inter.noise 2014
MELBOURNE AUSTRALIA
16-19 NOVEMBER

Train noise - A psychoacoustic investigation for indoor aural comfort in high-rise urban environment in the tropics

Mahbub Alam SHEIKH[1]; Siew Eang LEE[2]

National University of Singapore, Singapore

ABSTRACT

Despite of many research on the assessment of negative impact (i.e. annoyance) of indoor aural environment, very limited research effort have been made on the positive assessment (i.e. aural comfort) of aural environment in residential settings subjected to environmental noise sources. Noise annoyance has often been related to different energy-based acoustical indicators such as L_{Aeq}, L_{DEN} etc. which are unable to consider the temporal and spectral patterns of the complex noise environment. The indoor aural environment has rarely been examined for different psychoacoustic quantities, the influence of which are still unknown on indoor aural comfort subjected to environmental noise sources specially in high-rise urban built-up settings. This research investigates the indoor aural comfort in high-rise naturally ventilated residential dwellings in Singapore subjected to Train Noise. A psychoacoustic experiment was carried out to examine the indoor aural comfort and relating it with different psychoacoustic indices. Loudness, Sharpness and Roughness were found significantly correlated with the assessment of 'Noisiness' and 'Noise Disturbance' in indoor environment. Train noise with a maximum Loudness of 8 Sone, mean Sharpness of 1.25 Acum and maximum Roughness of 33 centi-Asper were found attributing to a 'quiet' indoor aural environment. This paper presents statistical models developed for subjective 'noisiness' and 'disturbances' and discusses their relationships with these psychoacoustic quantities.

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

1. INTRODUCTION

Annoyance due to railway noise has often been reported as less annoying than road traffic noise in Europe (1-8). However, this is found not the case in many research studies in Asian Cities (9-12). Yano et al (1996) (10) explained that the factors influencing this judgment in Japan include differences in acoustical characteristics of road and train noise compared to European road and train noise, difference in attitude towards the noise sources, differences in housing factors such as windows insulation, difference in socio-cultural factors such as customs and lifestyles and difference in operation time of these noise sources. Much of these research investigations were based on energy-based acoustical indices (13, 14) such as L_{Aeq}, L_{DEN} etc. It is known that 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 (14, 15). As a result, railway noise annoyance assessments based on A-weighted noise level often do not consider the factors that might have an influence on the judgments assessing an aural environment. In addition, in contrary to the negative assessment of an aural environment subjected to train noise based on energy-based acoustical indices, research on the positive assessment of indoor aural environment and its correlations 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 Train Noise and investigates its correlations with several psychoacoustic indicators.

[1] alam@vipac.com.au
[2] bdgleese@nus.edu.sg

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 (16). 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 (17-19). High-rise housing is an inevitable consideration in many cities, such as Singapore, to meet the need of urban growth and housing shortage (20). 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 (21). During the last few decades, substantial researches were carried out to investigate the negative impact of aural environment such as noise annoyance related to train noise. However, little has been studied about the positive evaluation of the noise environment, i.e. 'aural comfort', in urban residential settings (22).

In this paper, the term 'aural comfort' is defined as the condition of mind which articulates satisfaction (or dissatisfaction) with the surrounding aural environment (23). 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.

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 (13) 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 (24-30). Genuit (31) 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 (15). 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 (15). 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 (15). 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 (15).

Marquis (22) 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 (30), though some researchers argue that psychoacoustic metrics such as fluctuation strength, roughness can co-vary with non-sensory aspects such as noise sensitivity

(32). 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 Train. 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 train noise (19).

3. PSYCHOACOUSTIC EXPERIMENT

Aural comfort model by Alam (23) 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 Train Noise in Singapore. To investigate the relationships between these subjective factors and different psychoacoustic quantities, a psychoacoustic experiment was planned. In this connection, it is to note that Singapore’s railway network is based on a rapid transit system and known as Mass Rapid Transit or MRT in short. The MRT network forms the backbone of the public transport system and spreads throughout the city state. Most of the train tracks are elevated (generally at a height of approximately 6-8 meters) and run between stations. The trains are generally of electric multiple unit (EMU) type. EMUs are popular on commuter and suburban rail networks around the world due to their fast acceleration and pollution-free operation.

For psychoacoustic assessment of different types of train sounds, binaural recording of the sounds were carried out at different stratified sampled locations. Stratification criteria were train noise with varying levels of noise exposures to the residents in the high-rise apartment. Binaural recording were carried out at 10 locations at different distance (30m, 40m, 50m, 60m and 70m) from MRT track to residential buildings. 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 elevated railway track. 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 distance between train track and residential building. 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 train 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 then analyzed and different psychoacoustic quantities were 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 (33).

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 (34). 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 train 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 train 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 train 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 SOUND 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 as 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 (15).

To examine the correlations between Sharpness and ‘noisiness of apartment’ and ‘disturbance by train 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 train 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 MRT trains located between 30m and 70m (at 10m intervals) are approximately 70 dBA, 67 dBA, 64 dBA, 60 dBA and 56 dBA respectively. Mean loudness of the reference sounds of these train noise categories varied between 11 Sone to 25 Sone. Mean sharpness for these train noises varied between 1.2 Acum to 1.5 Acum. Fluctuation strength (slow modulation up to 15Hz) was found to be between 3.3 centi-Vacil and 12.7 centi-Vacil while the Roughness (rapid modulation between 15 and 300 Hz) ranged between 26 centi-Asper and 36 centi-Asper.

5. STATISTICAL MODEL DEVELOPMENT

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

It is noted from Table 1 that 'rating of noisiness of apartment' is significantly correlated (to 0.01 significance level) with the overall noise level and Loudness (Mean and Maximum Loudness, Zwicker Loudness and Five percentile Loudness), Sharpness (Maximum, Mean and Five percentile Sharpness), Fluctuation Strength (Maximum, Mean and Five percentile Fluctuation Strength) and Roughness (Maximum Roughness, Mean Roughness and Five percentile Roughness).

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

Acoustical Quantities	Correlation Coefficient	
	Noisiness Rating	Disturbance Rating
Mean Level, L_{mean} (dBA)	0.759*	0.782*
Mean Level, L_{mean} (dB)	0.756*	0.768*
Maximum Loudness, N_{max} (Sone)	0.771*	0.794*
Mean Loudness, N_{mean} (Sone)	0.769*	0.786*
Zwicker Loudness, $N_{ISO532B}$	0.772*	0.788*
Five Percentile Loudness N_5 (Sone)	0.776*	0.795*
Maximum Sharpness, S_{max} (Acum)	0.424*	0.428*
Mean Sharpness S_{mean} (Acum)	0.587*	0.606*
Five Percentile Sharpness, S_5 (Acum)	0.485*	0.495*
Maximum Fluctuation Strength, F_{max} (Centi Vacil)	0.339*	0.342*
Mean Fluctuation Strength, F_{mean} (Centi Vacil)	0.305*	0.320*
Five Percentile Fluctuation Strength, F_5 (Centi Vacil)	0.330*	0.332*
Maximum Roughness, R_{max} (Centi Asper)	0.677*	0.705*
Mean Roughness, R_{mean} (Centi Asper)	0.741*	0.763*
Five Percentile Roughness, R_5 (Centi Asper)	0.715*	0.735*
*. Spearman's rho Correlation is significant at the 0.01 level (1-tailed).		

Like noisiness perception, 'rating of disturbance due to train noise' was found significantly correlated (at 0.01 significance level) to the overall noise level and Loudness (Mean and Maximum Loudness, Zwicker Loudness and Five percentile Loudness), Sharpness (Maximum, Mean and Five percentile Sharpness), Fluctuation Strength (Maximum, Mean and Five percentile Fluctuation Strength) and Roughness (Maximum Roughness, Mean Roughness and Five percentile Roughness).

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):

$$\boldsymbol{Rating\ of\ Noisiness\ of\ Apartment\ \ Subjected\ to\ MRT\ Train\ noise} = 0.114 * N_{max}\ \ Sone\ + 1.494 * S_{mean}\ \ Acum\ - 0.022 * R_{max}\ \ cAsper \tag{1}$$

Where,
$N_{max}\ \ Sone\ \ is\ the\ maximum\ Loudness\ in\ Sone$
$S_{mean}\ \ Acum\ \ is\ the\ mean\ Sharpness\ in\ Acum$
$R_{max}\ \ cAsper\ \ is\ the\ maximum\ Roughness\ in\ Centi\ Asper$

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 0.952). The adjusted R^2 value also illustrates that the model accounts for 95.2% of the variance in defining noisiness of the apartment due to train noise. The ANOVA test statistics (F Change) confirms that the model is statistically significant (p<0.05).

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
0.976[a]	0.952	0.952	0.76	0.952	9574.7	3	1437	0.00

a) Predictors: N_{max}, R_{max}, S_{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.

5.2 Statistical Model for 'Rating of Disturbance due to Train 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=0.952).

$$\boldsymbol{Rating\ of\ Disturbance\ due\ to\ MRT\ Train\ Noise\ =}$$
$$\mathbf{0.115} * \boldsymbol{N_{max}\ Sone}\ + \mathbf{0.803} * \boldsymbol{S_{mean}\ Acum} \tag{2}$$

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
0.976[a]	0.952	0.952	0.753	0.952	14345	2	1438	0.00

a) Predictors: S_{mean}, N_{max}
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 Loudness, Sharpness 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 Loudness, Roughness and Sharpness levels of the different train 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 maximum Loudness level of 17 Sone while the noisiness of the apartment is perceived as 'quiet' (rating scale 2) with a maximum Loudness level of 8 Sone. Figure 2 illustrates that the noisiness of an apartment is felt 'acceptable' with a mean Sharpness level of 1.35 Acum while the noisiness of the apartment is perceived as 'quiet' with a mean Sharpness level of 1.25 Acum. Noisiness of an apartment is found as 'acceptable' (rating scale 3) (refer to Figure 3) with a maximum Roughness level of 37 centi-Asper and is felt 'quiet' with a maximum Roughness level of 33 centi-Asper.

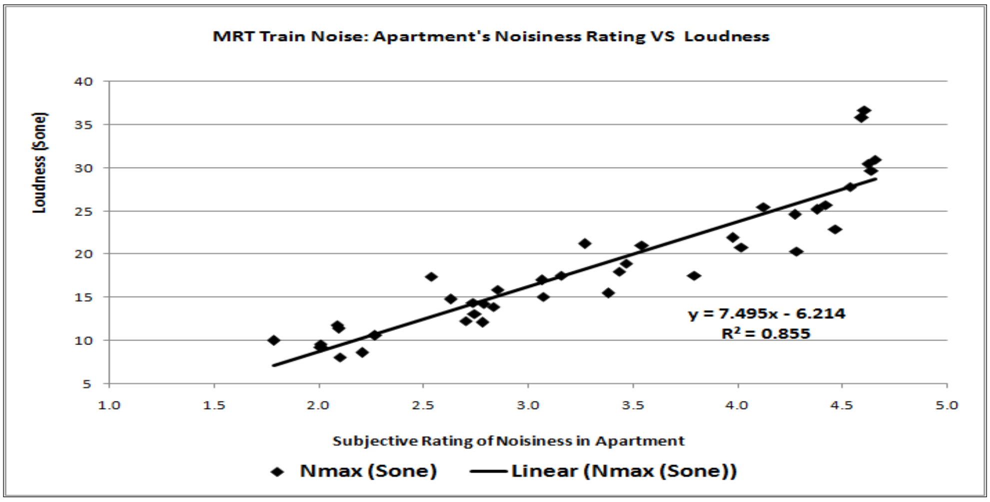

Figure 1 - Rating of apartment's noisiness for different Loudness levels of train noise

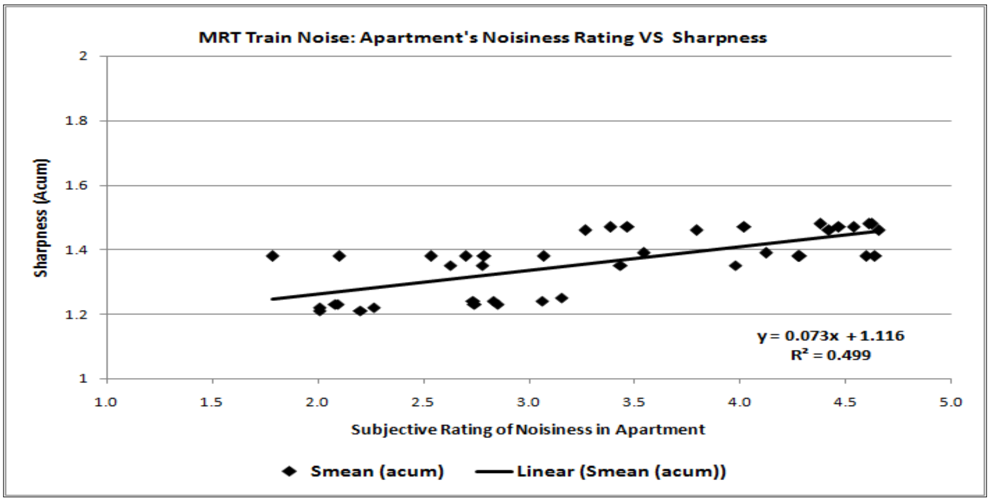

Figure 2 - Rating of apartment's noisiness for different Sharpness levels of train noise

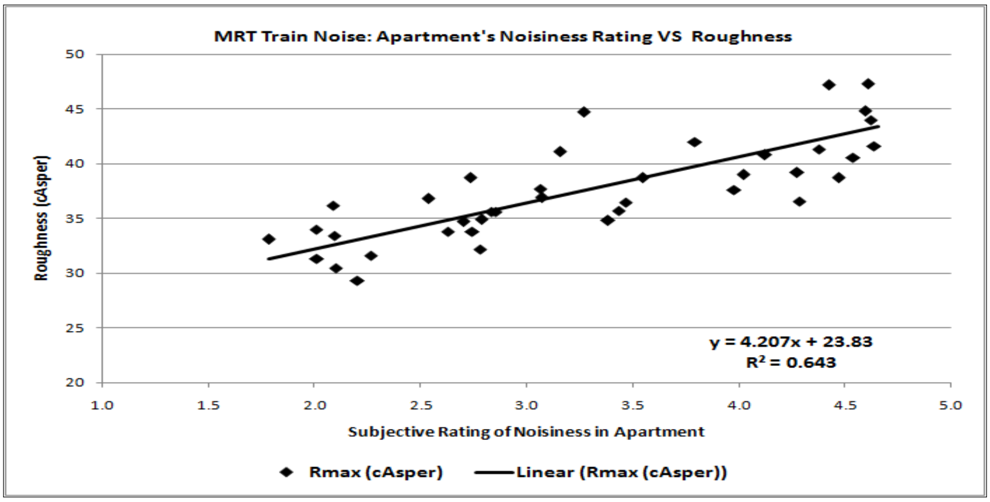

Figure 3 - Rating of apartment's noisiness for different Roughness levels

6.2 Influence of Loudness and Sharpness on Subjective Perception of Train Noise Disturbance

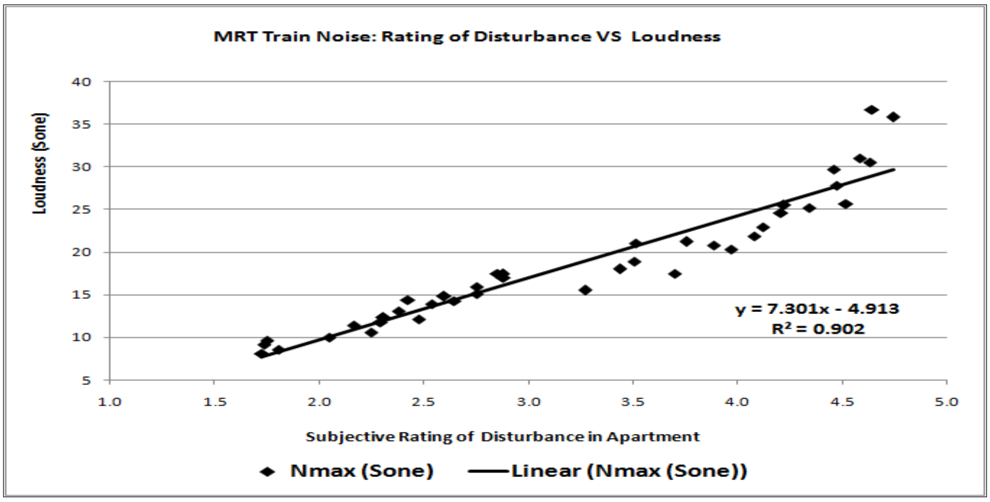

Figure 4 - Rating of noise disturbance for different Loudness levels of train noise

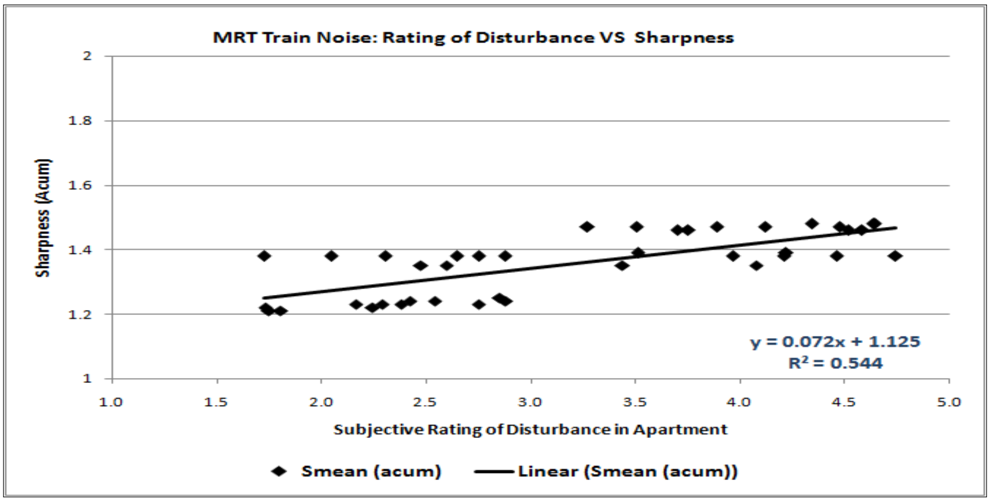

Figure 5 - Rating of noise disturbance for different Sharpness levels of train noise

Subjective ratings of 'Disturbance due to Train Noise' of the 36 test subjects were analyzed for their relation with different Loudness and Sharpness (factors in Equation 2) of the different train noise stimuli during the psychoacoustic experiment. Influence of these psychoacoustic factors on the subjective rating of noise disturbance due to train noise is presented in Figure 4 and Figure 5. Subjective rating of noise disturbance due to train 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 MRT train is perceived as 'a little disturbing' at a maximum Loudness level of 10 Sone. On the other hand, Figure 5 illustrates that noise disturbance is perceived as 'a little disturbing' at a mean Sharpness of 1.3 Acum.

7. CONCLUSION

High-rise apartments subjected to Train Noise are often exposed to higher noise levels (compared to the noise at the lower floors) due to vertical propagation of noise (17-19). 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) (23) 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 train noise and associated subjective rating of noisiness and noise disturbance reveals that noisiness of an apartment is dependent on the maximum Loudness, mean Sharpness and also on the maximum Roughness (rapid modulation between 15 and 300 Hz) levels of the train noise. In contrary, noise disturbance due to train is dependent on the maximum Loudness and the mean Sharpness level.

Established regression models illustrate that Maximum Loudness ($N_{\max}$) and Mean Sharpness (SR_{mean}) are the key factors influencing subjective aural comfort perception related to train 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 Mean Sharpness in the environmental noise management policy will be able to enhance the level of indoor aural comfort subjected to train noise in high-rise residential environment.

REFERENCES

1. Guski, R., Felscher-Suhr, U. and Schuemer, R. (1998). The concept of noise annoyance: what international experts tell. Proceedings of Inter-Noise, Christchurch, New Zealand, 1045-1048.
2. Fields, J.M. and Walker, J.G. (1982). The response to railway noise in residential areas in Great Britain. Journal of Sound and Vibration, 85 (2), 177-255.
3. Miedema, H.M.E. and Vos, H. (1999). Demographic and attitudinal factors that modify annoyance from transportation noise. Journal of Acoustical Society of America, 105, 3336-44.
4. Miedema, H.M.E. and Vos, H. (1998). Exposure-response relationships for transportation noise. Journal of Acoustical Society of America, 104(6), 3432-3445.
5. Miedema HME, Oudshoorn CGM (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect 109: 409-416.
6. Gidlof-Gunnarsson A, Ogren M, Jerson T. Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise Health 2012;14:190–201
7. EU (2002). Position paper on dose response relationships between transportation noise and annoyance. EU´s Future Noise Policy, WG2 – Dose/Effect. European Communities
8. Moehler U, Liepert M, Schuemer R, Griefahn B (2000). Differences between railway and road traffic noise. J Sound Vibr 231: 853-864.
9. Morihara T, Yano T, Sato T. Comparison of dose-response relationships between railway and road traffic noises in Kyushu and Hokkaido, Japan. Proceedings of the 31 st International Congress and Exposition on Noise control Engineering, Inter-Noise 2002. Dearborn, MI, USA; 2002, paper No 241.
10. Yano, T., Yamashita, T. and Izumi, K. (1996). Social survey on community response to railway noise - Comparison of responses obtained with different annoyance scales. Proceedings of Inter-Noise. Liverpool, England, 5, 2299-2302.
11. Yano T, Sato T, Morihara T. Dose-response relationships for road traffic, railway and aircraft noises in Kyushu and Hokkaido, Japan. Proceedings of Internoise 2007, CD-ROM. 2007
12. Lim C, Kim J, Hong J, Lee S. The relationship between railway noise and community annoyance in Korea. J Acoust Soc Am 2006;120:2037-42
13. Guski R. Personal and social variables as co-determinants of noise annoyance. Journal of Noise &

Health, 1999; 3; 45-56.
14. Morel J., Marquis-Favre C. Pierrette M., Gille L.A. Physical and perceptual characterization of road traffic noises in urban areas for a better noise annoyance assessment. Proceedings of Acoustics; 2012; Nantes, France.
15. Zwicker E., Fastl H. Psychoacoustics–Facts and Models. Heidelberg, Germany: Springer; 1990.
16. Moser G. Les stress urbains, Paris : Armand Colin; 1992.
17. Alam S.M., Lee S.E., and Johnny W.L.H. Vertical noise profile in high rise residential environment. Proceedings of INTER-NOISE; 2008; Shanghai, China.
18. Alam S.M. Lee S.E., and Johnny W.L.H. Vertical profile of train noise and indoor noise in high-rise residential environment. Proceedings of INTER-NOISE; 2009, Ottawa, Canada.
19. Alam S.M and Lee S.E. Evaluating aural comfort in tropical high-rise environment. Proceedings of Acoustics; 2012; Perth, Australia.
20. Belinda Y., Anthony Y., Stephen J. A., George E., John T. and Lanny K. K. High-rise living in Singapore public housing. Urban Studies. 2006; 43 (3); 583–600.
21. Ralf C. K. Classes of acoustical comfort in housing: Improved information about noise control in building. Applied Acoustics. 1997; 52(3/4); 197-210.
22. Marquis F.C, Premat E., Aubree D, and Vallet M. Noise and its effects – a review on qualitative aspects of sound. Part II: Noise and Annoyance. Acoustica United with Acta Acoustica. 2005; 91; 613-625.
23. Alam S.M. Assessing aural comfort of high-rise apartment dwellers in the tropics. Ph.D. Thesis. 2014. National University of Singapore; Singapore.
24. Fastl H. Psychoacoustic basis of sound quality evaluation and sound engineering. Proceedings of International Congress on Sound and Vibration. 2006, Vienna, Austria.
25. Berglund B., Nilsson M.E. On a tool for measuring soundscape quality in urban residential areas. Acta Acustica United with Acustica. 2006; 92; 938–944.
26. Genuit K. The use of psychoacoustic parameters combined with A-weighted SPL in noise description. Proceedings of INTER-NOISE; 1999; Fort Lauderdale, USA, 3, 1887-1892.
27. Dittrich K., Oberfeld D. A comparison of the temporal weighting of annoyance and loudness. Journal of Acoustical Society of America. 2009; 126 (6); 3168-3178.
28. Kryter K. Acoustical sensory, and psychological research data and procedures for their use in predicting effects of environmental noises. Journal of Acoustical Society of America. 2007; 122; 2601-2614.
29. Botteldooren D., De Coensel B., De Muer, T. The temporal structure of urban soundscapes. Journal of Sound and Vibration. 2006. 292; 105–123.
30. Ellermeier W., Zeitler A., and Fastl H. Predicting annoyance judgments from psychoacoustic metrics: Identifiable versus neutralized sounds. Proceedings of INTER-NOISE. 2004. Prague, Czech Republic.
31. Genuit K. Sound quality aspects for environmental noise. Proceedings of INTER-NOISE; 2002; Dearborn, USA.
32. Stansfeld S., Kamp V.I., Hatfield J., Ellermeier W., Griefahn B., Lopez-Barrio I., and Hofman W.F. An examination of parametric properties of four noise sensitivity measures: research proposal. Proceedings of INTER-NOISE; 2006, Hawaii.
33. Goodman A. Reference zero levels for pure-tone audiometers. ASHA; 1965; 7, 262–263.
34. Poulsen T. Influence of session length on judged annoyance. Journal of Sound and Vibration. 1990; 145(2), 217-224.