therefore, the harmful effects of IAP on human health have always attracted great attention and concern. According to the WHO, building-associated illness refers to any illness caused by indoor environmental factors, which commonly are divided into two categories: Sick building syndrome (SBS) and building-related illness (BRI) (USEPA, 2004). Their associated symptoms are shown in Figure 2.8.

SBS often refers to a group of symptoms that are linked to the physical environments of specific buildings; acute health and comfort effects of SBS will appear when patients spend a certain amount or duration of time in a building, but they and their causes are difficult to clearly identify (Marmot *et al.,* 2006). BRI describes illnesses and symptoms with an identified causative agent directly related to exposure to poor air quality in buildings. It is known that causative agents can be chemicals, such as formaldehyde, xylene, pesticides, and benzene, but biological agents are more widespread (Tran *et al.,* 2020).

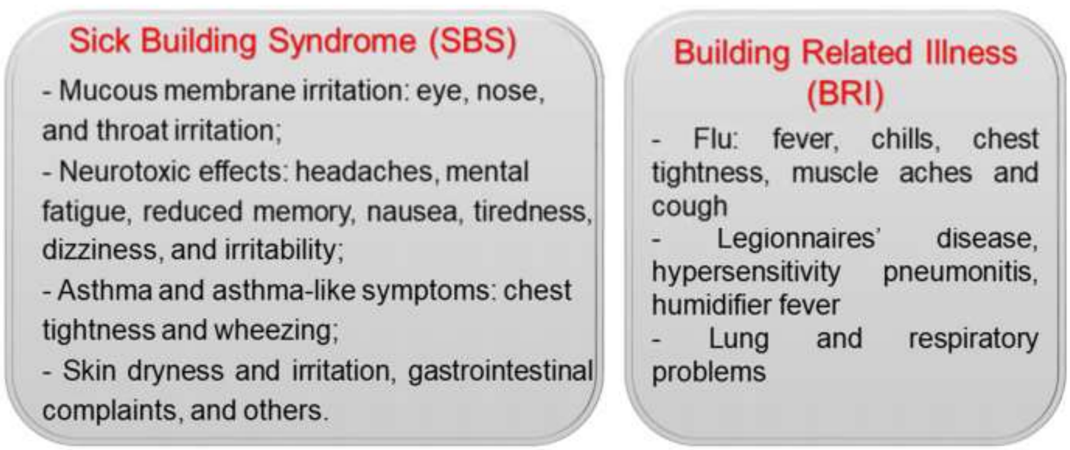

Figure 2.8: The common symptoms of sick building syndrome (SBS) and building related illness (BRI). Source: Tran *et al.* (2020).

Table 2.1. Indoor air contaminants list and related health impacts

Contaminants	Sources	Possible consequences	References
Biological Contaminants			
Allergens	Furry pets, dust mites	Asthma	Dales *et al.* (2008)
Endotoxins	Presence of cats and dogs, contaminated	Asthma, reduced lung function	Park *et al.* (2001)

	humidifiers, storage of food waste, lower ventilation rate, increased amount of unsettled dust		
Dampness and mold	Unattended plumbing leaks, leaks in building fabric, hidden food spills, standing water	Upper respiratory symptoms, cough, wheeze and asthma	Fisk *et al.* (2007)
Chemical Contaminants			
Smoke	Tobacco smoke	Premature mortality, lung cancer, coronary artery disease, childhood cough and wheeze, respiratory illness, infant death syndrome	U.S. Department of Health and Human Services, 2006
Coal and biomass fuels combustion product	Cooking and heating	Combustion of solid fuels releases CO, N_2O, particulates, poly-cyclic hydrocarbons, which increases the risk of lung cancer, childhood asthma	Mehta, 2002, Zhang and Smith, 2007
Carbon oxides (CO_x)	Vehicle exhaust from attached garages, gas stoves, furnaces, wood stoves, fireplaces and cigarettes, outdoor air, other gasoline powered equipment	Headache, nausea, fatique, impaired vision, reduced brain function	USEPA, 2020, Shimer & Thomas (2005)
Nitrogen dioxide (N_2O)	Combustion of fossil fuels e.g., gas or oil furnaces and stoves	Increased risks of respiratory symptoms	Spengler *et al.* (2001)

Pesticides	Contaminated soils, stored pesticide containers	Irritation to the eye, nose and throat, damage to central nervous system	Holt *et al.* (2017), USEPA, 2020
Ozone (O_3)	Outdoor sources, photocopying, air purifying, disinfecting devices	DNA damage, lung damage, asthma, decreased respiratory functions	Salonen *et al.* (2018), Huang *et al.* (2019)
Sulphur dioxide (SO_2)	Cooking stoves, fireplaces, outdoor air	Impairment of respiratory Function, Asthma, chronic obstructive pulmonary disease (COPD), and cardiovascular diseases	Seow *et al.* (2016)
Off Gassing Emissions (Gases released from indoor materials)			
Volatile Organic Compounds (VOCs)	Paints, stains, varnishes, solvents, pesticides, adhesives, wood preservatives, waxes, polishes, cleansers, lubricants, sealants, dyes, air fresheners, building materials and furnishings	Eye, nose and throat irritation, headaches, loss of coordination and nausea, damage to liver, kidney and central nervous system, some organics can cause cancer	Tang *et al.* (2015)
Plastic Compounds	Polyvinyl chloride for flooring, plastic wall material	Bronchial obstruction, Asthma, wheeze, cough and phlegm	Jaakkola *et al.* (2000)
Formaldehyde (HCHO)	Wood based products assembled using urea-formaldehyde resins, cigarette smoke, paints, vanishes, floor finishes	Eye, nose, throat irritation, asthma, bronchitis, and possible carcinogen	WHO, 2010, USEPA, 2016.
Carcinogens			

Radon	Natural decay of Uranium	Lung cancer, Leukemia	WHO, 2010
Heavy metals	Pb, Cd, Zn, Cu, Cr, As, Ni, Hg, Mn, Fe, Outdoor sources, fuel-consumption products, incense burning, smoking and building materials	Cancers, brain damage, Mutagenic and carcinogenic effects: respiratory illnesses, cardiovascular deaths	Komarnicki (2005), Rashed (2008)
Particulate Matter (PM)			
Ultra-fine particles	Cooking, combustion activities	Serious impact on heart and lungs	WHO, 2010, Prajakta, (2013)

Source: Tran *et al.* (2020); Mannan and Al-Ghamdi (2021)

RESEARCH METHODOLOGY

The quantitative research method was used using the BASE (Building Assessment and Evaluation) strategy. This was done in two parts; which comprises of the occupants' survey and the instrument survey. The BASE strategy was first used in 1994 by USEPA (U.S. Environmental Protection Agency) to characterize key characteristics of IAQ, occupant health symptoms and perceptions of IAQ in public and commercial office buildings (Girman *et al.,* 1997). It involves these processes; select and recruit buildings, initial visit to eligible buildings, create a study team, select study areas and monitoring locations, monitor study areas, survey occupants of study areas, validation of data as specified in the quality assurance project plan. The selected building for this survey was the Male Hostel Block A.

Case Male Hostel, Block A

This is an accommodation space open for use only to the undergraduate males. It is building having 83 rooms, 12 kitchens, 48 toilet and bath spaces, one common room and a central courtyard all planned in 3 floors (ground, first and second floors). Each room by design has an occupancy of 5 bed spaces with a total of 415 bed spaces. However, this block is overcrowded.

Data Collection and Sampling Technique

A short term monitoring was conducted in the male hostel block A, taking three rooms as the monitor locations. Rooms 118, 152, and 182 all at the ground, first and second floors respectively. The instrument placed at the monitor rooms is the Air Node. It can measure temperature, Humidity, PM 2.5, PM 10, CO_2 and VOCs. The instrument was placed in each room for a period of 12 hours spanning from 6PM to 6AM. At this period all occupants of the rooms are available and most activities for the day occur. The accuracy of the device is as follows; temperature; -10 to +40°C, Humidity; 0 to 100%, CO2; 400 to 10000 ppm, PM 2.5; 0.3 to 2.5μm (0–100 μg/m³).

Figure 3.1 Air visual node monitoring device. Source: https://airvisual.com/node

For the occupants' survey, the official population size for the hostel is 415 persons and the sample population is 83 persons which are randomly selected from each room at an average of one person per room (20% of the population size). This ensures an even spread and selection of the respondents surveyed thus generalizations can be made towards the entire population size. A structured closed-ended questionnaire was used to collect data from respondents and the responses were analyzed.

Data Analysis

Reliability Test

A Cronbach alpha reliability test was conducted to measure the internal consistency of the responses; a value of 0.7 and above is considered acceptable (Saunders *et al.,* 2015). For this research, a value of 0.71 was obtained.

Descriptive Statistics

This is used to organize and summarize characteristics of a set data (Pritha (a), 2020). For the occupant's survey, demographics in form of charts and tables were presented. For statements that were asked using the Likert scale, weighted scores and weighted means were computed and ranked using the ordinal scale. For the instrument survey, air contaminants were statistically presented stating the concentration levels of the contaminants and the room atmospheric conditions recorded during the monitoring period. The table 3.3 below shows how the range of mean responses will be interpreted.

Table 3.1 Interpretation of Mean Scores for Individual Statements

Range of Mean	Quantitative Description	Qualitative Description
4.21 to 5.00	5	Strongly agree
3.41 to 4.20	4	agree
2.61 to 3.40	3	neutral

1.81 to 2.60	2	disagree
1 to 1.80	1	Strongly disagree

Source: Adopted from Arceno, (2018, pp.245)

Inferential Statistics

This helps you to conclude and make predictions and inferences based on your data set. An in-depth understanding of the larger population from the sample taken can be achieved (Pritha (b), 2020). Correlation was used to obtain inference based on relationships between variables from the sample population (Mukaka, 2012). Statistically, the relationship between two variables is represented using the letter r which could be positive (+) or negative (-); this r value is considered strong when it is equal to or greater than 0.7 (Moore *et al.,* 2013). The variables of indoor air contaminants are associated with each other which can be characterized by correlation (Kim *et al.,* 2021).

Evaluation Metrics for Indoor Air Contaminants

Air Quality Index (AQI), is a system for reporting the severity of air quality levels. Following the US EPA standards as published the air visual node manual, there are categories of values for AQI. A value of 0 – 50 is deemed good, 51 – 100 moderate, 101 – 150 unhealthy for sensitive groups, 151 – 200 unhealthy, 201 – 300 very unhealthy and above 300 is hazardous. Sensitive groups comprise of people with respiratory or heart disease, children and the elderly. The adopted standard for the PM 2.5, PM 10 and CO_2 is stated in the table 3.2 below.

Table 3.2: Evaluation metrics for indoor air contaminants

	Remark	PM $_{2.5}$ (ug/m^3)	PM $_{10}$ (ug/m^3)	CO_2 (ppm)
Reference		Kim *et al.* (2021)	Kim *et al.* (2021)	Air visual node manual
Grade	Good	0 - 15	0 - 30	0 - 700
	Normal	16 - 35	31 - 80	701 - 1000
	High (bad)	36 - 75	81 - 150	1001 - 1500
	Unhealthy (very bad)	Above 75	Above 150	1501 - 2500
	Very unhealthy			2501 - 5000
	Hazardous			5001 – 10 000

Source: Adapted from Kim *et al.* (2021) and air visual node manual.

RESULTS AND DISCUSSION

The method in which the data were collected, involved an occupant survey using a questionnaire and an instrument survey (air visual node) as stated in the research methods. For the occupant survey, a Cronbach alpha test was conducted to test for internal consistency (reliability). A value of 0.71 was obtained as shown in table 4.1. This means that the data presented in this research paper is reliable.

4.1 Table of Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.705	0.730	47

General Characteristics of the Respondents

The demographics of the respondents are shown in table 4.2. There exists an underlining issue of overcrowded spaces as 83.1% of the respondents stay in a room of 5 – 12 occupants against the allocated 5 persons. Overcrowding of space impacts the indoor air quality. The distribution of the respondents across the various levels is such that majority of them are between 200 level and 500 level (96.8%). This implies that a good number of respondents have stayed in the hostel environment for a good period of time as against the 100 level respondents. Staying in an indoor space for 6 months is enough for the nature of the air to affect the occupant. 71.1% of the respondents have stayed a period of 4 – 6 months in these hostel rooms. This means that deductions drawn in the later stages of this chapter is abiding to the respondents.

Table 4.2: Descriptive statistics showing demographics of respondents

Respondents based on Education Year		
Education Year	**Frequency**	**Percentage %**
100 Level	6	7.2
200 Level	18	21.7
300 Level	29	34.9
400 Level	19	22.9
500 Level	11	13.3
Respondents based on Number of Persons sharing a Room		
Number	**Frequency**	**Percentage %**
1 - 4 Persons	14	16.9
5 - 8 Persons	41	49.4
9 - 12 Persons	28	33.7
Respondents based on Duration of Stay		
Number	**Frequency**	**Percentage %**
1 - 3 Months	20	24.1
4 - 6 Months	59	71.1
7 - 9 Months	02	2.4
10 - 12 Months	02	2.4
Total	83	100

Occupant Behavior and Indoor Air Particulate Concentrations

As established in the literature review, occupants behaviour affect indoor air particulate concentrations through various activities. From the occupants' survey, the activities relating to the indoor environment are presented in table 4.3. it is important to note that occupants behaviours that influence indoor air particulate concentrations are in two categories namely; activities within the indoor space that increases indoor air particulate concentrations such as indoor smoking and activities that creates an interaction between the indoor air and outdoor air such as opening of fenestrations.

Table 4.3: Distribution of respondents based on activities within the indoor space

Respondents based on Cooking Tools Used		
Cooking Tools	**Frequency**	**Percentage**
Electric Cooker	30	36.1
Kerosene	51	61.4
Charcoal	02	02.4
Respondents based on Place of Cooking		
Cooking Place	**Frequency**	**Percentage**
Inside room	37	44.6
Along the Corridor of the Room	27	32.5
Separate room in the Hostel (i.e. kitchen)	19	22.9
Respondents based on Indoor Smoking Habit		
Response	**Frequency**	**Percentage**
Yes	6	7.2
No	77	92.8
Total	83	100

It is seen from table 4.3 that indoor air particulate concentrations will naturally increase due to the occupants behaviours. 61.4% of them use kerosene to cook. Kerosene stove is a combustion stove which produces CO_2 whenever there is complete combustion and CO when combustion is complete. 44.6% of the occupants, cook inside their rooms. This will increase the CO_2 content of the rooms from the already existing ones created as a result of an overcrowded room. For this reason, an instrument survey was conducted to determine the exact concentration levels.

Three rooms were surveyed using the air node device namely; rooms 118, 152 and 182 all in the dry season. The statistical observations are presented in table 4.4. It was observed that Room B has the worst conditions of all three rooms. Room A has daily temperature and humidity averages of 28^{o}C and 21% respectively. The room has temperatures as high as 30^{o}C and humidity as high as 25%. The air is too dry for breathing and too hot for a comfortable environment. Room B also had high temperatures with an average of 27°C a little bit above the normal room temperature of 25°C.the average humidity was recorded at 27%, with a maximum of 44% which is abnormal in the dry season. This means that some activity within the room must have influenced it. Room C located at the second floor had an average temperature of 28°C and a maximum of 30°C. This means the temperature is generally high which will require a good ventilation system and cooling system if possible. Average humidity recorded is 27% with a maximum value of 30%. This indoor conditions affects occupants behaviour which influences indoor air particulate concentrations.

Table 4.4: Statistical observation of indoor air contaminants

Indoor Air Variables (Room A)						
Parameters	**PM 2.5 (ug/m^3)**	**PM 10 (ug/m^3)**	**CO_2 (ppm)**	**Temperature °C**	**Humidity (%RH)**	**AQI (US)**
Mean	68.47	97.56	676.68	28.12	21.11	134.94
SD	38.848	60.388	28.333	1.635	.675	43.956
Min	11	12	641	25	20	46
Max	147	213	832	30	25	198
Indoor Air Variables (Room B)						
Parameters	**PM 2.5 (ug/m^3)**	**PM 10 (ug/m^3)**	**CO_2 (ppm)**	**Temperature °C**	**Humidity (%RH)**	**AQI (US)**
Mean	72.2326	99.3609	757.6502	27.7760	27.3863	158.9581
SD	15.78244	22.11439	157.07922	2.30154	5.26154	9.50847
Min	45.00	53.00	633.00	24.30	22.00	124.00
Max	174.20	232.00	1283.00	31.10	44.00	224.00
Indoor Air Variables (Room C)						
Parameters	**PM 2.5 (ug/m^3)**	**PM 10 (ug/m^3)**	**CO_2 (ppm)**	**Temperature °C**	**Humidity (%RH)**	**AQI (US)**
Mean	50.939	67.105	827.326	28.588	27.347	130.306
SD	15.2324	21.9751	166.0399	2.0596	3.1171	26.1547
Min	34.281	42.392	708.71	25	20	46
Max	75.233	101.572	1136.51	30	30	198

The air contaminants that the device could measure include PM 2.5, PM 10 and CO_2. For the Room A, the average values of $PM_{2.5}$, PM_{10} and CO_2 respectively are 68 ug/m^3, 98 ug/m^3, and 677 ppm. Room B had 72 ug/m^3, 99 ug/m^3, and 757 ppm. Room C had 51 ug/m^3, 67 ug/m^3, and 827 ppm. Generally, the AQI for the three rooms are above 100.

This is unhealthy for sensitive cases. Room B had an average AQI of 159, a minimum value of 124 and a maximum value of 224. This is very unhealthy.

H_{01} Occupant behavior is the primary mechanism determining indoor particulate concentrations

When placed in indoor spaces with similar properties in terms of ventilation, room size and room population, it becomes a need to understand why these indoor spaces have varying indoor particulate concentrations. Activities such as indoor cooking, smoking, keeping unhealthy plates, pots and spoilt food items all affect indoor air particulate concentrations. As shown in table 4.3, one of the major factors that affects indoor particulate concentration in the case hostel is indoor cooking.

Table 4.5 The hourly average of air contaminants in the various rooms

Hourly average	Room A			Room B			Room C		
	$PM_{2.5}$	PM_{10}	CO_2	$PM_{2.5}$	PM_{10}	CO_2	$PM_{2.5}$	PM_{10}	CO_2
Hour 1 (7 pm)	19.90	25.64	717.18	57.61	78.28	1119.77	54.591	72.939	1136.51
Hour 2 (8 pm)	32.33	39.90	711.99	63.17	86.71	913.63	61.264	82.050	1081.67
Hour 3 (9 pm)	35.68	43.61	703.15	67.42	90.39	826.34	65.554	88.519	1088.04
Hour 4 (10 pm)	27.98	34.79	686.23	80.32	105.79	908.01	64.331	87.317	823.91
Hour 5 (11 pm)	33.71	43.72	668.83	82.33	111.72	707.54	75.233	101.572	726.88
Hour 6 (12 am)	45.35	61.54	664.95	71.55	95.76	675.48	65.436	87.047	722.20
Hour 7 (1 am)	77.54	111.74	677.03	65.90	87.97	667.04	44.830	57.708	728.06
Hour 8 (2 am)	102.14	149.54	667.37	68.14	94.21	650.85	38.558	49.661	708.71
Hour 9 (3 am)	111.77	164.48	660.63	80.04	114.59	648.38	34.281	42.392	741.99
Hour 10 (4 am)	114.81	170.76	652.45	75.63	107.55	656.91	34.983	43.008	736.98
Hour 11 (5 am)	115.75	170.87	648.54	77.41	110.19	666.40	34.569	43.572	722.93
Hour 12 (6 am)	116.78	172.99	656.65	77.27	109.17	651.45	37.636	49.469	710.04

The period in which the survey was conducted was from 6:00 PM to 6:00 AM (12 hours). This period was chosen as it was a time were most members of the rooms are presented due to day to day activities. It is also the period when most chores take place. The cooking activities spans from 7pm to 11pm sometimes even early hours of the morning considering it is the male hostel and they do not have a restriction to the time of cooking. Occupants of Rooms B and C cook inside the room as against occupants of room A who cook along the corridor. This activity is as a result of the distance from the kitchen to their rooms. It is observed that the CO_2 content of the indoor air for room A is normal (moderate) having the highest hourly average to be 717 ppm (the cooking period in which CO_2 gases could have diffused into the room from the corridor or other outdoor sources). This room also is not overcrowded (6 persons against the standard 5). Rooms B and C have high values of CO_2 with the highest average been 1120 ppm and 1136 ppm respectively. This is not healthy. The high CO_2 contents of these room is as a result of the cooking activities in the rooms

Particulate Matter PM are sourced majorly from migration of particles from outdoor environment and particles generated from indoor activities such as cooking, smoking (Tran *et al.,* 2020). $PM_{0.1}$ is obtained majorly from fossil fuel (this cannot be detected by the device), $PM_{2.5}$ and PM_{10} are obtained indoors majorly from cooking and smoking. Room A had normal values for both even during the cooking period. This further proves the absence of cooking activities going on in the room. However, the values went high so much that it became unhealthy (117 ug/m^3). This is possible only if the windows of the rooms were open considering the dry season and the outdoor air has influenced the indoor air. Table 4.6 shows that occupants frequently open windows during dry season. It is expected that the PM values of rooms B and C to be high considering the cooking activities in the rooms, which was so. However, there was a decline during the early hours of the day for both $PM_{2.5}$ and PM_{10} for room C after cooking where as that of Room B increased. This is possible because after cooking hours there was a general drop in the PM values for about 2 hours averagely before the different changes as a result of outdoor influencing indoor concentrations. room C had their windows closed while room B had theirs open. This further proves that occupants behaviours influence indoor air particulate concentrations. Activities relating to the interactions between the indoor and outdoor concentrations as obtained from the occupants' survey is shown in table 4.6

Table 4.6 Occupants activities that results in indoor outdoor air interactions.

Frequency of Opening Windows During Dry and Raining Season		
Seasons	**WS**	**WM**
Dry Season	315	3.80
Raining Season	270	3.25
Number of respondents = 83; WS = Weighted Score; WM = Weighted Mean		
Respondents based on Conditions for Window Opening		

Conditions	Frequency	Percentage
When it's windy outdoor	57	30
When it's dusty outdoor	61	32
When it's raining	72	38
Total	190	100
Multiple responses by 83 respondents		
Respondents based on Window Coverings Used		
Window Coverings	Frequency	Percentage
Shutters	40	48.2
Louvres	37	44.6
Window blinds (i.e. curtains)	20	24.1
Total	97	100

Multiple responses by 83 respondents

Indoor air is not only influenced by activities of occupants that generates pollutants but also activities that allows the migration of outdoor particles indoor such as opening of windows and doors. It was observed that a most respondents open their windows more during the dry season and the reasons been for good air circulation. This particle migration can be reduced with the use of window blinds and curtains whereas shutters and louvres have to be open for effective ventilation. The reason for high PM in rooms with who open the windows are as a result of the need for good ventilation. Rooms B and C faced the wind direction. This means that an opened window without curtains or blinds will allow an influx of PMs. Only few rooms have curtains in them.

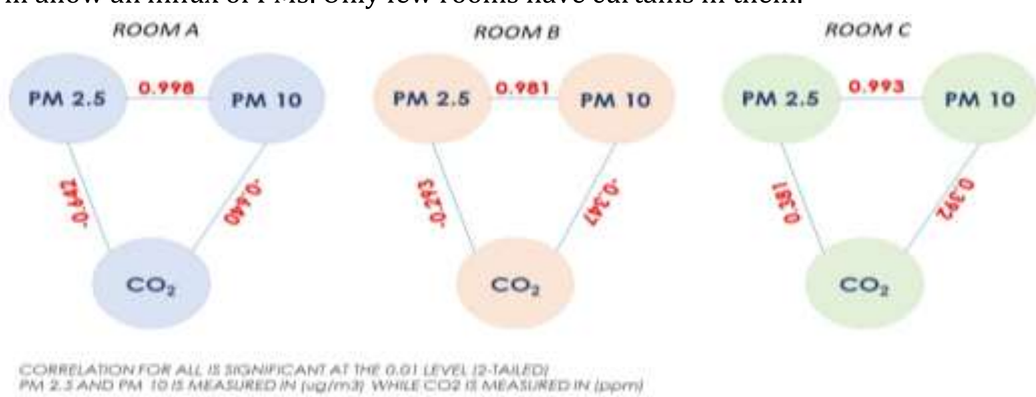

Figure 4.1: Correlation of Indoor Air Contaminants as obtained from SPSS 25

According to Kim *et al.* (2021), indoor air contaminants are correlated and as much as correlation are used to the quantify the existent relationship between two variables, these two variables can be correlated with other variables. In this case, two indoor contaminants are correlated with each other as well as other contaminants especially if their source is similar. They are also correlated to outdoor contaminants if there is a significant interaction. PM $_{2.5}$ and PM $_{10}$ showed a strong positive relationship in the three rooms. There is a moderate negative relationship between CO2 and the PMs in room A. This negative relationship exists as a result of outdoor interactions from opening of windows as seen also in room B with a weak negative interaction between CO2 and the PMs. Room C however had a positive correlation with the PMs as there was little or no outdoor interactions with the indoor space resulting from open windows. This means that for room A and B there exists a heterogeneous relationship with outdoor concentrations greatly influencing indoor concentrations whereas room C had a homogenous relationship with outdoor concentrations having little or no influence on the indoor concentrations.

Indoor Air Quality and Health Status of the Occupants.

From table 4.2 it was established that 71% of the respondents have spent 6 months in the hostel space. This duration is long enough for the air in that space to affect the occupants of the space. Table 4.7 shows the exposure hours of the occupants of the various rooms surveyed. Room A had no bad exposure to CO2 but had 6 hours and 8 hours of exposure to high $PM_{2.5}$ and PM_{10} levels respectively. Exposure to high PMs levels generally causes asthma and increased respiratory symptoms. It can cause death to sensitive groups (Tran *et al.,* 2020). Room B had 11 and 12hours of exposure to high levels of $PM_{2.5}$ and PM $_{10}$ respectively coupled with 1-hour exposure to high levels of CO_2. Room C had 5, 9 and 3 hours of exposure to high levels of $PM_{2.5}$, PM_{10} and CO_2 respectively. From tables 4.3 and 4.6 it is safe to say the entire hostel will experience similar period of exposure to high levels of indoor air contaminants considering similar behaviours and same outdoor air concentration. The effects through symptoms and signs is in table 4.8

Table 4.7: Respondents duration of Exposure to different levels of indoor air contaminants

Room	Grade	Observation period	PM 10		PM 2.5		CO_2	
			Hours	%	Hours	%	Hours	%
A	Good	12 Hrs.	1	08.3	0	0	9	75.0
	Normal		5	41.7	4	33.3	3	25.0
	Bad		6	50.0	8	66.7	0	00.0
B	Good	12 Hrs.	0	0	0	0	7	58.4
	Normal		1	8.3	0	0	4	33.3
	Bad		11	91.7	12	100	1	08.3
C	Good	12 Hrs.	0	0	0	0	0	00.0
	Normal		7	58.3	3	25	9	75.0

	Bad		5	41.7	9	75	3	25.0

Table 4.8: Distribution of the signs and symptoms experienced by the respondents.

Signs and Symptoms of Diseases		Frequency & (%)		
		Dry Season	**Raining Season**	**None**
1	Headaches and a stiff neck	64 (77)	19 (23)	0 (0)
2	Dizziness	54 (65.1)	27 (32.5)	02 (2.4)
3	A tingling/pins/needles feeling	45 (54.2)	17 (20.5)	21 (25.3)
4	Difficulty or fast breathing	54 (65.0)	18 (21.7)	11 (13.3)
5	Increased heart rate	31 (37.3)	25 (30.1)	27 (32.5)
6	Loss of consciousness (i.e. fainting)	31 (37.3)	18 (21.7)	34 (41.0)
7	Weakness/fatigue	39 (47.0)	34 (41.0)	10 (12.0)
8	Sore throat	60 (72.3)	19 (22.9)	04 (4.8)
9	Muscle pains	51 (61.4)	23 (27.7)	09 (10.8)
10	Severe watery or loose diarrhea (i.e. more than three runny stools per day)	18 (21.7)	57 (68.7)	08 (9.6)
11	Nausea (i.e. the feeling that you are going to vomit	42 (50.6)	30 (36.1)	11 (13.3)
12	Vomiting everything	10 (12.0)	53 (63.9)	20 (24.1)
13	A bad (severe) cough that lasts 3 weeks or longer	35 (42.2)	25 (30.1)	23 (27.7)
14	Pain in the chest	38 (45.8)	22 (26.5)	23 (27.7)
15	Coughing up blood or sputum (mucus from deep inside the lungs)	32 (38.6)	34 (41.0)	17 (20.5)
16	Sore or itchy eyes	39 (47.0)	22 (26.5)	22 (26.5)
17	Skin complaints/rashes/eczema	45 (54.2)	33 (39.8)	05 (6.0)

Multiple responses from 83 Respondents

Some of the symptoms observed are not directly related to the air contaminants mentioned. However, other contaminants exist which were mentioned in the literature review. The diseases mentioned in table 4.9 is a list of common illnesses amongst the respondents. The most common disease is malaria. The next two ranking diseases is respiratory related, asthma and influenza. This shows there is a serious need to consider improving indoor air quality. There are other possible respiratory problems which might be inherent amongst the respondents which has not been be tested for from the symptoms mentioned such as cardiovascular diseases, Chronic Obstructive Pulmonary Disease (COPD) all resulting from cooking stoves (SO_2; Seow *et al.,* 2016)

Table 4.9: Distribution of Respondents based on Reported Diseases in the Hostel Rooms

Reported Diseases	Weighted Score	Weighted Mean	Rank
Tuberculosis (TB)	157	1.89	8th
Pneumonia	161	1.94	7th

Asthma	177	2.13	2nd
Meningitis	169	2.04	5th
Measles	170	2.05	4th
Chicken Pox	165	1.99	6th
Influenza	171	2.06	3rd
Malaria	262	3.16	1st

Hostel Facilities and Indoor Air Quality

The state of the hostel facility affects the indoor air. The outdoor environment, the general spaces, kitchens and sanitary spaces all affect indoor air quality. The outdoor environment is not well landscaped which could have improved air purity through the trees planted. But beside the outdoor environment what is the state of the hostel facility? Table 4.10 focused majorly the facilities that affect indoor air quality in the hostel directly. This hostel has no air conditioners or air extractors. The ventilation is basically through windows and fans. It has a courtyard to aid cross ventilation as well as stack ventilation. The window type is basically side hung double leaf. This allows 100% air into the rooms. Although some rooms do not receive enough air due to building orientation.

Distribution of Respondents based on means of Ventilation Available		
Available Means	**Frequency**	**Percentage**
Air Condition	0	0
Fans	79	95.2
Windows only	83	100
Distribution of Respondents based on their Responses on Window Type		
Window Type	**Frequency**	**Percentage**
Side hung window (i.e. Casement type)	31	37.3
Louvers Window	52	62.7
Total	83	100

The louvre is for the walls facing the courtyard. This is where the major challenge comes as some of these windows are damaged. From table 4.11 the hostel generally has good natural lighting but a moderate ventilation. This shows why the occupants leave the windows open for long hours. There is a high level of bad odour and stuff smell which is as a result of overcrowded spaces and poor environmental hygiene of drainages and sanitary spaces. This is a source of biological contaminants. The thermal comfort is moderate which tells why the temperatures are high even during the dry season. Mold is moderately present in the rooms which can cause asthma, allergies and respiratory infections.

Table 4.11: Rating level of indoor environmental variables in the Hostel facility

Variables	WS	WM	Decision Rule	Rank
Natural ventilation	243	2.93	Moderate	5th
Natural daylight	321	3.87	High	1st
Bad odour or stuffy smell	310	3.73	High	2nd
Presence of mould (i.e. black and growing in moist places)	229	2.76	Moderate	7th
External Noise	292	3.52	High	3rd
Thermal comfort	231	2.78	Moderate	6th
Illumination (Brightness of light)	263	3.17	Moderate	4th

Number of Respondents = 83; WS = Weighted Score; WM = Weighted Mean

Table 4.12 is a correlation table between the reported diseases in the case hostel and the influence the indoor environmental quality variable play in the existence. The Pearson coefficient for this survey is generally low, therefore a correlation threshold is set at 1.5. There is a negative relationship between asthma and presence of mold. Tran et al. (2020) indicated that presence of mold can cause asthmatic occupants. Presence of mold also had a relationship with influenza but this time a positive one. The strongest correlation was seen between influenza and bad odour which was positive as well as between asthma and bad odour but this time a negative one. This proves that there exists a great ton of biological contaminants in the case hostel and a more intrinsic study be carried out to determine the existence of such allergens.

Indoor Air Contaminants and their Role as Disease Vectors

The pandemic as placed a demand for a preparedness for indoor infectious disease that goes beyond the current indoor codes and standards (Awada *et al.,* 2021). It has been verified through research that poorly or non-ventilated spaces can encourage aerosol spread of air borne diseases such as COVID 19, an insufficient ventilation in closed spaces has a probable long range virus transmission and infection even through the air. Chang *et al.* (2021) opined that $PM_{2.5}$ and PM_{10} could be good carriers of infections diseases amongst other air contaminants and this does not only pose a threat of the potential effect of the contaminants but also the disease causative agents they carry. Further studies will be needed to ensure that appropriate air quality standards are developed in such as a way to enhance sustainable indoor air contaminants control including the probability that could be vectors for infectious diseases.

Table 4.12: Correlation between IEQ variables and the common diseases reported by respondents

		Tuberculosis	Pneumonia	Asthma	Meningitis	Measles	Chicken Pox	Influenza	Malaria
Natural ventilation	Pearson Correlation	-0.017	-0.021	0.005	-0.036	0.058	-0.042	-0.031	0.064
	Sig. (2-tailed)	0.882	0.851	0.964	0.749	0.604	0.709	0.781	0.567

Natural daylight	Pearson Correlation	-0.187	0.125	-0.063	-0.164	-0.159	-.226*	-0.087	0.016
	Sig. (2-tailed)	0.090	0.261	0.572	0.137	0.152	0.040	0.436	0.884
Bad odour or stuffy smell	Pearson Correlation	0.169	0.094	-.261*	-0.191	-0.113	-0.141	.358**	0.174
	Sig. (2-tailed)	0.126	0.397	0.017	0.084	0.308	0.205	0.001	0.115
Presence of mould (i.e. black and growing in moist places)	Pearson Correlation	.267*	.313**	-.255*	-.272*	-0.167	-0.192	0.187	0.150
	Sig. (2-tailed)	0.015	0.004	0.020	0.013	0.130	0.082	0.091	0.177
External Noise	Pearson Correlation	0.048	0.184	-0.080	-0.099	0.002	-0.085	0.045	0.125
	Sig. (2-tailed)	0.666	0.095	0.470	0.374	0.987	0.443	0.688	0.261
Thermal comfort	Pearson Correlation	-0.140	-0.118	0.137	0.115	0.028	0.072	0.082	-.219*
	Sig. (2-tailed)	0.207	0.288	0.216	0.302	0.802	0.515	0.462	0.046
Illumination (Brightness of light)	Pearson Correlation	-0.186	0.004	-0.025	-0.064	-0.097	-0.123	-0.003	-0.029
	Sig. (2-tailed)	0.093	0.968	0.826	0.568	0.381	0.267	0.978	0.796

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed).

RECOMMENDATIONS AND CONCLUSION

Recommendations

The strength of every research is the positive solutions that the researcher(s) can proffer even after establishing various issues regarding the study area and its respondents. The recommendations are to two parties relating to the occupants of the space as well as the hostel management. They include;

- There should be no indoor cooking activities or even cooking along the corridors. All cooking activities should be done in the kitchens even if it is a little bit far. Illnesses do not appear instantly on first exposure but it is gradual and deliberate. Laundry activities can be done in the laundry rooms and if none should be done in the open air in the courtyard or around the hostel premises.

- A good indoor hygiene should be maintained. This prevents the brooding of biological contaminants.
- Considering the state of ventilation in the spaces, curtains should be placed and maintained on each window and door so as to reduce outdoor particle migration even when there is a need to open windows.
- Try as much as possible to reduce overcrowding of spaces through squatting as it creates more contaminants even from added human activities and life.
- Occupants are encouraged to harbour indoor plants. This helps in purifying the air through oxygen fixation. These however should be maintained.
- The hostel management should be more meticulous when it relates to hostel hygiene and sanitation. Staff should be employed and equipped with the necessary safety equipment for good thorough sanitation especially in the sanitary areas. The occupants can be involved through tangible incentives for the cleanest rooms.
- The major way to combat overcrowding is by building more hostel spaces. The school management is advised to build more hostel and maintain a strict non squatting policy through management and design.
- Landscaping of the courtyard and hostel environs should be implemented. This will add new trees that purifies the air. Also drying areas can then be implemented
- Air extractors and or air conditioners should be installed in each roof to extract and regulate used air in the spaces. This controls CO_2 emissions. Indoor air sensors can be placed to gather information about the facilities.
- An efficient management system be placed that penalizes indoor cooking activities as well as indoor laundry activities. Cooking should be done in the kitchens. If the hostel management can handle food supply and students patronize at a non-interest rate, it will eliminate totally cooking activities by occupants.
- For the new designs recommended, the hostel should consider grouped kitchen or if possible individual kitchens for each rooms or a group of rooms. However, each room should have private sanitary areas and indoor hygiene and sanitation be maintained.
- The school should go as far as create awareness and offer tests for students who have shown or complained about respiratory related symptoms.

Conclusion

Indoor air quality is an important aspect of human existence. The air we breathe has a great effect on our human systems and as such attention be given to it especially when it relates to enclosed spaces where good hours are spent daily. The impact of the air quality was seen even as a number of respiratory symptoms and diseases were reported, although some might be inherent and untested for. Occupants' behaviour had a major influence on indoor air particulate concentrations through the basic chores as well as the opening of fenestrations. Indoor air quality remains a vital factor in ensuring human sustainability even in this post pandemic era.

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