

Indoor Environmental Quality and health Outcomes among Students in Naturally Ventilated Hostels of a University in Sub-Sahara African Region

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Abstract

This study examined variances between the effect of aspects of Indoor Environmental Quality (IEQ) as against that of overall IEQ on health outcomes among hostel occupants in a university within the sub-Saharan African region. IEQ parameters considered are Thermal, Visual, Acoustics, and Indoor Air Quality. These, along with the overall IEQ, were examined in selected rooms to establish the relationships between them and occupants' health outcomes. A questionnaire was administered to 462 occupants toward the end of taking physical measurements of IEQ parameters in the rooms for four weeks in a row during the wet and dry seasons. Physical health outcomes reported by occupants were documented using the questionnaire. The sub-indexes for the IEQ aspects were calculated using z-score normalization method based on the mean values and the standard deviation of the data, while the overall IEQ was aggregated from the parameters of the four aspects using a geometric mean equation. Multiple regression analysis showed that individual parameters accounted for 14.5% of the variance in cold symptoms compared to 4.4% for the overall IEQ, and 4.3% for headaches compared to 1.3% for the overall IEQ. For fatigue, both models had very low explanatory power (0.9% and 0.7%, respectively). The study concludes that composite IEQ indices have limited potentials in forecasting discomfort that is related to specific health outcomes.

Keywords: Indoor Environmental Quality, Health outcomes, Naturally Ventilated Hostels, Self-reported health, Students housing

1. Introduction

Indoor Environmental Quality (IEQ) has become an important topic in building science since the global energy crisis of the 1970s led to more airtight and energy-efficient buildings. While these developments improved energy performance, they also raised concerns regarding the quality of indoor environments and their implications for occupants' comfort, health, and productivity. Because people spend a substantial proportion of their time indoors, the quality of indoor environments plays a significant role in determining overall well-being. Previous studies have consistently demonstrated that indoor environmental conditions influence occupants' health, comfort, and performance (Turunen et al., 2014; Loupa et al., 2017; Nduka et al., 2021). Consequently, improving IEQ has become an essential component of sustainable building design and operation.

IEQ is commonly evaluated through four principal environmental domains: thermal comfort, indoor air quality, lighting conditions, and acoustic environment. These parameters have been widely recognized as the primary physical determinants of occupants' experience of indoor environments and have been incorporated into international building standards and guidelines such as those developed by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Numerous studies have examined the influence of these individual parameters on occupant satisfaction, comfort, and health outcomes.

Despite extensive research on IEQ, much of the existing literature has focused on individual environmental parameters or has examined IEQ primarily within occupational environments

such as offices and schools (Frontczak and Wargocki, 2011; Roskams and Haynes, 2021). While such studies provide valuable insights into the relationships between indoor environmental conditions and occupant comfort or performance, their findings may not fully capture the health implications of IEQ in residential environments, where occupants typically experience longer exposure durations (Godish, 2016; Brasche and Bischof, 2005). Exposure-response relationships suggest that prolonged exposure to indoor environmental conditions can have significant health implications (Wolkoff et al., 2007; Bluyssen, 2020). Therefore, understanding IEQ in residential contexts is particularly important.

Another limitation in existing IEQ research is the tendency to evaluate environmental parameters independently, even though these factors interact to influence occupants' overall perception of indoor environments. Previous studies have shown that environmental parameters such as temperature, air quality, lighting, and acoustics can interact and jointly influence occupants' perceptions and responses to indoor conditions (Arif et al., 2016; Tang et al., 2020). As a result, assessing IEQ through a composite or integrated framework has been increasingly proposed as a more comprehensive approach to understanding the overall quality of indoor environments.

Several researchers have attempted to develop composite IEQ indices that aggregate multiple environmental parameters into a single indicator. Approaches such as the Analytic Hierarchy Process (AHP) and other weighting techniques have been used to assign relative importance to different IEQ components (Chiang and Lai, 2002; Heinzerling et al., 2013; Gomes and Esteves, 2016; Wei et al., 2020; Quesada-Molina and Astudillo-Cordero, 2023). However, existing methods vary considerably in terms of weighting schemes, input variables, and methodological complexity, which limits their comparability and practical application in different contexts (Laskari et al., 2017). Furthermore, relatively few studies have examined how overall IEQ indices relate to occupant health outcomes, particularly in residential environments.

This study addresses these gaps by examining IEQ in student hostel environments, which represent a form of residential building where occupants spend extended periods of time indoors. The study integrates objective measurements of key environmental parameters with subjective assessments of occupant health outcomes and develops an overall IEQ indicator that aggregates the four principal IEQ domains. By comparing the relationships between individual IEQ parameters and occupant health outcomes with those obtained using an aggregated IEQ index, the study aims to provide insights into whether a composite IEQ approach offers a more comprehensive understanding of indoor environmental influences on occupant health.

To achieve this, this study assessed the individual indoor environmental parameters in occupied hostel spaces; developed an overall IEQ index based on the aggregation of key environmental factors; examined the relationships between individual IEQ parameters and occupants' health outcomes; and compared these relationships with those obtained using the overall IEQ indicator. Through this integrated approach, the study contributes to ongoing efforts to develop practical methods for evaluating indoor environmental quality and its

implications for occupant health in residential environments.

2. Study Area

The study area, which is a university campus, is situated in a city in southwestern Nigeria. It is roughly 275 meters above sea level and lies between latitudes $7^{\circ} 28' N$ and $7^{\circ} 34' N$ and longitudes $4^{\circ} 27' E$ and $4^{\circ} 35' E$. Lagos, the historic capital of Nigeria on the western Atlantic Ocean coast, is roughly 230 kilometres away from the city. The city, and of course, the University is located within a warm humid climate with distinct wet and dry seasons. The dry season typically extends from November to March, while the wet season lasts from April to October. During the dry season monitoring period for this study (January-February), mean daily outdoor temperatures ranged between $30^{\circ}C$ and $34^{\circ}C$, with relative humidity averaging 45-60% and negligible rainfall (<5 mm total monthly average). In contrast, during the wet season monitoring period (June-July), mean daily temperatures ranged between $26^{\circ}C$ and $29^{\circ}C$, with relative humidity of 75-90% and average monthly rainfall exceeding 150 mm. This is based on data from Micro-Meteorological Experiment (NIMEX) of Atmospheric Research Group, Department of Physics, Obafemi Awolowo University Ile-Ife. Regarding outdoor air quality, previous assessments in Ile-Ife and nearby urban centres (Owoade et al., 2012; Omokungbe et al., 2023) have reported that ambient particulate matter ($PM_{2.5}$) concentrations typically range between 25-45 $\mu g/m^3$ in the wet season and 40-70 $\mu g/m^3$ in the dry season.

The monitored spaces were student rooms located in different residential hostel blocks within the university campus. The buildings were constructed between the late 1970s and early 1990s using reinforced concrete frames with sandcrete block infill walls, cement plaster finishes, and corrugated asbestos roofing sheets. The rooms have an occupancy ratio of between 7 m^2 to 12 m^2 per person, and a headroom of about 2.7 m. The rooms are naturally ventilated through louvered windows positioned on opposite walls to promote cross ventilation. No mechanical cooling or heating systems were installed, although ceiling fans were available in some rooms at different stages of disrepair. The selected rooms are typical of the university's student residential buildings in terms of age, layout, and construction, and therefore provide representative conditions for student hostel environments across the campus.

3. Materials and Methods

Physical measurements of four different aspects of the quality of the indoor environment in some selected rooms in students hostels within a university campus were taken. These were air temperature and relative humidity for thermal condition, illumination levels for visual condition, sound pressure levels for acoustic condition, as well as concentrations of Particulate matters ($PM_{2.5}$ and PM_{10}), Carbon dioxide (CO_2) and Total Volatile Organic Compounds (TVOC) for indoor air quality. For illumination levels, IN07175 Light level data loggers were used. It has a measuring range of 0 to 40 kLux and a resolution of 0.1 Lux. It has a memory capacity for 32,000 recordings and a measuring rate of 2 seconds to 24 hours. The accuracy is +/-5%. For sound pressure levels, DT-173 High Accuracy Digital Sound Noise Level Data Loggers were used. It has a measuring range of 30 to 130dB and a data memory of 129,920 samples. It has a dynamic range of 50dB, a frequency range of 31.5Hz to 8kHz, and an accuracy of +/-1.4dB.

Air Mentor PRO, a 6-in-1 Indoor Air Quality Monitor, was used to measure the other aspects of the indoor environment. It can measure temperature, relative humidity, CO₂, VOC, CO, PM_{2.5}, and PM₁₀ concentrations. It operates between 5 °C and 40 °C. With a range of 0 to 300 µg/m³ and a resolution of 1.0 µg/m³, the particulate matter sensor can identify particles larger than 1.0µ m, or PM_{2.5}/PM₁₀ µg/m³. Alcohols, aldehydes, aliphatic hydrocarbons, amines, aromatic hydrocarbons, CO, CH₄, LPG, ketones, organic acids, and other volatile organic compounds can all be detected by its TVOC/gas pollution sensor. It features a resolution of 1.0 ppb and a range of 125 to 3500 ppb (parts per billion). The CO₂ sensor is NDIR (Non-dispersive Infrared), with a resolution of 1.0 ppm and a sensor range of 400-2000 ppm (parts per million). Its temperature sensor has a precision of 0.1 °C and a range of -20 °C to 80 °C. Its relative humidity sensor has a resolution of 1.0% and a range of 0 to 100%. The Air Mento PRO sensors were factory-calibrated and further validated before deployment. Sensor readings were validated through co-location with reference instruments. One of which is a HOBO MX1101 temperature and relative humidity logger. Sensors showing deviations greater than ±2% for temperature and humidity or ±5 µg/m³ for particulate matter were recalibrated in accordance with the manufacturer's calibration protocol. During the monitoring period, weekly spot checks were conducted to confirm stability and detect potential drift.

Data on all the Indoor Environmental Quality parameters were taken at 15-minute intervals continuously day and night at the centre and work plane (taken to be 1200 mm from floor level) of the rooms for a period of four consecutive weeks during the peaks of the two main seasons in the city. That is between January and February for dry season, and between June and July for wet season. These are the most climatically stable parts of the wet and dry seasons, based on long-term meteorological records from Micro-Meteorological Experiment (NIMEX) of Atmospheric Research Group, Department of Physics, Obafemi Awolowo University Ile-Ife. A comparison with the 10-year mean values of rainfall and temperature indicates that these periods represent typical seasonal conditions. Because of the limited number of monitoring instrument, indoor parameter measurement was performed sequentially across selected 44 out of the 1408 hostel rooms. Stratified random sampling was used for the selection to ensure that each of the nine identified room design layouts are proportionally represented. All monitoring occurred within the same four-week period for each season (January-February for the dry season and June-July for the wet season). Each room was monitored for approximately equal durations under comparable weather conditions, as confirmed by daily outdoor climate data from NIMEX. This sequential but seasonally consistent deployment approach has been applied in similar field studies (Villanueva et al., 2024 and Miech et al., 2023) and ensured the comparability of data across rooms.

Furthermore, a questionnaire was administered to the occupants of the monitored rooms. The health symptom section of the questionnaire was adapted from the Örebro Indoor Climate Questionnaire, a widely used instrument for assessing building-related symptoms. The questionnaire was administered toward the end of the environmental monitoring period to ensure that occupants had experienced both dry and wet season conditions. However, data collected from one of the rooms were not used due to faulty datalogger. At the end, the responses of 492 occupants, which was 6.4% of the entire student population in the hostels,

were used for analysis. The questionnaire elicited information regarding the activities carried out in the rooms and the frequency at which occupants opened the fenestration, as well as the occupancy ratio. Although these observations were not used for quantitative analysis, but served to indicate typical behavioural patterns among occupants during the study periods. The same questionnaire was used to capture the self-reported physical health status of the occupants as a function of the frequency at which they observed some physical health symptoms.

The data was analysed with IBM Statistical Package for Social Sciences (SPSS) version 26. Multicollinearity among independent variables was assessed using Variance Inflation Factors (VIF). Standard regression diagnostics were also conducted to evaluate model assumptions, including linearity, normality of residuals, and homoscedasticity. To further ensure robustness, cluster-robust standard errors were estimated to account for potential clustering of observations within the same rooms. Mean values of the measured parameters were calculated based on different periods of the day categorized into morning (12am to 11:59am), afternoon (12noon to 5:59pm), and evening (6pm to 11:59pm). Mean values for each measured parameter were examined within the context of recommended ranges for human comfort (ASHRAE, 2019) [21]. These recommended ranges are as shown in Table 1. The sub-indexes for the four aspects of the IEQ were calculated from the original data points using z-score normalization method which is based on the mean values and the standard deviation of the data collected (as shown in equation 1). For Thermal condition and Indoor Air Quality which were measured with more than one parameter, a weighted summation model with equal weighting scheme was used to calculate index for each. Thereafter the overall IEQ was aggregated from the sub-indexes using a weighted summation model (as shown in equation 2).

$$Z = (X - \mu) / \sigma \quad (1)$$

Where: Z = z-score, X = original data point, μ = mean, and σ = standard deviation

$$IEQ = \sum (w_i \times I_i) \quad (2)$$

Where: IEQ is the Overall Indoor Environmental Quality, w_i is the weight assigned to each environmental quality parameter, I_i is the value of each environmental quality parameter.

Table 1. IEQ comfort or allowable ranges and associated health implications

IEQ Parameter	Comfort/allowable range	Health effect when exposed beyond allowable range
Air Temperature	20 - 24(winter); 23 - 26 (summer);	Heat stroke, hypothermia
Relative Humidity	30-70%	Dry eye and throat, respiratory illness
Illumination level	200 -300 lux	Glare, causing eye strain and headaches
Sound pressure level	30 - 50 dB(A)	Headaches, fatigue, and reduced sleep quality
Particulates (PM ₁₀)	150µg/m ³ (24-hr)	Breathing / respiratory problems
Particulate (PM _{2.5})	35µg/m ³ (24-hr)	Breathing / respiratory problems
Total Volatile Organic Compounds (TVOC)	300ppb (parts per billion)	Irritation of the eyes, nose and throat, nausea, difficulty in breathing
Carbon dioxide (CO ₂)	1000ppm (parts per million)	Headache, dizziness, restlessness, difficulty in breathing, tiredness

Source: adapted from *ASHRAE Handbook—HVAC Applications*, Chapter 62: Indoor Environmental Health, ASHRAE, 2019

The weighted summation model involves multiplying each environmental quality indicator by its corresponding weight and summing the results. This is similar to the model used by Piasecki, et al (2020). The weights are typically assigned based on the relative significance of each indicator. This study employed assigned weight of 30% for Thermal condition, 30% for Indoor Air Quality, 20% for Lighting, and 20% for Acoustic condition. This weighting approach, based on prior IEQ studies and established frameworks, allows the index to capture the relative importance of major indoor environmental factors while maintaining a balanced representation of the overall indoor environment. Descriptive statistical analyses were used to examine the different aspects of IEQ. Regression analyses were used to determine the relationships between each aspect of IEQ and occupants' health outcomes; the relationship between the overall IEQ and occupants' health outcomes; as well as the variance between the effect of various aspects of IEQ as against the effect of the overall IEQ on health outcomes among occupants. These analyses were done across the two major seasons in the climatic region.

4. Results and Discussion

4.1 Indoor Environmental Quality Parameters in the Spaces

Data on the parameters used to measure the different aspects of IEQ in the rooms for different periods of the day, as well as their 24-hour mean values (for some of the parameters) during dry and wet seasons were analysed and the results are presented and discussed below. Although this study did not include a quantitative analysis of outdoor-indoor relationships, field observations and existing studies in similar climatic contexts suggest that outdoor temperature, humidity, and air quality conditions significantly influence indoor environments, especially in naturally ventilated buildings. The extent of this penetration depends largely on factors such as building orientation, envelope characteristics, and ventilation practices. This implies that individuals can modify their indoor conditions by regulating window openings, improving cross-ventilation control, using shading devices, and maintaining clean openings to minimize dust infiltration. Such behavioural and design adaptations are important for

enhancing indoor comfort and air quality, particularly in buildings without mechanical conditioning systems.

Thermal Comfort Parameters. During the dry season, the mean air temperature was between 27.99°C and 30.91°C, while it was between 26.63°C and 27.95°C in the wet season. The mean values of Relative humidity during the dry season were between 41.06% and 61.44% while that of the wet season was between 82.32% and 86.18%. With the ASHRAE standard for summer thermal comfort zone limit being between 23°C and 26°C in summer and 20°C to 24°C in winter, the mean indoor air temperature in the morning periods was over the recommended range during 88.3% of the dry season. Specifically, it was over the recommended range at both the afternoon and evening every time during the dry season. During the wet season, there was no period of the day that the mean indoor air temperature fell within the acceptable limits. This supports the results of a related study conducted in the same field by Olanipekun (2014). The study discovered that over a considerable amount of time, the recorded interior air temperature ranged from 28.1°C to 34°C.

During the dry season, the measured mean relative humidity in the spaces generally met the ASHRAE Standard range of 30% to 70%. Only in the evening did it fall within the recommended range 100% of the time. Measured relative humidity was above the recommended limit 31.6% of the time in the morning and below the recommended range 12.1% of the time in the afternoon. The spaces were consistently found to have an unacceptable relative humidity throughout the wet season. Throughout the season, measured relative humidity was 100% above the permissible threshold.

A weighted summation model with equal weighting scheme was used to calculate the overall thermal condition in the spaces. The results showed that the measured thermal condition varied during both seasons. It was however observed that thermal conditions were better during the dry season with over 60% of the spaces falling under the average category as against less than 1% during the wet season. Less than 80% the respondents were satisfied with the physical conditions within the thermal environment during both seasons.

Visual Comfort Parameter. This study found that the mean value for illumination level for both dry and wet seasons are 78.83 lux and 67.48 lux respectively. When compared with the standards (European Standard EN 12464-1), the measured illumination in the spaces were far below acceptable levels during both seasons. There were significant positive correlations between the window to floor area and the window to wall area ratios with the measured illumination levels during both seasons. It was noteworthy that over 80% of the respondents felt that the illumination levels in the spaces were acceptable and adequate for them to carry out their tasks in the spaces during both seasons. This seems not to align with objective measurements. The favourable responses of the occupants to unacceptable measured illumination levels in this study could be traceable to their use of electric lighting in the spaces. Analysis showed that 50.5% of the respondents put on electric light in the spaces all the time during the study period. This thus confirms the findings of Mardaljevic et al. (2011), who established that when extra artificial illumination is utilized to complement the daylight for routine occupations like reading, illuminance levels of 100 to 300 lux may be appropriate.

Acoustic Parameter. The mean measured sound pressure level was 48.77dB during the dry season and 46.41dB during the wet season. According to the Nigerian Federal Environmental Agency (FEPA, 1990), these were within the maximum permissible limit. During both seasons, over 80% of the respondents felt that the sound pressure levels in the spaces were acceptable.

Indoor Air Quality Parameters. During the dry seasons, 24 hours average values of PM_{2.5}, PM₁₀, CO₂, and TVOC were 151.29 µg/m³, 515.03µg/m³, 557.34 parts per million, and 201.19 parts per billion respectively. While during the wet season they were 24.97 µg/m³, 141.72 µg/m³, 548.65 parts per million, and 193.42 part per billion respectively. Carbon Dioxide (CO₂) concentration levels during both seasons were below the maximum allowable limit. There was a slight increase in the mean indoor CO₂ concentration level during the dry season over that of the wet season by 1.58%. Since occupants are the main source of CO₂ indoors (Persily, and de Jonge, 2017; Baudet et al 2022), this average increase was expected especially in view of the increase in the floor area per occupant observed in the wet season. Moreover, the mean 24 hours' concentration level for both particulate matters considered (PM_{2.5} and PM₁₀) were below the maximum allowable throughout the wet season. This was different from the observation during the dry season likely because the occupancy ratio of the spaces increased during the wet season. Furthermore, when compared with the maximum allowable concentration level, the 24 hours mean concentration level of Total Volatile Organic Compounds (TVOC) were below allowable limits during both seasons. There was a highly significant negative relationship between TVOC concentration levels and occupancy ratio at $p < 0.01$ with correlation coefficient of 0.45, showing that it may be a more obvious indication of space occupancy than CO₂ measurements, confirming studies like Varnosfaderani, et al (2021), as well as Sørensen and Kristensen (2024).

4.2 Overall Indoor Environmental Quality Values in the Spaces

The overall Indoor environmental Quality (IEQ) of the spaces were estimated using a weighted summation model. They were later categorized into “poor”, “moderate”, “good”, and “excellent”. This study found that during the dry season, the IEQ values of the spaces ranged from “good” through “moderate” to “poor”. As shown in Table 2, a significant 74.5% of the spaces were estimated to have a “moderate” IEQ during the dry season, and 19.2% of the spaces were estimated to have a “poor” IEQ during the same period.

Table 2. Indoor Environmental Quality categories during the dry season

	Frequency	Valid Percent	Cumulative Percent
Good	13	6.3	6.3
Average	155	74.5	80.8
Poor	40	19.2	100.0
Total	208	100.0	

On the other hand, during the wet season, as shown in Table 3, the IEQ values of the spaces ranged between “good” and “moderate”. Table 3 showed that a significant 94.9% of the spaces were having IEQ estimated as “moderate” while none of the spaces was estimated as

having “poor” IEQ. This showed that the IEQ in the spaces varied across seasons. This is corroborating the findings of Langer et al (2016). The study found that the sampling season influenced the majority of the IEQ parameters. This study also affirmed the findings of Basil et al, (2024); Osseini et al, 2024, and Saetae et al (2025) which were carried out within a similar tropical region. The studies not only established seasonal variations in parameters used to measure IEQ, they specifically reported that measured environmental conditions were worse during dry season as observed in this study.

4.3 Self-reported Health Outcomes of the Occupants

The self-reported health outcomes of occupants that could be linked to measured indoor environmental quality of the studied spaces were examined across the two seasons. It is acknowledged that administering the questionnaire toward the end of the monitoring period may introduce some recall bias, particularly for short-term symptoms. However, since the questions targeted commonly experienced and persistent outcomes, the influence of this bias on overall findings is expected to be minimal. Moreover, this approach tried to mitigate the methodological issue of “time lag” identified by Gasparrini and Armstrong (2010) and Bhaskaran et al, (2013), showing that an exposure to extreme conditions or high concentration of particulate matter on a day may only have health effect several days after.

Table 3. Indoor Environmental Quality categories during the wet season

	Frequency	Valid Percent	Cumulative Percent
Good	11	5.1	5.1
Average	204	94.9	100.0
Total	215	100.0	

During both seasons, cold, fatigue and headache were the physical health outcomes with significantly high percentage of observation among the respondents. During the dry season it was 71.4%, 65%, and 62.7% respectively, while during the wet season it was 68.2%, 62%, and 58.9% respectively. Further analysis revealed that for cold, 8.7% of the respondents reported observing it almost every day during the dry season. During the wet season, however, a lower percentage (6.2%) of the respondents reported observing it almost every day. This result was similar to that of Prapamontol et al., (2021) carried out within a similar climatic region but among junior high school students. The study also found that cold related health outcomes were more common during the dry season. This was however different from the findings of Mizoue et al. (2016). The study reported observing more of mucous membrane and skin related health outcomes and not cold, fatigue nor headache. This difference may be due to the different context of the study. Mizoue et al. (2016) was carried out in a temperate climatic region with different climatic parameters.

The respondents were also asked to rate their physical health status on a scale of one to five, with one for “excellent” and five for “poor”, adapting the rating system in Turunen et al, (2014). Observation revealed that only 13.6% of the respondents reported that their general physical health status was excellent during the dry season. This was different from the

observation of Turunen et al, (2014) which was carried out during the summer of a cold climatic region. The study found that 55.5% of the respondent rated their health status as excellent. Apart from the different climatic context, this marked difference may be due to the difference in the method used by Turunen et al, (2014) to elicit information on the self-reported health status which was through the parents of the occupants, all of whom were elementary school children. According to Selinheimo et al, (2021), parents' health perceptions appear to influence reporting of children's indoor environment-related symptoms, which may misguide findings from indoor air surveys. The findings in this study however were based on the responses of the occupants themselves.

4.4 Relationships among Measured IEQ Parameters, Measured IEQ and Self-reported Health Outcomes of the Occupants

As earlier discussed, the three health outcomes with significantly high percentage of observation among the respondents during both seasons were Cold, Fatigue and Headache. Multiple regression analysis was used to examine the relationships among each of these three and the measured independent variables. These are the IEQ parameters and the estimated overall IEQ. A Variance Inflation Factor (VIF) analysis confirmed the likely effect of multi-collinearity since the overall IEQ is strongly related to the IEQ parameters. (Results showed that all predictors had VIF values below 4.6 (less than the accepted threshold of 5), confirming that collinearity among explanatory variables was not substantial). Moreover, the regression model for the IEQ parameters was separated from that of the overall IEQ so as to avoid the negative effect of inflated variance of the regression coefficients, which could make interpretation of the results challenging, potentially leading to incorrect conclusions. The coefficients, standard errors, standardized beta values, t-statistics, and significance levels were examined to evaluate the predictive strength of independent variables for each health outcome.

4.4.1 Measured IEQ Parameters, and Self-reported Health Outcomes of the Occupants

An analysis of variance explained by each IEQ parameter regarding the frequency of observation of Cold, Fatigue, and Headache as health outcomes among respondents during the two seasons was carried out. The result for the dry season is as presented in Tables 4, 5, and 6. There was a statistically significant correlation between reported cold symptoms and indoor environmental quality (IEQ) parameters, according to the regression model for cold symptoms ($F(4, 236) = 10.002, p < 0.001$). A modest match was suggested by the model, which explained around 14.5% of the variance in the result ($R^2 = 0.145$). The only one of the four predictors that exhibited a statistically significant negative correlation with cold symptoms was thermal comfort ($\beta = -0.230, p = 0.003$).

This implies that reports of cold-like sensations may be decreased by perceived thermal discomfort, either as a result of occupant focus shifting or competing discomforts obscuring the sense of cold. The illumination and sound indices did not show any significant correlation, however the IAQ showed a marginally significant positive link ($\beta = 0.162, p = 0.080$). This result is consistent with studies by Mendell, (2009) and Weng et al. (2022), which found that indoor air temperature, a subset of the thermal environment, greatly influences subjective

symptom reporting, particularly in tropical regions.

Table 4. IEQ parameters and Cold during dry season

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.494	.667		2.239	.026
IAQ	.007	.004	.162	1.758	.080
THERMAL	-.017	.006	-.230	-2.969	.003
ILLUMINATION	.002	.004	.103	.680	.497
SOUND	.003	.005	.095	.645	.520

The results of the fatigue regression analysis showed that the variables explained less than 1% of the variation ($R^2 = 0.009$), and the model was non-significant ($F(4, 232) = 0.515$, $p = 0.725$). There were no statistically significant IEQ parameters. This implies that others factor like psychological or occupational factors may have a greater impact on occupants' subjective feelings of fatigue than do physical environmental elements. The study by Kalender Smajlović et al. (2019) revealed similar findings, indicating that there was little association between assessed indoor environmental parameters and general Sick Building Syndrome, prominent among which is fatigue. The findings of studies like Lee et al, (2019) and Chang et al, (2022) however differ. This may be due to the different context of the studies. While this study and Kalender Smajlović et al. (2019) was carried out in naturally ventilated non-Green buildings, the study of Lee et al, (2019) was based on controlled laboratory context, and Chang et al, (2022) was done in Green buildings.

Table 5. IEQ parameters and Fatigue during dry season

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.937	.682		1.373	.171
IAQ	-.003	.004	-.088	-.883	.378
THERMAL	5.384E-6	.006	.000	.001	.999
ILLUMINATION	.000	.004	-.006	-.038	.970
SOUND	.001	.005	.026	.165	.869

Table 6. IEQ parameters and Headache during dry season

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.544	.609		.894	.372
IAQ	-.006	.004	-.155	-1.590	.113
THERMAL	-.007	.005	-.107	-1.310	.191
ILLUMINATION	.009	.003	.429	2.680	.008
SOUND	.009	.005	.301	1.931	.055

Although the headache regression model had a low explanatory power ($R^2 = 0.043$), it was statistically significant ($F(4, 236) = 2.666$, $p = 0.033$). Among the predictors, illumination was found to be a significant positive predictor ($\beta = 0.429$, $p = 0.008$), indicating that

increased light intensity may raise the chance of headaches being reported. The sound index was marginally significant ($\beta = 0.301$, $p = 0.055$), suggesting that headache prevalence may be influenced by auditory distress. This finding is slightly similar to that of studies by Lee et al. (2019) and Kim et al. (2017), which individually highlighted the impact of lighting and acoustic comfort respectively on occupants' observation of headache in indoor environments. The studies found statistically stronger relationships likely because each of them isolated the IEQ parameter considered.

Similar regression analysis was carried out during the wet season with the same independent variables. The result is as shown in Tables 7, 8 and 9. There was a statistically significant correlation between reported cold symptoms and indoor environmental quality (IEQ) measures, according to the regression model for cold symptoms ($F(4, 206) = 3.214$, $p = 0.014$). The model indicated a modest but statistically significant fit, accounting for roughly 5.9% of the variation in the result ($R^2 = 0.059$). At the 0.05 level, none of the four predictors were statistically significant. IAQ, on the other hand, came close to reaching marginal significance ($\beta = -0.141$, $p = 0.085$), indicating a potential trend toward fewer reports of cold symptoms as air quality improved. There were no discernible correlations between THERMAL, ILLUM., and SOUND. These findings imply that whereas IEQ components collectively have a moderate impact on the incidence of cold symptoms, their individual effects are negligible. This association may be moderated by additional contextual factors, such as exposure to outside conditions or individual health profiles. The idea that cold symptoms could be caused by a number of interrelated factors other than measured IEQ is supported by the comparatively low variation explained.

Table 7. IEQ parameters and Cold during wet season

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.896	.777		1.153	.250
IAQ	-.011	.007	-.141	-1.729	.085
THERMAL	.008	.007	.097	1.166	.245
ILLUMINATION	.003	.004	.088	.909	.364
SOUND	-.008	.005	-.161	-1.546	.124

Table 8. IEQ parameters and Fatigue during wet season

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.277	.747		-0.371	.711
IAQ	-.010	.006	-.126	-1.531	.127
THERMAL	.015	.006	.195	2.356	.019
ILLUMINATION	.005	.003	.138	1.419	.157
SOUND	-.002	.005	-.054	-.512	.609

With an R^2 value of 0.058, the fatigue regression model was likewise statistically significant ($F(4, 203) = 3.147$, $p = 0.015$). This suggests that changes in IEQ parameters account for

around 5.8% of the variation in weariness. Only THERMAL was statistically significant among the variables ($\beta = 0.195$, $p = 0.019$), indicating a correlation between greater fatigue and heat discomfort. SOUND, ILLUM., and IAQ did not exhibit statistical significance. Interestingly, IAQ got close to the marginal significance level ($p = 0.127$), suggesting that air quality might play a part. Although the modest R^2 value suggests that other, potentially psychological or occupational factors are stronger drivers of fatigue, these findings suggest that thermal conditions have a small but measurable effect on fatigue, supporting previous research by Suryo et al, (2024), who found little or no significant relationship between thermal stress and fatigue.

Table 9. IEQ parameters and Headache during wet season

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.801	.651		1.229	.220
IAQI	.002	.005	.036	.444	.658
THERMALI	.004	.006	.063	.763	.446
ILLUMINATION I	.000	.003	.009	.097	.923
SOUNDI	-.008	.004	-.205	-1.976	.050

The headache regression model explained almost 6.6% of the variance in self-reported headache symptoms ($R^2 = 0.066$) and produced a significant result ($F(4, 204) = 3.609$, $p = 0.007$). As observed during the dry season, SOUND was a moderately significant predictor ($\beta = -0.205$, $p = 0.050$), suggesting that headache symptoms and perceived sound discomfort may be inversely related. Although the exact causative relationship was not investigated, this finding raises the possibility that improved acoustic circumstances are associated with a lower incidence of headaches as earlier observed by Kim et al. (2017). ILLUM, THERMAL, and IAQ did not exhibit any notable effects.

4.4.2 Measured overall IEQ and self-reported health outcomes of the occupants

An analysis of variance explained by the overall IEQ regarding the frequency of observation of Cold, Fatigue, and Headache as health outcomes among respondents during the two seasons was carried out. The result for the dry season is as presented in Table 10.

Table 10. Overall IEQ and Cold, Fatigue, and Headache during dry season

Dependent Variable	R^2	Adjusted R^2	F(df)	Beta	p-value
Cold	0.044	0.040	10.875 (1, 239)	0.209	0.001
Fatigue	0.007	0.003	1.675 (1, 235)	-0.084	0.197
Headache	0.013	0.008	3.055 (1, 239)	0.112	0.082

The findings showed a positive correlation between reports of cold symptoms and overall IEQ ($R^2 = 0.044$, $p = .001$). The standardized coefficient ($\beta = .209$) indicates that the overall IEQ is a small but statistically significant predictor of cold-related symptoms, despite the limited explained variance (4.4%). This finding suggests that the occupants' experience of cold-like symptoms may be influenced by specific indoor environmental factors measured by

the IEQ, such as humidity, air quality, or thermal conditions. This supports other research showing that unfavorable air and temperature conditions might worsen respiratory discomfort or resemble symptoms of a cold even in climatic regions different from that of this study (D'Amato et al., 2018; Lee and Yoon, 2024).

On the other hand, overall IEQ and fatigue did not significantly correlate ($R^2 = .007$, $p = .197$). The physical environmental condition as measured by overall IEQ may not be a significant predictor of fatigue, as indicated by the low explained variance (<1%) and a weak, non-significant negative beta coefficient ($\beta = -.084$). This is consistent with research showing that fatigue is mostly a complex phenomenon, impacted more by environmental factors, ergonomic stressors, mental workload, and personal lifestyle characteristics (Kalender Smajlović et al. 2019; Barzarni and Yilmaz, 2022).

There was a slight positive effect size ($\beta = .112$) and a trend toward significance ($R^2 = .013$, $p = .082$) in the relationship between IEQ and headache symptoms. This result merits attention even though it is not statistically significant at the conventional 0.05 level. It implies that indoor environmental elements, including air quality and acoustic discomfort, which are frequent causes of headaches in occupied spaces, may not have a strong correlation with headache symptoms. This association may be clarified in future research using more detailed environmental measurements and control for psychosocial stresses.

The result for the wet season is as presented in Tables 11 below. There was a very weak and statistically insignificant correlation between overall IEQ and the regression model that predicted cold as a health outcome. Overall IEQ barely explained 0.3% of the variance in cold sensation, according to the model's R^2 of 0.003, which is shown in the Table. $\beta = 0.056$ ($p = 0.419$) was the standardized beta coefficient for overall IEQ, indicating a small and uncertain effect size. The adjusted R^2 was negative (-0.002), indicating that the model performs worse than a model without predictors, and the ANOVA test verified that the model was not significant ($F(1,209) = 0.657$, $p = 0.419$). These findings suggest that occupants' reports of feeling cold are not significantly predicted by overall IEQ especially in the wet season.

Table 11. Overall IEQ and Cold, Fatigue, and Headache during wet season

Dependent Variable	R ²	Adjusted R ²	F (df)	Beta	p-value
Cold	0.003	-0.002	0.657 (1,209)	0.056	.419
Fatigue	0.014	0.009	2.979 (1,206)	0.119	.086
Headache	0.012	0.008	2.583 (1,207)	0.111	.110

The model for fatigue symptoms produced a weaker but marginally greater correlation. With an R^2 of 0.014, overall IEQ explained 1.4% of the variation in fatigue levels. With a p-value of 0.086 and a normalized beta of $\beta = 0.119$, the results are just above the significance level of 0.05. The total model was not statistically significant, according to the F-statistic of 2.979 ($p = 0.086$), but the result does point to a pattern that merits more investigation. Fatigue is a cumulative and complex symptom that may be more susceptible to changes in the general quality of the environment.

Additionally, a slight and statistically insignificant correlation was shown by the third model, which predicted headaches. 1.2% of the variation in headache symptoms was explained by overall IEQ ($R^2 = 0.012$, $\beta = 0.111$, $p = 0.110$). The adjusted R^2 stayed low (0.008), and the F-statistic ($F(1,207) = 2.583$, $p = 0.110$) was not significant. Despite a modest upward trend, the findings imply that overall IEQ is not a reliable indicator of headache symptoms.

In general, during both seasons, analysis revealed that the effect of the overall IEQ on reported health outcomes in occupants was minimal as observed by Nduka et al, (2021) done within a similar context. This also aligns with the findings of Suryo et al, (2024). The study, despite being done in a different context of air-conditioned office building, found that the extent to which IEQ can predict health outcomes in occupants is low.

4.5 Extent of Variance Explained by the IEQ Parameters and the Overall IEQ

For the dry season, the comparison is shown in Table 12. According to the table, the regression model that included the four distinct IEQ parameters described 14.5% of the variation in cold symptoms ($R^2 = 0.145$), while the overall IEQ - based model only explained 4.4% ($R^2 = 0.044$). This suggests that certain environmental factors, especially thermal comfort, are more important in causing cold-like symptoms than the overall composite score. Similarly, the overall IEQ described just 1.3% of the variance in headache symptoms ($R^2 = 0.013$), whereas the model with individual parameters explained 4.3% ($R^2 = 0.043$). The results indicate that lighting and acoustic parameters, which showed near-significant effects, may contribute considerably to the beginning of headaches and are better captured when measured independently, despite the relatively low predictive power indicated by both models. On the other hand, neither the overall IEQ model ($R^2 = 0.007$) nor the individual component model ($R^2 = 0.009$) showed significant explanatory power for fatigue. This suggests that elements of the indoor environment not included in the considered IEQ parameters or non-environmental factors may have an impact on self-reported fatigue.

Table 12. Variance explained by the IEQ parameters and the overall IEQ in dry season

Dependent Variable	R^2 (Individual IEQ parameters)	R^2 (Overall IEQ)	Change in Variance Explained
Cold	0.145	0.044	▼ ↓ by 0.101 (10.1%)
Fatigue	0.009	0.007	Slight ↓ by 0.002 (0.2%)
Headache	0.043	0.013	▼ ↓ by 0.030 (3.0%)

Overall, the results showed a significant decrease in variance explained when switching from individual IEQ parameters to the aggregated overall IEQ, especially for headache symptoms (a difference of 3.0%), and cold symptoms (a difference of 10.1%). During the wet season, similar trend was observed. The extent to which overall IEQ could accurately predict frequency of health outcomes compared to that of the IEQ parameters diminished as compared to the dry season. This emphasizes the possible drawbacks of assessing the health effects of indoor environments using composite indices. However, studies like Moschandreas and Sofuoglu, (2004), and Savelieva et al, (2019), concluded otherwise. It is however noteworthy that Moschandreas and Sofuoglu, (2004), was done in office buildings where

respondents spent less than a third of their time, while Savelieva et al, (2019), was based on expert assessment of IEQ and not physical measurements. This shows that indices such as the overall IEQ provide a useful summary metric, they may mask the unique impact of specific environmental stressors.

5. Conclusion

In general, Cold, Fatigue, and Headache were the health outcomes with highest frequency of observance among occupants during both seasons, but the influences of IEQ parameters on the health outcomes differ across seasons. The explained variances by individual IEQ parameters are not very high for the three health outcomes. This shows that while environmental factors play a role in symptom reporting, their impact is little when taken into account separately. The most significant predictor was consistently thermal comfort, especially for fatigue, whereas acoustics and air quality had very minor effects on headache and cold sensations, respectively. On the other hand, a significantly smaller amount of variance in health outcomes was explained by the overall IEQ. Of the models that used the overall IEQ alone, only one was statistically significant. These results highlight how crucial component-level IEQ evaluations are for assessing health outcomes in indoor spaces. They also draw attention to the necessity of more comprehensive models that incorporate contextual or personal factors in addition to environmental ones. This emphasizes the drawbacks of evaluating indoor environmental health impacts only using aggregate indices. More reliable insights are obtained via disaggregated, parameter-level evaluations.

This study, therefore, concludes that composite IEQ indices are not very useful for forecasting discomfort that is related to specific health outcomes. Rather, specific IEQ parameters have more predictive power. Therefore, domain-specific design responses should take precedence over dependence on aggregate ratings in architectural and health-based interventions. While composite indices are useful for broad bench-marking, they obscure the influence of specific parameters and are not very effective for focused health evaluations.

A limitation of this study is that the environmental sensors were not deployed concurrently across all rooms due to limited equipment availability. Instead, measurements were taken sequentially within each four-week seasonal window under comparable outdoor conditions. While this approach may introduce minor temporal variability, it has been adopted in indoor environmental monitoring where sensor resources are constrained (Villanueva et al., 2024 and Miech et al., 2023). Sequential deployment also enabled periodic calibration verification, minimizing inter-device bias. Future research could benefit from expanding the number of concurrently deployed sensors to allow simultaneous multi-room measurement and improve temporal resolution; however, the sequential strategy used here provides a valid and reliable characterization of seasonal indoor environmental variations in tropical dormitory settings. Furthermore, although not common in IEQ studies, future research could explore multi-year IEQ observations and monitoring, which could provide a broader basis for generalization.

6. Practical Implications

The findings of this study have practical implications on architectural and facility

management interventions. These should prioritize targeted environmental improvements rather than relying solely on generalized IEQ ratings. Furthermore, for facility managers and hostel administrators, the results underscore the importance of regular monitoring and maintenance of indoor environmental conditions. Lastly, from a policy perspective, the study highlights the need for residential building guidelines and campus accommodation standards in tropical regions to move beyond generalized environmental performance criteria toward more health-oriented IEQ assessment frameworks.

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Authors Contribution

1. **Bode Abiodun Orola** conceived the study, developed the research framework, defined the study objectives, carried out the field survey, coordinated data collection, contributed to the data analysis as well as interpretation of the results, and wrote the first draft of the manuscript.
2. **Pius Kofoworola. Olayeni** curated the dataset, performed data cleaning, and prepared it for analysis.
3. **Sunday Aderemi David** conducted the literature review, developed the theoretical background of the study, and contributed to the data analysis as well as interpretation of the results.
4. **Dolapo Amole** managed the project administration and coordination.
5. **Babatunde Jaiyeoba** proofread the manuscript
6. **All authors** reviewed, edited, and approved the final manuscript.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. Verbal consent in place of written consent was obtained because in this study area, signing documents is associated with legal or political matters, creating mistrust or fear of creating a paper trail that could link participants to the study. Verbal consent feels less intimidating and culturally appropriate, and no separate waiver document was issued.

Ethical Statement

This research was conducted in accordance with the principles embodied in the Declaration of Helsinki and in accordance with local statutory requirements of Obafemi Awolowo University, Nigeria.

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data presented in this study are available on request from the corresponding author due to copyright issues.

Data sharing statement

No additional data are available.

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