



Evaluation of acoustic conditions, occupants' satisfaction and comfort in open - plan offices: a case study of select places in Akwa Ibom State, Nigeria

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Abstract

This paper examines the acoustic comfort of occupants of open- plan offices in different indoor environments such as workplace, healthcare and learning environments considering the environmental effects on speech privacy, concentration when under-taking a task and acoustic satisfaction. It has also identified the major sources of office noise that help degrade the indoor qualities of open- plan offices and the possible ways of eradicating or minimising them. Digital sound level meter SL-5868P was used to measure the ambient and background noise levels of these environments to ascertain the relationship between the objective assessment of the environments and the open -plan office occupants subjective rating. The average ambient noise levels in the workplace, healthcare and learning environment under study were 59.8 dB (A), 60.0 dB(A) and 64.0 dB(A) respectively while the average background noise levels were 42.3 dB(A), 43.7 dB(A) and 46.1 dB(A) in that order.

These are all within the accepted standards. A total of 570 (Five hundred and seventy) questionnaires were equally distributed to both male and female office occupants (respondents) in the three environments under study, out of which 439 (Four hundred and thirty nine) responses were received. This is 77% of the questionnaires given out. The overall rating scores of 2.85, 2.89 and 2.80 for workplace, healthcare and learning environments respectively by the respondents for speech privacy is not encouraging. . This is a poor perception of the acoustic condition of the offices which has led to poor speech privacy. Just like speech privacy, the overall rating of 2.90, 2.72 and 2.61 of concentration during task performance is equally poor. The speech privacy and lack of concentration when performing a task informed the ratings of 2.52, 2.50 and 2.35 for acoustic satisfaction of the respondents which again is low. These are all due to the poor acoustic conditions of the offices which have resulted to the dissatisfaction of the respondents with their offices. There were very high correlation of 99.1%, 99.7% and 97.1% between the responds of office occupants in workplace and health,

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workplace and learning, health and learning environments under study respectively. Generally the occupants of these open-space offices in the three environments perceived poor acoustic comfort, poor acoustic satisfaction and poor speech privacy due to the poor acoustic conditions of the offices. Workers spend a greater part of their time in their offices and poor environmental condition might affect productivity, health and comfort. Therefore improving on the satisfaction and general comfort of the workers while in office is inevitable.

Keywords: Open-plan office; acoustic comfort; workplace environment; healthcare environment; learning environment

1.0 Introduction

Acoustic comfort is defined as a state of contentment with acoustic conditions (Antoniadis and Papadopoulos, 2017). It may be seen as the availability of noise free environment where occupants can go on their activities without disturbance. It can be said to be a concept that is characterised by absence of unwanted sound and opportunities for acoustic activities without annoying other people (Rindel, 2002).

Hydes and Davidson (2016) defined employee satisfaction as the degree to which the working environment meets the requirements and relative needs of the employee. Offices are designed according to their need and research has shown that open-plan offices are today commonly preferred due to some reasons. Open-plan office offers several managerial, economic and working advantages such as space saving due to elimination of corridors, better communication between occupants and better environmental conditions (Boyce, 1974).

Some schools of thought are of the opinion that open-plan office facilitates teamwork, some say that communication between colleagues is

enhanced; better space economy, spaciousness and flexibility are provided (DeCroon *et al.*, 2005). While users adapt to their buildings, office buildings are of great service to their users.

However open-plan office workers may be exposed to environmental stress which may include exposure to noise. Many are of the thinking that such offices set up face some acoustic problems ranging from lack of acoustic comfort, lack of speech privacy, loss of concentration which all result in degradation of labour productivity. Becker *et al.*, (1983), Danielsson (2005) and Pejtersen *et al.* (2006) in their cross sectional surveys of different office lay-out have shown that the most severe factor causing office dissatisfaction is noise and dissatisfaction with noise and privacy was highest in large open-plan offices and lowest in cellular offices. It was also found that the percentage of occupants complaining about noise was tenfold in large offices compared to cellular offices.

Poor acoustic design of open-plan offices could cause unwanted reverberation and echoes thereby affecting the comfort of the occupants of such offices. The reverberation time of a room is the acoustic property that plays an important role in the enrichment of sound for the listening audience and is defined as the time it takes to reduce the sound intensity from a level of 60dB above the threshold of audibility to an audible threshold. It is known that the reverberation time should be long enough to enhance the blending sounds but short enough to avoid excessive overlapping and confusion (Akpan *et al.*, 2003). Tang *et al.*, (2006) measured the reverberation time and noise levels in the classrooms of primary and middle schools in Hong Kong and derived a relationship between the reverberation times and speech transmission indices for speech transmission design. Zannin *et al.*, (2009)

measured the reverberation times and indoor – outdoor sound insulation efficiency in public schools facilities in Brazil and studied the actual conditions of the acoustic environment quality. Sale and Vljanen (1995) in their investigation of optimal acoustic treatment for speech rooms concluded that the optimal arrangement for sound absorption materials to achieve acceptable conditions for speech involved the distribution of material in at least two surfaces (ceiling and wall) and covering at least 30% of the total walls and ceiling.

Distraction affects speech intelligibility which may have negative effect on productivity and speech has been seen as the most distracting source of noise. Many people today work in open- plan offices where the most annoying element is irrelevant speech. A study that involved more than 40000 workers in 300 US office buildings showed that enclosed private offices clearly outperformed open- plan layouts in most aspects of indoor environmental qualities particularly in acoustics, privacy and in proxemics issues.(Kim and De Dear, 2013; Varjo *et al.*, 2015). It has been consistently affirmed that open- plan offices offer worse environmental conditions than traditional offices due to lack of individual space, the lack of acoustics and privacy requirements (Boubekri and Haghghat , 1993; Sylke, 2013; Freihofer *et al.*, 2015; Vellenga *et al.*, 2017).

The layout of open- plan environment makes acoustic problems common to such environments. In a barrier free environment, sound is bound to transmit effortlessly. With no barriers to attenuate the transmitted sound, problems with noise is typical in open- plan environments.

Banbury and Berry (2005) found that the controllable /necessary sounds are causing less discomfort than the uncontrollable and unwanted sound. They also discovered in the

same research that the phone calls and conversation noises are more disruptive and distractive compared to noise from ventilation equipment. Though open-space work provide advantages like more interaction and information exchange between office occupants by removing the table division panels and shortening the distances between co-workers, the acoustic privacy of the office occupants is affected and some occupants are not comfortable of the increased noise levels in the offices (Brand and Smith, 2005; Hongisto, 2005; Brocolini, Parizet and Chevret, 2016).

However in an earlier survey carried out in the learning environment to find out how the students perceived the environmental quality of their lecture halls, it was discovered that they were generally satisfied when considering the acoustic, daylight and air quality of their lecture halls (Akpan, 2021).

1.1 Aims and objectives of the study.

Occupants of open- plan offices in different indoor environments are influenced in various ways. This paper examines the acoustic comfort of such occupants in workplace, healthcare and learning environments when considering effects on their speech privacy, concentration when undertaking a task, and acoustic satisfaction. It also aimed at identifying the major sources of office noise that help degrade the indoor qualities of these open- plan offices and the possible ways of eradicating or minimising them.

1.2 Research questions

The research questions for this study were:

- (a) How do occupants of open-plan offices perceive the acoustic condition of their office as it affects their speech privacy or communication with others?
- (b) How do occupants of open-plan offices perceive the acoustic condition of your

office as it affects them when undertaking a task?

- (c) Are open-plan office occupants generally comfortable with the acoustic condition of their office?

1.3 Hypotheses of study

The following null hypotheses were used for the research:

- (a) There is no relationship between acoustic comfort of open-plan office and speech privacy of occupants.
- (b) There is no relationship between acoustic comfort of open-plan office and concentration of occupants when performing a task.

The alternative hypotheses were that,

- (a) There is a relationship between acoustic comfort of open-plan office and speech privacy of occupants.
- (b) There is a relationship between acoustic comfort of open-plan office and concentration of occupants when performing a task.

2.0 Materials and method

2.1. Data collection

Office acoustic questionnaire with well structured and close questions was developed for this survey for data collection on the respondents' perception of the acoustic comfort in their open offices. Questions to the respondents centred on the acoustic satisfaction with their offices when considering their privacy when making speech or communicating, concentration when performing a task and general acoustic comfort. A total of 570 (Five hundred and seventy) questionnaires were equally distributed to both male and female office occupants (respondents) in the three environments under study, out of which 439 (Four hundred and thirty nine) responses were received. This represents 77% of the questionnaires given out. Three different environments were selected for this survey

namely workplace environment, healthcare environments and learning environment. This was with a view to having a comparison of the effects on the occupants due to architectural or acoustic build up of the offices in these environments. The interviewed respondents were those occupying open-plan offices in these environments. Occupants of 14 open-plan offices in the three environments were interviewed in this survey.

In order to determine how these different environments affected their occupants, all the respondents answered the same questions.

Digital sound level meter SL-5868P was used to measure the ambient and background noise levels of these environments to ascertain the relationship between the objective assessment of the environments and the open-plan office occupants subjective rating. Measurements with the sound level meter were done at a height of 1.2m from the ground being the height of a sitting worker.

Quantitative analysis of data using Chi-square was carried out to test the respondents' assertion on acoustic comfort of their office.

$$X_c^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

where X_c^2 = calculated chi-square

O_i = Observed frequency

E_i = Expected frequency

$$x_t^2 = \alpha (r - 1)(c - 1) \quad (2)$$

where X_t^2 = Chi-square tabulated

r = Number of rows

c = Number of columns

Alpha was taken at 5% probability. The perceived qualities were rated very good (5), good (4), fair (3), poor (2) or very poor (1) by the respondents. Rank correlation coefficient was used to test how correlated the respondents ratings of perceived effects of noise in their

open-plan offices in the different environments were.

$$r = 1 - \frac{6 \sum D^2}{N^3 - N} \quad (3)$$

D = Difference between paired ranks

N = Number of pairs

Σ = Summation

where r = Coefficient of rank correlation

3.0 Results and discussion

Table 1.0: Rate of response

Type of environment	Code	Questionnaires given out	Questionnaires received	Percentage response
Workplace Environment	X	190	148	77.8
Healthcare Environment	Y	190	139	73.2
Learning Environment	Z	190	152	80.0
Total		570	439	77.0

A total of 570 (Five hundred and seventy) questionnaires were equally distributed to both male and female office occupants (respondents) in the three environments under study, out of which 439 (Four hundred and thirty nine) responses were received as shown in table 1.0 above. 77.8% of the occupants of open offices in workplace environment responded while 73.2% and 80.0% of the occupants in the health and

learning environments respectively also responded. On the average 77.0% of the questionnaires given out were responded to by the occupants of the surveyed offices in the study environments that constitute the respondents. The high percentages of responses show how interested the office occupants were in this research exercise. Figure 1.0 below shows the average ambient noise levels of the environments under study.

Average ambient noise levels dB(A)

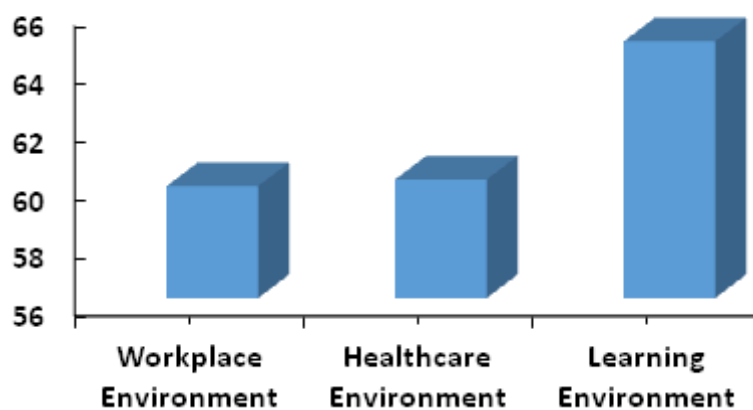


Figure 1.0: Average Ambient Noise Levels (dB(A))

The average ambient noise levels around these environments (Figure 1.0) were 59.8 dB (A), 60dB (A) and 64dB (A). Ambient noise is the total noise associated with a given environment and usually comprises sound from many sources both far and near. The ambient noise here includes vehicular

noise from cars, trucks and motorcycles they are all traffic noise. Students' activities outside such as conversations, plays etc constitute ambient noise in learning environment. The average background noise levels of the surveyed environments are as shown in figure 2.0

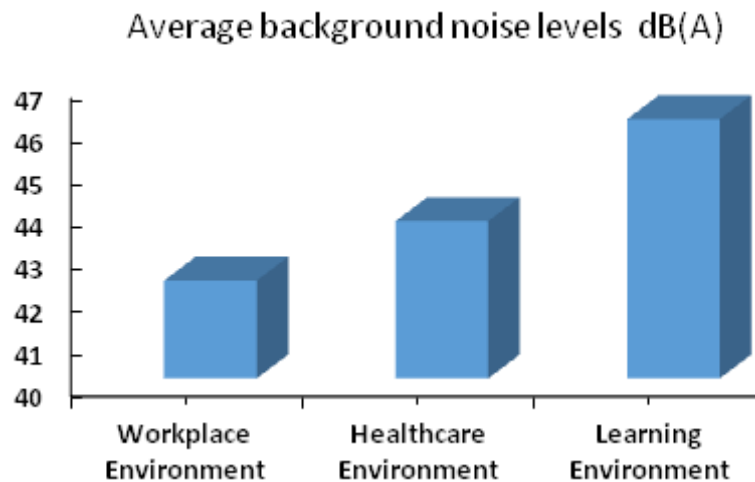


Figure 2.0: Average Background Noise Levels (dB(A))

Figure 2.0 above highlights the average background noise levels in the offices in the three different environments under investigation. Average background noise levels of 42.3 dB (A), 43.7 dB (A) and 46.1 dB(A) for the offices in the workplace, health and learning environment under survey could be considered convenient since they fall within the optimum values of 38-48 dB (A). Background noise is noise without any particular noise source in operation. The background and ambient noise fall within the acoustic recommended standards. Nigeria in her environmental impact assessment decree number 86 of 1992 had adopted an A-

weighted equivalent limit, L_{Aeq} of 90 dB(A) (Asuquo *et al.*, 2006) and the Occupational safety and Health Act (OSHA) 1970 permits

noise level of 90dB(A) for daily exposure time of 8 hours (Akpan and Onuu, 2004).

Table 2.0 below shows the overall perceived speech privacy rating of offices by the occupants. A comparison was accomplished by introducing scale values in form of numbers to represent the respondents' speech privacy rating. The numbers 5, 4, 3, 2, 1 represent "very good", "good", "fair", "poor" and "very poor" respectively.

Speech privacy viewed by 58.0% of the total respondents as being fair and 26.0% as being poor does not give the occupants the required comfort of working in open-plan offices. Only 15.5% and 3.4% of the respondents felt that speech privacy was good. The overall rating score of 2.85, 2.89 and 2.80 in workplace, healthcare and learning environments under study for open-plan offices as far as speech privacy is concerned

is not encouraging (Table 2.0). This is an indication of poor perception of the acoustic condition of the offices which results to poor speech privacy. This is contrary to the assertion by DeCroon *et al.* (2005) that communication between colleagues is enhanced in open-plan offices. Kim and De Dear, (2013); and Varjo *et al.* (2015) had observed that distraction affects speech intelligibility which may have negative effect on productivity and speech has been seen as the most distracting source of noise. They also observed that many people today work in open-plan offices where the most annoying element is irrelevant speech. Speech interference is usually one of the human effects from environmental noise pollution taken into consideration when setting noise standards or regulations (Akpan *et al.*, 2013). This in line with the findings of Brand and Smith, (2005), Hongisto, (2005)

and Brocolini, Parizet and Chevret, (2016) that although open-space work provide advantages like more interaction and information exchange between office occupants by removing the table division panels and shortening the distances between co-workers, the acoustic privacy of the office occupants is affected and some occupants are not comfortable of the increased noise levels in the offices

The overall perceived concentration rating of the offices by the occupants when undertaking a task is shown in table 3.0 below. Similarly a comparison was accomplished by introducing scale values in form of numbers to represent the respondents' concentration rating. The numbers 5, 4, 3, 2, 1 again represent "very good", "good", "fair", "poor" and "very poor" respectively.

Table 2.0: Overall Perceived speech privacy rating of offices by occupants

Environments	Perceived speech privacy rating					Response per environment (n)	Weighting rating (nr)	Average per environment (nr/n)
	Very good 5	Good 4	Fair 3	Poor 2	Very poor 1			
X	4	39	81	22	2	148	421	2.85
Y	4	11	91	32	1	139	402	2.89
Z	2	14	78	57	1	152	425	2.80
						$\Sigma r = 439$	$\Sigma(nr) = 1248$	$\Sigma(nr/n) = 8.54$

Table 3.0: Overall perceived concentration rating of offices when undertaking a task

Environments	Perceived concentration rating					Response per environment (n)	Weighting rating (nr)	Average per environment (nr/n)
	Very good 5	Good 4	Fair 3	Poor 2	Very poor 1			
X	6	12	91	39	0	148	429	2.90
Y	2	6	85	43	3	139	378	2.72
Z	0	5	89	51	7	152	396	2.61
						$\Sigma r = 439$	$\Sigma(nr) = 203$	$\Sigma(nr/n) = 8.23$

Concentration when performing a task was not equally well perceived by the office occupants hence a poor rating. 61% of the total occupants of these offices perceived this effect to be fair while 31% saw it poor. Only 10% and 27% perceived it as being good. Just like speech privacy the overall rating of 2.90, 2.72 and 2.61 is poor (Table 3.0). This is again due to the poor acoustic condition of the offices. It has been established that irregular burst of noise are more disruptive than steady noise and may sometime interfere with performance of tasks (Onuu and Akpan, 2006). The occupants of

these offices must have been confronted with steady or spontaneous types of noise while performing their duties and hence the low perception of their offices for task performance.

The office occupants rated their acoustic satisfaction of the offices as shown in table 4.0 below. Again a comparison was accomplished by introducing scale values in form of numbers to represent the respondents' acoustic satisfaction rating of their offices. The numbers 5, 4, 3, 2, 1 represent "very good", "good", "fair", "poor" and "very poor" respectively.

Table 4.0: Overall perceived acoustic satisfaction rating of office

Environments	Perceived acoustic satisfaction rating					Response per environment (n)	Weighting rating (nr)	Average per environment (nr/n)
	Very good	Good	Fair	Poor	Very poor			
	5	4	3	2	1			
X	3	17	55	52	21	148	373	2.52
Y	5	12	47	59	16	139	348	2.5
Z	2	12	49	63	26	152	357	2.35
						$\Sigma r = 439$	$\Sigma(nr) = 1078$	$\Sigma(nr/n) = 7.37$

Table 4.0 shows that the acoustic satisfaction of the office occupants has again been below the expectations of the occupants. The occupants of these offices have poor acoustic satisfaction as the overall ratings of 2.52, 2.50 and 2.35 show. Only 15% and 10.3% perceived a good acoustic satisfaction while 35.1% and 40.1% perceived it as fair and poor respectively. Lack of speech privacy and interference when performing a task has made the office occupants dissatisfied with the acoustic condition of their office environment. This is in line with an

experiment conducted by Veitch *et al.*, (2002) on acoustic satisfaction where participants rated their satisfaction after 15 minutes exposures to each of 15 different simulated ventilated sound spectra in combination with telephone conversations. Result showed that acoustic satisfaction decreased as hissiness increased, hissiness is a characteristic of excessive amount of high frequency noise.

The different perceived effect of ratings were correlated as shown in tables 5.0 a, b and c.

Table 5.0: Correlation Analysis of the Perceived Effect of Ratings in environments Using Rank Correlation

(a)

Perceived effects	Average rating per environment		D	D ²	R	% r
	X	Y				
Speech privacy	2.85	2.89	-0.04	0.0016	0.9914	99.1
Concentration	2.90	2.72	0.18	0.0324		
Acoustic Satisfaction	2.52	2.50	0.02	0.0004		
				$\Sigma D^2=0.0344$		

(b)

Perceived effects	Average rating per environment		D	D ²	R	% r
	X	Z				
Speech privacy	2.85	2.80	0.05	0.0025	0.997	99.7
Concentration	2.90	2.61	0.29	0.0841		
Acoustic Satisfaction	2.50	2.35	0.15	0.0225		
				$\Sigma D^2=0.012$		

(c)

Perceived effects	Average rating per environment		D	D ²	R	% r
	Z	Y				
Speech privacy	2.89	2.80	0.09	0.0081	0.9711	97.1
Concentration	2.72	2.61	0.11	0.0121		
Acoustic Satisfaction	2.50	2.35	0.15	0.0225		
				$\Sigma D^2=0.1156$		

Average correlation on perceived effects of rating from respondents in the three environments = 98.6%

Rank correlation shows that the perception of the occupants of these open-plan offices have in these environments on speech privacy, concentration while performing a task and acoustic satisfaction correlated highly which shows that the environment helped in no way to improve upon these effects. The high correlation of 99.1% between office occupants of workplace and healthcare environment, 99.7% between office occupants of workplace and learning environment and 97.1% between office occupants of learning and healthcare environment show that irrespective of the environment where the open-plan offices

were situated, the occupants had the same perception when it comes to speech privacy, concentration and acoustic satisfaction (Tables 5a, b and c).

The respondents were either comfortable or not with the acoustics of their offices as expressed in table 6.0. Only 33.9% of the office occupants felt comfortable while 66.1% majority were not comfortable. If the majority are not comfortable, then there are problems that need to be addressed. The response of the office occupants on the acoustic comfort of their offices was analysed using chi-square as shown in table 7.0 below.

Table 6.0: Overall response on acoustic comfort in open- plan offices in the different environments

Response	X	Y	Z	Total
A YES	57	43	49	149
B NO	91	96	103	290
Total	148	139	152	439

Table 7.0: Chi-Square analysis of response data on acoustic comfort in open- plan offices in the different environment of study

Responses	O _i	E _i	O _i -E _i	(O _i -E _i) ²	(O _i -E _i) ² /E _i
AX	57	50.232	6.768	45.806	0.911
AY	43	47.178	-4.178	17.456	0.370
AZ	49	51.590	-2.59	6.708	0.130
BX	91	97.768	-6.768	45.806	0.469
BY	96	91.822	4.178	17.456	0.190
BZ	103	100.41	2.59	6.708	0.067

Calculated X^2_c (chi-square) = 2.137

X^2 tabulated = X^2_t 0.05 (2-1)(3-1)

= X^2_t 0.05 (1) (2)

= X^2_t 0.05 (2)

= 5.99

Chi- square tabulated at 5% probability obtained from chi-square value under 2 (degree of freedom) is 5.99. Chi- square calculated which was 2.137 (table 7.0) is less than the tabulated (5.99) which affirms the assertion by the respondents that they are not comfortable with the acoustic condition of their open- plan offices and this has affected their speech privacy and concentration when performing a task as shown in their ratings in tables 2.0 and 3.0. This in turn has made them unsatisfied with the acoustic condition of their offices as shown in table 4...0. The alternative hypotheses that there is a relationship between acoustic comfort of open- plan office and occupants' speech privacy and concentration when performing a task is rather upheld. This confirms the fact that enclosed private offices clearly

outperformed open- plan layouts in most aspects of indoor environmental qualities

particularly in acoustics, privacy and in proxemics issues (Kim and De Dear, 2013; Varjo *et al.*, 2015).

The occupants identified the following to be the sources of noise that affect the indoor quality of the offices:

- i) Ventilation noise from air conditioners and ceiling fans.
- ii) Conversations by colleagues within and outside the office.
- iii) Noise from office equipment such as photocopiers, refrigerator, tea machines and computers.
- iv) Opening and closing of doors, table drawers and cupboards.

- v) Students interaction with colleagues (in learning environments)
- vi) Noise from electronic appliances such as radio and television sets.
- vii) Ringing of phones and phone conversations
- viii) Ambient (environmental) noise from outside the office.
- ix) Noise from footsteps while walking.

4.0 Conclusion

Generally the occupants of these open-plan offices in the three environments perceived poor acoustic comfort, poor acoustic satisfaction and poor speech privacy due to the poor acoustic conditions of the offices. We therefore recommend that building regulations that could help curb this menace of noise in open-plan offices be put in place.

It needs a combined effort of building owners and users to minimise if not eradicate this noise problem in open-plan offices by adhering to the sound masking regulations, sound proofing measures, room acoustic and behavioural recommendations.

For countries that do not have building regulations, the building acoustic regulations that took effect in Finland in 2018 can be of great help (Vellenga *et al.*, 2017).

For sound masking system, global sound masking are recommended to produce steady background noise within 160 – 5000Hz and Brown noise spectrum is also recommended (Valtteri, 2018). Best available sound absorbers should be installed to cover at least 80% of the ceiling while such sound absorbers should be installed to cover at least 50% of non transparent areas for maximum absorption; use of textile floor covering such as rug carpets is also recommended.

For sound proving measures, open-plan offices should be properly isolated from corridors, coffee areas and meeting rooms. Recent studies show that a sufficient number of silent workrooms are associated with speech privacy and environmental satisfaction; therefore it is recommended that anonymous rooms for silent work by an amount of 1 room per 5 employees should be provided (Hogisto *et al.*, 2018).

The office users have roles to play; provision of high quality headsets during phone conversations and internet meetings reduces the noise level and improves communication. To further reduce the noise level the employees should create a common agreement concerning the use of space by demarcating silent zones ,conversational zones and making rules for using silent work rooms. Mobile sound proof booths for phone conversations, virtual meetings and small group working pods in the vicinity of the workstation should be provided (Haapakangas *et al.*, 2009). For work that requires high speech privacy, high screens of about 170cm should be provided. The screen should be sound absorbing up to 130 cm and sound isolating (Hogisto *et al.*, 2018; Virjonen *et al.*, 2007).

The benefits of good architectural acoustic design to occupants of a building include increase in productivity, improved health, good perception of surrounding activities in terms of their satisfaction and preference, good logical thinking, better attention and alertness to surrounding activities and high motivation to work (Akpan *et al.*, 2021).

The relationship between environmental, physical qualities and satisfaction is very important because workers spend a greater part of their time in their offices and poor

environmental conditions might affect productivity, health and comfort. Therefore improving on the satisfaction and general comfort of the workers is inevitable.

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