Acoustics as an Ergonomic Design Factor In an Open Plan Selected Computer Operator Work Stations: The Cyber Cafés Perspective

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Abstract

Purpose: The aim of this research is to study selected cyber cafe workstations to establish the current practices with reference to acoustic parameters. Also to re-design the work station, if necessary, in order to improve productivity, health safety and comfort of the operators in the work station.

Design/Methodology/Approach: Optimising the acoustic design of the work stations can be a complex task because of the number of design parameters that must be considered. This problem has been made much easier by designing for the permissible acoustic limit. Because of the nature of the selected work station, Nomograph estimation method was used. Finally Doppler Effect was used to calculate the permissible acoustic distances between the sources of noise and operators in the work station.

Finding: The work station have been examined under the combination of different acoustic parameters. The analysis of the results indicates some deficiencies in the design of the workstation based on the design parameters and standard values from the literatures. Based on the analysis of these results the operators and their clients may likely be exposed to fatigue, work stress and other related diseases.

Research Limitation/Implication: For demonstration of the application of the permissible acoustic design approach, a computer operator work station (Open Plan Cyber café) has been re-designed as a real case. The new design it is hoped will contribute to improvement in productivity, health safety and comfort of the operators in the workstation

Practical Implication: The proposed permissible acoustic design approach encourages Industrial/Design Engineers that standard permissible acoustic limit must be strictly followed, for the safety of the workers and site of computer operator work station should be in a place of reasonable serenity for maximum concentration.

Originality/Value: Reports reveal that acoustic design of an open plan computer operator work station has never been done using multiple acoustic design parameters. The acoustic level of the computer operator work station was re-designed to conform to the standard permissible acoustic level using multiple acoustic design parameters.

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1.0 Introduction

Open plan cafes have existed for many years, and they have gradually become the predominant format of cyber cafe for a wide range of work activities [1]. Older designs incorporating stand-alone screens and furniture have usually been replaced by modular workstations that are frequently referred to as cubicles [1]. There are modern trends to experiment with so-called innovative designs such as 'team spaces' and other variations where the partial height panels between users are absent or much reduced in size. However the vast majority of open plan cafes today consist of the rectangular cubicle format. This paper is concerned with the design of this type of open plan cafe.

Conventional open plan cafes are said to be less costly to construct and less costly to rearrange to meet changing accommodation needs [1]. Of course, there are counter arguments that lack of privacy and increased distraction will make cafe users less efficient, and that at least point to the need for good acoustical design. Optimizing the acoustical design of an open plan cafe can be a complex task because of the number of design parameters that must be considered [1]. This problem has recently been made much easier to solve as a result of the development of some methods like designing for the permissible acoustic limit, increasing room noise absorption level and sound masking [5]. Using these methods one can conveniently and quite accurately predict the speech privacy of a particular open plan cafe design.

The research aimed at study selected cyber cafe workstations to establish the current practices with reference to acoustic parameters. Also to re-design the work station, if necessary, in order to improve productivity, health safety and comfort of the operators in the work station.

2.0 LITERATURE REVIEW

Acoustic as a Design factor in an Open Plan Office

Noise is the most disturbing factor of indoor environment in open offices [2] [3]. Several independent laboratory experiments have shown that noise, especially speech, reduces task performance of cognitively demanding tasks [7].

According to Hongisto et al [5], task performance reduces with increasing speech intelligibility. The acoustic design of open offices should, therefore, aim at the reduction of speech intelligibility between workstations. This can be achieved mainly by the following methods: increasing room noise absorption, increasing masking sound level, ergonomic design of permissible acoustic level [5].

Sound Masking

Appropriate masking is necessary to reach acceptable speech privacy between two neighbouring workstations. Masking means that the stable background noise of the office is raised controllably to minimize the intelligibility of nearby speech without creating a new source of distraction. In Finland, the recommended level of masking is 40 to 45 dBA [4]. Optimum masking sound is smooth and unnoticeable, e.g. ventilation noise. Sound pressure level and spectrum need to be considered to obtain a balance between acoustic comfort and efficient masking performance. In many cases, ventilation creates an appropriate masking. In large and high open offices, constant occupant activities and babble can create an appropriate masking. But in many cases, the creation of optimum masking requires an electronic audio system.

Wangs and Bradley [11] defined the following acoustic parameters as follows:

SII = Speech Intelligibility Index
SAA = Sound Absorption Average
STC = Sound Transmission Clear
IOSL = Intermediate Office Speech Level
AI = Attenuations Index
PAL = Permissible Acoustic Limit/Level

Relationship between SII and AI

Measured attenuations in a series of mock up workstation tests were used to calculate both AI and SII values [5] [11]. By repeating these calculations for a range of speech and noise levels a very wide range of values of each measure was obtained. The resulting SII values are plotted versus AI values. The regression line shown on this plot is a fourth order polynomial that very accurately fits the data between AI values of 0 and 0.5. Its equation is as follows [11].

$$SII = 0.0194+1.942\,AI - 5.263\,AI^2 + 11.731\,AI^3 - 9.247\,AI^4 \quad (1)$$

Alternatively one can approximate the relationship by two simple straight lines.

For $0 \leq AI \leq 0.05$, $SII = 1.9755\,AI + 0.016$ (2)

$0.05 \leq AI \leq 0.5$, $SII = 0.9915\,AI + 0.0721$ (3)

Design of Permissible Acoustic Level

The permissible acoustic level of a particular workstation can be designed by determining the following parameters explained below.

Lex: this is the noise exposure level in decibel over a full period of working hours [8]. It is the sound level, energy-averaged over eight hours, which would give the same daily noise exposure dose as the varying noise over a typical full shift [8].

Leq: this is the equivalent steady sound level of a noise energy-averaged over time [8]. Because occupational noise is often a complex signal, the noise level needs to be averaged over a minimum sample time. The sample time can be short as a few minutes if the noise signal is steady or repetitive over a short cycle. Some jobs could require a full day monitoring. Whatever the actual duration, it should be a representative sample of the entire exposure.

Noise Dose: this may be given in terms of a value relative to unity or 100% of an acceptable amount of noise. It is another single descriptor for noise exposure [8]. As with Lex, it is easier to see that a noise dose of 160% (87dBA for 8h) exceeds the permissible 100% dose.

These parameters can be estimated by the following methods:

1. Use of Nomograph
2. Use of correction table and charts
3. Use of mathematical model [8].

Design using Nomograph

Steps in carrying out the acoustic design using Nomograph are listed below:

1. Use the sound level meter to measure the Leq values of each of the respondents with a sampling time of 5minutes
2. Determine the daily working hour of each respondents
3. Sum up all the corresponding Leq and duration of the respondents to get total Leq and total duration of daily working hours.

Correction Table Method

From the literature [8], the correction table method is given by,

Lex = Leq + correction for shift length (4)

It is closely related to Leq which can be measured. In fact, Lex could be regarded as being the measured Leq with a small correction.

Mathematical Model

From the literature [8], the mathematical model is given by,

4. From the Nomograph, determine the corresponding noise dose in percentage of each respondent using the measured Leq and daily working hours.
5. Sum up the noise dose of each respondent to get the total noise dose of all respondents
6. Join the total noise dose to total daily working hours on the Nomograph read shift Leq.
7. Join the total noise dose to 8 hour, extend the straight line, to read Lex [8].

$$Lex = 10\,Log_{10}\,(DOSE/100) + 85dBA \quad (5)$$

Other factors that determine the acoustic level of the workstation are the environmental and climatic factors like the locations of the workstations, mode of operations, temperature and humidity. Of all these factors, mode of operation is of major interest in this work and is pursued further.

3.0 METHODOLOGY

Field Experiment

A random sample of thirty respondents was selected from two different cyber cafes in equal proportions. The two cyber cafes are about twenty kilometres apart, six and five meters respectively to the road side. They both operate mostly on diesel plant, and these constitute more to the noise exposure of the respondent.

The study was divided into two phases. Firstly, a survey was conducted using questionnaire and observation method, focusing on the acoustic level. These were done to identify the level of ergonomic awareness, and the level of implementation of ergonomic programmes in the design of the workstation.

The second phase of the study was the ergonomic re-design of the workstation using data from the-Lex/Leq measurements and the standard parameter from the literature.

Doppler Effect

This is defined as the perceived change in frequency of sound emitted by a source moving relative to the observer. The frequency of the emitted sound is directly related to the intensity or the sound level, which is inversely related to the distance between the source and the observer.

Let F_o = frequency of the sound from a central source

V = speed of the sound = 3.0X 10^8m/s

λ = sound wave length

χ = distance between the source and the observer

If the source has frequency F_o, the time interval T_o between the sound wave crest leaving the source is

$$\mathbf{T_o = 1/ F_o} \qquad \mathbf{(6)}$$

As a fresh wave crest is emitted, the previous crest has travelled a distance λ

$$V\,T_o = \lambda$$

$$\text{Therefore } \boldsymbol{\lambda F_o = V} \qquad \mathbf{(7)}$$

It is evident that, as a result of the motion of the source, waves travelling longitudinal have a longer wave length than they had when the source was at rest.

Steady source velocity V_s in time $T_o = 1/F_o$ between crest being emitted the source will have moved a distance V_sT_o. At the same time, the previous emitted crest will itself have moved to the left a distance λ

The actual distance between crests emitted to the left will be

$$\boldsymbol{\lambda^1 = \lambda - VsTo} \qquad \mathbf{(8)}$$

These waves, having left the source, are of course moving at the same speed of sound relative to the air. The motion of the source does not affect the speed of sound.

Observer at the other side toward the source will hear a frequency $F^1 = V/\lambda^1$

By parallel argument, for a source moving away from the observer at steady speed V_s, the frequency is lower by the corresponding factor

$$\mathbf{F^1 = F_o\,(1/1+V_s/V)} \qquad \mathbf{(9)}$$

If the source is moving away from the initial position, the distance χ between the source and the observer is increasing. This will reduce both the frequency and the intensity.

Acoustic Design

The acoustic design of the workstation puts into consideration the following acoustic design parameters:

Ceiling Absorption, Screen/ Panel Height, Screen/ Panel Absorption, Workstation Plan Size, Floor Absorption, Screen Transmission Loss, Ceiling Height, Permissible Sound Level, Permissible Acoustic Distance. The acoustic design was carried out by Normograph method.

The above parameters have been properly canvassed and presented in the main literature [5] [9] [10]

4.0 RESULTS

Result of Survey on Acoustic Design

The results of the survey are presented in tables 1and 2

Table 1: Response on Optimum Acoustic Level

Part	Profile	Category	Frequency	Percentage
Optimal acoustic level	What is the major source of noise in the office	Telephone ring Background music Offices machines Side talks Street noise	13 6 1 14 30	20.32 9.40 1.56 21.90 46.87
	At what level does noise begin to affect you	Very high pitch High pitch Medium pitch Low pitch Not at all	7 10 8 3 2	23.33 33.33 26.67 0.10 6.67
	What is the major impact of noise on your health and operation	Reduce performance Cardiac problem Loss of mind Fatigue Psychological distress	10 3 16 4 5	28.57 8.57 45.71 11.43 14.29
	Which part is always affect	Brain Heart Entire body	15 5 10	50.00 16.67 33.33

Results of the Respondents Acoustic Measurements of Duration, Leq and Noise Dose

Table 2: Respondents Duration and Average Leq, Noise Dose Values

Site	**Total Duration (hr)**	**Total Noise Dose (%)**	**Nomograph Leq (dBA)**	**Nomograph Lex (dBA)**
CAFÉ 1	**65**	**2610**	**90**	**99.30**
CAFÉ 2	**62**	**835**	**85**	**94.20**

Results Discussion

Analysing the acoustic level of the workstation, 47.87% of the respondents agreed that most of the noise was from the environment (street noise). 21.9% chose side talks, 20.32% said telephone ringing and 9.4% consented to back ground music source. 33% of the respondents are always disturbed by high pitch noise, 10% by low pitch and 6.67% not disturbed by any level of noise. 45% of the respondents consented to absenteeism of mind as the major impact of noise on their health system and operation, followed by reduction in performance level, psychological distress, fatigue and cardiac problem with 28.57%, 14.29%, 11.43% and 8.5% respondents respectively.

Half of the respondents were affected in the brain, while 33.33% of the respondents were affected at the different parts of their body.

From table 2, results of Lex obtained for the first and second Cyber cafes were 99.30dBA and 94.22dBA respectively. The results show that respondents in the first Cyber café are more exposed to noise than the second Cyber café. All the respondents in both Cyber café were over exposed to noise because their Lex values > 85dBA (Standard permissible level) [5]

The computations of parameters of work station 1 are summarized in Table 3

Table 3: Comparison of Existing Design of Cafe 1with Ergonomic Standard Values

Work station 1 Design Parameter	Standard Values	Existing Design Values
Ceiling Absorption	SAA = 0.95	SAA = 0.85
Screen/Panel Height	1.7m (5.6ft)	1.7m (5.6ft)
Screen/Panel Absorption	SAA = 0.90	SAA = 0.90

Workstation Plan Size	Min 3.0m by3.0m (9.8ft by9.8ft)	5m by 5m
Floor Absorption	SAA = 0.19	SAA = 0.05 (non-absorption floor)
Screen Transmission Loss	STC = 21	STC = 21
Ceiling Height	2.7m (8.9ft)	2.4m
Speech Level	Leq = 53.2dBA	Leq = 62.2dBA
Permissible Noise Level	Lex = 85dBA Noise Dose = 100% Permissible Distance = Optimum Distance	Lex = 99.3dBA Noise Dose = 2610% Distance from the source = 6m

The computation of parameters of work station 2 are summarized in Table 4

Table 4: Comparison of Existing Design of Cafe 2 with Ergonomic Standard Values

Work station 2 Design Parameter	Standard Values	Existing Design Values
Ceiling Absorption	SAA = 0.95	SAA = 0.88
Screen/Panel Height	1.7m (5.6ft)	1.7m (5.6ft)
Screen/Panel Absorption	SAA = 0.90	SAA = 0.85
Workstation Plan Size	Min 3.0m by3.0m (9.8ft by9.8ft)	3m by 5m
Floor Absorption	SAA = 0.19	SAA = 0.05 (non absorption floor)
Screen Transmission Loss	STC = 21	STC = 20
Ceiling Height	2.7m (8.9ft)	2.7m
Speech Level	Leq = 53.2dBA	Leq = 59.2dBA
Permissible Noise Level	Lex = 85dBA Noise Dose = 100% Permissible Distance = Optimal	Lex = 94.2dBA Noise Dose = 835% Distance from the source = 5m

Analysis of the computation parameters of the Cafes

The comparative analysis of the acoustic design parameters of the existing design computer workstation and standards from the literatures shows that the existing computer workstation is poorly designed. The ergonomic standards for acoustic design were not been considered.

Mathematical Computation of Permissible Acoustic Level for the first Cafe

To design the workstation to attain Standard permissible acoustic level of 85dBA, the principle of Doppler Effect was considered.

The initial frequency F_o that correspond to 99.3dBA noise level exposed to in the first café, with the distance between the source of noise and the observer equal to 6 meters. The speed of sound in the air is 330m/s.

Recall

$$VT_o = 2\chi$$

$$T_o = 2 \text{ x } \chi/V = 2 \text{ X}6/330 = 0.036\text{sec.}$$

Therefore, the frequency F_o is equal to the reciprocal of the Period T_o.

$$F_o = 1/T_o = 1/0.036 = 27.78\text{Hz}$$

Note $[1/ (1 + V_s/V)]$ is constant because V_s is steady and less than V.

The frequency F_o that corresponded to the noise level 99.3dBA is 27.78Hz. Increasing the distance between the source and the observer twice, the distance, χ = 12 meters.

$$T_1 = 24/330 = 0.072\text{sec.}$$

$$F_1 = 1/T_1 = 13.88\text{Hz.}$$

Since there is direct relationship between frequency and Intensity (Loudness), the noise level has decrease twice. Therefore, the new noise level was 49.65dBA.

Note: Frequency is directly proportional to intensity and inversely proportional to distance.

To determine the frequency of the noise that correspond to 85dBA, interpolate the frequency and noise level at χ = 6m and 12m respectively.

Interpolation is used, because chat is not available.

$$\frac{27.78 - X}{X - 13.89} = \frac{99.30 - 85}{85 - 49.65}$$

= 23.78Hz

The frequency of the noise that corresponds to 85dBA is 23.77Hz. The Period T_x of the noise waves was given by the reciprocal of the frequency F_x.

$$T_x = 1/F_x = 1/23.77 = 0.042sec.$$

The design distance χ to place the source, so that the workstation will attain the permissible noise level of 85dBA is calculated thus,

$$\chi = VT_x/2 = 330 * 0.042/2$$
$$= 6.94 = 7.0m$$

The workstation and the noise source should be 7m apart, so that the noise level will not exceed 85dBA.

Mathematical Computation of Permissible Acoustic Level for the Second Cafe

For the second Café

L_{ex} value (sound level) = 94.22dBA

Distance (χ) between the source and the observer = 5m

Speed (V) of sound in the air = 330m/s

Period T_o = 0.030sec

Frequency F_o that corresponds to 94.22dBA= 33.33Hz

When double the distance (χ) between the source and the observer, χ = 10m

Period T_1 = 0.06sec

Frequency F_1 when the distance is doubled = 16.66Hz

L_{ex} value (sound level) when the distance is doubled = 47.11dBA

To determine the value of the frequency that corresponds to 85dBA by interpolating the initial frequency and sound level values with the values when doubled the distance between the source and the observer.

Frequency (F_x) = 30H_z

Period (T_x) = 0.033sec

The distance (χ) between the source and the observer that produce the permissible sound level of 85dBA is 5.5m

The re- designed workstations were presented below

In redesigning the workstations, the following factors were considered:

Ceiling Absorption, Panel Height, Panel Absorption, Work station Plan Size, Floor Absorption, Screen Transmission Loss, Ceiling Height, Light Fixtures and Speech Level.

Ceiling Absorption

Reducing the ceiling absorption much below SAA=0.95 significantly increases SII, thus increasing sound clarity. If the ceiling absorption is less than SAA=0.90, it is not possible to achieve acceptable sound level in an otherwise well designed workstation such as that of the ergonomic standard. Earlier work had recommended this same minimum ceiling absorption. The ceiling is the most important reflecting surface in open plan cafes and it is most important that it be as highly absorbing as possible.

Screen /Panel Height

The partial height panels separating workstations must be high enough to block the direct path of speech sounds from one workstation to another and also must be high enough that the level of the sound diffracted over the panel is reduced enough to make possible acceptable sound level. When seated the mouth of a talker and the ear of the listener in adjacent workstations are approximately 1.2 m above floor level. The height of the separating panel must be substantially greater than this to make it possible to achieve acceptable sound level. However above a height of 1.7 m, further increases in the height of the separating panel have quite small effects on calculated SII values [5].

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Screen/Panel Absorption

Decreasing the SAA from 0.9 to 0.6 increased the calculated SII from 0.19 to 0.22 [5]. However, using non-absorbing workstation panels (SAA=0.10) is seen to increase the SII much more to a value of 0.29. It is important to have sound absorbing panels but the change in sound level between typical medium and higher absorption workstation panels is small.

Work station Plan Size
Workstation plan size was varied from a minimum of 2 m by 2 m to a maximum of 4 m by 4 m. SII values systematically decrease as the workstation size is increased. This is due to the increasing distance between the source and receiver at the centre of each workstation. Clearly there is an advantage to having larger workstations when attempting to achieve good sound level. Decreasing the workstation size below the ergonomic standard (3 m by 3 m) decreased sound level [5]. Even the 2.5 m by 2.5 m (8.2 ft by 8.2 ft) workstation would not quite meet the ergonomic sound level criteria.

Floor Absorption
When the floor absorption of the ergonomic standard workstation design is varied among thin carpet (SAA=0.19), thick carpet (SAA=0.25) and a hard non-absorbing floor (SAA=0.05), there are only very tiny differences between the two calculations for varied carpet thickness. However, having a non-absorbing floor does increase the sound level far above the acceptable SII value. There are other reasons to recommend the use of carpet too. It will reduce some sources of noise such as footsteps and the moving of chairs. It will also help to minimize sound propagation through gaps at the bottom of screens. Although there is no reason to select thicker carpets, it is important to include a carpeted floor in open plan cafes.

Screen Transmission Loss
Some recommendations specify that the transmission loss of the separating partial height panel should have a STC of at least 20 [5]. This is intended to ensure that the propagation of speech sound energy through the separating panel does not limit normal sound level. Decreasing the panel STC from 21 to 15 increased sound level to a little above the ergonomic standard criterion [5] [6]. However, increasing the transmission loss of the panel from STC 21 to STC 25 produced only a negligible improvement in SII. A minimum STC of 20 for the separating panel is seen to be adequate to avoid degrading ergonomic standard sound level.

Ceiling Height
The height of the ceiling in most open plan cafes is usually quite similar to that of the ergonomic standard (2.7 m) [5]. From the literatures, it shows that increasing the height to 3.5 m had a negligible effect on the SII. However, decreasing the height from 2.7 m to 2.4 m has the tendency to increase the SII above ergonomic standard criterion. One should therefore avoid particularly low ceiling heights in open plan cafes.

Speech Level
Voice level can have a very large effect on the resulting SII values. Clearly it is important to use a representative speech level. However, there are further large benefits to be obtained by encouraging cafe operators to talk with lower voice levels. It is important to promote an office etiquette that encourages the use of lower voice levels and relocating to closed meeting rooms when more extensive discussions are needed. It may be difficult to accommodate work and includes telephone conversations of a more confidential nature in open plan environments.

The computations of parameters of re- designed work stations are summarized in Table 5

Table 5: Results of the Re- designed Work stations

Work station Design Parameters	Standard Design Values	Re- Design Values for Workstation 1	Re- Design Values for Work station 2
Ceiling Absorption	SAA = 0.95	SAA = 0.95	SAA = 0.95
Screen/Panel Height	1.7m (5.6ft)	1.7m (5.6ft)	1.7m (5.6ft)
Screen/Panel Absorption	SAA = 0.90	SAA = 0.90	SAA = 0.90
Work station Plan Size	3.0m by 3.0m (9.8ft by 9.8ft)	5m by 5m	4m by 5m
Floor Absorption	SAA = 0.19	SAA = 0.19 Thick Carpet	SAA = 0.21 Thin Carpet
Screen Transmission Loss	STC = 21	STC = 21	STC = 21
Ceiling Height	2.7m (8.9ft)	2.7m	2.7m
Speech Level	Leq = 53.2Dba	Leq = 53.2dBA	Leq = 53.2dBA

Permissible Noise Level	Lex = 85Dba Noise Dose = 100% Permissible Distance = Optimal	Lex = 85dBA Noise Dose = 100% Permissible Distance = 7m	Lex = 85dBA Noise Dose = 100% Permissible Distance = 6m

CONCLUSIONS

Conclusions

The conclusions drawn from this work are:

(1) Too much noise in the workstations affects mostly the brain.

(2) High acoustic level affect productivity as there is always loss of mind, Cardiac problem, Fatigue, Psychological distress when the acoustic level is imbalance.

Recommendations

The recommendations from this work are

(1) The standard acoustic permissible limit must be strictly followed, for the safety of the workers

(2) Site of workstation should be in a place of reasonable serenity, for maximum concentration or sound proof generating set can be used instead.

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