Proactive Adaptive Ventilation and Indoor Air Quality Management in Overcrowded University Lecture Theatres in South East, Nigeria: A Review

Dominic Anosike Obodoh, Chiamaka O. Obiora and Arinze U. Okeke
Department of Building, Nnamdi Azikwe
University Awka, Anambra State, Nigeria
Corresponding Author's Email : da.obodoh@unizik.edu.ng
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Abstract
Overcrowding in university lecture theatres in South-East Nigeria has exacerbated poor Indoor Air Quality (IAQ) and inadequate ventilation, with adverse effects on students' health, comfort and academic performance. This systematic review examines the need for a proactive adaptive ventilation and IAQ management framework in this context. Literature from 2015-2025 indicates that theatres in institutions such as UNN, FUTO, and NAU often operate at over 250% of design capacity, with recorded CO2 concentrations of 2000-4000 ppm and indoor temperatures above 31°C, significantly exceeding ASHRAE 62.1 and WHO thresholds of 1000 ppm and 27°C respectively. Existing ventilation systems are largely natural, static and reactive, incapable of responding to dynamic occupancy fluctuations. Furthermore, most intelligent ventilation models are developed for temperate climates and are cost-intensive. This review synthesizes evidence on IoT sensing, predictive analytics, and adaptive control to propose a low-cost, four-layer framework encompassing data acquisition, processing and prediction, decision and control, and feedback management. The framework provides a proactive strategy for sustaining healthy learning environments in overcrowded South-East Nigerian universities.

Key Words: *Indoor Air Quality, Ventilation, Indoor Environmental Quality, lecture theatres, Thermal Comfort, University.*

1.Introduction

The education sector is widely recognized as a critical pillar in global, regional, and national development agendas aimed at improving human capital and sustainable development outcomes in developing countries. Global frameworks such as the Sustainable Development Goals (SDGs, 2015–2030), particularly Goals 3 (Good Health and Well-being) and 4 (Quality Education), as well as continental initiatives such as the African Union Agenda 2063, emphasize the need for safe, inclusive, and effective learning environments. At the national level, Nigeria's education policies continue to promote increased access to tertiary education, leading to rising student enrolment across public universities. However, this expansion has not been matched by proportional growth in physical infrastructure, resulting in overcrowded university lecture theatres with inadequate ventilation and poor indoor air quality (IAQ). Overcrowding in enclosed learning spaces poses significant risks to students' health, comfort, cognitive performance, and disease transmission,

thereby undermining the objectives of quality education. The absence of proactive and adaptive ventilation strategies in many public universities has raised concerns about the capacity of existing lecture theatre environments to support effective teaching and learning under increasing occupancy pressures. Globally, research indicates that indoor air pollution contributes substantially to adverse health outcomes, with poor ventilation identified as a major risk factor in densely occupied indoor environments. The World Health Organization (WHO) in 2025 reports that exposure to poor indoor air quality is responsible for millions of preventable illnesses annually, while studies in educational settings show that elevated carbon dioxide (CO_2) levels above recommended thresholds are associated with reduced concentration, impaired decision-making, and lower academic performance. Asaju (2026) investigated the frequent experiences of students in lecture theatre occupancy levels and the study revealed that the occupancy levels far exceeded the design capacity due to increased enrolment and limited infrastructure expansion. Empirical studies in tertiary institutions within Sub-Saharan Africa have documented CO_2 concentrations well above internationally recommended limits during lecture periods, reflecting inadequate ventilation and limited air exchange. Despite these documented risks, most university lecture theatres continue to rely on static or non-responsive ventilation approaches that do not account for fluctuating occupancy levels or real-time indoor air conditions.

The quality of the air we breathe is a fundamental aspect of our overall health and well-being, and this is particularly true in educational settings where students and lecturers spend a significant portion of their day. University lecture theatres, in particular, pose a unique challenge due to their high occupant density, variable usage patterns, and often inadequate ventilation systems. In Nigeria, where the tropical climate can exacerbate indoor air quality (IAQ) issues, the need for effective IAQ management is paramount.

The well-being of individuals in an educational setting should be given utmost priority, as indoor air pollution has emerged as one of the top five environmental risks to public health worldwide (Tran et al, 2020). These environmental risk in recent years, has birthed the concern over poor indoor air quality (IAQ) with alarming consequences for the health of its population globally especially in Europe (González-Martín et. al 2021). While in Nigeria, due to the tropical climates, high temperature, humidity and poor ventilation are stressors of poor indoor air pollutant build-up. These pollutants are considered to be unacceptable in an enclosed space. The America Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE,1999) defined acceptable IAQ as “air in which there are no known contaminants or harmful concentrations as determined by cognizant authorities and with which a substantial majority of the people exposed do not express dissatisfaction”. Meanwhile, International guidelines World Health Organization (WHO) and ASHRAE have emphasized adequate ventilation as IAQ critically affects health and cognitive function since people spend most of their time indoors (Ode et. al 2020) and studies consistently link poor classroom IAQ to respiratory problems, headaches, fatigue and lowered test scores (Wolkoff et al., 2021).

Poor IAQ is a significant concern worldwide, with the World Health Organization (WHO) estimating that it is responsible for approximately 1.6 million premature deaths annually (Wolkoff et al., 2021). In educational settings, the consequences of poor IAQ are far-reaching, impacting not only the health and well-being of students and lecturers but also academic performance and productivity. Symptoms of poor IAQ include respiratory problems, headaches, discomfort, and decreased cognitive function, all of which can negatively impact learning outcomes.

Despite the importance of IAQ, many universities in Nigeria struggle to provide a healthy and comfortable learning environment. Overcrowding, inadequate ventilation, and lack of effective IAQ monitoring systems are common challenges faced by these institutions. The consequences of poor IAQ are often addressed reactively, with measures taken only after complaints arise, rather than proactively managing IAQ to prevent issues from occurring in the first place (Adio-Moses 2016) Recent advances in sensor technology, data analytics, and building automation systems have created opportunities for proactive IAQ management. Predictive frameworks that integrate real-time IAQ monitoring, data analytics, and adaptive ventilation strategies have been shown to be effective in maintaining good IAQ in various building types. However, the application of these technologies in Nigerian universities is still in its infancy, and there is a need for research that focuses on developing context-specific solutions for IAQ management in overcrowded university lecture theatres (Ode et al, 2020)

This study aims to address this gap by developing a predictive framework for proactive IAQ management and adaptive ventilation in overcrowded university lecture theatres in Nigeria. The framework will leverage real-time IAQ data, machine learning algorithms, and building automation systems to enable universities to anticipate and mitigate IAQ issues, optimize ventilation systems, and create a safe and productive learning environment for all occupants. The findings of this study will contribute to the development of effective IAQ management strategies in Nigerian universities, with potential applications in other educational institutions and building types.

2. Literature Review

Definition of Indoor Environmental Quality (IEQ)

IEQ is an essential element that can affect occupants in a building, especially in school settings where students spend so much time. IEQ refers to the quality of a building's indoor environment as assessed through various physical, chemical, and biological and psychosocial factors. These include IAQ (e.g., volatile organic compounds (VOCs), carbon dioxide (CO2), thermal comfort, lighting, acoustics, ventilation effectiveness, humidity, odors, presence of biological agents (such as mold and allergens), and elements influencing psychological comfort and stress, such as noise levels, visual privacy, and occupants perceived control over their environment (Toyinbo, 2023). According to Toyinbo (2019), IEQ and IAQ are sometimes used to mean the same thing in some literature whereas there are fundamental differences between the two terms. IAQ only deals with the indoor air condition and its effect of building occupants while IEQ deals with the entire indoor environmental condition which includes IAQ, noise, temperature, lighting, relative humidity etc. Thus, IAQ is a subset of IEQ. Kubba (2010) defines IEQ as the combined influence of IAQ, lighting, thermal conditions, and acoustics on occupants' health and productivity, emphasizing its physical components. However, more recent school based research has highlighted that students' perceptions and psychological responses to IEQ conditions also play a significant role. For example, a large Finnish study involving over 8,700 primary school pupils (grades 3 to 6) and more than 3,400 secondary school pupils (grades 7 to 9) found that psychosocial 6 factors such as worry about IEQ, school satisfaction, and personality traits like neuroticism were significantly associated with reported symptoms, even when expert assessed physical IEQ conditions were considered (Savelieva et al., 2020). In some cases, particularly among secondary school pupils and parents, psychosocial factors explained more of the variation in symptom reporting between schools than physical IEQ. This suggests that the psychological dimension of IEQ is important in

understanding its impact on student well-being. According to Baird (2010), IEQ refers to the overall condition of a building's interior environment as it relates to occupant health, comfort, and performance. This definition argues that IEQ is not limited to IAQ and acoustic conditions but also includes access to daylight, views, and occupant control over features such as lighting and temperature. Baird (2010) further emphasizes that functional building elements such as an accessible and adequate spatial layout are integral components of IEQ. This is particularly relevant in educational settings where efficient space utilization is essential. For example, Barrett et al. (2015) conducted a large-scale study of UK primary schools and found that IEQ factors such as lighting, thermal comfort, air quality, and spatial flexibility significantly influence student learning outcomes. Their findings highlight that students typically occupy less space per person than adults in office environments, making well-designed classrooms important for supporting both comfort and performance. Therefore, the study of IEQ in schools goes beyond environmental comfort and must align with the operational and pedagogical demands of educational institutions. IEQ improvements should enhance learning conditions without disrupting routines or significantly increasing costs. Figure 1 represents some components of Indoor Environmental Quality (IEQ).

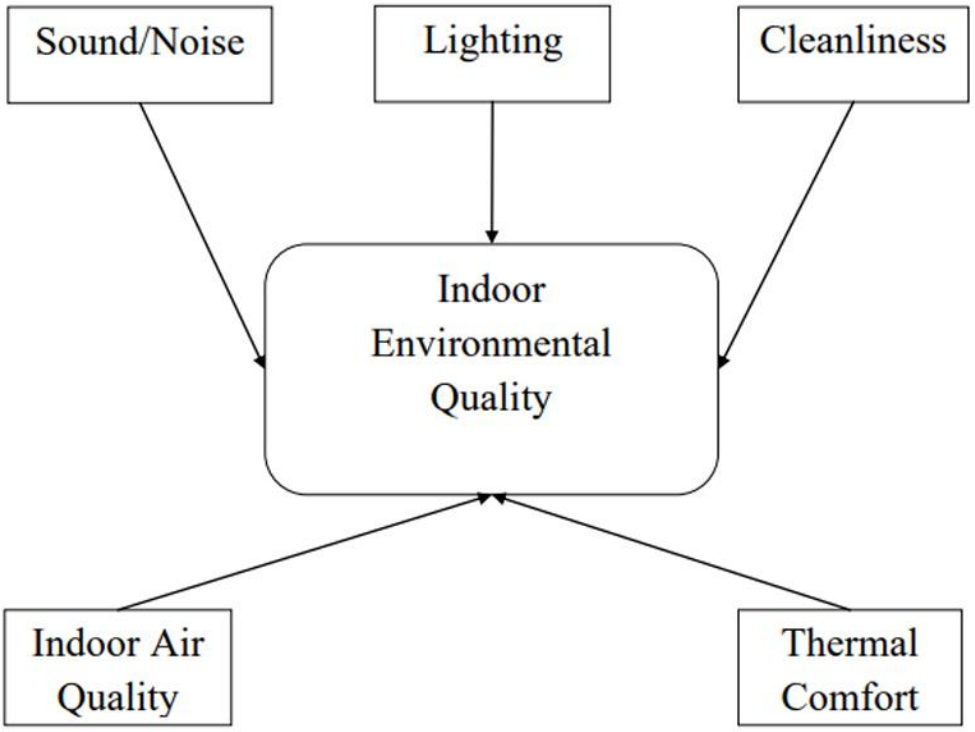


Figure 1: Components of IEQ (Toyinbo, 2012)

Indoor Air Quality

IAQ index encompasses four main aspects: thermal comfort, indoor air quality (IAQ), visual comfort, and acoustic comfort. It plays a crucial role in ensuring the comfort, health, and wellbeing of occupants in buildings (Korsavi et al. 2020). Many school buildings face various challenges regarding the thermal environment and indoor air quality. A report from the Public Health Agency

of Sweden indicated that 15% of Swedish schools were classified as having a 'bad' or 'poor' IAQ Index (Cabovska et al. 2022). Inadequate IAQ can result in Sick Building Syndrome (SBS), which presents symptoms such as feeling cold, experiencing headaches, dizziness, confusion, nausea, fatigue, respiratory problems, and irritation of the eyes, throat, nose, and skin. Furthermore, AQI significantly impacts buildings' lifecycle costs and energy consumption (Korsavi et al. 2020). Sufficient IAQ can be achieved through incorporated ventilation systems (Elsaid & Ahmed 2021). The primary objective of ventilation is to remove or diminish the concentration of pollutants in the air, which can originate from building materials, occupants, and indoor activities (Liu et al. 2017). Ventilation rates specific to indoor environments are defined by international and national standards and legal regulations (Cabovská et al. 2022). According to Montazami et al. (2015), It's essential to ensure that classrooms provide maximum comfort in every aspect, as the learning experience involves multiple senses like hearing, speaking, and visualizing. Hence, improving the Indoor Air Quality (IAQ) index is vital for boosting productivity and performance. Failing to address thermal comfort issues may compromise learning and academic activities due to discomfort or distractions (Singh et al. 2019). De Giuli et al. (2012) conducted a study on Indoor Environment Quality in primary schools in Italy. Their findings highlighted significant issues such as excessively high levels of CO2, inadequate lighting, uncomfortable thermal conditions, and acoustic discomfort as the primary concerns observed in the studied schools. Further, Turanjanin et al. (2014) investigated IAQ and its impact on students' health in Finland. They found a significant statistical correlation between temperature and self-reported poor IAQ. Additionally, lower ventilation rates and higher temperatures were associated with more reports of unsatisfactory indoor air quality by students (Turanjanin et al. 2014). The study by Ghita and Catalina (2015) aimed to assess the indoor AQI in three different types of rural schools (old, new, and renovated) over an extended period from autumn 2013 to spring 2014. The researchers used long-term measurements and spot recordings to evaluate Indoor Environment Quality (IEQ). The findings revealed that the new and renovated buildings rank class C on the IEQ index scale, whereas the old building is rated D class (IEQ). Catalina and Iordache (2012) carefully selected IEQ index thresholds to represent different IEQ classes optimally. Class A classification is assigned to IEQ index values exceeding 90, while Class B includes IEQ index values falling between 67.5 and 90. For Class C, IEQ index values range from 32.5 to 67.5, Class D contains IEQ index values between 10 and 32.5, and any IEQ index below 10 is categorized as Class E. Furthermore, Indoor air pollutants emanate from various indoor sources, such as smoking, cooking, building materials, furnishings, space heaters, pesticides, personal care products, office equipment, cleaning agents, and paints (Rivas et al., 2019). Additionally, outdoor sources, including fuel combustion processes in power plants and industrial facilities, vehicular traffic, biomass burning, and the re-suspension of road dust, contribute to indoor air pollutants (World Health Organization, 2021). Table 1 shows the Common indoor air pollutants, their potential sources, and their effects on human health.

Table 1 Indoor air pollutants, their potential sources, and their effects on human health

Pollutants	Source	Health effects	References
Particular Matter (PM)	Transport, smoking, cooking, heating, candles and incense burning, cleaning, and personal care products.	Allergies, discomfort, eye, nose and throat irritation, bronchitis, cardiovascular diseases, respiratory diseases, Asthma, lung cancer and heart attacks	(Abdel-Salam, 2022; Hamanaka & Mutlu, 2018; Li et al., 2017)
Carbon Monoxide (CO)	Cooking stoves, smoking, traffic emissions, vehicle exhaust	Headache, nausea, fatigue, chest pain, reduced brain function, impaired vision and coordination, dizziness, and reduced brain functioning	(Hoskins, 2011; (Maynard, 2019)
Carbon Dioxide (CO_2)	Combustion emissions, metabolic activities, and smoking, cooking, and heating.	headache, sleepiness, fatigue, and concentration difficulty	(Azuma et al., 2018; Zhang et al., 2017)
Nitrogen Dioxide (NO_2)	Gas-fuelled cooking and heating appliances	Increased asthmatic reactions, respiratory damage, and airway inflammation	(Salonen et al., 2019; Weichenthal et al., 2007)
Ozone (O3)	Outdoor sources, photocopiers, disinfecting devices, air purifiers, and printers	DNA damage, Chest pain, cough, asthma, lung inflammation, airway narrowing, and decreased respiratory functions.	(Huang et al., 2019; Salonen et al., 2018)
Volatile Organic Compounds (VOCs)	Paints, varnish, wood preservatives, aerosol sprays, cleaning products, consumer products, cosmetics, pesticides, adhesives, paints, dyes, polishes, dry-cleaned cloths, lubricants, smoking, perfumes, office equipment such as laser printers and photocopiers	Eye, nose and throat irritation, nausea, loss of coordination, asthma, bronchial hyper-reactivity, damage to the liver, kidney and central nervous system, respiratory illness, and cancer	(Huang et al., 2011; Tang et al., 2015)

Lighting

Lighting is an essential factor that influences both the physical and psychological aspects of the learning environment. Effective classroom lighting involves a balanced combination of natural daylight and artificial illumination that ensures adequate brightness, uniform distribution, minimal glare, and low flicker. According to the European Standard EN 12464.1, illuminance levels of 300 to 500 lux are recommended for general classroom tasks, with up to 750 lux for visually demanding

activities. In addition, appropriate lighting should maintain good colour rendering (CRI ≥ 80) and a correlated colour temperature (CCT) of 4000K to 5000K to mimic natural daylight. The Chartered Institution of Building Services Engineers (CIBSE, 2011) also recommends a minimum of 300 lux in classroom settings. From a sustainability perspective, maximizing the use of daylight through well placed windows and skylights can reduce reliance on artificial lighting and lower energy consumption. This approach is particularly relevant in regions affected by energy poverty or where financial constraints limit investment in lighting infrastructure. For example, Booysen (2021) reported that many classrooms in South Africa experience inadequate natural and artificial lighting, reinforcing the need for efficient and context sensitive solutions. However, daylight must be controlled to avoid issues such as glare or overheating, commonly mitigated through shading devices and light shelves (Konstantoglou & Tsangrassoulis, 2016). When artificial lighting is necessary, energy efficient LED systems are recommended due to their long lifespan (up to 50000 hours), low energy demand, and compatibility with occupancy and daylight sensors (Powers & Saad 2022; Chakraborty et al., 2023). Booysen et al. (2021) found that lighting accounted for 31% to 57% of annual electricity costs in South African schools before LED retrofits. Following LED installation, total electricity bills were reduced by 21% to 39%, and the lighting share of electricity usage fell to between 12% and 30%, demonstrating the cost effectiveness of such upgrades in under resourced educational settings. In designing learning environments, it is also important to incorporate biophilic design principles such as maximizing access to natural light and outdoor views, and adaptive lighting controls that allow teachers and students to adjust brightness levels based on task and time of day. Determan et al. (2019) found that classrooms featuring dynamic daylight, nature views, and adjustable lighting reduced stress and improved attention and cognitive function. Overall, sustainable lighting strategies can support student well-being, enhance learning performance, and align with broader environmental and energy efficiency objectives.

Thermal Comfort, temperature and relative humidity

Thermal comfort refers to "the condition of mind that expresses satisfaction with the thermal environment" (ASHRAE Standard 55, 2023). It is influenced by a combination of environmental and personal factors, including air temperature, relative humidity, air velocity, clothing insulation, and metabolic activity. In school environments, achieving thermal comfort is essential because discomfort caused by temperature extremes can impair students' concentration, reduce academic performance, and increase fatigue or restlessness (Haverinen-Shaughnessy & Shaughnessy, 2015; Wargocki et al., 2019; Toyinbo, 2023). Temperature is one of the most critical components of thermal comfort. While 10 perceptions of comfort vary among individuals, ASHRAE Standard 55 (2023) recommends maintaining indoor temperatures between 20°C and 24°C during winter, and between 23°C and 26°C during summer, depending on clothing and activity levels. In tropical regions such as Nigeria, indoor temperatures between 20°C and 25.5°C have been suggested as optimal for comfort in educational settings (NESREA, 2014). This range may also be appropriate for similar climatic zones, such as the coastal regions of Tanzania, including Dar es Salaam, where environmental conditions closely resemble those in southern Nigeria. Relative humidity also plays a crucial role in thermal comfort. Extremes in humidity can amplify the sensation of heat or cold and affect IAQ by influencing the transmission and survival of airborne pathogens (Aune et al., 2021; Romero et al., 2022). ASHRAE Standard 62.1 (2022) recommends an upper limit of 65% for indoor relative humidity to minimize microbial growth and maintain acceptable IAQ. While no lower limit is prescribed, several studies associate levels below 30% with dryness of mucous

membranes, respiratory discomfort, and increased risk of airborne viral transmission. In Nigeria, where climatic conditions are similar to those in Tanzania, indoor relative humidity that ranges between 40% and 70% is considered acceptable for comfort and health in school environments (NESREA, 2014). Maintaining thermal comfort in classrooms is particularly important in naturally ventilated buildings or in regions with limited access to heating, ventilation, and air conditioning (HVAC) systems. In such settings, passive design strategies such as shading, thermal mass, cross-ventilation, and building orientation are essential for moderating indoor temperatures and ensuring occupant comfort throughout the school day. This is particularly relevant in schools located in tropical climates, where incoming warm air is often unconditioned. A study by Toyinbo et al. (2019) demonstrated this in Nigerian primary schools, where the indoor-to-outdoor (I/O) temperature ratio was approximately 1.0, with mean indoor temperatures around 30.6°C and outdoor temperatures around 31.6°C. The minimal difference indicates that the school buildings provided little to no thermal buffering from outdoor heat, resulting in uncomfortable indoor conditions. It should also be noted that many classrooms assessed in the study had poor ceiling conditions and degraded building materials, which may have further contributed to the 11 lack of insulation and thermal protection. While some research on thermal comfort exists for the East African context, most studies conducted in Tanzania have focused on urban outdoor thermal comfort, particularly in relation to public spaces and pedestrian environments (Eyre et al., 2017; Baruti et al., 2020; Baruti et al., 2024). There is a notable lack of empirical data on indoor thermal conditions in schools, where resource constraints and climatic challenges may significantly affect learning environments. This gap highlights the need for further investigation into indoor thermal comfort in Tanzanian schools, using locally relevant benchmarks and considering passive design strategies, building materials, and the seasonal variability of thermal conditions.

Acoustics/Noise/Sound

Noise, commonly defined as unwanted or disruptive sound, is a key component of IEQ and plays important roles in learning environments. According to the World Health Organization, "physically, there is no distinction between sound and noise. Sound is a sensory perception and the complex pattern of sound waves is labeled noise, music, speech etc. Noise is thus defined as unwanted sound" (Berglund et al., 1999). In classrooms, noise interferes with speech intelligibility, concentration, and cognitive processing, particularly for younger students, nonnative language learners, and those with hearing impairments (Shield & Dockrell, 2003; Abdullah et al., 2021). Controlling environmental noise has been more challenging than managing other pollutants, partly due to limited understanding of its health effects and the absence of clearly defined exposure response criteria. Although noise pollution is sometimes viewed as an issue primarily affecting developed nations, the reality is that exposure levels are often higher in developing countries. This is largely due to inadequate urban planning and substandard building design. As a result, the health impacts of noise, both immediate and long term, are equally relevant in these settings. Effective management of environmental noise therefore requires evidence-based strategies that are grounded in sound scientific data, including research on exposure levels and associated health outcomes. These efforts should be framed within structured risk assessment and risk management processes (Berglund et al., 1999). The WHO (2011) recommends that background noise levels in classrooms should not 12 exceed 35 dB(A) during teaching activities to allow for effective verbal communication. Specific limits for reverberation time have also been established in some instances to ensure clear speech transmission. For example, Building Bulletin 93 (BB93, 2015), a UK

government guideline that specifies minimum acoustic performance standards for schools, recommends that nursery and primary classrooms have reverberation times no greater than 0.6 seconds in new buildings and 0.8 seconds in refurbished buildings, while secondary classrooms should not exceed 0.8 seconds and 1.0 second respectively. However, studies have shown that actual noise levels in many schools, particularly in low- and middle-income countries, exceed these limits due to external sources such as traffic and playgrounds, poor building design, and inadequate acoustic treatment (e.g., Quartey et al., 2021; Amoatey et al., 2023). Despite this evidence, acoustics is often one of the most neglected aspects of school design, particularly in resource limited contexts. Poor acoustics can diminish academic performance and increase teacher vocal strain and fatigue (Nusseck et al., 2022; Moreno et al., 2025). As such, incorporating cost effective acoustic design such as strategic layout of classrooms, use of local sound absorbing materials, and proper window and door sealing is essential for fostering a conducive learning atmosphere.

Measurement of Indoor Air Quality (IAQ) in Educational Settings

Indoor air quality (IAQ) has become a critical concern in educational buildings due to its direct implications to health, comfort, and academic performance. Students and staff spend extended periods indoors, making classrooms and lecture theatres high-risk environments for pollutant accumulation when ventilation is inadequate (González-Martín et al., 2021). Common indoor pollutants in educational spaces include carbon dioxide (CO_2), particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), temperature, and relative humidity, all of which influence occupants' physiological and cognitive responses (WHO, 2021).

Previous studies consistently report that IAQ in higher-education classrooms often fails to meet international guidelines, particularly in densely occupied spaces. Ode et al. (2020) observed that university buildings in tropical regions experience elevated indoor temperatures and humidity, which exacerbate pollutants build-up and thermal discomfort. Similarly, González-Martín et al. 2021) identified poor ventilation as a major contributor to indoor pollutant concentration across public buildings, including educational facilities.

The Measurement of IAQ in educational environments typically involves continuous or spot monitoring of CO_2 concentration, particulate matter, temperature, and humidity using calibrated indoor air quality monitors. CO_2 concentration is widely used as a proxy for ventilation adequacy and occupancy density (Persily, 2022). Research has shown that sustained CO_2 levels above 1,000 ppm indicate insufficient outdoor air supply and are commonly recorded in overcrowded classrooms (ASHRAE, 2016).

Advanced studies have employed tracer gas decay methods and sensor networks to assess air-change rates and ventilation effectiveness in lecture halls (Corsi et al., 2022). These approaches enable the identification of under-ventilated spaces and provide evidence for the need for adaptive ventilation strategies. In developing countries, however, most universities rely on basic monitoring approaches due to limited infrastructure, resulting in delayed detection of poor IAQ conditions (Ode et al., 2020).

Overcrowding and Ventilation Performance

Overcrowding is a dominant factor influencing IAQ in university lecture theatres, especially in public institutions where enrolment growth has outpaced infrastructure development. High occupancy density reduces the per-capita ventilation rate, leading to rapid accumulation of CO_2 and other pollutants (ASHRAE, 2016). Toyinbo et al. (2019) reported that classrooms with

occupancy levels exceeding design capacity consistently recorded CO_2 concentrations above recommended thresholds.

In the Nigerian context, overcrowding is exacerbated by aging infrastructure and reliance on natural ventilation systems, which are highly dependent on outdoor conditions and user behaviour. Ode et al. (2020) observed that naturally ventilated university buildings often experience stagnant indoor air during peak lecture periods, particularly in hot and humid climates. These conditions increase the risk of airborne disease transmission and thermal discomfort, underscoring the need for proactive ventilation control in overcrowded lecture theatres.

Adaptive and Proactive Ventilation Strategies

Adaptive ventilation systems have been proposed as effective solutions for maintaining acceptable IAQ under varying occupancy conditions. Demand-controlled ventilation (DCV), which adjusts airflow based on real-time CO_2 levels or occupancy, has been shown to improve indoor air quality while reducing energy consumption (Al Assaad et al., 2022). Such systems respond dynamically to fluctuations in lecture theatre occupancy, making them particularly suitable for overcrowded educational environments.

Studies also highlight the role of supplemental air cleaning and filtration in poorly ventilated spaces. Corsi et al. (2022) demonstrated that the use of portable air cleaners significantly reduced pollutant concentration in classrooms with inadequate mechanical ventilation. These findings support the integration of sensor-based monitoring, adaptive ventilation, and filtration into a comprehensive IAQ management approach for universities.

Assessment of indoor air quality

The assessment of IAQ is varied and can be approached from different angles. This is reflected in the opinion that IAQ can be described as "a domain rather than a discipline" (Nazaroff et al., 2003), as investigations generally begin with a concern or issue followed by research into how to address the problem. A holistic approach to IAQ assessment may be beneficial (Bluyssen, 2009) as the comfort of the occupants is the main reason for any IAQ assessment. In the built environment, the assessment of IAQ can involve different methods. The assumption that indoor conditions are well mixed is used in several IAQ assessment methods. These approaches assume that air entering the space is instantly and completely mixed with the air already present. Consequently, any pollutant concentration, temperature or humidity are considered to be the same at all points in the space (Waters and Simons, 2002). Indoor air quality in lecture theatres has not been studied as much as in other building types. In universities, the IAQ comfort provided in lecture theatres is frequently inadequate, as the delivery of adequate thermal comfort is a priority. For that reason, the way IAQ is assessed specifically in lecture theatres was selected as a research data

3. Methodology

The study adopts a Systematic Literature Review (SLR) guided by PRISMA 2020 protocol to establish the state-of-the-art and research gap.

The study area is South-East Nigeria, comprising five states: Abia, Anambra, Ebonyi, Enugu, and Imo. The region is located within the hot-humid tropical rainforest zone with mean annual temperature of 27-32°C and relative humidity of 70-85%. It was selected due to high tertiary education demand and documented overcrowding. Case study institutions will include:

1. University of Nigeria, Nsukka (UNN) - Enugu State

2. Federal University of Technology, Owerri (FUTO) - Imo State
3. Nnamdi Azikiwe University (NAU), Awka - Anambra State
4. Ebonyi State University (EBSU), Abakaliki – Ebonyi State
5. Abia State University Uturu, Abia State

These universities have large general lecture theatres with design capacity of 150-300 but accommodate 400-700 students during GST courses.

The population of the review is all peer-reviewed articles on IAQ, ventilation, and overcrowding in educational buildings from 2015-2026.

4. Results and Discussions

A total of 687 records were identified from 4 databases: Scopus (214), Web of Science (156), ScienceDirect (132) and Google Scholar (185). After removing 145 duplicates, 542 titles and abstracts were screened. 98 full-text articles were assessed for eligibility. Finally, 52 articles met inclusion criteria and were included for synthesis.

Peer-reviewed articles from 2015-2025 that focused on IAQ, ventilation, CO2, overcrowding in higher education lecture theatres; studies from Nigeria/South-East Nigeria and comparable tropical climates were included in the review. Review shows current strategies are *static, reactive and manual: *

The review shows that 100% of South-East studies reported natural ventilation as primary mode. Effectiveness depends on wind and occupant behaviour (opening windows). In overcrowded condition, air changes per hour (ACH) drops to 0.8-1.5 ACH vs required 6-8 ACH.

It was observed that Ventilation is triggered after complaints of stuffiness are reported and not before. No predictive capability.

Where ceiling fans exist (IMSU, FUTO), they only circulate hot air, they do not introduce fresh air and there is no Demand Controlled Ventilation (DCV).

The Existing Adaptive/Proactive Frameworks show that 18 are designed for temperate climates where focus is energy saving, not overcrowding cooling while 15 use expensive BMS (Building Management Systems) costing $5,000-15,000 - not feasible for South-East Nigerian universities with limited TETFund intervention.

There are only 2 integrated PM2.5 sensing, critical for South-East during harmattan dust and none integrated four features needed for South-East such as: (a) low-cost IoT (b) overcrowding factor (c) predictive (proactive) model (d) filtered air intake for dusty tropical climate.

The convergence of three factors makes South-East unique: (i) Highest enrollment pressure due to high demand for federal universities (UNN, FUTO) (ii) Hot-humid climate (27-33°C, 75-85% RH) that increases metabolic CO2 production (iii) Harmattan dust and open burning increasing PM2.5. Foreign frameworks ignoring these will fail.

The finding that CO2 exceeds 1000ppm within 18-25 minutes of lecture start (from pooled data) means students spend >70% of lecture time in impaired cognitive state. Satish et al. (2012) showed 15-50% reduction in decision-making performance at 2500ppm - which aligns with subjective complaints of drowsiness and difficulty concentrating reported in 8 of 11 South-East studies.

Literature from UK (Wargocki et al., 2019) and China shows adaptive systems reduce CO2 by 40-60%. However, they are reactive - they act after CO2 exceeds threshold. Our synthesis shows proactive approach (predicting CO2[t+Δt]) is superior for overcrowded settings because it prevents accumulation rather than correcting it. With occupancy of 500+, delay of even 10 minutes leads to rapid spike from 1000 to 2500ppm.

The reviewed Nigerian studies (Owolabi et al 2024, Ode 2023) recommend mechanical ventilation but ignore cost and power outage realities. Our synthesis justifies the proposed 4-layer PAV-IAQ framework: Layer 1 (low-cost ESP32 + MH-Z19B ~ $50 per theatre) vs BMS $5000, Layer 2 (LSTM/ARIMA prediction) enables proactiveness, Layer 3 (3-condition logic with PM2.5 filter check) addresses harmattan peculiarity, Layer 4 (traffic-light dashboard + SMS) addresses low technical skill of facility staff in South-East universities.

In essence, results prove that while IAQ crisis in South-East Nigerian lecture theatres is well-documented, solution frameworks are absent. Existing solutions are not transferable without adaptation. This justifies development of a proactive, adaptive, low-cost, and dust-aware framework.

5.Conclusion and Recommendations

This review has established that overcrowding in university lecture theatres in South-East Nigeria constitutes a critical Indoor Air Quality (IAQ) crisis that directly undermines effective teaching and learning. Evidence from UNN, FUTO, EBSU, NAU and ABSU reveals that occupancy levels frequently exceed design capacity by 150-300%, resulting in CO2 concentrations of 2000-4000 ppm, indoor temperatures above 31°C and elevated PM2.5 during harmattan, all of which far exceed the ASHRAE 62.1 (1000 ppm) and WHO acceptable limits.

The study confirms that the prevailing ventilation strategy in South-East Nigerian universities - predominantly fixed natural ventilation via windows and doors - is static, reactive and grossly inadequate for dynamic overcrowded conditions. It operates on a binary principle rather than an adaptive, load-responsive mechanism.

Furthermore, literature analysis shows that existing smart ventilation frameworks are largely developed for temperate, energy-saving contexts in Europe and North America, and are characterized by high cost and complex Building Management Systems (BMS) that are not feasible for resource-constrained Nigerian universities.

The proposed four-layer Proactive Adaptive Ventilation and IAQ Management Framework (PAV-IAQ) - comprising (1) Data Acquisition, (2) Processing and Prediction, (3) Decision and Control, and (4) Feedback and Management - offers a paradigm shift from reactive to proactive control. By predicting IAQ deterioration before threshold exceedance and adaptively modulating ventilation, the framework provides a low-cost, IoT-enabled, and sustainable solution tailored to the hot-humid and dusty tropical conditions of South-East Nigeria.

Based on the findings of this review, the following recommendations are made:

IAQ monitoring should be integrated as a key performance indicator for lecture theatre accreditation and TETFund intervention projects in South-East universities by the university management. Allocation should prioritize low-cost IoT-based ventilation retrofits over construction of new static halls alone.

Future implementation of the PAV-IAQ framework in South-East Nigeria should incorporate dust filtration (PM2.5 filters) in motorized louvers to address harmattan dust ingress, and integrate solar-powered backup to mitigate frequent power outages.

A proactive maintenance culture should be adopted where facility managers utilize real-time dashboards and SMS alerts for early intervention, rather than responding only after student complaints or health incidents.

Future research should move beyond assessment to experimental prototyping and validation of the PAV-IAQ framework in selected overcrowded theatres in UNN and FUTO, with quantitative measurement of its impact on CO2 reduction and students' cognitive performance.
The National Universities Commission (NUC) and NESREA should develop and enforce a specific national guideline for minimum ventilation rates and maximum CO2 thresholds in tertiary educational buildings, as currently no enforceable local standard exists.

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