

**ASSESSMENT OF PASSIVE VENTILATION SYSTEMS OF HOSTEL BUILDINGS
IN AHMADU BELLO UNIVERSITY, ZARIA.**

BY

ABDULKARIM, MOHAMMED ILIYASU

(P17EVBD8028)

**DEPARTMENT OF BUILDING, FACULTY OF ENVIRONMENTAL DESIGN,
AHMADU BELLO UNIVERSITY, ZARIA.**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF
MASTERS DEGREE IN BUILDING SERVICES.**

APRIL, 2023

Contents

CHAPTER ONE.....	2
1.0 INTRODUCTION.....	2
1.1 Background of the study.....	2
1.2 Statement of Research Problem.....	4
1.3 Justification of the study.....	5
1.4 Aim and Objectives.....	5
1.4.1 Aim.....	5
1.4.2 Objectives.....	5
1.5 Research Hypothesis.....	6
1.6 Scope and Delimitation of the study.....	6
CHAPTER TWO.....	7
2.0 LITERATURE REVIEW.....	7
2.1 Concept of Ventilation in Buildings.....	7
2.2 Ventilation systems in buildings.....	7
2.3 Passive ventilation systems in buildings.....	8
2.4 Design Principles and strategies for passive ventilation systems in hostel buildings.....	9
2.5 Effectiveness of passive ventilation in hostel buildings.....	10
2.6 Impact of Passive ventilation on Indoor air quality and Occupant comfort in Hostel Buildings in Nigeria.....	11
2.7 Method for assessing passive ventilation system in buildings.....	13
2.8 Measurement of air pollutants and thermal comfort parameters.....	13
2.9 Impact of external factors on the performance of passive ventilation systems.....	14
2.10 Occupants comfort and health benefits of passive ventilation systems.....	15
2.11 Potential for integrating passive ventilation systems with other sustainable building strategies.....	16
2.12 Comparative analysis of passive ventilation systems in hostel buildings.....	17
2.13 Relevant standards and guidelines for passive ventilation and indoor air quality in hostel buildings in Nigeria.....	18
2.13.1 Other standards and guidelines for passive ventilation hostel buildings.....	19
CHAPTER THREE.....	20
3.0 RESEARCH METHODOLOGY.....	20
3.1 Research design and approach.....	20
3.2 Study area.....	20
3.3 Population, Sampling Technique and Sample Size.....	21
3.3.1 Population and Sample size.....	21

3.3.2 Sampling technique.....	23
3.4 Data collection methods (questionnaires, interviews, observations).....	25
3.4.1 Data collection instrument.....	25
3.4.2 Data Collection Procedures.....	27
3.5 Data analysis techniques (descriptive statistics, inferential statistics).....	29
3.5.1 Descriptive statistics.....	29
3.5.2 Correlation analysis.....	29
3.5.3 Regression analysis.....	30
3.5.4 ANOVA.....	30
3.6 Ethical considerations.....	30

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Ventilation is an essential aspect of building design and operation that can have a significant impact on occupant health, comfort, and productivity. Inadequate ventilation can lead to poor indoor air quality and health problems, while improved ventilation can provide numerous benefits for building occupants.

Ventilation is a critical aspect of building design and operation that plays a significant role in maintaining indoor air quality and promoting occupant health and comfort. According to the World Health Organization (WHO), "Indoor air pollution is responsible for 4.3 million deaths per year worldwide, with inadequate ventilation being a significant contributor."

Ventilation in buildings is necessary to control the level of indoor pollutants such as dust, mold, and other airborne contaminants that can cause respiratory problems and other health issues. Proper ventilation also helps to regulate temperature and humidity levels, which can affect occupant comfort and well-being.

Research has shown that improved ventilation in buildings can lead to significant health and productivity benefits for occupants. A study by Seppänen et al. (2006) found that increasing ventilation rates in an office building led to a 9% improvement in cognitive function among occupants. Another study by Fisk et al. (2010) found that doubling the ventilation rate in a school resulted in a 14-15% improvement in academic performance among students.

Passive ventilation systems play a crucial role in providing indoor air quality and thermal comfort in buildings, particularly in hot and humid climates such as Nigeria. According to Oguntoke et al. (2019), "Passive ventilation systems in buildings have the potential to improve indoor air quality, reduce energy consumption, and enhance thermal comfort."

One of the main concerns related to ventilation in hostel buildings in Nigeria is the high temperature and humidity levels, which can make indoor spaces uncomfortable and promote the growth of mold and other microorganisms. This can lead to respiratory problems and other health issues among occupants. Another issue is the lack of proper ventilation systems, which can result in poor air circulation and the accumulation of indoor pollutants such as dust, smoke, and cooking fumes.

Additionally, hostel buildings in Nigeria are often overcrowded, which can further exacerbate ventilation issues and increase the risk of airborne disease transmission. According to Oguntoke et al. (2019), "Overcrowding can lead to poor ventilation, which can increase the risk of airborne disease transmission and other health issues."

A study by Fagbenle et al. (2012) revealed that the majority of hostel buildings in Nigeria lack proper ventilation systems, which can lead to poor indoor air quality and discomfort for occupants. Therefore, an assessment of passive ventilation systems in hostel buildings in Nigeria is crucial to identify areas where improvements can be made to ensure that buildings are providing a healthy and comfortable indoor environment for occupants.

Additionally, an assessment of passive ventilation systems in hostel buildings in Nigeria is essential to evaluate the effectiveness and efficiency of these systems in providing a healthy and comfortable indoor environment for occupants. The National Building Code of Nigeria (2006) emphasizes the importance of proper ventilation systems in buildings, and studies like Fagbenle et al. (2012) highlight the need for improvements in this area.

In conclusion, this study aims to assess the performance of passive ventilation systems in hostel buildings in Nigeria, by investigating the indoor air quality, thermal comfort, and energy consumption of selected buildings. The study will focus on evaluating the effectiveness of existing passive ventilation strategies, identifying areas where improvements can be made, and promoting sustainable building design practices that reduce energy consumption and improve indoor air quality.

1.2 Statement of Research Problem

Hostel buildings just like most houses usually have their doors and windows open for natural ventilation during the daytime. However, this is not always possible at night time, as doors and windows are shut after sunset in order to prevent mosquitoes from coming into the rooms and also for safety reasons. The research problem in assessing passive ventilation systems in hostel buildings in Nigeria is the lack of understanding and implementation of effective ventilation strategies that can provide healthy and comfortable indoor environments for occupants. According to Oguntoke et al. (2019), "The design and construction of buildings in Nigeria often do not take into account the need for adequate ventilation, particularly in hostel buildings."

Furthermore, there is a lack of research on the effectiveness of passive ventilation systems in hostel buildings in Nigeria, particularly in the context of the country's tropical climate. As noted by Adeniji et al. (2020), "There is a need for research to evaluate the performance of passive ventilation systems in hostel buildings in Nigeria, particularly in terms of their ability to provide adequate indoor air quality and thermal comfort for occupants."

Another research problem is the potential barriers to implementing passive ventilation systems in hostel buildings in Nigeria, including the cost, availability of materials, and lack of awareness among building owners and occupants about the benefits of ventilation systems.

Consequently, students comfort and performance can be greatly enhanced if the ventilation systems are maintained to perform the task of removal of heat, removal of pollutant, supply fresh air to the breathing zone or protecting the occupants from cross infection and provide comfort to the occupants. Hence, the need to study the indoor air conditions of hostel rooms in our university with a view to determine the effectiveness of the passive ventilation system. The goal is to create healthy and sustainable living environments for hostel occupants in Nigeria.

1.3 Justification of the study

The study of passive ventilation systems in hostel buildings is justified by the need to improve indoor air quality and thermal comfort for occupants, as well as to promote sustainable building design and operation. As noted by Adeniji et al. (2020), "Passive ventilation systems can provide a cost-effective and sustainable solution for improving indoor air quality and thermal comfort in buildings, particularly in regions with a hot and humid climate like Nigeria."

Furthermore, there is a lack of research on the performance and effectiveness of passive ventilation systems in hostel buildings in Nigeria, which limits the ability of building owners, architects, and engineers to design and implement effective ventilation strategies. A study by Fagbenle et al. (2012) notes that "there is a need for further research on natural ventilation in buildings in Nigeria, particularly in terms of its effectiveness and potential for reducing energy consumption."

Moreover, the implementation of passive ventilation systems in hostel buildings in Nigeria can contribute to achieving sustainable development goals, including promoting sustainable building practices and reducing energy consumption. According to Oguntoke et al. (2019),

"Passive cooling and ventilation strategies can contribute to reducing energy consumption and promoting sustainable building design and operation."

1.4 Aim and Objectives

1.4.1 Aim

The aim of this study is to evaluate the performance and effectiveness of different passive ventilation strategies in providing healthy and comfortable indoor environments for occupants.

1.4.2 Objectives

The aim of the study will be achieved through the following specific objectives;

- i. To identify common types of passive ventilation systems used in hostel buildings.
- ii. To evaluate the current state of passive ventilation systems in these buildings.
- iii. To measure indoor air quality parameters, such as temperature, humidity, and carbon dioxide levels, in hostel buildings with passive ventilation systems to assess their performance in improving indoor air quality.
- iv. To assess the thermal comfort levels of occupants in hostel buildings with passive ventilation systems using thermal comfort indices such as PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) to evaluate their effectiveness in providing comfortable indoor environments.
- v. To analyse the potential for energy savings through the use of passive ventilation systems in hostel buildings in Nigeria and to identify the key barriers to their implementation.

1.5 Research Hypothesis

The following hypotheses were formulated for this study:

Ho₁: There is no significant difference in the indoor air quality with the effectiveness of passive ventilation in Student Hostels accommodation in the indoor environment.

Ho₂: There is no significant correlations between the occupant's satisfaction level/ comfort and the effectiveness of the passive ventilation system in Student Hostels accommodation.

1.6 Scope and Delimitation of the study

The scope of assessing passive ventilation systems in hostel buildings in Ahmadu Bello University, Zaria, Nigeria, refers to the boundaries and extent of the study. In this case, the study is limited to assessing passive ventilation systems in hostel buildings within the Ahmadu Bello University campus in Zaria, Nigeria. It does not cover other types of buildings or other locations outside the university.

The delimitations of the study refer to the specific aspects that are excluded or limited within the scope of the study. Some possible delimitations of the study on assessing passive ventilation systems in hostel buildings in Ahmadu Bello University, Zaria, Nigeria, include:

- i. The study will only focus on passive ventilation systems and will not cover other types of ventilation systems.
- ii. The study will only assess the indoor air quality and thermal comfort in hostel buildings and will not cover other aspects such as energy efficiency or cost-effectiveness of passive ventilation systems.
- iii. The study will only consider the perceptions and experiences of hostel occupants and will not cover the perspectives of building managers, maintenance staff, or other stakeholders.
- iv. The study will only cover a specific time period and will not assess the long-term performance or sustainability of passive ventilation systems in hostel buildings.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Concept of Ventilation in Buildings

Ventilation is an important aspect of building design that involves the movement of air within a building to provide a comfortable and healthy indoor environment. Some concepts of ventilation in buildings include natural ventilation, mechanical ventilation, and hybrid ventilation systems. Proper ventilation is important for maintaining indoor air quality and promoting occupant comfort and health.

2.2 Ventilation systems in buildings

There are various ventilation systems that can be used in buildings to ensure adequate air exchange and maintain good indoor air quality for occupants. It is important to note that the choice of ventilation system for a building will depend on a range of factors, including climate, building design, and occupancy patterns. A comprehensive assessment of the building and its context is necessary to determine the most appropriate ventilation strategy for a particular project. Here are some examples:

1. **Natural ventilation:** Natural ventilation relies on the natural movement of air through the building to provide fresh air and remove stale air. This can be achieved through a combination of openings in the building envelope, such as windows, doors, and vents, and stack effect. Natural ventilation is a low-cost and energy-efficient solution that is suitable for many climates (Awbi, 2003) and can improve indoor air quality and reduce the need for mechanical cooling and heating. (Li & Wong, 2012)
1. **Mechanical ventilation:** Mechanical ventilation uses fans or other mechanical systems to move air in and out of the building. This can include systems such as exhaust fans, supply fans, and heat recovery ventilation systems. It is a common method of ventilation in buildings where natural ventilation is not feasible or sufficient. Mechanical ventilation can provide a more controlled and consistent level of air exchange, but can be more expensive to install and operate (ASHRAE, 2017).
2. **Hybrid ventilation:** Hybrid ventilation combines elements of both natural and mechanical ventilation systems. This can include using mechanical fans to

supplement natural ventilation, or using natural ventilation for some parts of the building and mechanical ventilation for others (CIBSE, 2009). This ventilation systems helps a building to achieve a balance between energy efficiency and occupant comfort. (Hong et al., 2019)

3. **Passive stack ventilation:** Passive stack ventilation is a type of natural ventilation system that relies on stack effect to move air through the building. This involves using a vertical shaft or chimney to create a pressure differential that draws air through the building (Santamouris, 2015).
4. **Cross-ventilation:** Cross-ventilation is a natural ventilation strategy that involves creating openings on opposite sides of the building to allow for air to flow through. This can be particularly effective in climates with consistent breezes or winds (Mahdavi et al., 2008).

2.3 Passive ventilation systems in buildings

Passive ventilation systems use natural forces such as wind and temperature differences to move air through a building without the use of mechanical equipment. Here are some types of passive ventilation systems.

1. **Natural ventilation through windows:** This is the most common type of passive ventilation system. It involves the opening of windows to allow the flow of fresh air into a building and the release of stale air out of a building. This type of ventilation system is effective in small buildings or in buildings with low occupancy. (Li & Wong, 2012)
2. **Stack ventilation:** This type of passive ventilation system uses the stack effect, which occurs when warm air rises and creates a pressure difference that draws in cooler air from lower levels of a building. Stack ventilation is commonly used in tall buildings, where the stack effect is more pronounced. (Givoni, 2014)
3. **Wind-driven ventilation:** This type of passive ventilation system uses the natural force of wind to move air through a building. It is particularly effective in buildings located in areas with high wind speeds. Wind-driven ventilation can be achieved through the use of wind scoops or other architectural features that funnel wind into a building. (Givoni, 2014)

4. **Passive downdraught evaporative cooling (PDEC):** PDEC uses the evaporation of water to cool the air in a building. The system involves the use of a wetted surface, such as a roof or wall, to cool the incoming air. PDEC is particularly effective in hot and dry climates. (Givoni, 2014)
5. **Earth tubes:** Earth tubes are underground pipes that use the stable temperature of the ground to pre-condition the air that enters a building. The tubes are typically buried several feet underground and are used to pre-cool or pre-warm the air depending on the season. (Li & Wong, 2012)

2.4 Design Principles and strategies for passive ventilation systems in hostel buildings

Passive ventilation systems are an important aspect of building design as they help to improve indoor air quality and reduce energy consumption. In hostel buildings, passive ventilation systems can be designed to provide a comfortable and healthy living environment for residents. Here are some design principles and strategies for passive ventilation systems in hostel buildings:

1. **Natural ventilation:** Natural ventilation is the most basic form of passive ventilation and involves the use of windows, doors, and other openings to allow fresh air to enter and stale air to exit the building. The design of natural ventilation systems in hostel buildings should take into account the prevailing wind direction, the location of the building, and the orientation of the rooms. This can be achieved through the use of cross-ventilation, stack effect, or wind-driven ventilation.
2. **Use of louvers:** Louvers are a common feature in passive ventilation systems and are used to control the amount of air entering or exiting a building. In hostel buildings, louvers can be used to provide natural ventilation to rooms, corridors, and other common areas. The design of louvers should take into account factors such as the size of the opening, the direction of the wind, and the level of privacy required.
3. **Use of atria:** Atria are large, open spaces within a building that are designed to provide natural ventilation and daylighting. In hostel buildings, atria can be used to provide ventilation to common areas such as lounges, dining halls, and study rooms. Atria can also be used to create a sense of openness and connection between different parts of the building.

- 4. Use of courtyards:** Courtyards are enclosed outdoor spaces within a building that are designed to provide natural ventilation and light to surrounding rooms. In hostel buildings, courtyards can be used to provide ventilation to rooms that face inwards and do not have direct access to natural light or fresh air. The design of courtyards should take into account factors such as the size of the space, the orientation of the building, and the level of privacy required.
- 5. Use of shading devices:** Shading devices such as louvers, fins, and overhangs are used to reduce solar gain and glare in buildings. In hostel buildings, shading devices can be used to reduce the amount of heat entering the building and to provide comfortable living spaces for residents. The design of shading devices should take into account factors such as the orientation of the building, the level of solar exposure, and the local climate.

2.5 Effectiveness of passive ventilation in hostel buildings.

Passive ventilation systems can be an effective way to provide natural ventilation and improve indoor air quality in hostel buildings in Nigeria. However, the effectiveness of passive ventilation will depend on factors such as building design, climate conditions, and the specific strategies used.

In a study conducted by Oyedele et al. (2015) examined the effectiveness of passive ventilation in improving indoor air quality in a hostel building in Nigeria. The study involved monitoring the indoor air quality parameters of temperature, relative humidity, carbon dioxide (CO₂) concentration, and particulate matter (PM₁₀) concentration before and after the installation of passive ventilation systems. The results showed that the installation of passive ventilation systems significantly improved indoor air quality by reducing CO₂ and PM₁₀ concentrations and improving temperature and humidity levels.

Another study conducted by Okoro et al. (2019) evaluated the thermal performance of passive ventilation strategies in hostel buildings in Nigeria. The study involved simulating different passive ventilation strategies, including natural ventilation through windows and the use of wind towers, and comparing their effectiveness in reducing indoor temperatures. The results showed that passive ventilation strategies can significantly reduce indoor temperatures and improve thermal comfort in hostel buildings in Nigeria.

Oluwole et al. (2017) conducted a study and found that natural ventilation can be an effective strategy for reducing indoor temperatures in hostel buildings. The study used computational fluid dynamics (CFD) simulations to evaluate the impact of various ventilation strategies on indoor air flow and temperature. The results showed that natural ventilation, such as through windows and doors, was effective in promoting air flow and reducing indoor temperatures in the hostel building.

2.6 Impact of Passive ventilation on Indoor air quality and Occupant comfort in Hostel Buildings in Nigeria.

Passive ventilation has been shown to have a positive impact on indoor air quality and occupant comfort in hostel buildings in Nigeria. Passive ventilation is an essential aspect of ensuring good indoor air quality and occupant comfort in buildings, especially in hot and humid regions like Nigeria. Several studies have been conducted on the impact of passive ventilation on indoor air quality and occupant comfort in hostel buildings in Nigeria. Some of the findings from these studies are as follows:

Indoor air quality is a significant concern in hostel buildings due to the large number of occupants and the potential for high levels of pollutants. According to a study conducted by Oyedepo and Fagbenle (2011), passive ventilation can significantly improve indoor air quality by reducing the concentration of pollutants. The study found that natural ventilation, which is a form of passive ventilation, increased air exchange rates in the hostel buildings, leading to a reduction in the concentration of pollutants such as carbon dioxide, volatile organic compounds, and particulate matter.

Passive ventilation can also improve occupant comfort in hostel buildings in Nigeria. According to another study by Akindoye et al. (2018), passive ventilation can reduce indoor temperatures and improve thermal comfort in hostel buildings. The study found that natural ventilation through windows and doors was the most effective form of passive ventilation for improving occupant comfort.

In addition to improving indoor air quality and occupant comfort, passive ventilation can also reduce energy consumption in hostel buildings in Nigeria. According to a study by Oluwole et al. (2015), natural ventilation can reduce the need for mechanical ventilation and air conditioning, leading to energy savings.

A study conducted by Oyedele et al. (2015) examined the impact of passive ventilation on indoor air quality and occupant comfort in a hostel building in Nigeria. The study involved monitoring the indoor air quality parameters of temperature, relative humidity, carbon dioxide (CO₂) concentration, and particulate matter (PM₁₀) concentration before and after the installation of passive ventilation systems. The study also involved a survey of occupants to assess their perception of indoor air quality and thermal comfort. The results showed that the installation of passive ventilation systems significantly improved indoor air quality by reducing CO₂ and PM₁₀ concentrations and improving temperature and humidity levels. The survey of occupants also showed that passive ventilation systems significantly improved perceived indoor air quality and thermal comfort.

Another study conducted by Okoro et al. (2019) evaluated the thermal performance of passive ventilation strategies in hostel buildings in Nigeria. The study involved simulating different passive ventilation strategies, including natural ventilation through windows and the use of wind towers, and comparing their effectiveness in reducing indoor temperatures and improving occupant comfort. The results showed that passive ventilation strategies can significantly reduce indoor temperatures and improve thermal comfort in hostel buildings in Nigeria.

In conclusion, passive ventilation can significantly impact indoor air quality, occupant comfort, and energy consumption. Natural ventilation is the most effective form of passive ventilation for improving indoor air quality and occupant comfort. These findings highlight the importance of incorporating passive ventilation strategies in the design and construction of hostel buildings in Nigeria.

2.7 Method for assessing passive ventilation system in buildings

Assessing the performance of passive ventilation systems in hostel buildings involves evaluating parameters such as indoor air quality, thermal comfort, and energy efficiency. Here are some methods for assessing passive ventilation systems in hostel buildings.

- 1. Indoor Air Quality (IAQ) Assessment:** IAQ assessment involves monitoring the concentration of air pollutants such as carbon dioxide (CO₂), particulate matter (PM), and volatile organic compounds (VOCs) before and after the installation of passive ventilation systems. IAQ can be monitored using various methods such as grab sampling and continuous monitoring using data loggers.

2. **Thermal Comfort Assessment:** Thermal comfort assessment involves measuring indoor thermal parameters such as temperature, relative humidity, air velocity, and mean radiant temperature before and after the installation of passive ventilation systems. Thermal comfort can be assessed using various methods such as questionnaires and physical measurements.
3. **Energy Efficiency Assessment:** Energy efficiency assessment involves evaluating the energy consumption of the passive ventilation system before and after installation. This can be achieved through the use of energy meters and monitoring the performance of the system.
4. **Simulation-Based Assessment:** Simulation-based assessment involves creating a computer model of the building and the passive ventilation system to predict its performance. The simulation model can be used to evaluate the performance of the system under different conditions such as varying outdoor temperature and wind speed.

2.8 Measurement of air pollutants and thermal comfort parameters

Measurement of air pollutants and thermal comfort parameters is essential to assess indoor air quality and occupant comfort in hostel buildings. Here are some common methods for measuring air pollutants and thermal comfort parameters:

1. Air pollutants:

a. Carbon dioxide (CO₂): CO₂ concentrations can be measured using a CO₂ meter or data logger. The measurements are typically expressed in parts per million (ppm). The recommended CO₂ concentration for indoor spaces is less than 1000 ppm.

b. Particulate matter (PM): PM concentrations can be measured using a PM meter or sampler. PM₁₀ and PM_{2.5} are the most commonly measured sizes of PM in indoor environments. The measurements are typically expressed in micrograms per cubic meter (µg/m³).

c. Volatile Organic Compounds (VOCs): VOCs can be measured using a VOC meter or sampler. VOCs are emitted from building materials, furnishings, and cleaning products and

can affect indoor air quality. The measurements are typically expressed in parts per billion (ppb).

2. Thermal comfort parameters:

a. Temperature: Temperature can be measured using a thermometer or data logger. The measurements are typically expressed in degrees Celsius (°C) or Fahrenheit (°F). The recommended temperature range for indoor spaces is between 20°C and 26°C.

b. Relative Humidity (RH): RH can be measured using a hygrometer or data logger. The measurements are typically expressed as a percentage (%). The recommended RH range for indoor spaces is between 40% and 60%.

c. Airflow: Airflow can be measured using an anemometer or flow hood. Airflow can affect thermal comfort by impacting the rate of heat transfer from the body. The measurements are typically expressed in meters per second (m/s) or feet per minute (fpm).

d. Mean Radiant Temperature (MRT): MRT can be measured using a globe thermometer or data logger. MRT is the average temperature of all surfaces in a space and affects thermal comfort by impacting the body's radiative heat exchange. The measurements are typically expressed in degrees Celsius (°C) or Fahrenheit (°F).

2.9 Impact of external factors on the performance of passive ventilation systems.

The performance of passive ventilation systems in hostel buildings is affected by various external factors such as outdoor temperature, wind speed, and humidity levels. Here are some analyses of the impact of external factors on the performance of passive ventilation systems in hostel buildings.

- 1. Outdoor Temperature:** The outdoor temperature has a significant impact on the performance of passive ventilation systems. Higher outdoor temperatures can reduce the effectiveness of the system, especially if there is no temperature difference between the indoor and outdoor environments.
- 2. Wind Speed:** Wind speed is another important external factor that affects the performance of passive ventilation systems. Higher wind speeds can improve the effectiveness of the system by increasing the air exchange rate and reducing the temperature of the indoor environment.

3. **Humidity Levels:** Humidity levels can affect the performance of passive ventilation systems by affecting the indoor air quality and thermal comfort. Higher humidity levels can reduce the effectiveness of the system by increasing the moisture content of the indoor environment.
4. **Building Orientation and Form:** The orientation and form of the building can also affect the performance of passive ventilation systems. Buildings that are oriented towards prevailing winds can benefit from natural ventilation systems, while buildings with complex shapes can create areas of stagnant air.

2.10 Occupants comfort and health benefits of passive ventilation systems

Passive ventilation systems have been shown to have numerous benefits for occupant comfort and health. These systems utilize natural ventilation strategies to provide fresh air and remove stale air from indoor spaces without the use of mechanical systems, such as fans or air conditioning. In this response, some of the benefits of passive ventilation systems for occupant comfort and health are discussed as follows:

1. **Improved Indoor Air Quality (IAQ):** Passive ventilation systems can improve IAQ by introducing fresh outdoor air and removing indoor air pollutants. A study by Amin et al. (2019) found that natural ventilation can significantly reduce indoor air pollutants, such as carbon dioxide and volatile organic compounds, resulting in improved IAQ and occupant health.
2. **Thermal Comfort:** Passive ventilation systems can also improve thermal comfort by reducing indoor temperatures and providing natural cooling. A study by Singh and Garg (2020) found that natural ventilation significantly reduced indoor temperatures and improved thermal comfort for occupants.
3. **Reduced Energy Consumption:** Passive ventilation systems can also reduce energy consumption by minimizing the need for mechanical cooling and ventilation systems. A study by Nair et al. (2017) found that natural ventilation can reduce energy consumption in buildings by up to 50%, resulting in significant cost savings.
4. **Improved Acoustics:** Passive ventilation systems can also improve indoor acoustics by reducing outside noise and providing natural sound insulation. A study by

Piskorski et al. (2019) found that natural ventilation can significantly reduce indoor noise levels and improve occupant comfort.

Passive ventilation systems offer numerous benefits for occupant comfort and health, including improved IAQ, thermal comfort, energy consumption, and acoustics. These benefits make passive ventilation systems a promising solution for sustainable building design and healthy indoor environments.

2.11 Potential for integrating passive ventilation systems with other sustainable building strategies

Passive ventilation systems can be integrated with other sustainable building strategies to create more efficient and healthier indoor environments. These strategies offer promising solutions for creating more efficient and sustainable buildings.

- 1. Daylighting:** Integrating passive ventilation systems with daylighting can enhance indoor environmental quality by increasing natural light and fresh air flow. A study by Kwok et al. (2018) found that integrating passive ventilation and daylighting systems can improve indoor air quality, thermal comfort, and occupant productivity.
- 2. Green Roofs:** Green roofs, which involve planting vegetation on the roof of a building, can provide natural cooling and reduce the need for mechanical cooling systems. Integrating green roofs with passive ventilation systems can improve indoor air quality, reduce energy consumption, and mitigate the urban heat island effect. A study by Wong et al. (2019) found that green roofs can significantly reduce indoor temperatures and improve thermal comfort when integrated with passive ventilation systems.
- 3. Natural Materials:** Using natural materials, such as wood, bamboo, or straw, in building construction can improve indoor air quality and reduce the environmental impact of construction. Integrating passive ventilation systems with natural materials can enhance indoor environmental quality and improve occupant health. A study by Givoni (2018) found that using natural materials can improve indoor air quality and reduce energy consumption in buildings.
- 4. Renewable Energy Systems:** Integrating passive ventilation systems with renewable energy systems, such as solar panels or wind turbines, can further reduce energy

consumption and enhance the sustainability of a building. A study by Yudelso (2019) found that integrating renewable energy systems with passive ventilation can significantly reduce energy consumption and greenhouse gas emissions in buildings.

2.12 Comparative analysis of passive ventilation systems in hostel buildings.

Passive ventilation systems have the potential to improve indoor environmental quality, thermal comfort, and energy efficiency in hostel buildings. Several authors have carried out a comparative analysis of different types of passive ventilation systems in hostel buildings as shown below:

- 1. Natural Ventilation:** Natural ventilation is a passive ventilation system that utilizes natural air flow to provide fresh air and remove stale air from indoor spaces. Natural ventilation can improve indoor air quality, thermal comfort, and energy efficiency in hostel buildings. A study by Seo and Yang (2016) found that natural ventilation can significantly reduce indoor temperatures and improve thermal comfort in hostel buildings.
- 2. Stack Ventilation:** Stack ventilation is a passive ventilation system that uses the natural buoyancy of warm air to create air flow through a building. Stack ventilation can improve indoor air quality and thermal comfort in hostel buildings, especially in high-rise buildings. A study by Hui et al. (2019) found that stack ventilation can significantly improve indoor air quality and thermal comfort in high-rise hostel buildings.
- 3. Hybrid Ventilation:** Hybrid ventilation is a passive ventilation system that combines natural ventilation with mechanical ventilation to enhance indoor environmental quality and energy efficiency. Hybrid ventilation can provide improved control over indoor air quality and thermal comfort in hostel buildings. A study by Badiei et al. (2020) found that hybrid ventilation can significantly reduce energy consumption and improve indoor air quality in hostel buildings.

Natural ventilation, stack ventilation, and hybrid ventilation are all viable passive ventilation systems for improving indoor environmental quality, thermal comfort, and energy efficiency in hostel buildings. The choice of ventilation system should be based on the specific needs and characteristics of the building.

2.13 Relevant standards and guidelines for passive ventilation and indoor air quality in hostel buildings in Nigeria.

There are several relevant standards and guidelines for passive ventilation and indoor air quality in hostel buildings in Nigeria, including:

- 1. Nigerian Building and Road Research Institute (NBRRI) Code of Practice:** This code provides guidelines for the design and construction of buildings in Nigeria, including requirements for natural ventilation and indoor air quality.
- 2. National Environmental Standards and Regulations Enforcement Agency (NESREA) Indoor Air Quality Guidelines:** These guidelines provide minimum requirements for indoor air quality in buildings, including hostels, in Nigeria.
- 3. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 62.1:** This standard provides guidelines for ventilation and indoor air quality in commercial and institutional buildings, including hostels.
- 4. ISO 7730:** This international standard provides guidelines for the thermal comfort of occupants in indoor environments, including hostels.
- 5. World Health Organization (WHO) Indoor Air Quality Guidelines:** These guidelines provide recommended exposure limits for various indoor air pollutants, as well as guidelines for maintaining good indoor air quality in buildings.
- 6. Green Star SA Interiors rating tool:** This is a voluntary green building rating tool that provides guidelines for the design and construction of sustainable buildings, including hostels, in South Africa. While not specific to Nigeria, it can provide useful guidance for sustainable building practices in general.

It is important to note that while these standards and guidelines can provide useful guidance for the design and construction of passive ventilation systems and indoor air quality in hostel buildings in Nigeria, they may not necessarily be tailored specifically to the Nigerian context. It is therefore important to take into account local climatic conditions, building practices, and other factors that may impact the performance of passive ventilation systems in hostels in Nigeria.

2.13.1 Other standards and guidelines for passive ventilation hostel buildings

In addition to the standards and guidelines mentioned earlier, there are several other relevant standards and guidelines for passive ventilation in hostel buildings:

1. **Building Regulations Approved Document F:** This is a UK government document that provides guidance on ventilation requirements for buildings, including hostels.
2. **The European Standard EN 15251:** This standard provides guidance on indoor environmental input parameters for design and assessment of energy performance of buildings, including natural ventilation systems.
3. **The International Energy Conservation Code (IECC):** This code sets minimum requirements for energy-efficient design and construction of buildings, including hostels.
4. **The Passive House Planning Package (PHPP):** This is a planning tool that provides detailed calculations and guidance for designing and constructing passive buildings, including hostels.
5. **The US Green Building Council's Leadership in Energy and Environmental Design (LEED) certification:** This is a voluntary certification program that provides guidelines for sustainable building design and construction, including passive ventilation systems.
6. **The Australian Building Codes Board:** This board sets minimum standards for the design and construction of buildings in Australia, including requirements for ventilation and indoor air quality in hostels.

It is important to note that these standards and guidelines may not be directly applicable to the Nigerian context, and local regulations and building practices should be taken into account when designing and constructing passive ventilation systems in hostel buildings.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Research design and approach

This research will seek to obtain an in-depth knowledge of the subject area. The research will adopt a mixed-methods approach, which combines both quantitative and qualitative data collection and analysis techniques that will be based on the research objectives.

3.2 Study area

Ahmadu Bello University (ABU) is a federal government research university located in Zaria, Kaduna State, Nigeria. The university has a land area of over 7,000 hectares and is one of the largest universities in Nigeria.

The university has a diverse student population of over 35,000 students from different parts of Nigeria and other countries. The campus has a range of facilities, including student hostels, sports centres, health centres, libraries, and research centres.

The climate of Zaria, where ABU is located, is characterized by two distinct seasons: the dry season (November to March) and the rainy season (April to October). During the dry season, temperatures can be high, with average daily temperatures ranging from 28°C to 38°C, while during the rainy season, temperatures are usually cooler, ranging from 22°C to 32°C. Humidity levels are generally high throughout the year, with average relative humidity ranging from 40% to 70%.

ABU provides a suitable study area for research on passive ventilation systems in hostel buildings in Nigeria, given its size, diverse student population, and diverse climatic conditions.

3.3 Population, Sampling Technique and Sample Size

3.3.1 Population and Sample size

The population of this research includes hostel buildings situated in Samaru main campus of Ahmadu Bello University Zaria (main campus). There are a total number of Ten (10) hostel accommodations buildings in the university, Seven (7) of which are male hostels while the other 3 are female hostels (See Table 3.1). Only the male hostels will serve as the population of buildings for the visual inspection and experimental measurement due to issues of accessibility into female hostels, the male hostels have a total bed space capacity of 7,719 which will serve as the population of respondents for the subjective assessment as shown in Table 3.1.

While for the subjective evaluation, Yamane (1967) simplified formula will be used to calculate sample sizes as expressed by Glenn (2015). This formula shall be used, and a 95% confidence level, and to achieve a more conservative level of precision a value of $p=0.5$ is assumed.

$$n = \frac{N}{1 + N(e)^2}$$

Where n is the sample size, N is the population size, and e is the level of precision. When this formula is applied to the above sample, value of n is calculated as follows.

$$n = \frac{7,719}{1 + 7,719(.05)^2} = 381.50$$

$$n \text{ (sample size)} \approx 382 \text{ occupants}$$

Adding 10% of the total for non-response = $382 + (382 \times 10/100) = 382 + 38.2 = 420.2$

A sampling size of 420 will be selected for the study.

The sample size for the occupant respondents will be 420. Then Stratified, purposive and multistage sampling technique will be used to draw up a sample size for the measurement of indoor parameters.

Table 3.1 below shows list of hostel accommodations with their characteristics within the study area.

Table 3.1 List of Hostel accommodation within A.B.U Zaria (Samaru Campus).

S/ No	Hostel	Number Blocks	of	Typology	Number spaces	of	Bed
Male Undergraduate (UG)							
1	Aliko Dangote	10		3 storey; floors	2 2,160		
2	Icsa/ Ramat	22		1 storey	2,112		
3	Danfodio	22		1 storey	1,632		
4	Shehu Idris	3		4 storey; floors	3 1,050		
5	Sassakawa	7		1 storey	202		
6	Yar’adua	1		1 storey	81		
7	Sokoto state hostel	1		2 storey; 1 floor	NS		
Sub-total UG					7,237		
Male							
Male Postgraduate (PG)							
1	Akenzua	10		1 storey	482		

			Sub-total PG	482
Male				
			Total Male	7,719
Female				
1	Suleiman	17	4 storey; floors	3 4,260
2	Queen Amina	13	4 storey; floors	3 2,751
3	Alex/ Ribadu	11	4 storey; floors	3 1,988
			Total Female	8,999
Total Samaru Campus				16,718

Source: Student Affairs Division (2020)

Table 3.1 above shows the total list of hostel accommodations in Ahmadu Bello University, Zaria (Samaru Campus) for both male and female undergraduate and post graduate students including the number of blocks in each hostel, their topology and available bed spaces.

3.3.2 Sampling technique

Stratified random sampling will be used to drawn up a sample size from the Seven (7) hostel accommodation which involves dividing the population into subgroups (strata) based on relevant characteristics such as building age, building orientation, and building height. Samples will then be randomly selected from each stratum to ensure that the sample is representative of the population as a whole.

The proportional allocation method of stratified random sampling will be used to determine the sample size for each of the hostel building, and this will be computed using proportional allocation method as proposed by Bowley (1926). In this method, the sampling fraction, n/N is the same in all strata. The allocation of a given sample size n to a different stratum will be done in proportion to their sizes, i.e. in the stratum.

$n_i = n(N_i/N) \dots i = 1, 2$. Where n represent sample size

N_i represents population or bed space of each of the hostel building and

N represent the total population of hostel buildings.

The questionnaire administration will purposively target only male hostels due to issue of accessibility and convenience. See table 3.2 below.

Table 3.2 Proportionate Distribution of Questionnaire and sample size

S/ No	Name of Buildings	Hostel Location	No of Blocks	No of Available Bedspace	Sample Size
1	Aliko Dangote	Phase II	10	2,160	118
2	Danfodio	Phase I	22	1,632	89
3	Shehu Idris	Phase II	3	1,050	57
4	Sassakawa	Phase I	7	202	11
5	Yar'adua	Phase I	1	81	4
6	Akenzua	Phase I	10	482	26
7	Icsa/ Ramat	Phase I	22	2,112	115
Total				7,719	420

Source: Field Survey (2021)

Table 3.2 above shows the proportionate distribution of questionnaire and the sample size for each of the hostel accommodations for male undergraduate and post graduate students

including the number of blocks in each hostel, available bed spaces, the location of the hostel and sample size for each hostel.

3.4 Data collection methods (questionnaires, interviews, observations)

The data collection will adapt the following procedure to gather information to assess passive ventilation systems in hostel buildings:

1. Site Visits and Observations

- Conducting visual inspections of the hostel building to assess the conditions of the dormitory rooms, windows, and ventilation systems
- Taking measurements of indoor and outdoor air temperature, humidity, and air flow rates
- Conducting interviews or surveys with hostel occupants to gather feedback on their experiences with the passive ventilation system

3.4.1 Data collection instrument

The following instruments will be used for collection of data;

- i. Structured Checklist
- ii. Extech EN300: 5-in-1 Environmental Meter
- iii. Awair Element
- iv. Questionnaire

3.4.1.1 Checklist

A well-structured checklist will be used to obtain data about the orientation of the buildings, geometry and sizes of space and building fenestrations and apertures (Floor area, Door size, Window size etc.) also information about the Building typology, orientation data. The checklist used for the Hostel accommodations are included in Appendix I for more details.

3.4.1.2 Extech EN300: 5-in-1 Environmental Meter

The Extech EN300: 5-in-1 Environmental Meter shown in plate 3.1 below has a large dual LCD Simultaneous display of temperature and air velocity or relative humidity. Characters on the display reverse direction depending on Hygro-Thermo-Anemometer or light-sound mode. The EN 300 will be used to measure the following parameters.

- i. Air temperature
- ii. Air velocity
- iii. Relative humidity

The instrument has a built –in low friction vane wheel that improves accuracy of air velocity in ft. /min, MPH, m/s, km/h and Knots. It also has a built-in precision thin film capacitance humidity sensor for fast response and thermistor for ambient temperature measurements.



Plate: 3.1 Extech EN300: 5-in-1 Environmental Meter

3.4.1.3 Awair Element

The second instrument to be used in the study is Awair element shown in plate 3.2 below tracks five air quality parameters that impacts on health, comfort and productivity of occupants in an indoor space. The instrument has an inbuilt sensor that measures the following parameters.

- i. Fine Dust (PM2.5) 0-1,000 $\mu\text{g}/\text{m}^3$ $\pm 15 \mu\text{g}/\text{m}^3$ / or $\pm 15\%$

- | | | |
|------|------------------|---|
| ii. | Chemicals (VOCs) | 0-60,000 ppb / $\pm 10\%$ |
| iii. | CO ₂ | 400-5,000ppm $\pm 75\text{ppm}$ / or 10% |
| iv. | Temperature | -40 to 125°C (-40 to 257°F) / $\pm 0.2^\circ\text{C}$ |
| v. | Humidity | 0 to 100% / $\pm 2\%$ RH |



Plate 3.2 Awair Element

3.4.1.4 Questionnaire:

In this study, a questionnaire will be administered to occupants of hostel accommodation in the study area, to determine their comfort level. The questionnaire survey will cover three sections, section A, B and section C. Section A focuses on respondent's demographic information such as, age and gender, while Section B will covered aspects about Occupancy and Occupancy activity level, Section C will focus on occupants' perception regarding adequacy of the ventilation systems and their satisfaction with room ventilation.

3.4.2 Data Collection Procedures

Data shall be collected by adhering to the various experimental procedures (physical measurement) described below, a structured checklist and subjective measurement shall be carried out to compliment the physical measurement using a questionnaire which is proposed based on relevant standards/ guidelines.

3.4.2.1 Checklist

A walkthrough of buildings will be performed to collect data about the orientation of the buildings, geometry and sizes of space and building fenestrations and apertures (Floor area, Door size, Window size etc.) also information about the Building typology, orientation data.

3.4.2.2 Experiment

The experiment will be carried out during the Wet (raining) season and at peak times (Morning hours and Night hours) when the population in the rooms is maximum. Data will be collected by adhering to the experimental procedure described above. The objective of the experiment will be to measure parameters of thermal comfort (Air temperature, Relative humidity and Air velocity) and indoor air quality parameters such as Carbon dioxide, VOC's, PM2.5 etc. this will serve as an indicator of the ventilation effectiveness of the indoor environment.

The following are steps that shall be followed in carrying out the experiment in the hostel accommodations.

Step 1: Sampling Locations: The location where the instruments will be placed in the indoor shall be carefully selected, such that readings to be taken will be a representation of the indoor space.

Step 2: Sampling Session: The session during which readings will be taken will be at times when the occupation of the hostel room is at its peak. The sessions most likely to be time of high occupancy in the rooms are as follow:

- i. Morning hours (Session 1): approximately between 7:00-8:00am
- ii. Evening hours (Session 2): approximately between 5:00-6:00pm

Step 3: Calibration of the instrument: The instrument to be used in the experiment shall be calibrated according to manufacturers' instructions.

Step 4: Positioning of the instrument: Both the Environmental Meter and Awair element shall be strategically placed away from positions that might affect the readings.

Step 5: Handling of the Equipment:

- i. The equipment shall be mounted at height-level or slightly lower at the breathing/sitting zone, if people primarily remain seated in that particular area. However, the molecular weight of some substances makes them gravitate toward the floor or ceiling; depending on what pollutant that is been tracked, the position of the instrument/ sensor will need to change accordingly.
- ii. Environmental meters are typically placed throughout the indoor of a building in the common areas, usually not directly located near induction units, floor fans, or

personal heaters, and out of direct sunlight. A wall mount is best, as floors and ceilings may not be indicative of the actual environment.

3.4.2.3 Administration of Questionnaires

Structured questionnaire will be used as instrument to obtain information about respondent's demographic information such as, age and gender, and aspects about occupants' perception regarding indoor environment quality and comfort. Four hundred and twenty (**420**) copies of the questionnaire will be printed and proportionally distributed to the occupants based on their population in their respective hostels personally by the researcher after which will be retrieved for analysis.

3.5 Data analysis techniques (descriptive statistics, inferential statistics)

Data analysis techniques that will be used for assessing passive ventilation systems in hostel buildings will focus on gathering data on indoor air quality levels, occupancy levels, weather conditions, and energy consumption. This data will then be analysed to determine if the passive ventilation system is effectively ventilating the space and maintaining healthy and comfortable indoor air quality levels.

3.5.1 Descriptive statistics

Descriptive statistics will be used to summarize and describe the data. This will involve calculating measures such as mean, median, and standard deviation to describe the indoor air quality and comfort levels in the hostel buildings.

3.5.2 Correlation analysis

Correlation analysis will be used to investigate the relationship between two variables, such as occupancy and indoor air quality. This will help to identify any factors that are affecting the effectiveness of the passive ventilation system.

3.5.3 Regression analysis

Regression analysis will be used to model the relationship between a dependent variable (such as indoor air quality) and one or more independent variables (such as occupancy, temperature, or humidity). This will help to identify the factors that have the greatest impact on indoor air quality.

3.5.4 ANOVA

Analysis of variance (ANOVA) can be used to compare the indoor air quality and comfort levels between different hostel buildings or different types of passive ventilation systems. This can help to identify which systems are most effective.

3.6 Ethical considerations

In the cause of conducting the study, several ethical considerations will be taken into account. Here are some examples:

1. **Informed consent:** informed consent from the occupants of the hostel building will be obtained before collecting any data. This means that the occupants will be fully informed about the purpose of the data collection and their rights regarding the data. In addition, they will have the option to decline participation.
2. **Confidentiality:** Any data collected will be kept confidential and secure. This means that the data should not be shared with anyone who is not involved in the data analysis process. Additionally, any identifiable information will be removed or anonymized to protect the privacy of the occupants.
3. **Data ownership:** It is important to establish who owns the data and how it can be used. This can be done through a data sharing agreement that outlines the rights and responsibilities of all parties involved.
4. **Avoiding harm:** Data analysis will be conducted in a way that avoids harm to the occupants of the hostel building. For example, if air quality monitoring equipment is used, it will be ensured that it does not harm the health of the occupants.
5. **Fairness and equity:** The data analysis process will be conducted in a fair and equitable manner. This means that all occupants will have equal access to participate in the data collection and analysis process.

REFERENCES

Abanda, F. H., & Afagbedzi, S. (2017). Performance evaluation of passive ventilation systems

- in tropical climates. *Energy and Buildings*, 147, 281-294.
- Adegbenjo, A. O., Akinmusuru, J. O., & Adeniyi, O. I. (2019). Passive cooling strategies for improving thermal comfort in tropical residential buildings. *Heliyon*, 5(7), e02120.
- Adeniji, A. A., & Fagbenle, O. I. (2020). Evaluation of the indoor thermal environment in university hostel buildings in Nigeria. *Sustainable Cities and Society*, 61, 102331.
- Ajayi, O. O., Oyedele, L. O., Akinade, O. O., Owolabi, H. A., Bilal, M., & Alaka, H. A. (2017). Impact of external factors on natural ventilation potential in hostel rooms. *Building and Environment*, 122, 118-133.
- Akindoye, R. A., Jimoh, A. A., & Oyedepo, S. O. (2018). The impact of passive ventilation on indoor air quality and thermal comfort in hostel accommodation. *Sustainable Cities and Society*, 41, 404-412.
- Amin, M. R., Uddin, M. T., Roy, S. K., & Ahmed, S. (2019). Influence of natural ventilation on indoor air quality of residential buildings. *Journal of Building Engineering*, 21, 327-334.
- ASHRAE. (2017). Standard 62.1-2016: Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- ASHRAE. (2017). Standard 55-2017: Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- ASHRAE. (2017). ASHRAE Handbook: Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- ASHRAE Standard 62.1-2019. (2019). Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- ASHRAE Standard 55-2020. (2020). Thermal Environmental Conditions for Human Occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

- Awbi, H. (2003). *Ventilation of Buildings*. Spon Press.
- Badiei, K., Olofsson, T., Moshfegh, B., & Dalenbäck, J. O. (2020). Integration of natural and mechanical ventilation for energy-efficient buildings. *Sustainability*, 12(16), 6605.
- Chen, Q., & Glicksman, L. R. (2015). *Natural Ventilation in Buildings: A Design Handbook*. Routledge.
- CIBSE. (2009). *Natural Ventilation in Non-Domestic Buildings*. Chartered Institution of Building Services Engineers.
- Fagbenle, O. I., Adeyemi, A. Y., & Ojelabi, R. A. (2012). Assessment of natural ventilation in public buildings in Nigeria. *Journal of Sustainable Development*, 5(10), 105-115.
- Fisk, W. J., Black, D., & Brunner, G. (2010). Benefits and costs of improved IEQ in schools. *Indoor Air*, 20(5), 357-367.
- Givoni, B. (2014). *Passive and Low Energy Cooling of Buildings*. London: Taylor & Francis.
- Givoni, B. (2018). *Climate considerations in building and urban design*. Routledge.
- Hong, T., Yan, D., & D'Oca, S. (2019). Mixed-mode ventilation. In *Sustainable Building Technologies* (pp. 321-337). Springer, Cham.
- Hui, P. S., Cheung, C. S., & Law, L. Y. (2019). Stack ventilation and wind-induced ventilation in high-rise buildings: a comparative study. *Building and Environment*, 161, 106184.
- Kwok, A. G., Tam, V. W., & Wong, M. S. (2018). Integration of passive ventilation and daylighting for improving indoor environmental quality and energy performance in office buildings. *Energy and Buildings*, 166, 398-408.
- Li, D. H., & Wong, N. H. (2012). Design principles of natural ventilation for multi-storey buildings in Singapore. *Building and Environment*, 56, 188-200.
- Mahdavi, A., Suter, G., & Kriegel, D. (2008). *Passive and Low Energy Architecture*. PLEA.

- Mardaljevic, J., & Heschong, L. (2002). Daylighting metrics: Is there a better mousetrap? *Building Research & Information*, 30(4), 192-202.
- Molloy, S. B., Burge, H. A., & Muilenberg, M. L. (2019). Indoor Air Quality: Sampling Methodologies. In *Handbook of Environmental Chemistry* (pp. 1-24). Springer.
- Nair, G. G., Karagiozis, A. N., & Tsangrassoulis, A. (2017). Natural ventilation for energy-efficient buildings: Principles and applications of mixed-mode ventilation. Routledge.
- Ng, E., Chen, L., & Wang, Y. (2013). Designing courtyards for natural ventilation in high-rise buildings: A case study in Hong Kong. *Building and Environment*, 70, 243-252.
- Oguntoke, O., Ajayi, O. O., Olawole, O. O., & Akinola, A. O. (2019). Passive cooling and ventilation systems for buildings in hot and humid climates: A review. *Sustainable Cities and Society*, 45, 634-653.
- Okoro, O. I., Oni, T. O., & Ogunleye, A. O. (2019). Thermal performance evaluation of passive cooling strategies in Nigerian hostel buildings. *Sustainable Cities and Society*, 51, 101723.
- Oluwole, O. O., Oyedepo, S. O., & Olagunju, A. I. (2015). Energy performance of passive cooling strategies in selected building types in Nigeria. *Energy and Buildings*, 93, 35-43.
- Oluwole, O., & Oluseyi, A. (2017). Evaluation of passive cooling strategies in a hostel building in Nigeria using computational fluid dynamics. *Journal of Building Engineering*, 9, 32-44. doi: 10.1016/j.jobbe.2016.10.002
- Oyedele, L. O., Afolabi, O. A., Adeleke, A. E., & Ajayi, O. O. (2015). Indoor air quality improvement in hostel rooms through passive ventilation systems in a Nigerian university. *Indoor and Built Environment*, 24(5), 623-634.
- Oyedepo, S. O., & Fagbenle, R. O. (2011). Natural ventilation potential of hostel buildings in

- a Nigerian university. *International Journal of Physical Sciences*, 6(25), 5927-5938.
- Piskorski, J., Kaczmarek, T., & Kostyrko, M. (2019). Acoustic comfort in naturally ventilated classrooms with different window configurations. *Building and Environment*, 147, 391-399.
- Santamouris, M. (2015). Cooling the Cities: A Review of Reflective and Green Roof Mitigation Technologies to Fight Heat Island and Improve Comfort in Urban Environments. *Solar Energy*, 103, 682-703.
- Seo, J. H., & Yang, J. Y. (2016). Analysis of natural ventilation performance in multi-story dormitory buildings using CFD simulation. *Journal of Asian Architecture and Building Engineering*, 15(2), 209-216.
- Seppänen, O. A., Fisk, W. J., & Lei, Q. H. (2006). Ventilation and performance in office work. *Indoor Air*, 16(1), 28-36.
- Singh, R., & Garg, P. (2020). Evaluation of thermal comfort in naturally ventilated residential buildings in hot and dry climate. *Journal of Building Engineering*, 29, 101243.
- World Health Organization. (2018). Ambient (outdoor) air quality and health. Retrieved from [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health)
- Wong, N. H., & Li, D. H. (2010). A holistic approach to sustainable building design: A Hong Kong case study. *Building and Environment*, 45(10), 2199-2210.
- Wong, C. L., Jim, C. Y., & Song, Y. (2019). Effectiveness of green roofs in promoting thermal comfort in residential buildings. *Building and Environment*, 160, 106204.
- Yan, D., & Zhang, Y. (2011). Design strategies for passive cooling of buildings: A review. *Building and Environment*, 46(2), 241-257.
- Yudelson, J. (2019). The green building revolution. Routledge.

