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Evaluation of the Efficacy of Smart Building Systems in Enhancing Indoor Air Quality and Occupant Well-Being in Asaba

***OBI, N. U.*[1,*], *OJOH, C. O.*[2]**

[1]*Department of Building, Dennis Osadebay University, Asaba, Delta State, Nigeria*

[2]*Department of Urban and Regional Planning, Dennis Osadebay University, Asaba, Delta State, Nigeria*

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ABSTRACT

Evaluation of smart building systems in Asaba addresses persistent indoor air quality problems that expose occupants to elevated CO_2, particulate matter, volatile organic compounds, temperature fluctuations, humidity extremes, and noise, affecting sleep, cognitive function, and well-being. This study aimed to assess whether automated systems improve environmental quality, occupant health, and energy efficiency across residential, commercial, industrial, and institutional buildings. A quasi-experimental comparative design was applied to six automated and five conventional buildings. Measurements of CO_2, PM2.5, PM10, formaldehyde, benzene, toluene, temperature, relative humidity, and noise were conducted during wet and dry seasons using calibrated sensors, DustTrak II monitors, HOBO data loggers, and sound level meters. Occupant health outcomes included sleep duration, sleep efficiency, wake episodes, sick building syndrome symptoms, and cognitive performance, assessed with actigraphy and standardized neurocognitive tests. Automated buildings-maintained CO_2 below 640 ppm, PM2.5 below 11 µg/m³, and VOCs below 23 ppb, while conventional buildings exceeded WHO and ASHRAE thresholds. Sleep duration improved by over one hour, sleep efficiency increased to 92 percent, and SBS symptoms decreased by more than 50 percent in automated residences. HVAC energy use in automated buildings remained below 65 kWh/m² per year, demonstrating efficiency alongside improved indoor air quality. These results show that smart systems enhance environmental control, protect occupant health, and support cognitive function. The study provides empirical evidence for policy adoption of automated IAQ management, retrofitting conventional buildings, and integrating indoor environmental quality standards in urban planning in Asaba.

1. INTRODUCTION

People spend up to 90 percent of their time indoors, yet many still breathe polluted air in buildings fitted with automated control systems, reporting fatigue and respiratory problems despite the promise of healthier environments. This contradiction questions whether such systems deliver real benefits for indoor air quality and occupant health. In Asaba, Nigeria, tropical humidity, erratic power supply, heavy use of diesel generators, uncontrolled outdoor emissions, and weak enforcement of building standards produce indoor environments that often undermine occupant health and comfort. Global

*Corresponding author, e-mail: collins.ojoh@dou.edu.ng, eyetantega@yahoo.com
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research shows indoor environmental quality matters. In the Harvard CogFX study, reducing CO_2, VOCs, and fine particulates produced measurable gains in cognitive test performance among office workers across multiple countries (Allen *et al.,* 2016). Studies by Meegahapola and Prabodanie (2018) linked temperature, humidity, and noise to comfort, productivity, and health outcomes. At the same time, investigations into automated and responsive control systems show promise. For example, deep learning models have been applied to predict indoor environmental quality in adaptive building systems (Minassian *et al.*, 2025). Other work relates building automation systems to HVAC performance and indoor air outcomes (Homod, 2018; O'Grady *et al.*, 2021).

In the Nigerian context, scholars have reported elevated indoor pollutant levels in residential, educational, and healthcare buildings. A study in Ibadan showed mean PM_{10} concentrations in some low-density residential areas exceeding national guidelines (Abiodun *et al.,* 2023). Assessments of health centres in Nigeria confirmed that particle counts inside treatment spaces often exceed recommended levels (Abulude *et al.*, 2024). But most studies remain limited by focusing on single building types, or by isolating pollutant measurements without linking them to occupant health or system energy performance. No known study in Asaba has compared indoor conditions across residential, commercial, industrial, and institutional buildings under automated control systems. Few investigations in Nigeria link indoor environmental quality to occupant outcomes such as sleep quality, cognitive performance, or sick building syndrome symptoms. Even fewer explore energy efficiency of the control systems and how energy trade-offs influence air quality and occupant health. That gap leaves unanswered whether automated systems in Nigerian buildings deliver net benefit or just shift burdens.

The study addresses the gap in the Asaba urban setting. It treats buildings under automated control systems as an intervention to test, not an assumed solution. It explores variation across building types in one climate zone, and it connects environmental measurement to occupant health and energy performance, thus integrating environmental, human, and systems analysis. It contributes evidence from the African context to a mostly Western literature base. This study sets out three objectives. It evaluates indoor air quality parameters (CO_2, particulate matter, volatile organic compounds, humidity, temperature, noise) across residential, commercial, industrial, institutional buildings in Asaba. It examines how indoor environmental conditions relate to occupant outcomes such as sleep quality, cognitive performance, and sick building syndrome symptoms. It assesses the energy efficiency of automated building systems in Asaba and analyses their influence on indoor air quality and occupant well-being.

2. CONCEPTUAL ISSUES

Indoor Environmental Quality (IEQ) is a multidimensional construct that links building characteristics with occupant health, comfort, and productivity. It integrates indoor air quality (IAQ), thermal comfort, acoustic conditions, lighting, and spatial functionality (Jia *et al.*, 2021).

Evaluations of IEQ are becoming central to smart building research, as automated systems incorporate sensors and adaptive controls to regulate environmental conditions. IEQ receives particular attention because of its strong associations with respiratory health, cognitive outcomes, and general well-being (Grassie *et al.*, 2025). Many studies assess IEQ variables in isolation (Diaz *et al.*, 2021; Franke and Nadler, 2021; Quesada-Molina and Astudillo-Cordero, 2023). In practice, smart systems affect multiple dimensions simultaneously. For example, a ventilation system designed to regulate CO_2 levels alters humidity and thermal balance as well. Another conceptual challenge is the divergence between expert and occupant priorities. Professionals often emphasize quantifiable variables such as pollutant levels and lighting intensity, whereas occupants report satisfaction in relation to thermal comfort and control (Bellia *et al.*, 2021). In Asaba, with its humid climate and culturally specific practices, subjective well-being must be integrated into system assessments.

Smart building models often assume fixed schedules and passive occupants. In practice, window opening, indoor cooking, and the use of combustion appliances shape pollutant exposure patterns. Studies of residential environments demonstrate how window-opening behaviour influences IEQ, sometimes negating the effects of advanced filtration systems (Torresin *et al.*, 2024; Pourtangestani *et al.*, 2024). In Asaba, where solid fuel use and natural ventilation practices are common, behavioural variability is critical to the performance of smart systems. Evaluations that ignore such behaviour risk overstating technological efficacy. Much of the literature originates in temperate contexts, where outdoor air is often assumed to be relatively clean. In Asaba, outdoor air quality is degraded by generator emissions, dust, and traffic pollutants. Treating outdoor air as a neutral source underestimate risk. Smart ventilation systems that increase outdoor air intake without effective filtration could degrade IEQ rather than improve it (Nor *et al.*, 2025). Research must therefore situate evaluations in their local environmental conditions. Smart systems also degrade over time due to sensor drift, poor calibration, and inconsistent maintenance. Without longitudinal monitoring, evaluations risk overstating immediate improvements while overlooking performance decline. For Asaba, where building maintenance practices are inconsistent, temporal variability is a crucial factor in assessing system efficacy.

Integration of biometric and physiological data remains rare in IEQ studies, despite growing interest. Environmental metrics such as CO_2 or humidity explain conditions but do not fully capture their effects on occupants. Occupant-centered approaches propose linking IEQ with biometric indicators such as heart rate variability, electrodermal activity, or skin temperature (Choi, 2021). This strengthens causal claims by bridging environmental change with physiological response. In Asaba, incorporating such indicators would deepen insights into the relationship between smart systems and well-being. Smart systems are often promoted as improving both outcomes simultaneously. In Asaba, where building layouts often include open courtyards, shared kitchens, and variable ventilation, spatially resolved measurement is

essential. Without it, evaluations risk generalizing system performance across environments that differ substantially. These conceptual gaps highlight the need for more comprehensive approaches in assessing the efficacy of smart building systems in Asaba. IEQ must be treated as multidimensional, with overlapping variables and occupant perceptions integrated into assessments. Nonlinear responses, behavioural practices, local climate conditions, longitudinal performance, biometric data, and energy trade-offs all shape outcomes. Addressing these gaps strengthens the theoretical and empirical basis for evaluating how smart systems influence indoor air quality and occupant well-being in tropical urban environments.

3. MATERIALS AND METHOD

The study was carried out in Asaba, the capital of Delta State, Nigeria, located at approximately 6°12′N and 6°44′E (Ojoh *et al.*, 2023). Asaba lies on the western bank of the River Niger and has grown into an urban and administrative hub. The vegetation in the region is classified as moist tropical rainforest, with secondary growth due to urban expansion (Ojoh *et al.*, 2023). Economic activities include public administration, trade, small-scale manufacturing, education, and services, alongside growing real estate and construction. The climate is tropical with two main seasons: the wet season from April to October and the dry season from November to March. Mean annual temperature ranges between 22°C and 33°C, with relative humidity levels varying from 40 percent in the dry season to over 80 percent in the wet season (Ojoh *et al.*, 2023). The geology is characterized by sedimentary formations, predominantly sandy soils with lateritic layers, which support extensive urban development. This setting is ideal for evaluating smart building systems because rapid urbanization has increased demand for sustainable housing and workplace solutions. Indoor environmental quality is a growing concern in Asaba, where traditional construction often results in poor ventilation, high energy demand, and negative health outcomes. Linking the local climate and geology to the research problem is essential, as these factors affect building performance and occupant well-being.

The study used a quasi-experimental comparative design. Buildings with sensor-controlled Heating, Ventilation, and Air Conditioning (HVAC) systems were compared with conventional buildings lacking automation. This design enabled direct assessment of environmental and health outcomes within the same climatic and urban setting. Data collection focused on three domains: indoor environmental quality, occupant health, and energy performance. Environmental measurements included carbon dioxide concentration (PPM), particulate matter ($PM_{2.5}$ and PM_{10}, µg/m³), temperature (°C), relative humidity (%), volatile organic compounds (formaldehyde, benzene, toluene, ppb), and noise (dB(A)). Health-related data covered sleep quality, sick building syndrome symptoms, and cognitive function. HVAC energy consumption (kWh/m² per year) was also monitored. All values were obtained from primary field measurements. The sampling framework was stratified across major functional zones of Asaba, covering residential, office, educational, and

industrial categories. The zones included Nnebisi Road, Okpanam Road, GRA Phases I and II, Cable Point, Summit Junction, Umueze, Umuonaje, and the Asaba Industrial Estate. In each zone, both automated and conventional buildings were selected, ensuring balanced representation across building types. The final distribution of sampled buildings is shown in Table 1.

Table 1: Distribution of Sampled Buildings

Zone	Automated Buildings	Conventional Buildings	Total
Nnebisi Road	1 Automated Office	0	1
Okpanam Road	0	1 Conventional Office	1
GRA Phase I	1 Automated Residential	0	1
GRA Phase II	1 Automated Residential	0	1
Cable Point	0	1 Conventional Residential	1
Summit Junction	1 Automated Office	0	1
Umueze	1 Automated Residential	0	1
Umuonaje	0	1 Conventional Residential	1
Asaba Industrial Estate	0	1 Conventional Factory	1
DOU Campus (Anwai)	1 Automated Classroom	1 Conventional Classroom	2
Total	**6**	**5**	**11**

Data were collected during both wet and dry seasons in 2024 to capture seasonal variation. The wet season measurements were taken from June to August, while the dry season measurements were taken from December to February. All instruments were factory-calibrated before deployment to ensure accuracy. Carbon dioxide (ppm) was measured with nondispersive infrared CO_2 sensors, while particulate matter ($PM_{2.5}$ and PM_{10} in µg/m³) was assessed with DustTrak II Aerosol Monitors. Indoor temperature (°C) and relative humidity (%) were recorded with HOBO Data Loggers and MX1101 hygrometers. Volatile organic compounds, including formaldehyde, benzene, and toluene (ppb), were sampled with ppbRAE 3000 photoionization detectors. Indoor noise (dB(A)) was monitored with Casella CEL-633C sound level meters. All devices were installed in occupied rooms at breathing height (1.2 to 1.5 meters above floor level) and logged data at 10-minute intervals. Measurements were taken across both residential and occupational spaces to reflect true exposure levels. This procedure ensured that seasonal differences were captured in temperature, humidity, air pollutants, and noise. Collected data were compared with thresholds set by the World Health Organization (WHO) for air pollutants and noise, and by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) for thermal comfort and carbon dioxide. These benchmark standards are summarized in Tables 2 and 3.

Table 2: WHO Indoor Air Quality and Health Guidelines

Parameter	Threshold Value
PM2.5	15 µg/m³ annual mean
PM10	45 µg/m³ annual mean
Indoor Noise	45 dB(A)

Source: WHO (2021)

Table 3: ASHRAE Indoor Environmental Standards

Parameter	Threshold Value	Standard
Temperature	20–24°C	ASHRAE 55, 2017
Relative Humidity	30–60%	ASHRAE 55, 2017
Carbon Dioxide	≤1000 ppm	ASHRAE 62.1, 2019
HVAC Energy Use	≤65 kWh/m² per year for offices	ASHRAE 90.1, 2016

All data were downloaded weekly, stored in encrypted formats, and backed up. Processing and analysis were performed with SPSS version 27 and Microsoft Excel 365. Descriptive statistics summarized air quality, thermal comfort, and health outcomes. Inferential analysis included canonical correlations to test associations between pollutants and health indicators. Reliability was ensured through calibration of all instruments before deployment and at intervals during fieldwork. Validity was achieved by benchmarking data against World Health Organization and ASHRAE standards, and by aligning measurement protocols with established indoor environmental quality research practices.

4. RESULTS AND DISCUSSION

Table 4: Carbon Dioxide Levels in Asaba Building Zones

Area	Building Type	Morning Avg	Afternoon Avg	Evening Avg	Standard (ASHRAE 62.1)
Nnebisi Road	Automated Office	530	640	590	1000
Okpanam Road	Conventional Office	860	1280	1010	1000
GRA Phase I	Automated Residential Building	520	610	570	1000
Cable Point	Conventional Residential Building	790	1200	960	1000
Asaba Industrial Estate	Conventional Factory	900	1350	1100	1000

Source: Field measurements with nondispersive infrared CO_2 sensors (2024)

Table 4 shows that automated buildings in Asaba maintained carbon dioxide levels well below the ASHRAE 62.1 standard of 1000 ppm across all times of day, with offices on Nnebisi Road ranging from 530 to 640 ppm and residential units in GRA Phase I between 520 and 610 ppm. In contrast, conventional buildings recorded persistent exceedances. Offices on Okpanam Road reached 1280 ppm in the afternoon, while Cable Point residences peaked at 1200 ppm. Factories in the Industrial Estate recorded the highest values, averaging 1350 ppm during peak hours. These findings demonstrate that smart building systems reduced exposure to poor indoor air quality, aligning with prior studies linking automation with improved indoor environmental quality and occupant health (Wang *et al.*, 2024). High concentrations in conventional spaces highlight risks of reduced comfort and productivity, reinforcing the need for policy-driven adoption of automated systems in Delta State.

Table 5 shows that automated buildings maintained particulate matter concentrations below the World Health Organization (WHO) thresholds. Summit Junction offices recorded $PM_{2.5}$ at 11 µg/m³ and PM_{10} at 20 µg/m³, while automated residences in Umueze reported PM2.5 at 10 µg/m³ and PM10 at 19 µg/m³

Table 5: Particulate Matter Concentrations ($PM_{2.5}$ and PM_{10}) in Asaba Indoor Environments

Area	Building Type	$PM_{2.5}$ Avg	PM_{10} Avg	WHO $PM_{2.5}$	WHO PM_{10}
Summit Junction	Automated Office	11	20	15	45
Okpanam Road	Conventional Office	32	63	15	45
Core Area (Umueze)	Automated Residential Building	10	19	15	45
Cable Point	Conventional Residential Building	28	57	15	45
Asaba Industrial Estate	Factory	46	92	15	45

Source: Field measurements with DustTrak II Aerosol Monitor, TSI Inc (2024)

In contrast, conventional offices on Okpanam Road had elevated levels of 32 µg/m³ for $PM_{2.5}$ and 63 µg/m³ for PM_{10}, while Cable Point residences showed 28 µg/m³ and 57 µg/m³, both above WHO limits. The Industrial Estate factory presented the highest readings, with $PM_{2.5}$ at 46 µg/m³ and PM_{10} at 92 µg/m³. These findings indicate that smart systems are effective in lowering indoor pollutant loads, supporting earlier research that links filtration and automation with improved indoor air quality and reduced respiratory risk (Mata *et al.*, 2022; Pongboonkhumlarp and Jinsart, 2022). The higher concentrations in conventional and industrial buildings suggest unequal exposure risks that influence housing desirability and urban growth patterns in Asaba.

Table 6: Seasonal Indoor Temperature Stability in Asaba Buildings

Area	Building Type	Wet Season Avg	Dry Season Avg	Seasonal Deviation	Comfort Range (ASHRAE 55)
Nnebisi Road	Automated Office	22.1	24.2	±1.6	20–24
Okpanam Road	Conventional Office	19	28.3	±4.5	20–24
GRA Phase II	Automated Residential Building	22	23.8	±1.5	20–24
Umuonaje	Conventional Residential Building	18.9	27.6	±4.2	20–24
Asaba Industrial Estate	Factory	29	34.2	±3.9	20–24

Source: Field measurements with HOBO Data Loggers, Onset Computer Corporation (2024)

Table 6 shows that automated buildings sustained thermal stability within the ASHRAE 55 comfort range across both seasons. Automated offices on Nnebisi Road recorded averages of 22.1°C in the wet season and 24.2°C in the dry season with a deviation of ±1.6°C. Automated residences in GRA Phase II followed the same trend, remaining between 22°C and 23.8°C. In contrast, conventional offices on Okpanam Road and residences in Umuonaje showed wide fluctuations, with dry season averages of 28.3°C and 27.6°C respectively, far outside the recommended range. Industrial buildings exhibited the poorest performance, with seasonal averages exceeding 29°C and deviations of ±3.9°C. These results show that automation reduced thermal stress and supported stable indoor conditions, consistent with findings that controlled systems improve occupant comfort and health outcomes (Erişen, 2023; Garzia *et al.*, 2023). Thermal instability in conventional buildings presents risks for productivity and long-term housing value in Asaba's urban growth areas.

*Corresponding author, e-mail: collins.ojoh@dou.edu.ng, eyetantega@yahoo.com
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Table 7: Relative Humidity Levels in Asaba Indoor Spaces

Area	Building Type	Wet Season Avg	Dry Season Avg	Comfort Range
Summit Junction	Automated Office	48	44	30–60
Okpanam Road	Conventional Office	70	27	30–60
GRA Phase I	Automated Residential Building	49	43	30–60
Cable Point	Conventional Residential Building	68	26	30–60
Asaba Industrial Estate	Factory	74	25	30–60

Source: Field measurements with hygrometers, HOBO MX1101 (2024)

Table 7 indicates that automated buildings maintained relative humidity within the ASHRAE comfort range of 30–60 percent across both seasons. Automated offices at Summit Junction recorded 48 percent in the wet season and 44 percent in the dry season, while automated residences in GRA Phase I remained stable at 49 percent and 43 percent. Conventional buildings deviated sharply. Offices on Okpanam Road showed 70 percent in the wet season and dropped to 27 percent in the dry season. Residential units in Cable Point followed the same pattern with 68 percent and 26 percent. Industrial facilities had the greatest instability, recording 74 percent in the wet season and 25 percent in the dry season. These findings show that smart systems supported consistent indoor humidity, which is linked to reduced respiratory problems and improved comfort (Jia *et al.*, 2021). Poor control in conventional spaces raises health risks and influences property demand in Asaba's housing market.

Table 8: Volatile Organic Compounds in Asaba Indoor Environments

Area	Building Type	Formaldehyde	Benzene	Toluene	WHO Limit
Nnebisi Road	Automated Office	11	2	22	100
Okpanam Road	Conventional Office	42	8	67	100
GRA Phase I	Automated Residential Building	12	3	23	100
Cable Point	Conventional Residential Building	43	7	69	100
Asaba Industrial Estate	Factory	55	11	110	100

Source: Field sampling with photoionization detector, ppbRAE 3000, RAE Systems (2024)

Table 8 shows that automated buildings-maintained VOC concentrations well below WHO limits of 100 ppb. Automated offices at Nnebisi Road recorded formaldehyde at 11 ppb, benzene at 2 ppb, and toluene at 22 ppb. Automated residences in GRA Phase I reported similar values with formaldehyde at 12 ppb, benzene at 3 ppb, and toluene at 23 ppb. Conventional offices on Okpanam Road exceeded these levels with formaldehyde at 42 ppb, benzene at 8 ppb, and toluene at 67 ppb. Cable Point residences recorded 43 ppb, 7 ppb, and 69 ppb respectively. Factories in the Industrial Estate had the highest readings, with formaldehyde at 55 ppb, benzene at 11 ppb, and toluene at 110 ppb, exceeding the WHO limit for toluene. These results indicate that smart building systems effectively reduce chemical exposure, supporting studies linking automated ventilation and filtration with

*Corresponding author, e-mail: collins.ojoh@dou.edu.ng, eyetantega@yahoo.com
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improved indoor air quality and occupant health (Wang *et al.*, 2022). High VOCs in conventional and industrial buildings increase health risks and influence housing valuation and urban growth in Asaba.

Table 9: Indoor Noise Levels in Asaba Building Zones

Area	Building Type	Day Avg	Evening Avg	WHO Guideline
Summit Junction	Automated Office	43	41	45
Okpanam Road	Conventional Office	56	52	45
GRA Phase II	Automated Residential Building	42	40	45
Umuonaje	Conventional Residential Building	55	51	45
Asaba Industrial Estate	Factory	68	65	45

Source: Field measurements with precision sound level meters, Casella CEL-633C (2024)

Table 9 shows that automated buildings maintained indoor noise levels below the WHO guideline of 45 dB. Summit Junction offices recorded 43 dB during the day and 41 dB in the evening. Automated residences in GRA Phase II reported similar values at 42 dB and 40 dB. Conventional offices on Okpanam Road exceeded the guideline with 56 dB in the day and 52 dB in the evening. Residential buildings in Umuonaje showed 55 dB and 51 dB. Factories in the Industrial Estate had the highest exposure at 68 dB and 65 dB. These findings demonstrate that automated systems contribute to reduced acoustic disturbances, supporting occupant concentration and well-being, consistent with prior research linking indoor noise control to productivity and health (Felipe Contin de Oliveira *et al.*, 2023; Chis *et al.*, 2025). High noise in conventional and industrial buildings may depress property value and influence housing demand in Asaba's urban growth zones.

Table 10: Sleep Quality in Residential Areas of Asaba

Area	Building Type	Avg Sleep Duration (hrs)	Wake Episodes	Sleep Efficiency (%)
GRA Phase I	Automated Residential Building	7.1	1.1	91
Cable Point	Conventional Residential Building	6	2.6	82
Umueze	Automated Residential Building	7.2	1.2	92
Umuonaje	Conventional Residential Building	6.2	2.5	83

Source: Actigraphy measurements with Actiwatch Spectrum Plus, Philips Respironics (2024)

Table 10 shows that residents in automated buildings experienced longer sleep duration and higher sleep efficiency than those in conventional buildings. GRA Phase I and Umueze recorded average sleep durations of 7.1 and 7.2 hours with sleep efficiency of 91 and 92 percent, and fewer wake episodes at 1.1 and 1.2 per night. Conventional residences in Cable Point and Umuonaje averaged 6 to 6.2 hours of sleep, sleep efficiency of 82–83 percent, and 2.5–2.6 wake episodes. These differences indicate that indoor environmental quality supported by smart building systems improves rest and reduces sleep disruption, consistent with studies linking controlled indoor conditions with better sleep and cognitive performance (Martinez *et al.*, 2021; Liao *et al.*, 2021). Poor sleep-in conventional

buildings may affect health, productivity, and the desirability of housing, influencing property valuation and urban growth patterns in Asaba.

Table 11: Sick Building Syndrome Symptom Incidence Across Asaba Zones

Area	Building Type	Headache	Eye Irritation	Fatigue
Nnebisi Road	Automated Office	9	7	13
Okpanam Road	Conventional Office	26	21	34
GRA Phase II	Automated Residential Building	8	6	12
Cable Point	Conventional Residential Building	25	22	36
Asaba Industrial Estate	Factory	29	25	38

Source: Medical records and field health surveys linked with WHO SBS protocols (2024)

Table 11 shows that automated buildings recorded lower incidence of Sick Building Syndrome symptoms than conventional buildings. Automated offices on Nnebisi Road reported 9 cases of headache, 7 of eye irritation, and 13 of fatigue. Automated residences in GRA Phase II had similar values at 8, 6, and 12 respectively. Conventional offices on Okpanam Road showed substantially higher symptom counts with 26 headaches, 21 eye irritations, and 34 fatigue cases. Cable Point residences recorded 25, 22, and 36 cases. Factories in the Industrial Estate had the highest incidence, with 29 headaches, 25 eye irritations, and 38 fatigue episodes. These results indicate that automated systems improve indoor environmental quality, reducing occupant discomfort and health risks, consistent with previous findings linking ventilation, air quality control, and smart building technologies to lower SBS prevalence (Aziz *et al.*, 2023). High symptom incidence in conventional and industrial buildings may depress housing value and influence urban growth in Asaba.

Table 12: Annual HVAC Energy Consumption in Asaba Building Zones

Area	Building Type	Consumption	ASHRAE 90.1 Standard
Summit Junction	Automated Office	59	65
Okpanam Road	Conventional Office	95	65
GRA Phase I	Automated Residential Building	61	65
Cable Point	Conventional Residential Building	92	65
Asaba Industrial Estate	Factory	110	65

Source: Metered data from Delta State Utility Company and building-level submetering (2024)

Table 12 shows that automated buildings in Asaba consumed less HVAC energy than conventional buildings, remaining below the ASHRAE 90.1 standard of 65 kWh/m² per year. Summit Junction offices recorded 59 kWh/m², and GRA Phase I residences used 61 kWh/m². Conventional offices on Okpanam Road consumed 95 kWh/m², residential buildings in Cable Point 92 kWh/m², and factories in the Industrial Estate reached 110 kWh/m². These findings indicate that smart systems reduce energy demand while maintaining indoor environmental quality, supporting occupant comfort and well-being. High energy use in conventional buildings shows inefficiencies in HVAC systems. Automated HVAC systems reduce energy use and improve indoor environmental quality (Broday *et al.*, 2023). Energy inefficiency in conventional buildings may increase operational costs, affecting

property valuation and urban development patterns in Asaba.

Table 13: Canonical Correlation on Cognitive Function Scores of Occupants in Asaba Buildings

		$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	Headache (%)	Eye Irritation (%)	Fatigue Fatigue (%)
PM2.5 (µg/m³)	Pearson Correlation	1	1.000	.952	.950	.928
	Sig. (2-tailed)		.000	.012	.013	.023
PM10 (µg/m³)	Pearson Correlation	1.000	1	.957	.956	.935
	Sig. (2-tailed)	.000		.011	.011	.020
Headache (%)	Pearson Correlation	.952	.957	1	.997	.995
	Sig. (2-tailed)	.012	.011		.000	.000
Irritation (%)	Pearson Correlation	.950	.956	.997	1	.998
	Sig. (2-tailed)	.013	.011	.000		.000
Fatigue (%)	Pearson Correlation	.928	.935	.995	.998	1
	Sig. (2-tailed)	.023	.020	.000	.000	

a. Listwise N=5

Source: SPSS Computation

Table 13 presents correlations between particulate matter ($PM_{2.5}$ and PM_{10}) and occupant symptoms, showing strong positive associations with cognitive impairment indicators. $PM_{2.5}$ correlated with headache ($r = 0.952$), eye irritation ($r = 0.950$), and fatigue ($r = 0.928$). PM_{10} showed similar patterns with headache ($r = 0.957$), eye irritation ($r = 0.956$), and fatigue ($r = 0.935$). Headache, eye irritation, and fatigue were highly intercorrelated ($r \geq 0.995$), suggesting that indoor air pollution directly affects occupant cognitive function and well-being. These findings align with prior studies demonstrating that elevated PM levels reduce attention, memory, and decision-making performance in office and residential environments (Laurent *et al.*, 2021; Wu *et al.*, 2021). Automated buildings in Asaba, maintaining lower PM concentrations, support better cognitive performance, highlighting the role of smart building systems in enhancing IEQ, occupant health, and productivity, with implications for housing valuation and urban growth patterns in the region.

The results demonstrate that automated buildings in Asaba consistently maintain superior indoor environmental quality compared to conventional and industrial structures. Carbon dioxide levels, particulate matter, and volatile organic compounds remained within recommended thresholds, supporting healthier indoor air and lower occupant exposure to pollutants. Automated systems stabilized temperature and relative humidity across seasonal variations, improving thermal comfort and reducing physiological stress. Noise measurements indicate reduced acoustic disturbances, while sleep data show longer duration, fewer awakenings, and higher efficiency for residents in automated buildings. Sick Building Syndrome symptoms were markedly lower, reflecting the direct impact of smart ventilation and air quality management on occupant well-being. Energy consumption in automated spaces remained below ASHRAE 90.1 standards, highlighting efficiency without compromising comfort. Strong correlations between PM concentrations and cognitive function reinforce the link

between air quality and mental performance. These findings demonstrate that automated building systems enhance IEQ, support health and productivity, and influence housing desirability, property valuation, and sustainable urban growth patterns in Asaba, aligning with evidence from prior studies on smart building efficacy (Niza *et al.*, 2023; Garzia *et al.*, 2023).

5. CONCLUSION

The study demonstrates that smart building systems in Asaba maintain superior indoor environmental quality, reducing exposure to carbon dioxide, particulate matter, volatile organic compounds, and noise while stabilizing temperature and relative humidity. Residents in automated buildings experienced longer, more efficient sleep, fewer Sick Building Syndrome symptoms, and improved cognitive function, indicating direct benefits for health, comfort, and productivity. Conventional and industrial buildings consistently exceeded recommended thresholds, exposing occupants to thermal stress, poor air quality, and higher pollutant loads. Energy consumption in automated spaces remained below ASHRAE 90.1 standards, showing that efficiency and occupant well-being are achievable simultaneously. These findings highlight that integrating smart ventilation, filtration, and control systems enhances IEQ, supports occupant health, and strengthens housing value. Policy implications include mandating automated air quality management in public and commercial buildings, providing incentives for retrofitting conventional structures, and incorporating IEQ standards into urban planning regulations. Implementing these measures will improve resident health outcomes, optimize energy use, and guide sustainable urban growth in Asaba, ensuring that housing developments meet both environmental and public health objectives.

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Data Availability

The datasets generated and analysed during the current study are not publicly available due to confidentiality restrictions but are available from the corresponding author on reasonable request. All relevant materials and documentation required to replicate the analyses can also be provided upon request.

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