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An Assessment of Indoor Acoustic Condition in Students Hostels within Obafemi Awolowo University, Nigeria

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Abstract

It has been hypothesized that objective assessment for building acoustic conditions only may not always be representative of the users' perception in occupied indoor spaces. This study objectively and subjectively examined indoor acoustic condition in rooms within students' hostels in Obafemi Awolowo University, Nigeria. The objective assessment considered the physical measurement of sound pressure level in the rooms in relation to the rooms' physical characteristics like window to external wall area and window to floor area ratios. The subjective assessment considered the occupants' perception of the acoustic condition in the rooms in relation to their personal characteristics like age, gender, body mass index, metabolic rate, and body skin area. The sound pressure level was measured in each of the randomly selected 44 rooms at 15 minute intervals between 7 hours and 19 hours daily through a period of eight weeks. The measurement was done with High Accuracy Digital Sound Noise Level Data Loggers placed at work plane at the centre of the rooms. The geometry of the rooms was documented through physical measurements. All the occupants of the selected rooms as well as the two adjoining rooms, amounting to 696 respondents, were purposively selected to fill a questionnaire regarding activities carried out in the rooms, the frequency of fenestration opening, the personal characteristics of the occupants and the rooms' occupancy ratio. This study established a strong correlation between the objective and subjective assessments of the acoustic condition in the spaces. Moreover, out of all the occupants' personal characteristics considered, it was the age that has a relationship with the occupants' perception of the acoustic condition that is closest to significant level. The relationship between their perception and measured sound pressure level was slightly more pronounced among the male gender than the female with correlation coefficients of 0.115 and 0.096 respectively. This study concluded that none of

the considered occupants' personal characteristics can effectively predict their response to indoor acoustic condition in the spaces.

Keywords

Acoustic Condition, Sound Pressure Level, Personal Characteristics, Occupants' Perception, Objective And Subjective Assessments

1. Introduction

It has been established that the indoor acoustic condition is one of the main factors that determine the quality of the indoor environment in general (Bluyssen, 2010) [1]. Therefore, it is strongly related to the performance, comfort, and health of occupants of indoor spaces within the built environment. An indoor space with acceptable acoustic environment is one that can control excess noise pollution from both indoor and outdoor sources. Hence, acoustic comfort has been defined as a state of contentment with acoustic conditions. Furthermore, the acoustic condition has been defined by ISO 12913-1 (2014) [2] as the acoustic environment as perceived or experienced, and/or understood by a person or people, in context. This identified with a robust definition by Rasmussen and Rindel (2005) [3]. The study remarked that acoustic comfort is a concept that can be characterized by the absence of unwanted sound, desired sounds with the right level and quality, opportunities for acoustic activities without annoying other people.

The acoustic condition is however mostly associated in engineering to only sound pressure levels low enough not to cause discomfort or annoyance (Nikolaos-Georgios Vardaxis *et al.,* 2018) [4]. Hence, many scholars assessed it purely through objective measurements in laboratories and not in the field where occupants in the built environment experience real life situations (Osasona *et al.,* 2011 [5]; Kim *et al.,* 2013 [6]; Spah *et al.,* 2013 [7] and Kylliainen *et al.,* 2016 [8]). However, studies have shown that the use of only objective assessment for building acoustic conditions may have limited potentials in guiding building design. This is because it may not always be representative of the perception of users of occupied indoor spaces (Ljunggren *et al.*, 2014) [9]. This, therefore, suggests that a synergy between objective and subjective assessment may produce more credible results to improve on available standards and to accurately predict the responses of occupants of indoor spaces.

The quality of the acoustic environment is linked to numerous physical parameters, which include both the physical properties of sound itself and the physical properties of the indoor space (Osasona, *et al.,* 2011 [5]; Vermeir and Van der Bergh, 2003 [10]; Iordache *et al.*, 2013 [11]). Sound is characterized by the sound pressure level in a short-term and long-term period and by sound frequency. The acoustic environment is influenced by such physical room properties as sound insulation, absorption and reverberation time (Frontczak, and

Wargocki, 2011) [12]. Generally, acoustic comfort assessments are based on some objective acoustic models. Fundamental to the models is the reverberation time which is the time required for the sound pressure level in a room to decrease by 60 dB after being stopped at the emission source (Harris and Shade, 1994 [13]; Jian, 2006 [14]).

There are many other models used in various acoustic comfort studies with their different strength and weaknesses. First is the Geometric model which assumes that the rays leave evenly acoustic source mirroring the environment. This leads to reflections and every surface that the rays come in contact will suffer attenuation. The acoustic ray theory is based on the idea that sound is propagated in the form of a ray, with properties similar to those found in the geometrical optics (Gerges, 2000) [15]. Such assumption may only be reliable when the wavelength is extremely smaller than the dimensions of the room where it occurs. Hence geometric model evaluations may not be satisfactory at low frequencies (Vieira and de Sousa Costa, 2012) [16].

Second is the Image-Source model which treats each sound reflection as a virtual source, which is out of the environment and consists of the source image, across the wall. According to Vieira and de Sousa Costa, (2012) [16], it is the most commonly used model in rectangular environments such as schools, offices and homes. However, it does not take into account the diffusion effects of reflections or mirroring caused by irregular surfaces. The third is the Ray-Tracing model which takes into account the diffuse reflections and requires a computational time only proportional to the length of the impulse response, but does not provide results with good temporal resolution (Vieira and de Sousa Costa, 2012) [16].

Other acoustic quality models include Speech Privacy index which is mainly applied for open plan offices and relates to the degree of speech disturbance between two individuals who are not in conversation with each other; Speech Intelligibility index which evaluates the degree of understanding or non-understanding of speech in rooms; and Articulation Index which is a signal-to-noise ratio assessment and reflects the degree to which intruding speech contents, from adjacent work stations, exceeds the ambient sound pressure level at the listener's ear in an indoor space (Osasona *et al.*, 2011 [5]; Andersson and Chigot, 2004 [17]).

In recent times, however, the instrumentation for the measurements and evaluation of acoustic quality has been aided by development within the field of sound recording as well as the development of laptops (Andersson and Chigot, 2004) [17]. Moreover, Horrall, Pirn, and Markham, (2003) [18] concluded that a portable computer with integrated soundboard and a suitably amplified loudspeaker and test microphone are all that are needed to perform in-situ measurements of Articulation Index or other accepted indices. In line with this, Andersson and Chigot, (2004) [17] remarked that such instrumentation allows technicians to survey a large number of working places economically. There are cost efficient tools meeting the requirements for testing in most common environments where oral privacy is likely to be required. In view of the foregoing, this

study employed the use of sound level data logging instruments in conjunction with relevant computer software to objectively assess the acoustic quality in relation to the overall indoor environmental quality in indoor spaces within the study area.

Much of studies regarding the assessment of the acoustic condition within the built environment has been done either at the urban scale or in non-domestic buildings like worship centres, learning and teaching environment as well as care facility centres (Astolfi and Pellerey, 2008 [19]; Ana *et al.*, 2009 [20]; Osasona *et al.*, 2011 [5]; Yilmazer and Acun, 2018 [21]; Aletta *et al.*, 2018 [22]). Some of the studies carried out in domestic buildings, including residences, were mostly done within a context far different from the ones existing in residential neighbourhoods in Africa as a whole and in Nigeria in particular (Nikolaos-Georgios Vardaxis *et al.*, 2018 [4]). This is noteworthy because it has been established that occupants' response to aspects of the indoor environment is linked to their personal and socio-cultural characteristics, and that this relationship has not been adequately examined (Frontczak and Wargocki, 2011 [12]). This is further corroborated by the definition of acoustic condition according to ISO 12913-1 (2014) [2], which emphasized the "context" of its assessment or perception.

The main aim of this study was, therefore, to assess the acoustic condition in the rooms within occupied student's hostels in Obafemi Awolowo University, Ile-Ife, Nigeria both objectively and subjectively. The peculiarity of this context is evident in its location and the primary task for which the rooms were designed. First, the spaces were sleeping cum reading rooms within the campus of a University community. They do not require an acoustic condition exactly the same with that expected of a classroom or a library, but still need an acoustic condition acceptable for reading while carrying out other domestic activities within the same space. Second, the spaces were largely occupied by occupants form a socio-cultural background whose perception has not received adequate examination in acoustic comfort studies (Nikolaos-Georgios Vardaxis *et al.*, 2018 [4]). Hence, the specific objectives of this study were first, to examine measured sound pressure level in the hostel rooms in relation to the physical characteristics of the rooms. Third, examine the occupants' perception of the acoustic condition in the rooms in relation to their personal characteristics. At last, analyse the relationships between the two.

2. The Study Area

The studied student hostels are within the campus of Obafemi Awolowo University which is located within Ile-Ife, a small city in South-western Nigeria located between latitudes 7°28'N - 7°34'N and longitudes 4°27'E - 4°35'E with an elevation of about 275 m above sea level. There are nine main hostel buildings within the neighbourhood with a combined capacity of 10,344 students. These are the Murtala Mohamed Post-graduate hall, Adekunle Fajuyi hall, Moremi hall, La-

doke Akintola hall, Alumni hall, ETF hall, Angola hall, Awolowo hall, and Mozambique hall.

Each hostel building has study cum sleeping rooms as the main spaces with other ancillary spaces like kitchenettes, bathrooms and laundry at one end of each of the block of rooms. Observation revealed that the walls are of sandcrete blocks rendered on both sides with cement and sand plaster, and painted with matte finish. The windows are made of glass louver to achieve natural ventilation. With the exception of Angola and Mozambique halls which have ceiling fans installed in all the rooms, the rooms within most of the hostel buildings were designed with no mechanical ventilation system. Their doors are timber flush doors. The roofs are made of corrugated asbestos with asbestos ceiling. Among different design and layout features characterizing the different hostel buildings which might influence the quality of the acoustic environment in the spaces areterraces and balconies, as well as vegetation and green spaces that serve as a buffer from street noise (Zhao *et al.,* 2009 [23]; Dzhambov and Dimitrova, 2014 [24]).

3. Material and Methods

The indoor sound pressure level in the selected rooms was measured with DT-173 High Accuracy Digital Sound Noise Level Data Loggers shown in Plate 1 with a measuring range of 30 dB to 130 dB and data memory of 129,920 samples. It has a dynamic range of 50 dB, a frequency range of 31.5 Hz to 8 kHz, and an accuracy of +/−1.4 dB. The data loggers were connected to Personal Computers (PC) and placed at work plane (1.0 m above the finished floor level) at the center of the selected rooms. The data was taken in each of the rooms at 15-minute intervals between 07 hrs and 19 hrs daily through a period of eight weeks altogether spanning between the month of February and July, 2018. The data was then downloaded into PC using the sound data logger application software for analysis.

Selected rooms for measurements were 44 in all. These were randomly selected such that at least four rooms represented each of the nine main room layout types identified within the students' hostels. All the selected rooms have the same wall, window and ceiling material finishes. The geometry of the rooms was documented through physical measurement using measuring tape. This was used to generate data on the window area, the wall area, the floor area, the window to floor area ratio and the window to wall area ratio. Data regarding the floor area per occupant in each room was also collected for it determines the amount of sound absorbing furniture in each room. All the occupants in the selected rooms, as well as the two adjoining rooms, were purposively selected to fill a questionnaire. This amounted to 696 respondents. The questionnaire elicited information regarding the activities carried out in the rooms and the frequency at which occupants opened the fenestrations. The same questionnaire was used to capture other data about the occupants' gender, age and complexion, as well

Plate 1. DT-173 High accuracy digital sound noise level data logger.

as the occupants' perception of the acoustic condition in the rooms. Other personal characteristics like weight and height were measured using Generic height and weight scale. These were used to calculate the Body Mass Index (BMI), the Body Metabolic Rate (BMR), and the Body Skin Area (BSA). The BMI was calculated using Equation (1) (United States Department of Health and Human Services); the BMR was calculated using Equations (2a) and (2b) for male and female respectively (Frankenfield, Roth-Yousey and Compher, 2005 [25]); while the BSA was calculated using Equation (3) (Farlex Partner Medical Dictionary, 2012 [26]).

$$\text{Body Mass Index} = \text{Weight}\left(\text{kg}\right) \big/ \text{square of the height}\left(\text{m}\right) \quad (1)$$

$$655 + \left\{4.35 \times \text{weight(pounds)}\right\} + \left(4.7 \times \text{height}\left(\text{inches}\right) - 4.7 \times \text{age}\left(\text{years}\right)\right) \quad (2a)$$

$$66 + \left\{6.23 \times \text{weight}\left(\text{pounds}\right)\right\} + \left(12.7 \times \text{height}\left(\text{inches}\right) - 6.8 \times \text{age}\left(\text{years}\right)\right) \quad (2b)$$

$$0.202 \times \text{weight } 0.425\left(\text{kg}\right) \times \text{height } 0.725\left(\text{m}\right) \quad (3)$$

Each respondent was asked to indicate the most prominent indoor and outdoor noise source and to rank the extent to which they were satisfied with the acoustic condition in the room. The data collected were subjected to statistical analysis using the IBM SPSS Statistics 22. The mean measured sound pressure levels in each room layout type were objectively assessed with the standards according to the Nigerian Federal Environmental Agency (FEPA, 1990 [27]). The Agency stipulated that maximum permissible exposure limit for indoor acoustic comfort is 90 dB within an eight-hour period, and the exposure to impulsive or impact noise should not exceed 140 dB. Further analysis was also carried out to determine which of the physical characteristics of the rooms can best predict the sound pressure levels. Furthermore, a regression analysis was carried out to determine which of the occupants' personal characteristics can best predict their perception of the acoustic conditions in the rooms.

4. Results

Physical measurement revealed that the nine different room layouts studied have window to floor area ratio that ranged from 0.08 to 0.52. Their window to ex-

ternal wall area ratio ranged from 0.08 to 1.01, with 35.7% of the respondents occupying the room layout type that has the lowest window to floor ratio and window to external wall ratio of 0.08.

Out of the 696 administered questionnaires, 576 were returned. After the questionnaires were sorted however, 462 were usable for the analysis resulting in a 66.38% response rate. All the respondents were either undergraduate or post-graduate students in the University with 62.8% being males while 37.2% were females. The Body Mass Index (BMI) distribution of respondents showed that 67.3%, fell within normal range of 18.5 and 25, while 30.9% were either under-weight or over-weight, and 1.8% were obese. Regarding the metabolic rate (BMR), 57.6% of the respondents were having metabolic rates between 58.33 and 75 kcal/hour, 38.7% were below that range, while 3.8% were above the range. Regarding the Body Skin Area (BSA), 43.9% of the respondents were within the average range of between 1.7 m^2 and 2.0 m^2, 52.5% were below the range, while 3.6% were above the range. Moreover, only 9.8% of the respondents were not adult (below 18 years of age), while a majority 61.8% were between ages 18 and 23 years.

The mean measured sound pressure levels in each room layout ranged from 27.75 dBA to 56.29 dBA, with an overall mean value of 48.77 dB. The highest measured sound pressure level during the entire study period was far lower than 90 dB which was the maximum allowable limit value according to FEPA (1990) [27], Figure 1 and Figure 2 show the average distribution of the mean measured sound pressure level during the day in the room layouts with the lowest window to external wall area ratio and the highest window to external wall area ratio respectively.

This study found that the main contributors to indoor sound pressure levels in the spaces as rated by the occupants were indoor noise sources. Furthermore, Table 1 and Table 2 revealed the contributions of different identified external and internal noise sources to the acoustic environment of the spaces as rated by the occupants. Table 1 showed that 76% of the occupants regarded roommates chatting as the most prominent indoor sound source, followed by noise from electronic gadgets, while Table 2 showed that 54.1% of the occupants regarded noise from people walking along the adjoining corridor as the most prominent outside noise source followed by activities in the hostel common room. This is similar to Wang and Jan (2014) [28], who found that the highest percentage of occupants rated "talking within the space" as the most prominent source of noise affecting them. Moreover, as shown in Table 3, only 9% of the occupants were dissatisfied with the mean sound pressure levels in the spaces.

5. Discussions

This study established a strong correlation between the objective and subjective assessments of the acoustic condition in the spaces. The objective analysis revealed that the mean measured sound pressure levels in the nine room layouts
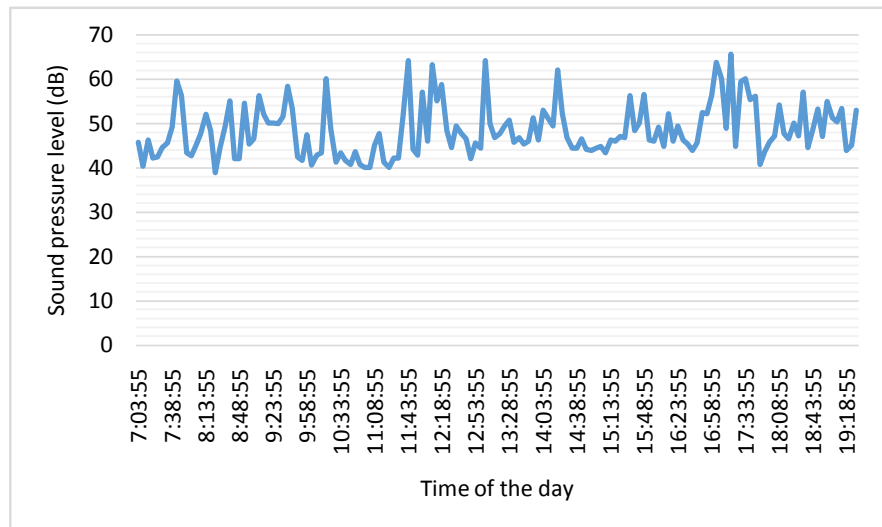
Figure 1. Mean measured sound pressure levels in the room layout with the lowest window to external wall area ratio.
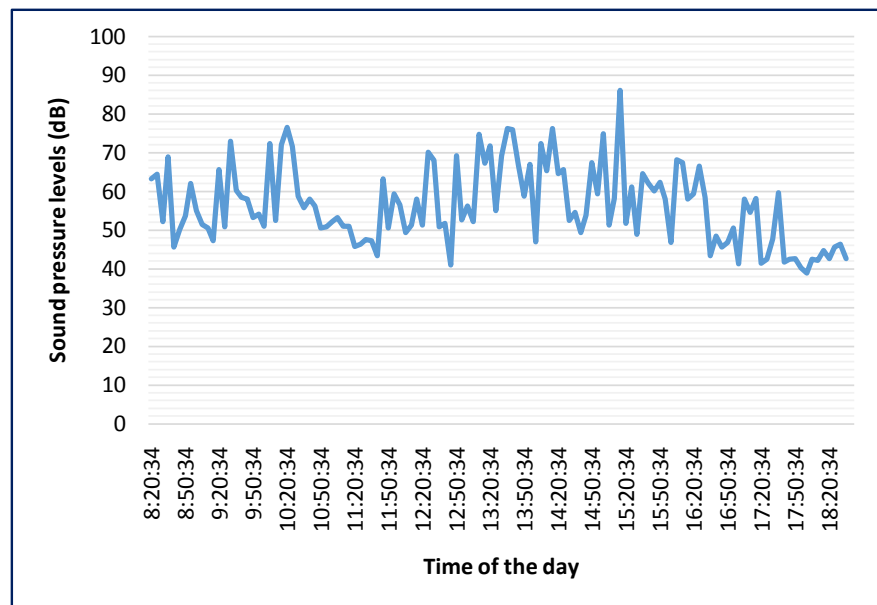

Figure 2. Mean measured sound pressure levels in the room layout with the highest window to external wall area ratio.

were less than the maximum allowable in the spaces by between 37.46% and 69.17%. This showed that the entire room layout met the recommended standard in Nigeria, and hence should provide significantly high level of acoustic comfort. This was confirmed by the subjective assessment by the occupants which revealed that over 80% of the occupants were satisfied with the acoustic condition in the spaces. This showed that objective measurements could be effectively used to predict responses of occupants to acoustic conditions in the students' hostels.

Further analysis revealed a direct significant relationship between the mean measured sound pressure levels and the window to floor area, as well as with the

Table 1. Most prominent indoor noise sources in the spaces.

	Frequency	Valid Percent	Cumulative Percent
none	16	3.5	3.5
roommates chatting	346	76.0	79.6
door slamming	25	5.5	85.1
noise from electronic gadgets	57	12.5	97.6
phone calls	11	2.4	100.0
Total	455	100.0	

Table 2. Most prominent outside noise source in the spaces.

	Frequency	Valid Percent	Cumulative Percent
none	14	3.1	3.1
religious activity	33	7.4	10.5
sporting activity	34	7.6	18.1
common room activities	99	22.1	40.3
people walking along the corridor	242	54.1	94.4
traffic noise	8	1.8	96.2
power generator	16	3.6	99.8
noise from next room	1	.2	100.0
Total	447	100.0	

Table 3. Occupants' perception of the indoor sound pressure level.

	Frequency	Valid Percent	Cumulative Percent
neutral	232	52.1	52.1
slightly high	173	38.9	91.0
too high	40	9.0	100.0
Total	445	100.0	

window to external wall area ratios of the spaces both at $\rho < 0.01$. This showed that the higher the ratios, the higher the measured sound pressure level. However, the correlation coefficient was higher for the window to external wall area ratio (0.45) than that for the window to floor area ratio (0.36). WhileShield and Dockrell (2004) [29]could not arrive at a conclusive confirmation for such relationship, several other studies like Aasvang *et al.* (2008) [30] carried out in bedrooms exposed to railway noise, and Tong *et al.* (2015) [31] carried out in unoccupied test rooms, established similar relationship between indoor sound levels with building characteristics related to the widow area and type. This suggests that direct relationship between indoor sound pressure levels and building characteristics related to window sizes exists in different outdoor/indoor acoustic context within which a building is located.

Furthermore, according to Frontczak and Wargocki, (2011) [12] little is known regarding the potential influence of building type (which include their physical characteristics) on acoustic comfort of occupants in indoor spaces. However, studies like Leder *et al.* (2015) [32] and Sakellaris *et al.* (2016) [33] suggests that the floor area is strongly related to occupants' satisfaction with the acoustic environment. In fact, Leder *et al.* (2015) [32] concluded that satisfaction with acoustics and privacy was most strongly affected by workstation size and office type. While this study did not establish an exactly similar relationship, it, however, found an inverse relationship at a statistically significant level (correlation coefficient of −0.102) between the floor area per occupant and the measured sound pressure level. Which means the higher the floor area per occupant the lower the measured sound pressure level is. This, therefore, shows that the relationship between the building characteristics and the quality of the acoustic environment is evidently significant not only in offices but also in residencies like students' hostels.

The relationship between the perception of the occupants regarding the acoustic condition in the spaces and some of their personal characteristics were analysed. The personal characteristics considered were their gender, age, Body Mass Index, Body Metabolic Rate and their Body Skin Area. Analysis revealed that it is the occupant's age that had a relationship closest to the significant level with the occupants' perception of acoustic condition as measured by the sound pressure level. It was an inverse relationship, which showed that the higher the occupant's age, the better their level of satisfaction with the acoustic condition. No other personal characteristics considered have relationship close to significant level with their perception of indoor acoustic condition. This is similar to the findings of Sakellaris *et al.* (2016) [33] Moreover, a regression analysis showed that a change in the age among occupants between ages 21 and 23 years, as well as in the metabolic rate among occupants with less than 58.33 kcal/hr. are statistically significant in predicting the occupants' perception of indoor acoustic condition. The former was however more significant.

Although Frontczak and Wargocki (2011) [12], remarked that very few studies provided convincing evidence regarding the impact of personal characteristics of occupants on level of satisfaction with indoor conditions, the findings of the few available studies were not totally the same with that of this study. While Kim *et al.* (2013) [34] gave evidence of gender differences in noise level and sound privacy satisfaction, Sakellaris *et al.* (2016) [33] showed that the relationship between indoor comfort and noise was higher among the male gender than the female, and that age was a significant determinant of occupants' perception of the acoustic environment. Although this study found no statistically significant relationship between occupants' gender and their perception of the indoor acoustic condition, it, however, found that the relationship between their perception and measured sound pressure level was slightly more pronounced among the male gender than the female with correlation coefficients of 0.115 and 0.096 respectively. However, Kim *et al.* (2013) [6] and Sakellaris *et al.* (2016)

[33] along with most others with similar conclusion were carried out within office environment with specified tasks, and occupants age distribution far different from those in this study. This may account for the difference in the findings of this study.

6. Conclusion

This study established a significant correlation between the objective and subjective assessments of the indoor acoustic condition using measured sound pressure level in the rooms within the students' hostels. This showed that physical measurements of indoor sound pressure levels in the rooms can be used to effectively predict occupants' perception of the indoor acoustic condition in the spaces. It also showed that physical characteristics of indoor spaces are major determinants of their acoustic condition. Moreover, out of all the occupants' personal characteristics considered, it was only the age that has a relationship with their perception of measured indoor sound pressure level closest to a level that is statistically significant (with correlation coefficient of -0.04). This study concluded that none of the considered occupants' personal characteristics can effectively predict their response to indoor acoustic condition in the spaces. However, because of the very close age distribution of the respondents, this relationship may have to be further explored among respondents with wider age distribution exposed to the same range of indoor sound pressure level. It may also be expedient for future research to carry out similar study among respondents with more varied personal characteristics.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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