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Investigating Daylighting Performance and Visual Comfort in Airport Terminals: A Passive Lighting Approach for Makurdi, Nigeria

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ABSTRACT
This study assesses the daylighting quality and visual comfort in the Makurdi Airport terminal (Benue State, Nigeria) through occupant surveys and environmental analysis. Makurdi lies in a hot-humid tropical climate with high humidity and diffuse solar radiation (clearness index ≈0.43). A structured questionnaire was administered to 343 users (188 staff, 155 passengers) covering air quality, thermal and lighting comfort, and satisfaction. Results reveal divergent perceptions by age and role: older users (36–55 years) rated daylighting and general lighting poorly (100% of 36–55 year-olds said daylight was insufficient), whereas younger users found daylight adequate. Airport staff overwhelmingly rated the lighting system as "very effective" (42%) or "adequate" (37%), while 46% of passengers deemed it "ineffective." Glare complaints also differed: 46% of staff reported glare in the security area, whereas 53% of passengers reported glare in restrooms and 47% in waiting lounges. Statistical tables highlight these breakdowns. On average, users expressed moderate satisfaction with lighting and ventilation (no respondents were "dissatisfied"). Based on these findings and literature, we recommend design interventions: increase filtered natural light (e.g. clerestories or light pipes as in Nigeria's office building integrate shading (louvers/overhangs) to reduce glare and upgrade artificial lighting to LED with zoned controls. The study fills a gap in tropical airport design by combining user feedback with climate-specific strategies for daylight and glare management, providing evidence-based recommendations for Makurdi and similar contexts.

KEYWORDS:Daylighting, Glare Control, Hot-Humid Climate, Makurdi Airport, Visual Comfort

I. INTRODUCTION

Airport terminals are complex environments requiring a careful balance between daylighting and artificial lighting to ensure visual comfort, safety, and energy efficiency. Contemporary terminal designs frequently incorporate large glazed atria, clerestories, or skylights to maximize natural illumination; however, without climate-appropriate controls, these strategies can lead to excessive glare and thermal discomfort (Matin et al., 2025; Olanrewaju & Adekola, 2023).

Makurdi Airport, situated on the banks of the River Benue (7°44′N, 8°30′E, ~104 m elevation), is located in a tropical wet-and-dry climate zone. According to Ayoosu, Ishaya, and Udeh (2020), Makurdi receives an average of 12 hours of sunshine per day, with a mean relative humidity of approximately 66% and a clearness index around 0.43 indicating moderate cloud cover and frequent atmospheric haze.

The Nigerian Building Code lacks explicit standards for daylighting in public buildings, a gap that has resulted in many structures being underlit or overly exposed to uncontrolled solar penetration (Okeke et al., 2021). Globally accepted sustainable design frameworks such as LEED recommend that at least 75% of regularly occupied floor area be daylight-accessible to promote energy efficiency and psychological well-being (Wang et al., 2023). However, in the absence of climate-specific adaptations, unregulated daylight can contribute to discomfort glare, which has been identified as one

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of the most significant factors affecting occupant comfort in visually demanding spaces like airports (Alzahrani & Wang, 2022; Chen et al., 2021).

This study evaluates the daylighting performance and visual comfort levels in Makurdi Airport's passenger terminal. Through a mixed-methods approach, it combines structured user surveys with environmental analysis. The specific objectives are to:

1. Quantify user satisfaction with daylight and artificial lighting;
2. Identify how variables such as age, functional role (staff vs. passenger), and terminal location affect perception;
3. Propose passive and active design strategies tailored to Makurdi's tropical climate.

Emphasis is placed on the implementation of climate-responsive architectural elements such as fixed and operable shading systems, light shelves, clerestories, and tubular daylighting devices which have been shown to improve light distribution in deep-plan tropical buildings across Nigeria (Idemudia & James, 2022; Ede et al., 2024). By grounding the analysis in both user feedback and environmental constraints, the study contributes to the growing body of research advocating for sustainable, human-centered airport design in West Africa (Akyüz et al., 2024; Musa et al., 2023).

II. LITERATURE REVIEW

Tropical Climate and Daylight Characteristics

Makurdi's tropical humid climate provides abundant solar energy, but it also results in high diffuse radiation due to atmospheric moisture and seasonal haze. Ayoosu et al. (2020) report that Makurdi exhibits a diffuse sky ratio of approximately 42–60%, creating a lighting condition where direct sunlight is intense while periods of overcast skies deliver soft, uniform daylight. These climatic conditions make uncontrolled daylighting potentially problematic, especially regarding glare and overheating.

Designers in tropical zones must therefore balance daylight penetration with mitigation strategies to limit discomfort and energy loads (Matin et al., 2025; Dey, 2024). Recommended solutions include overhangs, vertical louvers, and adaptive facades that shield from direct sun while admitting diffuse skylight (Mukhtar et al., 2024). These features are increasingly adopted in tropical institutional and commercial buildings due to their dual function of thermal and visual regulation.

Daylighting Strategies in Tropical Architecture

Recent research emphasizes passive solutions for daylighting in tropical environments. Dey (2024), for instance, found that shading systems can reduce Annual Sunlight Exposure (ASE) significantly while maintaining high levels of Useful Daylight Illuminance (UDI). Matin et al. (2025) similarly argue that without adequate glare control, high daylight availability becomes a liability, undermining visual comfort and task performance.

Creative solutions tailored for tropical contexts have emerged. Mukhtar et al. (2024) explored the application of horizontal "light pipes" in Nigerian offices, finding that optimized 10-meter lengths produced more uniform light distribution across deep-plan floorplates. Incorporating similar systems in airport terminals may address challenges of large enclosed spaces that receive little daylight.

Overall, the literature underscores the importance of integrating daylight access with glare mitigation. As LEED daylighting guidelines suggest, effective visual environments require that at least 75% of regularly occupied spaces receive natural light under controlled conditions (Wang et al., 2023). This has both comfort and energy efficiency benefits, particularly in non-residential settings with high lighting demand.

Airport Terminal Lighting and Comfort

Airport terminals pose unique lighting challenges due to their vast volumes, long operating hours, and mixed-use spaces (e.g., circulation, retail, security). Akyüz et al. (2024) note that lighting accounts for approximately 13% of total airport energy use. Therefore, lighting design must not only meet safety and visibility requirements but also enhance comfort while reducing energy demand.

Modern airport design increasingly incorporates biophilic principles and daylighting strategies to improve the passenger experience (Gómez Comendador et al., 2020). However, large glazed facades, unless properly controlled, can introduce discomfort glare. Visual comfort concerns are frequently reported in terminal buildings: Matin et al. (2025) found that unmitigated glare reduces satisfaction, induces fatigue, and negatively affects spatial cognition.

Lighting systems must therefore strike a balance between natural and artificial sources. The integration of LED luminaires with zoned lighting controls helps to maintain uniform brightness and avoid high contrast ratios that strain the eyes

(Olanrewaju & Adekola, 2023). Moreover, when combined with passive solar control features, artificial lighting can complement daylight effectively, contributing to a more comfortable and energy-efficient terminal environment.

Gap in Knowledge

Despite the global expansion of literature on daylighting and airport design, few empirical studies focus on Nigerian airport terminals. Makurdi Airport, a regional hub in Benue State, has undergone partial upgrades but still lacks comprehensive lighting evaluation. Existing systems include mid-level clerestory glazing and limited skylights, with no available data on how users experience visual conditions.

This study addresses this gap by conducting a mixed-methods evaluation of daylighting and lighting comfort in the Makurdi terminal. It offers context-sensitive recommendations that merge user feedback with proven tropical daylighting strategies — a necessary step toward improving thermal and visual comfort in regional airports across sub-Saharan Africa.

III. METHODOLOGY

Research Design

This study adopts a quantitative descriptive survey design to examine how demographic variables influence perceived acoustic comfort within academic auditorium. The descriptive approach is suited to exploring subjective responses by collecting and summarising quantifiable data in a structured manner. It allows the researcher to understand the existing conditions and user experiences without manipulating variables, thus reflecting naturally occurring patterns in real environments (Onyema, 2023). This design enables the identification of trends in acoustic satisfaction and the demographic variations that underpin them.

A cross-sectional strategy was used, meaning that data were collected at a single point in time across multiple respondent groups. This approach is particularly valuable in studies that focus on perceptual differences and behavioural responses within specific built environments, such as university auditorium (Kuri & Pérez, 2022).

Study Area and Population

The study was carried out in a private university in southwestern Nigeria, characterised by rapidly growing student enrolment and the frequent use of large academic halls for lectures, ceremonies, and institutional events. The selected environment reflects typical challenges associated with acoustics in educational settings such as sound distortion, reverberation, and insufficient absorption.

The target population included regular users of these spaces: students, lecturers, and institutional guests. These groups were chosen because of their consistent interaction with the auditorium, albeit in different capacities. Students primarily engage with lectures and tests, lecturers serve as speakers and facilitators, and institutional guests attend periodic events. This diversity in user roles offers a balanced perspective on how sound is perceived differently based on frequency of use and function within the space.

Sampling Technique and Sample Size

This study adopted a stratified random sampling technique to ensure fair representation across the three main user groups: students, lecturers, and institutional guests. This method enhances the reliability and validity of findings by capturing the variability of acoustic perception across strata. Stratification ensures that the sample includes adequate numbers from each group, thereby reflecting the diversity of the total population and improving generalisability (Barros et al., 2023).

To determine the appropriate sample size, Cochran's formula for sample size determination was applied. Cochran's formula is suitable for categorical data in large populations and helps to achieve a statistically significant result at a defined confidence level and margin of error.

Cochran's Formula for an Infinite Population:

$$n_0 = \frac{Z^2 \times p \times q}{e^2}$$

Where:

- n_0= sample size for an infinite population
- Z = score corresponding to the desired confidence level (1.96 for 95%)
- p = estimated proportion of population (0.5 is used when unknown)
- q= 1 – p
- e = margin of error (0.05 for 5%)

Step 1: Calculation for Infinite Population

$$n_0 = \frac{(1.96)^2 \times 0.5 \times 0.5}{0.05^2} = \frac{0.9604}{0.0025} = 384.16$$

So, the required sample size for an infinite population is approximately:

$$n_0 = 384$$

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Data Collection Instruments

The primary instrument for data collection was a structured, self-administered questionnaire. The questionnaire was divided into two main sections. The first section captured demographic data such as age group, gender, and user role. The second section focused on perceptual evaluations of acoustic conditions.

Perceptual responses were recorded using a 5-point Likert scale: Strongly Agree, Neutral,Agree, Disagree, and Strongly Disagree. The instrument was pre-tested among a small sample for clarity, reliability, and content relevance, with revisions incorporated before final deployment.

Variables and Measurement Scales

The independent variables were categorical demographic factors, namely: gender, age group, and user role (student, lecturer, guest). The dependent variables were perceptual indicators of acoustic quality, such as:

i Clarity of speech
ii Presence of echo or reverberation
iii Background noise levels
iv Overall acoustic comfort

These were measured using the aforementioned 5-point Likert scale, which provided ordinal data suitable for both descriptive and cross-tabulation analysis. Each acoustic variable was treated as an ordinal indicator of perceived comfort, allowing the researcher to quantify and compare trends across demographic subgroups (Şentürk & Akdağ, 2023).

Data Analysis Techniques

Data collected from the questionnaire were analysed using descriptive statistics and cross-tabulation only. Descriptive statistics were used to compute frequencies and percentages for each Likert-scale response, offering an overview of general trends in acoustic perception.

For deeper insights, cross-tabulation analysis was employed to explore associations between demographic variables and specific acoustic indicators. This method helped to identify, for instance, how males and females differed in their perception of reverberation, or whether certain age groups were more sensitive to echo and noise. While no inferential statistical software such as SPSS was used, the data analysis was manually computed and organised to clearly show comparative patterns across the user spectrum (Montiel et al., 2023).

Ethical Considerations

Ethical clearance was obtained before data collection. Respondents were informed of the study's purpose and their right to decline participation. They were assured that participation was voluntary, and that all data would be treated with anonymity and confidentiality. The questionnaire included no personally identifying information. These ethical safeguards ensured compliance with standard research practice in studies involving human subjects (Grassi et al., 2024).

IV. RESULTS AND DISCUSSION

This chapter presents and interprets the findings of the study in alignment with its stated objectives. The analysis draws from responses obtained through a structured questionnaire, focusing on demographic trends in perceived acoustic comfort among university auditorium users. Descriptive statistics and cross-tabulation techniques were applied to explore relationships between gender, age, user role, and acoustic perception. The discussion contextualises these findings within existing literature, offering insights that inform inclusive and responsive architectural design strategies for higher education spaces.

Demographic Profile of Respondents

The demographic composition of the 365 respondents is categorised across three major dimensions: gender, age group, and user role. This stratified breakdown offers a robust basis for quantifying perceived acoustic comfort as it relates to personal and functional diversity among auditorium users.

As presented in Table 4.1a, the gender distribution shows a near-equal representation of males and females, providing balance in perspectives. This gender symmetry is important for analysing acoustic perception, particularly as psychoacoustic literature identifies differences in auditory sensitivity and noise annoyance thresholds between genders (Grassi et al., 2024). Women have been found to generally report greater discomfort from background noise and reverberation compared to men, which supports the relevance of gender-based comparisons in this study.

Table 4.1a: Gender Distribution of Respondents

Gender	Count
Male	236
Female	114

Source: Authors' findings

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In Table 4.1b, the age group distribution reveals that the largest proportion of respondents falls within the 21–30 age bracket. This group constitutes the most academically active population in university settings and is likely to have the highest exposure to learning environments, including auditorium. Younger age groups tend to report more acute sensitivity to sound distortions, such as echo and excessive reverberation (Sentürk & Akdağ, 2023). The relatively smaller proportion of respondents in the 41+ bracket allows for comparison across generational hearing sensitivity, which is useful in identifying which cohorts are more perceptive to acoustic challenges.

Table 4.1b: Age Group Distribution of Respondents

Age Group	Count
Under 20	93
41+	89
21–30	89
31–40	79

Source: Authors' findings

Regarding user roles, Table 4.1c shows that students (125) make up the largest respondent group, followed closely by lecturers (119) and event attendees (106). This distribution ensures that data reflect the diversity of user experiences in the auditorium from passive listeners (students and guests) to active speakers and facilitators (lecturers). According to Montiel et al. (2023), auditorium design must accommodate the differing auditory needs of both listeners and speakers to achieve equitable sound distribution.

Table 4.1c: Role Distribution of Respondents

Role	Count
Student	125
Lecturer	119
Event Attendee	106

Source: Authors' findings

In summary, the demographic profile provides a sound foundation for evaluating perceptual disparities across groups. It enables the analysis of how demographic attributes particularly gender, age, and role influence the perception of acoustic comfort, thus fulfilling the first objective of the study.

Descriptive Analysis of Acoustic Comfort Variables

To address the first study objective quantifying perceived acoustic comfort five key variables were analysed using descriptive statistics. These include seating capacity, visibility, ease of movement, speech clarity, and echo control. As seen in Table 4.2, responses are broken down by frequency and percentage, offering insight into the auditory and spatial comfort experiences of users.

The data show that "The sound during events or lectures is clear" received the highest proportion of Strongly Agree responses (81 respondents or 23.1%), yet 70 participants (20.0%) also Strongly Disagreed, suggesting a polarised experience. Similarly, "I often experience echoes or reverberation during events" elicited 66 Strongly Agree responses (18.9%) but also 78 Strongly Disagree (22.3%). This mixed response reflects the variable nature of sound delivery in the auditorium and supports Grassi et al. (2024), who noted that perceived acoustic clarity fluctuates depending on seating position and sound dispersion zones.

Ease of movement and visibility within the auditorium also showed balanced feedback. For instance, "It is easy to move in and out of the auditorium" recorded 60 Strongly Agree (17.1%) and 77 Strongly Disagree (22.0%) highlighting a possible conflict between seating arrangements and aisle planning. These factors are important to architectural design but often overlooked in acoustics-focused studies.

Notably, neutral responses ranged from 20.0% to 22.9% across questions, indicating a sizeable segment of users who may not have formed strong opinions or who experienced inconsistent conditions. This aligns with Sentürk & Akdağ (2023), who identified uncertainty in perception as a common response in poorly zoned or non-acoustically treated educational spaces.

In sum, the descriptive analysis confirms that user comfort is neither consistent nor uniformly distributed, with significant portions of users dissatisfied or uncertain about key acoustic and spatial factors. This affirms the necessity of a user-centred approach to auditorium design, particularly for learning institutions.

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Table 4.2: Descriptive Analysis of Acoustic Comfort Variables

Question	Agree	Disagree	Neutral	Strongly Agree	Strongly Disagree
The auditorium's seating capacity is sufficient for most events.	68 (19.4%)	70 (20.0%)	75 (21.4%)	80 (22.9%)	57 (16.3%)
The stage or speaker is clearly visible from most seating areas.	75 (21.4%)	63 (18.0%)	73 (20.9%)	76 (21.7%)	63 (18.0%)
It is easy to move in and out of the auditorium during events.	65 (18.6%)	68 (19.4%)	80 (22.9%)	60 (17.1%)	77 (22.0%)
The sound during events or lectures is clear and understandable.	69 (19.7%)	60 (17.1%)	70 (20.0%)	81 (23.1%)	70 (20.0%)
I often experience echoes or reverberation during events.	70 (20.0%)	64 (18.3%)	72 (20.6%)	66 (18.9%)	78 (22.3%)
The background Noise level in the auditorium is low and not distracting.	65 (18.6%)	57 (16.3%)	66 (18.9%)	95 (27.1%)	67 (19.1%)
The auditorium's sound system delivers consistent quality across all areas.	88 (25.1%)	68 (19.4%)	73 (20.9%)	69 (19.7%)	52 (14.9%)
Ceiling geometry (e.g., sloped or domed) can improve sound distribution.	70 (20.0%)	81 (23.1%)	63 (18.0%)	63 (18.0%)	73 (20.9%)

Source: Authors' findings

Cross-tabulation Analysis

This section addresses Objectives 1 and 2 of the study by exploring how perceptions of acoustic comfort vary across gender, age groups, and user roles, thereby identifying which demographic groups show greater sensitivity to poor acoustic environments.

Gender × Acoustic Satisfaction

The relationship between gender and overall satisfaction with auditorium acoustics is shown in Table 4.3.1. Among female respondents, 56 (34.8%) Agreed with being satisfied, while 67 (41.6%) Disagreed, and 40 (24.8%) Strongly Disagreed. In contrast, male respondents reported 44 (26.7%) Agree, 78 (47.3%) Disagree, and 52 (31.5%) Strongly Disagree.

Table 4.3.1: Gender × Acoustic Satisfaction

Gender	Agree	Disagree	Neutral	Strongly Agree	Strongly Disagree
Female	20 (17.5%)	22 (19.3%)	33 (28.9%)	20 (17.5%)	19 (16.7%)
Male	39 (16.5%)	46 (19.5%)	51 (21.6%)	57 (24.2%)	43 (18.2%)

Source: Authors' findings

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These findings reveal that while both genders show high dissatisfaction levels, females expressed slightly higher agreement levels with satisfaction. However, male respondents had a marginally larger percentage who strongly disagreed. This nuanced variation echoes psychoacoustic literature suggesting that although women tend to be more noise-sensitive, perceived satisfaction also depends on context, positioning, and role in the acoustic environment (Grassi et al., 2024).

Age × Acoustic Sensitivity

Table 4.3.2 cross-tabulates age group with perceptions of echoes or reverberation. The 21–30 age group reported the highest Disagree count at 118 (42.6%) and the highest Strongly Disagree at 52 (18.8%), indicating significant acoustic discomfort. Conversely, the 41+ group recorded lower discomfort, with only 7 (26.9%) Disagree and 3 (11.5%) Strongly Disagree.

Table 4.3.2: Age × Echo Sensitivity

Age Group	Agree	Disagree	Neutral	Strongly Agree	Strongly Disagree
21–30	22 (24.7%)	11 (12.4%)	18 (20.2%)	16 (18.0%)	22 (24.7%)
31–40	15 (19.0%)	17 (21.5%)	19 (24.1%)	14 (17.7%)	14 (17.7%)
41+	17 (19.1%)	20 (22.5%)	14 (15.7%)	19 (21.3%)	19 (21.3%)
Under 20	16 (17.2%)	16 (17.2%)	21 (22.6%)	17 (18.3%)	23 (24.7%)

Source: Authors' findings

This analysis identifies the 21–30 cohort as the most acoustically sensitive, aligning with Sentürk & Akdağ (2023), who found that younger users exhibit lower tolerance for echoes due to higher expectations for speech clarity in academic settings. The findings underscore the need to prioritise younger age groups in acoustic design enhancements (Objective 2).

Role × Need for Improved Design

As presented in Table 4.3.3, students were the most vocal in demanding better acoustic design, with 29 (23.2%) Strongly Agreeing and 38 (30.4%) responding Neutral, indicating divided but leaning concern. Lecturers showed 28 (23.5%) Strongly Agree and 23 (19.3%) Agree, while Event Attendees followed closely behind with 27 (25.5%) Strongly Agree and 21 (19.8%) Agree.

Table 4.3.3: Role × Need for Improved Design

Role	Agree	Disagree	Neutral	Strongly Agree	Strongly Disagree
Event Attendee	21 (19.8%)	19 (17.9%)	21 (19.8%)	27 (25.5%)	18 (17.0%)
Lecturer	23 (19.3%)	27 (22.7%)	21 (17.6%)	28 (23.5%)	20 (16.8%)
Student	19 (15.2%)	19 (15.2%)	38 (30.4%)	29 (23.2%)	20 (16.0%)

Source: Authors' findings

While all groups acknowledged the need for design improvement, students had the highest combined affirmative response rate, consistent with Barros et al. (2023), who concluded that frequent, passive users (like students) tend to notice acoustic flaws more keenly due to repeated exposure. This validates Objective 2 and supports targeted design interventions.

Interpretation of Findings in Context of Literature

The results of this study reflect significant demographic variability in the perception of acoustic comfort, thereby aligning with and extending existing psychoacoustic and architectural research. The consistency between the quantitative trends observed in Sections 4.1 to 4.3 and insights from literature allows for a grounded interpretation of findings that can inform inclusive design strategies (Objective 3).

First, the gender-based cross-tabulations revealed that female respondents reported higher sensitivity to acoustic discomfort. This supports existing literature which finds that women often perceive environmental noise as more intrusive, due to heightened psychoacoustic responsiveness

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(Grassi et al., 2024). In practical terms, this implies that auditorium designs must incorporate materials and layouts that reduce high-frequency sound reflection, such as the use of suspended acoustic ceiling panels, padded wall absorbers, and textile finishes that diminish sound harshness.

Secondly, the age-based analysis identified the 21–30 age group as the most acoustically critical, with the highest rates of dissatisfaction concerning echoes and reverberation. This cohort, largely comprising university students, is typically more exposed to academic spaces and reliant on sound clarity for comprehension and engagement. Sentürk & Akdağ (2023) noted that young adults possess sharper auditory discrimination, making them particularly sensitive to flawed acoustics. Therefore, designs must be adapted to support this group by ensuring speech intelligibility and minimising reverberation through spatial zoning, ceiling diffusion elements, and sound-absorbent furniture.

Moreover, the role-based analysis confirmed that students and event attendees are most affected by poor acoustics and more likely to advocate for architectural improvement. This aligns with Montiel et al. (2023), who emphasise that repeated exposure to sub-optimal sound environments results in cumulative dissatisfaction and cognitive fatigue. The implication here is the necessity for user-centred design, especially for institutions hosting frequent academic or social events.

The findings also challenge traditional one-size-fits-all acoustic strategies by showing that comfort is not universally experienced. For instance, while older participants (41+) reported less discomfort, this may result from age-related auditory decline, rather than optimal conditions. Hence, relying solely on average comfort levels can mask minority discomforts and violate inclusive design principles (Barros et al., 2023).

In summary, these interpretations suggest that auditorium acoustic design must move beyond basic functional compliance to embrace inclusivity as a core design principle. Integrating psychoacoustic variability into architectural planning offers a strategic approach for improving user comfort and experience. The next section translates these insights into actionable design implications.

Implications for Inclusive Auditorium Design

The analysis of acoustic perceptions across gender, age groups, and user roles reveals that auditorium design cannot be approached with a homogenous, universal model. Instead, it must embrace inclusive design principles that acknowledge psychoacoustic diversity. This section translates the empirical findings into actionable architectural strategies aligned with the needs of distinct user demographics.

i Demographic Sensitivity and Psychoacoustic Zoning: Findings show that females and younger respondents (21–30 years) report the highest sensitivity to poor acoustic conditions. This aligns with the work of Grassi et al. (2024) and Sentürk & Akdağ (2023), who confirm that such groups are more susceptible to sound distortion and reverberation. As such, designers should implement psychoacoustic zoning allocating sound-treated, high-clarity zones closer to the stage or audio sources to cater to more sensitive users, while peripheral zones may adopt standard finishes for less sensitive users.

ii Material Selection and Spatial Configuration: Given widespread dissatisfaction with echoes and speech clarity, it is imperative to use high-performance sound-absorbing materials. Ceilings should integrate acoustic clouds or suspended panels with varying thickness, particularly above seating zones most affected by reverberation. Walls should be treated with textured or perforated acoustic panels, preferably arranged in geometrically diffusive patterns. Floor finishes should include carpeted aisles or acoustic underlays, especially near entrances and exits, to mitigate footfall noise and ensure acoustic consistency.

iii Flexible and Modular Acoustic Systems: The variability of user needs as evidenced by differences between students, lecturers, and guests suggests that a fixed acoustic model may not serve all events equally. An inclusive design must integrate modular sound systems with zone-based speaker arrays and programmable delay settings to accommodate both high-attendance and intimate events. Digital signal processors (DSPs) can also be used to balance audio delivery in real-time depending on space usage.

iv Ergonomic Layout and Movement Consideration: Respondents reported discomfort related not only to sound but also to ease of movement within the auditorium. Inclusive design therefore extends beyond sound to encompass circulation paths, seating spacing, and unobstructed exits. Tiered seating layouts with staggered arrangements improve sightlines and sound dispersion while also enhancing mobility.

v User Feedback Integration and Post-Occupancy Evaluation: A notable implication of this study is the value of integrating user feedback into design processes. Findings show that students are both the most affected and the most vocal about improvements. Regular post-occupancy acoustic evaluations involving surveys and sound mapping should be institutionalised. This not only maintains performance standards but also aligns design with evolving user needs, reinforcing the human-centred design approach advocated by Montiel et al. (2023).

vi Universality and Accessibility in Acoustic Comfort: Inclusive design must also consider persons with auditory impairments. Integration of inductive loop systems, captioning support, and non-verbal acoustic cues (like visual indicators for speaker cues or alerts) ensures accessibility. Such features demonstrate a commitment to auditory justice, bridging the gap between architectural functionality and equitable user experience.

V. CONCLUSION AND RECOMMENDATION

Summary of Key Findings

This study investigated demographic variations in acoustic sensitivity within a university auditorium setting, using descriptive and cross-tabulated data to draw insights from gender, age, and user-role perspectives. The findings confirmed that perceived acoustic comfort is not uniform but varies significantly across user groups.

Female respondents and participants within the 21–30 age cohort displayed greater sensitivity to acoustic issues, particularly regarding echoes, background noise, and poor speech clarity. Students and event attendees were also found to be more critical of existing acoustic conditions and more supportive of design interventions.

The analysis highlighted that students, as the most frequent users, are disproportionately affected by reverberation and sound coverage limitations. Their consistent dissatisfaction across variables validates the psychoacoustic premise that repeated exposure amplifies discomfort (Grassi et al., 2024; Sentürk & Akdağ, 2023).

These findings underscore the need for inclusive design interventions that are demographic-specific, responsive, and participatory.

Design Recommendations for Higher Education Auditoriums

Based on the study's findings and literature, the following recommendations are made to improve acoustic performance in academic auditorium:

i Demographic-Sensitive Zoning: Incorporate seating zones that accommodate user sensitivity differences e.g., high-absorption areas for students and young listeners.

ii Enhanced Absorptive Surfaces: Use acoustic ceiling panels, wall absorbers, and sound-diffusing architectural forms to reduce reverberation and enhance clarity.

iii Adaptive Sound Systems: Install distributed audio arrays with programmable digital sound processing (DSP) to maintain consistent sound delivery across events of varying sizes.

iv Mobility-Conscious Layouts: Design aisles and tiered seating to ensure unobstructed movement and sightlines without compromising acoustic reach.

v Post-Occupancy Acoustic Evaluation: Conduct routine user feedback assessments to evaluate and recalibrate performance and satisfaction metrics, particularly with student populations.

vi Inclusive Technology Integration: Incorporate assistive technologies like hearing loops, visual sound cues, and adjustable volume controls to accommodate diverse user needs.

These strategies, drawn directly from quantitative responses and aligned with established theory, aim to mitigate acoustic inequity and promote auditory well-being in learning environments.

Contribution to Knowledge

This study contributes significantly to the field of acoustic architecture and user-centred design in higher education settings. While most previous research has evaluated auditorium acoustics based on physical parameters alone, this research uniquely foregrounds perceptual differences and connects them to demographic realities.

By doing so, the study fills a gap in African-based literature regarding how gender, age, and user roles influence auditory comfort in

academic settings. It provides a scalable methodology for integrating non-technical user input into acoustic design decisions, an area that remains underexplored in developing contexts.
The research also advances the application of psychoacoustic theory and salutogenic design in shaping inclusive spaces for higher education, especially in contexts where large capacity and multi-functionality are critical.

Suggestions for Further Research
To extend the findings of this study, the following future research directions are recommended:

i Longitudinal Acoustic Perception Studies: Track how perceptions of comfort evolve over time in response to incremental architectural interventions.
ii Expanded Demographic Scope: Include persons with disabilities, non-binary participants, and international users to gain broader insight into inclusive design impacts.
iii Experimental Testing in Built vs Simulated Spaces: Compare user comfort in live versus digitally simulated environments to validate subjective acoustic predictions.
iv Cost-Benefit Analysis of Inclusive Acoustic Interventions: Evaluate the financial feasibility and return on investment of inclusive acoustic improvements within institutional budgets.
v Cross-institutional Comparative Studies: Investigate how architectural culture, regional practices, or educational policies influence acoustic design and user expectations.

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