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A psychoacoustic assessment of road traffic noise for indoor aural comfort in high-rise built environment

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ABSTRACT

Research over the past few decades investigated noise annoyance in indoor residential settings and related it to several physical noise indicators such as L_{Aeq}, L_{A1}, L_{A10}, L_{Amax}, L_D, L_N, L_{DEN} etc. Recent researches show that A-weighted level is unable to consider mutual masking among the components in a complex sound and also the asymmetry of masking patterns produced in the auditory system. Rationally, A-weighted noise level is found as a poor indicator of loudness and annoyance. In contrary to the negative evaluation, research on the positive assessment of indoor aural environment and its association with different psychoacoustic parameters are very limited in the literature.

This research investigates the indoor aural comfort in high-rise residential setting and its correlations with several psychoacoustic indicators. A psychoacoustic experiment was carried out to investigate indoor aural comfort subjected to road traffic noise and its relationships with different psychoacoustic indices. Loudness and Roughness were found significantly correlated with the assessment of 'Noisiness of Apartment' and 'Noise Disturbance' in indoor environment subjected to road traffic noise. Road traffic noise with a maximum Loudness of 9 Sone and a maximum Roughness of 27 centi-Asper were found attributing to a 'quiet' indoor aural environment. This paper presents statistical models for subjective 'noisiness of apartment' and 'noise disturbances' and discusses their relationships with these psychoacoustic quantities.

Keywords: Aural, Comfort, High-rise, Built Environment, Psychoacoustics. I-INCE Classification of Subjects Number(s): 63.2, 63.7, 66.1

1. INTRODUCTION

With the rapid urbanization of cities worldwide, noise is increasingly found as a major environmental concern and a key quality of life issue by city dwellers (1). This assertion is often recognized in high-rise high-densely built-up environment due to the close proximity of the residential dwellings to the noise sources such as Road Traffic and Trains (2-4). High-rise housing is an inevitable consideration in many cities, such as Singapore, to meet the need of urban growth and housing shortage (5). In an increasingly noisy urban environment, quietness has to be ensured at least in the residential dwellings. Unfortunately not many people enjoy such living conditions (6). During the last few decades, substantial researches were carried out to investigate the negative impact of aural environment such as noise annoyance related to road traffic noise. However, little has been studied about the positive evaluation of the noise environment, i.e. 'aural comfort', in urban residential settings (7).

In this paper, the term 'aural comfort' is defined as the condition of mind which articulates satisfaction (or dissatisfaction) with the surrounding aural environment (8). Being a qualitative evaluation of the aural environment, aural comfort does not depend on the physical noise level alone, rather it depends on the inter-relations among the factors that contribute to people's satisfaction in his/hers surrounding aural environment (8).

Researches on noise annoyance generally reveal that that approximately only one third of the variation in noise annoyance can be explained by energy-based acoustical indices (9, 10). In addition to that, recent researches show that A-weighted level is unable to consider mutual masking among the

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components in a complex sound and also the asymmetry of masking patterns produced in the auditory system (11) that has an influence on the judgments assessing an aural environment (10). Rationally, A-weighted noise level is found as a poor indicator of loudness and annoyance.

In contrary to the negative evaluation of an aural environment based on energy-based acoustical indices, research on the positive assessment of indoor aural environment and its association with different psychoacoustic parameters are very limited in the literature. This has not been investigated in high-rise context as well. This research paper focuses on the assessment of aural comfort of high-rise apartment dwellers in Singapore subjected to Road Traffic Noise and investigates its correlations with several psychoacoustic indicators.

2. ASSESSMENT OF INDOOR AURAL ENVIRONMENT

The assessment of the 'quality' of an aural environment involves three sets of factors: Acoustical Factors (related to physical sound evaluation), Non-acoustical Factors (psychological factors related to auditory evaluation) and Psychoacoustic Factors (related to auditory perceptions). Guski (9) observed that approximately one third of the variation in noise annoyance can be explained by acoustical factors (e.g. sound level, peak level, sound spectrum and number of noise events) and a second third by non-acoustical factors. The last third can either be attributed to measurement errors, the presence of yet unknown factors which influence noise annoyance or stochastic variation related to idiosyncrasies of individuals.

Psychoacoustic analysis is not very common in research on noise annoyance or aural comfort in relation to environmental noise in residential perspective. Psychophysics can contribute substantially to the assessment of noise annoyance (12-18). Genuit (19) noted that the acoustical quality of a sound environment is generally negative when the aural environment generates an auditory event as annoying while a positive acoustical quality means that the aural environment is not perceived as auditory event or not annoying and generates a pleasant aural impression.

Psychoacoustic factors that have been investigated widely in relation to noise annoyance include Loudness, Sharpness, Roughness and Fluctuation Strength. Human sensation perception that corresponds most closely to the sound intensity of the stimulus is Loudness. Loudness of a sound is a perceptual measure of the effect of the energy content of sound on the ear. 'Sone' is the unit of loudness. The level of 40 dB of a 1 kHz sine tone is defined as a loudness of 1 Sone (11). Sharpness is a measure of the high frequency content of a sound. If one sound signal has more high-frequency content than another, it is said to have more sharpness than the other. Sharpness is employed in the computation of a sensory pleasantness metric and an unbiased annoyance metric (11). Unit of sharpness is Acum'. One Acum is defined as a narrow band noise one critical band wide at a centre frequency of 1kHz (8.5 Bark) having a level of 60 dB. Another key psychoacoustic metric is Fluctuation Strength. A sound which has a strong time-dependent fluctuation in sound pressure level is more annoying than a steady sound (11). The unit of fluctuation strength is 'Vacil'. One Vacil is defined as the fluctuation strength generated by a 1000Hz tone of 60dB which is 100% amplitude modulated at 4Hz. Roughness is another important psychoacoustic quantity that quantifies the subjective perception of rapid (15-300 Hz) amplitude modulation of a sound. 'Asper' is the unit of roughness. One Asper is defined as the roughness produced by a 1kHz tone of 60dB which is 100% amplitude modulated at 70Hz (11).

Marquis (7) noted that most of the research related to these psychoacoustic factors has been carried out in laboratories, i.e. in a controlled environment, and that except in the case of loudness; no investigation using these indices has been applied to field studies or to data resulting from in situ surveys.

Each of the mentioned psychoacoustic indices on its own is not sufficient to predict the annoyance felt, but the relevance of one or of many indices depends on the type of noise, and for the same noise, on its level. Psychoacoustic metrics are unable to consider the non-sensory aspects used in the evaluation of a noise environment (18), though some researchers argue that psychoacoustic metrics such as fluctuation strength, roughness can co-vary with non-sensory aspects such as noise sensitivity (20). However, consideration of the attitude towards the noise environment together with the quantitative acoustical and psychoacoustic parameters is important for a complete evaluation of an aural environment.

Assessment of aural comfort of high-rise apartment dwellers in a tropical environment is not much studied in the literature. In temperate countries, windows and doors are kept closed and well-sealed for much of the year to prevent heat loss. This results in a quiet indoor aural environment. In contrary, in tropical environment windows at the facades are left open for natural ventilation which results in higher exposure to outdoor environmental noise such as noise from road traffic. Due to limited land space in Singapore, high-rise residential buildings are developed to meet housing shortage requirements and the transport networks are brought closer to the residential buildings. As a result, the context of indoor aural environment in high-rise tropical areas is different to that of temperate countries. It is therefore important to investigate the psychoacoustic factors related to the aural comfort of high-rise dwellers in the context of a tropical environment subjected to road traffic noise (4).

3. RESEARCH METHODOLOGY

Aural comfort model by Alam (8) for high-rise apartment dwellers in the tropics demonstrates that day-time indoor aural comfort is significantly influenced by 'rating of noisiness of apartment' and 'noise disturbance' due to Road Traffic Noise in Singapore. To investigate the relationships between these subjective factors and different psychoacoustic quantities, a psychoacoustic experiment was planned.

For psychoacoustic assessment of different types of road traffic sounds, binaural recording of the sounds were carried out at different stratified sampled locations. Stratification criteria was road traffic noise with varying levels of noise exposures to the residents. Binaural recording were carried out at 10 locations (2 locations per each category of roads) near different categories of roads such as Expressway, Major Arterial, Minor Arterial, Primary Access and Local Road. Recording of the sounds were generally carried out in front of the open window of the apartments (generally on the 10th floor of the building), facing the road. This is to ensure that the psychoacoustic evaluations are made for those stimuli which are experienced by the residents during their living in high-rise naturally ventilated buildings.

Binaural Recording System from 01-dB Metravib was used for the measurement which utilizes a binaural headset to record the sound through dBSonic software on a laptop computer. Once recorded, each stimulus was equalized for a duration of 6 seconds and an amplitude of A-weighted equivalent noise level of 75 dB. After equalization, each of these sounds was referred as the 'Reference Level' (also called as 'Ref + 0 dB') for each respective class of road. Afterwards, the equivalent noise level of each stimulus was changed to three different levels such as +3 dB, -3 dB and -6 dB relative to the ‘Ref +0 dB’ level (L_{Aeq}). As a result, a total of 40 binaural road traffic sounds were generated for psychoacoustic evaluation. In addition to the overall noise level (L_{Aeq}) psychoacoustic quantities such as Loudness, Sharpness, Fluctuating Strength and Roughness were examined for their correlations with noisiness and noise disturbance. The recorded stimuli were analyzed in dBSonic software and different psychoacoustic quantities were then computed in dBSonic software.

A total of 50 subjects volunteered for the psychoacoustic experiment. However 36 subjects completed all the experiments with valid data. For inclusion of the subjects in the psychoacoustic experiment, subjects were required to undergo audiometric test to confirm that they had a normal hearing condition as per Goodman criteria (21).

Each of the 40 stimuli was of 6 seconds in length. Studies showed that the duration of listening session (length of stimulus) does not influence the ratings of noise annoyance if the evaluation question refers to the home situation (22). As a result, shorter session length with the evaluation question relating to home environment reduces the experimental time significantly. Each subject was expected to evaluate a maximum of 10 sessions per day which generally takes about 30 minutes. A maximum of 13 subjects were scheduled per day (during the weekdays only) starting from 10am in each 30 minutes interval.

The listening system for the stimulus evaluation was operated and controlled by the Jury Test software package from 01 dB Metravib. Stimuli were sent from Jury Testing Software on a notebook computers equipped with a 24 bit professional sound card to a binaural headset (Sennheiser HD650) for listening. The headset was factory calibrated. Stimuli sent by the Jury Listening Software were listened to by the subjects through the Binaural Headset and they rated their perception on a continuous scale shown on the computer screen.

Subjective assessment of the 'noisiness of the apartment' and 'disturbance by the road traffic noise' was carried out in Absolute Evaluation approach using a continuous scale of 1 to 5. For noisiness rating of the apartment, ‘1’ refers to 'Very Quiet', ‘2’ refers to 'Quiet', ‘3’ refers to 'Acceptable', ‘4’ refers to 'Noisy' and ‘5’ refers to 'Very Noisy'. In contrary, for disturbance rating due to road traffic noise, ‘1’ refers to 'Not At All Disturbed', ‘2’ refers to 'A Little Disturbed', ‘3’ refers to 'Disturbed', ‘4’ refers to 'Very Disturbed' and ‘5’ refers to 'Extremely Disturbed'. Subjects were asked how they would rate the 'noisiness of the apartment' and the 'noise disturbance' due to road traffic sound they listened to considering their home environment during the day.

The study on aural comfort requires a conducive environment to carry out the psychoacoustic research experiment. Based on the experimental design, criteria for such environment include a signal-to-noise ratio of 10 dB and thermal, visual and spatial comfort. 'Staff Lounge', generally used for the resting of the academic staff of the school, was deemed to satisfy all the requirements and hence selected for the experiment. Prior to the psychoacoustic research investigations, an ethical approval was received from the National University of Singapore Institutional Review Board (NUS-IRB) to conduct the study (Approval number: NUS 1118).

4. ANALYSIS OF THE TRAFFIC NOISE STIMULI

Psychoacoustic analyses of all the 40 test stimuli were carried out in dBSonic Software. The psychoacoustic quantities that were computed in dBSonic to examine Loudness are Maximum Loudness (N_{max}), Mean Loudness (N_{mean}), Zwicker's Loudness ($N_{ISO532B}$) and Five percentile loudness (N_5). Zwicker's loudness ($N_{ISO532B}$) is generally used for stationary sound signals and the computation procedure has been standardized in DIN 45631 and ISO 532B. Even though the sound signal under investigation is non-stationary in nature, this parameter is still used in the aural comfort study since the nature of some road traffic noise is approximately steady-state (i.e. due to constant uninterrupted traffic flow in expressway) and it may be interesting to investigate the correlations between this parameter and aural comfort. Loudness for non-stationary signals is denoted by (N_{mean}). The five percentile loudness (N_5) is also examined as much research has shown its correlation with perceived noise annoyance (11).

To examine the correlations between Sharpness and ‘noisiness of apartment’ and ‘disturbance by road traffic noise’, three psychoacoustic indices relating to sharpness were computed using dBSonic. They are Maximum Sharpness (S_{max}), Mean Sharpness (S_{mean}) and Five percentile Sharpness (S_5).

Almost all signals technically show Modulations and Fluctuations produced by periodic or stochastic processes. Therefore, in addition to Loudness and Sharpness, Roughness and Fluctuation strength were of interest for non-stationary signals such as road traffic noise. Research has shown the relevance of these parameters in noise annoyance. The Maximum, Mean and Five percentile Roughness and Fluctuation Strength were computed in dBSonic.

Analysis showed that the average reference noise levels for Category 1 to Category 5 roads are approximately 71 dBA, 66 dBA, 65 dBA, 63 dBA and 58 dBA respectively (generally at a distance of 20m-25m and at 10^{th} floor level of a building facing the road traffic). Mean loudness of the reference stimuli varied between 12 Sone and 25 Sone. Mean sharpness for these traffic noises ranged between 1.2 Acum and 1.3 Acum. Fluctuation strength (slow modulation up to 15Hz) was found to be between 1.8 centi-Vacil and 9.6 centi-Vacil while the Roughness (rapid modulation between 15 and 300 Hz) ranged between 26 Centi Asper and 33 Centi Asper.

5. DEVELOPMENT OF REGRESSION MODEL

The different psychoacoustic quantities of the road traffic noise were correlated with the subjective perceptions of 'apartment's noisiness' and 'noise disturbance' due to road traffic noise. Spearman Rank Correlation test statistics are presented in Table 1 below.

Table 1 – Correlations between noisiness, disturbance and acoustical quantities of road traffic noise

Psychoacoustic Quantities	Correlation Coefficient	
	Noisiness Rating	Disturbance Rating
Mean Level, L_{mean} (dBA)	0.736*	0.737*
Mean Level, L_{mean} (dB)	0.679*	0.674*
Maximum Loudness, N_{max} (Sone)	0.731*	0.731*
Mean Loudness, N_{mean} (Sone)	0.745*	0.743*
Zwicker Loudness, $N_{ISO532B}$	0.740*	0.738*
Five Percentile Loudness N_5 (Sone)	0.730*	0.729*
Maximum Sharpness, S_{max} (Acum)	0.002	0.007

Psychoacoustic Quantities	Correlation Coefficient	
	Noisiness Rating	Disturbance Rating
Mean Sharpness S_{mean} (Acum)	-0.008	-0.016
Five Percentile Sharpness, S_5 (Acum)	0.029	0.029
Maximum Fluctuation Strength, F_{max} (Centi Vacil)	0.417*	0.433*
Mean Fluctuation Strength, F_{mean} (Centi Vacil)	0.472*	0.486*
Five Percentile Fluctuation Strength, F_5 (Centi Vacil)	0.427*	0.443*
Maximum Roughness, R_{max} (Centi Asper)	0.716*	0.710*
Mean Roughness, R_{mean} (Centi Asper)	0.744*	0.742*
Five Percentile Roughness, R_5 (Centi Asper)	0.732*	0.726*
* Spearman's rho Correlation is significant at the 0.01 level (1-tailed).		

It is noted from Table 1 that 'rating of noisiness of the apartment' is significantly correlated (at 0.01 significance level) to the Overall Noise Level and to Loudness (Mean and Maximum Loudness, Zwicker Loudness and Five percentile Loudness), Fluctuation Strength (Maximum, Mean and Five percentile Fluctuation Strength) and Roughness (Maximum Roughness, Mean Roughness and Five percentile Roughness). Noisiness of an apartment was found not to be correlated with Sharpness.

Like noisiness perception, 'rating of disturbance due to road traffic noise' was found significantly correlated (at 0.01 significance level) to the Overall Noise Level, Loudness (Mean Loudness, Maximum Loudness, Zwicker Loudness and Five percentile Loudness), Fluctuation Strength (Maximum, Mean and Five percentile Fluctuation Strength) and Roughness (Maximum Roughness, Mean Roughness and Five percentile Roughness). Noise disturbance due to road traffic was found not correlated significantly with Sharpness.

5.1 Statistical Model for Rating of Noisiness of Apartment

Linear regression in Least Square Method was carried out to develop a statistical model relating rating of 'Noisiness of Apartment' with different correlated psychoacoustic quantities as found from correlation analysis. The established model can be written as shown in Equation (1):

$$\boldsymbol{Rating\ of\ Noisiness\ of\ Apartment\ \ Subjected\ to\ Road\ Traffic\ noise} = 0.063 * L_{mean}\ \ dBA - 0.129 * N_{max}\ \ Sone + 0.235 * N_{mean}(Sone) + 0.025 * R_{max}\ \ cAsper - 0.1 * R_{mean}\ (cAsper) \quad (1)$$

Where,

$L_{mean}\ \ dBA\ \ is\ the\ A - weighted\ overall\ noise\ exposure\ level$

$N_{max}\ \ Sone\ \ is\ the\ maximum\ Loudness\ in\ Sone$

$N_{mean}\ \ Sone\ \ is\ the\ mean\ Loudness\ in\ Sone$

$R_{max}\ \ cAsper\ \ is\ the\ maximum\ Roughness\ in\ Centi\ Asper$

$R_{mean}\ \ cAsper\ \ is\ the\ mean\ Roughness\ in\ Centi\ Asper$

Table 2: Test statistics - 'goodness of fit' of the model

R	R Square[b]	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
				R Square Change	F Change	df1	df2	Sig. F Change
0.984[a]	0.969	0.969	0.6413	0.969	8963.7	5	1435	0.00

a) Predictors: L_{mean}, N_{max}, N_{mean}, R_{max}, R_{mean}

b) For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This cannot be compared to R Square for models which include an intercept.

The 'goodness of fit' test statistics of the model is presented in Table 2. This illustrate that the established model is a good fit model (R^2 0.969). The adjusted R^2 value also illustrates that the model accounts for 96.9% of the variance in defining noisiness of the apartment due to road traffic noise. The ANOVA test statistics (F Change) in Table 2 confirms that the model is statistically significant (p<0.05).

5.2 Statistical Model for 'Rating of Disturbance due to Road Traffic Noise'

Linear regression in the least square method was carried out to establish a statistical model relating noise disturbance with different correlated psychoacoustic quantities as shown in Table 1. The established model can be written as shown in Equation (2). The 'goodness of fit' test statistics of the model, presented in Table 3, illustrates that the established model is a good fit model (R^2=0.949).

$$\boldsymbol{Rating\ of\ Disturbance\ due\ to\ Road\ Traffic\ Noise} = 0.06 * L_{mean}\ dBA - 0.114 * N_{max}\ Sone + 0.252 * N_{mean}\ Sone - 0.098 * R_{mean}\ cAsper \quad (2)$$

Table 3: Test statistics - 'goodness of fit' of the model

R	R Square[b]	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
				R Square Change	F Change	df1	df2	Sig. F Change
0.974[a]	0.949	0.949	0.7516	0.949	6542.3	4	1436	0.00

a) Predictors: L_{mean}, N_{max}, N_{mean}, R_{mean}

b) For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This cannot be compared to R Square for models which include an intercept.

6. PARAMETRIC STUDY

6.1 Influence of Overall A-weighted Noise Level, Loudness and Roughness on Subjective Perception of Noisiness of Apartment

To examine the influence of each of the acoustic (psychoacoustic) factors in Equation 1 on 'Rating of Noisiness of Apartment', the subjective ratings of noisiness of the 36 test subjects were analyzed for their relation with different Noise Exposure Levels, Loudness and Roughness levels of the different road traffic noise stimuli which the test subjects listened to during the psychoacoustic experiment. Influence of these psychoacoustic factors on the subjective rating of noisiness of apartment is presented in Figure 1 to Figure 3. Subjective rating of noisiness of apartment was measured on a continuous scale of 1 to 5 where 1 refers to 'very quiet', 2 refers to 'quiet', 3 refers to 'acceptable', 4 refers to 'noisy' and 5 refers to 'very noisy'.

Figure 1 illustrates that the day-time noisiness of an apartment is perceived 'acceptable' (rating scale 3) with a mean A-weighted noise exposure level of about 60 dB while it is perceived as 'quiet' (rating scale 2) with a mean A-weighted noise exposure level of 53 dB. Figure 2 illustrates that the noisiness of an apartment is perceived as 'acceptable' (rating scale 3) with a mean Loudness level of 15 Sone and maximum loudness level of 17 Sone. On the other hand, noisiness of an apartment is perceived as 'quiet' (rating scale 2) with a mean Loudness level of 7 Sone and maximum Loudness level of 9 Sone.

Noisiness of an apartment was found as 'acceptable' (rating scale 3) (refer to Figure 3) with a mean Roughness level of 27 centi-Asper and maximum Roughness of 34 centi-Asper. On the other hand, noisiness of an apartment was felt 'quiet' (rating scale 2) with a mean Roughness level of 24 centi-Asper and maximum Roughness level of 27 centi-Asper.

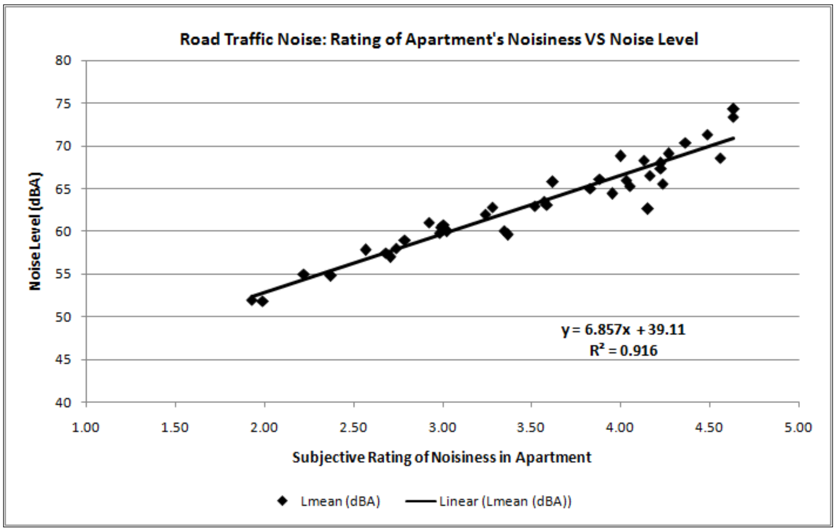

Figure 1 - Rating of apartment's noisiness for different noise exposure levels

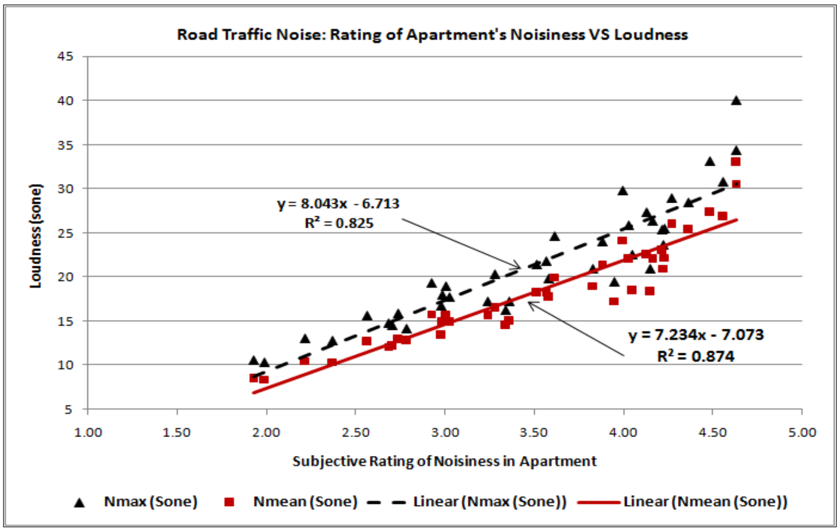

Figure 2 - Rating of apartment's noisiness for different Loudness levels

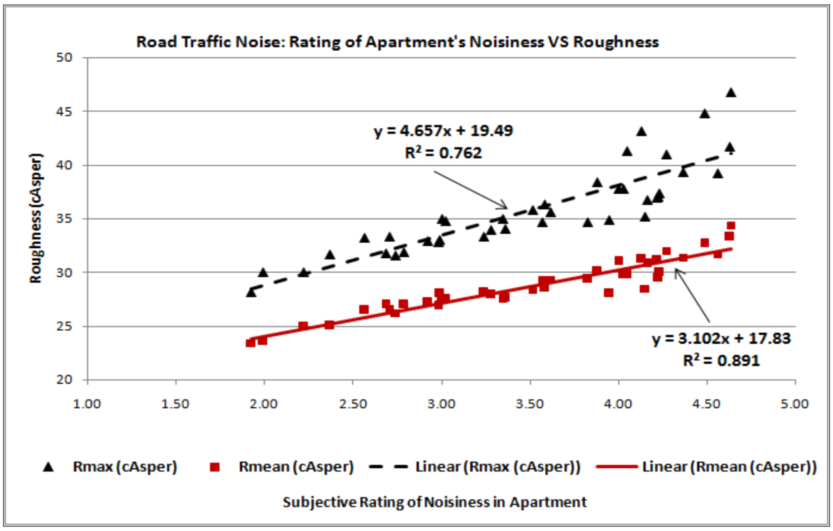

Figure 3 - Rating of apartment's noisiness for different Roughness levels

6.2 Influence of Overall A-weighted Noise Level, Loudness and Roughness on Subjective Perception of Road Traffic Noise Disturbance

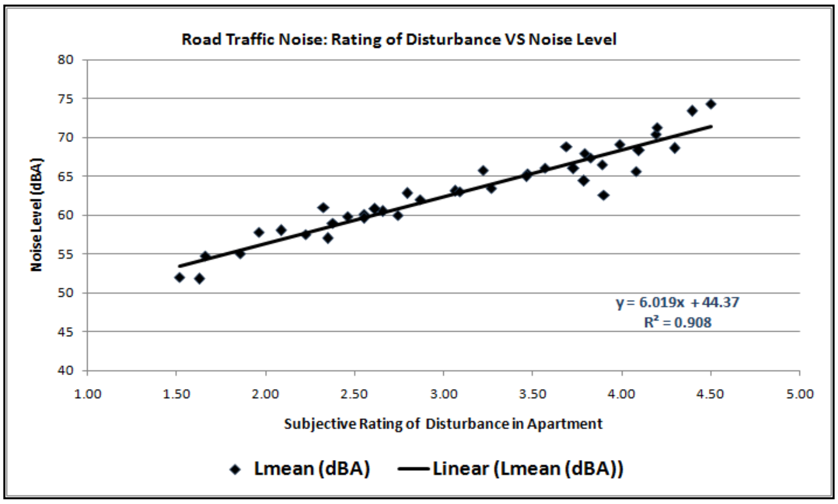

Figure 4 - Rating of noise disturbance for different noise exposure levels

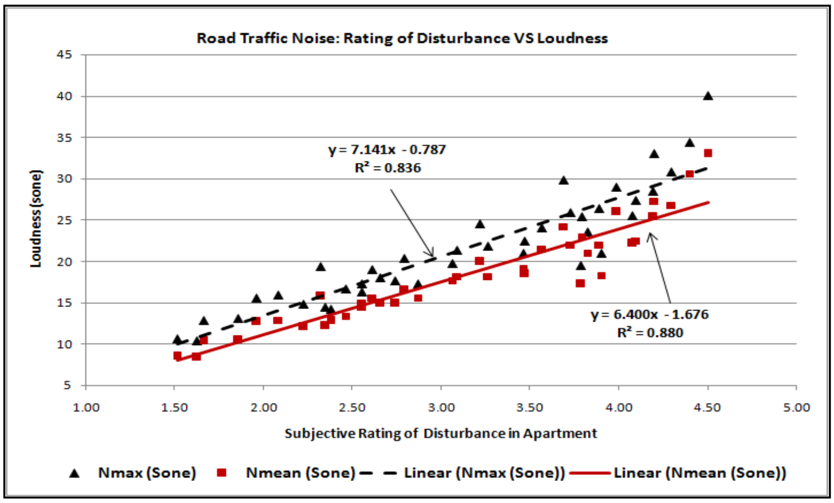

Figure 5 - Rating of noise disturbance for different Loudness levels

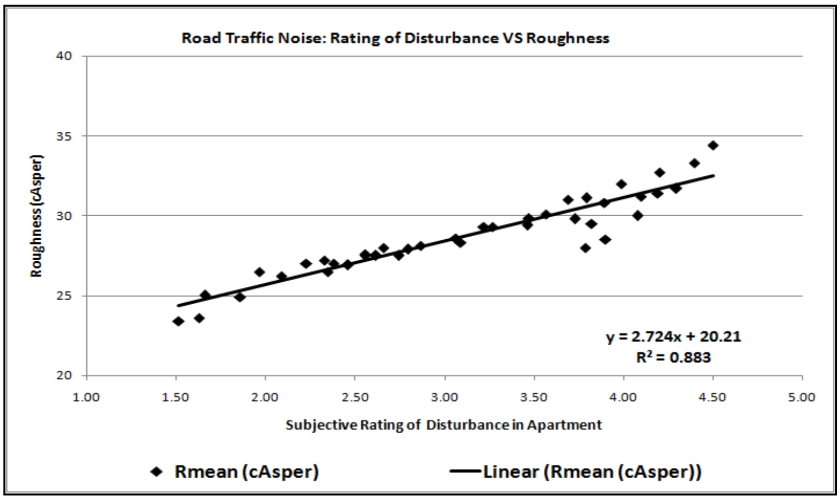

Figure 6 - Rating of noise disturbance for different Roughness levels

Subjective ratings of ‘Disturbance due to Road Traffic Noise’ of the 36 test subjects were analyzed for their relation with different Noise Exposure Levels, Loudness and Roughness (factors in Equation 2) of the different road traffic noise stimuli during the psychoacoustic experiment. Influence of these psychoacoustic factors on the subjective rating of noise disturbance due to road traffic is presented in Figure 4 to Figure 6. Subjective rating of noise disturbance due to road traffic was measured on a continuous scale of 1 to 5 where 1 refers to 'not at all disturbed', 2 refers to 'a little disturbed', 3 refers to 'disturbed', 4 refers to 'very disturbed' and 5 refers to 'extremely disturbed'.

Figure 4 illustrates that the noise disturbance due to road traffic is perceived as 'a little disturbing' (rating scale 2) with a mean A-weighted noise exposure level of about 57 dB. Figure 5 illustrates that the noise disturbance is felt to be 'a little disturbing' with a mean Loudness level of 11 Sone and maximum Loudness level of 13 Sone. Noise disturbance is perceived as 'a little disturbing' with a mean Roughness of 26 centi-Asper (Figure 6).

7. CONCLUSION

High-rise apartments subjected to Road Traffic are often exposed to higher noise levels (compared to the noise at the lower floors) due to vertical propagation of noise (2-4). In order to achieve a higher thermal comfort and reduce energy dependency in building design in the tropical environment, provision of natural ventilation is a key design strategy. As a result, with the windows left open at the facade, air-borne noise from nearby sources find their way to indoor environment and thus aural comfort is compromised. Due to limited research on aural comfort in high-rise tropical environment, key factors influencing aural comfort are not identified in greater detail and the influence of different acoustic and psychoacoustic factors on aural comfort are left unknown. As a result, the noise management policies often lack theses information in order to provide a better indoor aural environment.

Alam’s Aural Comfort Model (ACM) (8) demonstrates that four factors are responsible for day-time aural comfort in high-rise tropical environment. These are noise level in the apartment, subjective noisiness rating of the apartment, subjective disturbance due to road traffic noise and subjective disturbance due to train noise.

However, since overall A-weighted noise level is not a sole indicator for aural comfort, a reduced level does not necessarily increase the level of aural comfort. Aural comfort is dependent on subjective 'noisiness of apartment' and 'disturbance' due to road traffic and train noise which in turn related to several psychoacoustic quantities. Psychoacoustic investigation of different road traffic noise and associated subjective rating of noisiness and noise disturbance reveals that noisiness of an apartment is dependent on the noise exposure level, mean and maximum Loudness and also on the mean and maximum Roughness (rapid modulation between 15 and 300 Hz) of the road traffic noise. Similarly, noise disturbance due to road traffic is dependent on the noise exposure level, mean and maximum loudness and also on the mean Roughness level.

Established regression models illustrate that Maximum Loudness ($N_{\max}$) and Maximum Roughness (R_{max}) are the key factors influencing subjective 'noisiness' perception related to road traffic noise. The magnitudes at which these psychoacoustic quantities provide quietness and reduce noise disturbance in achievement of daytime aural comfort are also presented in this paper.

A-weighted noise level is commonly used is in many countries as the criteria for building design, environmental noise control and noise annoyance management policy. Since the dependency on this indicator does not take care of the aural comfort entirely, the inclusion of the factors such as Maximum Loudness and Maximum Roughness in the environmental noise management policy will be able to enhance the level of indoor aural comfort subjected to road traffic noise in high-rise residential environment.

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