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An acoustic comfort model for dwellers in high-rise built environment in the tropics

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ABSTRACT

Researchers in past few decades investigated on the negative evaluation of the noise environment (i.e. annoyance). Despite of an extensive and rich literature on human noise annoyance experiences, there has been very limited research effort in the investigation of acoustic comfort among residential dwellers. With the technological advancement in many aspects of our living environment in recent years, quality of life issues become prime concern. Acoustic comfort is such a key aspiration of our living environment. Acoustic comforts among high-rise dwellers, especially in the dense urban residential environment in the tropics have not been investigated yet. Since research on acoustic comfort is nascent, there is a quest for a comprehensive evaluation framework and an acoustic comfort model, developed on sound theoretical basis. The current study endeavors to expand the conceptualization of the acoustic comfort among high-rise dwellers in the tropics. A novel acoustic comfort model based on the theory of noise annoyance by Stallen (1999) is proposed in this paper.To evaluate acoustic comfort among the high-rise dwellers in the tropics, a comprehensive noise survey, using stratified sampling technique (based on major environmental noise sources), among 604 households was conceived. Evaluation of acoustic comfort in the high-rise built environment was investigated with respect to major environmental and neighbour noise sources. Perceived acoustic comfort responses were correlated to several acoustical and non-acoustical factors related the indoor noise exposure due to major environmental noise sources. Besides, subjective acoustic comfort responses were also correlated to the perceived neighbour noise and associated disturbance. Factor analysis and multiple regressions analysis of the data from the noise survey resulted in the development of an acoustic comfort model which demonstrates that acoustic comfort is dependent on the perception of noisiness and associated perceived disturbance by major environmental noise sources in the high-rise residential environment in the tropics. Structural Equation Modeling (SEM) technique was then used to investigate the relationships between variables that influence acoustic comfort.

INTRODUCTION

City dwellers are exposed to different types of environmental stressors. Among these stressors, noise represents the most spectacular, the most often mentioned and the one on which the most complaints are concentrated (Moser, 1992). In a modern city, noise is increasingly found as a key quality of life issue (Atkinson 2007). In recent years, amid the debates of sustainable development and urban compactness, there have been widening interests to introduce high-rise living in cities (Belinda, 2006). High-rise residential building is an inevitable consideration in many cities' to meet the need of urban growth and housing shortage. The consensus on modern design is converging towards tall buildings as a model of sustainable building (Pank, 2002; Abel, 2003). Generally the dominant noise sources in the majority of the cities are large systematic sources such as road traffic and trains. This assertion is based both on the results of the corresponding noise level measurements and on the intensity of disturbance that these sources produces on urban residents (Amando, 2006). Environment noise is a major factor contributing to human's displeasure (Carter, 1996). Besides the environmental noise in the densely urbanized modern high rise cities, neighbour noise, that is to say noise made by residents which is a nuisance to other neighbours, is becoming an increasing problem in the society (Claude. 1991). Neighbourhood noise is a serious social problem in many countries. It is associated with an inhabitant's daily life and not easily solved by administrative regulation (Utley, 1988). 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 (Ralf, 1997).

This research study focuses on the evaluation of aural comfort among the high rise dwellers in densely urbanized environment in Singapore and investigates the key factors involved in acoustic comfort among the dwellers.

EVALUATION OF INDOOR AURAL ENVIRONMENT

The evaluation of sound is a complex system. A host of physiological, psychological, behavioral and contextual factors shape a person's engagement, experience and enjoyment of environmental conditions in building (Raymond, 2008). Evaluation of sound is related to a number of disciplines including acoustics, physiology, psychology, sociology and statistics (Jian Kang, 2007).

To qualitatively describe sound evaluation such as annoyance, two kinds of methods are commonly used – unidimensional and multidimensional (Marquis-Favre et al. 2005). The former, including category, discrimination and ratio scales, concerns the relationship between acoustical variable and the perceptual dimension of a stimulus sound, whereas the latter considers various perception dimension. Numerous investigations were carried out over past 30 years to understand different types of noise sources in the urban environment and their negative impact on human individuals around the world. Many of these studies have focused on factors influencing noise annoyance.

Generally, there are two sets of factors investigated for noise annoyance evaluation: a) Sound-related factors - physical characteristics of sound (type of noise, noise level, duration of exposure, frequency spectrum), time of the day when exposure occurs and previous experience with noise source. b) Person-related factors including physiological, psychological and social factors that affect the perception of noise and impair activities (communication, concentration, sleep, recreation or rest) (Ouis, 2001). Defining noise annoyance with such factors and evaluation approach individually do not demonstrate evaluation of sound environment at dwellings holistically. Guski (1999) concluded 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. Past studies that investigated relevant non-acoustical factors, however, have some major shortcomings. Firstly, the research can be characterized as highly inductive, which generally means that it lacks a sound theoretical basis. Many of the models which are tested by using path analysis are exploratory. As a result they do not adequately represent the processes of noise annoyance (Taylor, 1984). Secondly, the lack of elementary understanding related to the topic of noise annoyance can result in misspecification of the statistical model and hence even lead to false inferences related to the effect sizes of relevant variables. Thirdly, most of the models developed for noise annoyance are based on empirical evidence related to previously found correlations between noise annoyance and other variables. Since these associations between noise annoyance and non-acoustical factors were found in an exploratory manner, these models are based on implicit theory rather than on a predefined theory of noise annoyance (Maarten et. al., 2008). Beside the investigation on non-acoustical factors, a numerous numbers of research were carried out to establish the noise annoyance relationship with several sound-related factors. However, there is no one-on-one relationship established between noise exposure and noise annoyance (Maarten et. al., 2008).

Despite of an extensive and rich literature on human noise annoyance experiences, there has been very limited research effort in the investigation of acoustic comfort among residential dwellers. From the literature review, it is observed that noise annoyance study is limited to relating annoyance with specific acoustical and non-acoustical factors involved in the annoyance process in isolation. The concept of acoustic comfort evaluation process necessitates engagement with the noise sources, geographical and climatic condition, and physical environmental conditions within the dwelling and users attitude towards noise environment. All these requirements for comfort appraisal insist a dynamic and integrated nature of comfort evaluation process that is able to address these aspects holistically. This is why (Marquis-Favre et al. 2005) noted that one often speaks about annoyance (the negative perception of noise) and less about the positive perception of noise as a comfort. Marquis also noted that the combination of different types of noises, a relatively unstudied subject which requires more investigations. In the multidimensional context of a complex environment, it must be underlined the importance of other sensorial aspects which could figure in a more general methodology.

THE NEED FOR ACOUSTIC COMFORT STUDY IN THE TROPICS

Acoustics in non-acoustics building spaces in receiving increasing attention (Jian Kang, 2003). Only very recently Prof. Jian Kang from University of Sheffield carried out a number of research on acoustic comfort considering various building types/spaces including shopping mall atrium spaces, library reading rooms, football stadia, swimming spaces, churches, dining spaces, as well as urban open public spaces. Acoustic comforts among high-rise dwellers, especially in the dense urban residential environment have not been investigated yet.

In tropical countries like Singapore, where the air temperature and the relative humidity are generally high, the windows at the building facades are left open for provision of natural ventilation and thermal comfort, the aural comfort is reduced with relatively high noise levels in the apartments concerned. Besides the large systemic noise sources (road traffic and train) noise annoyance to the residents is also added from the localized community noise sources, such as food court, children playground, waste disposal truck etc and from internally transmitted neighbour noise between multi-storey high-rise residential apartments (Lee et al., 2008). The high rise apartments, surrounded by the large systemic noise sources in the close proximity, localized communal noise sources in close vicinity of the residential environment together with the need for natural ventilation requirement results in a complex phenomenon in the delivery of acoustic comfort among high-rise dwellers in Singapore. It is therefore essential to evaluate the aural comfort among high rise dwellers in a scientific approach and investigate the key parameters involved in the delivery of acoustical comfort among the dwellers in the tropics.

RESEARCH DESIGN

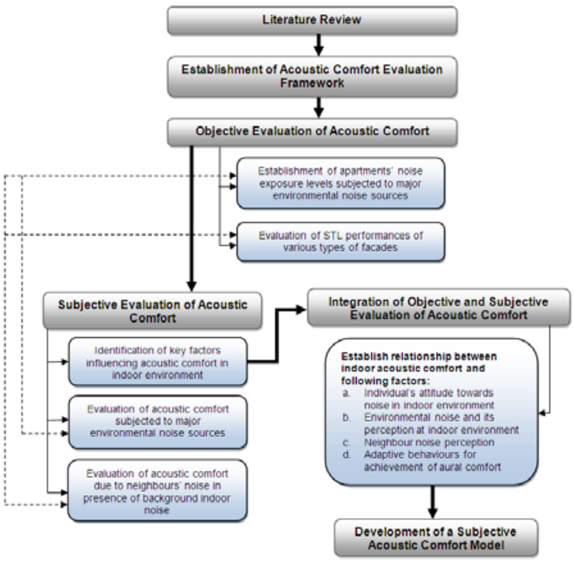

Figure 1. Research design

The research design for evaluation of acoustic comfort is presented in a flow diagram in Figure 1. Based on the findings from the literature review, an acoustic comfort evaluation framework is proposed. According to the comfort evaluation framework, objective and subjective factors affecting the indoor noise environment due to both outdoor and neighbour noise is evaluated. In objective evaluations, characteristics of various environmental and community noise sources are investigated. Establishment of high-rise apartments' noise exposure levels subjected to different environmental and community noise sources are also carried out in objective evaluations. This is done through software simulations and validations of the predicted results through field measurements. Evaluations of sound transmission loss performance of various types of façades are carried out through measurements in-situ condition. A subjective evaluation of acoustic comfort is then carried out to identify the key factors influencing acoustic comfort in indoor environment. This is done through a noise survey in stratified sampling technique. This subjective study evaluates the indoor acoustic comfort subjected to major environmental noise sources. The evaluation of acoustic comfort due to neighbour noise in presence of background indoor noise is also evaluated in the subjective study.

An acoustic comfort model is then established through investigation of the relationships between acoustic comfort and individuals' attitude towards noise, environmental noise exposure levels and its perception, neighbours' noise perception and individuals' adaptive behaviours towards achievement of aural comfort. Correlation, Factor Analysis and Multiple Regression analysis are generally carried out to establish an acoustic comfort model. A Structural Equation Modeling (SEM) technique is also used to ascertain the relationships between acoustic comfort and other factors.

PROPOSED ACOUSTIC COMFORT EVALUATION FRAMEWORK

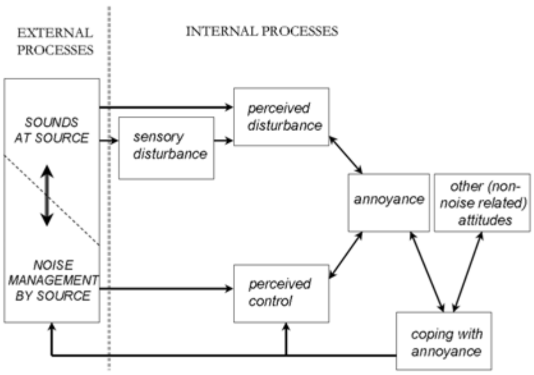

Figure 2. Stallen's conceptual model for noise annoyance

Stallen (1999) developed an theoretical framework for describing the process of noise annoyance based on the psychological stress theory of Lazarus (1966). As Maarten (2008) noted, this is the only theory that gives an explanation for noise annoyance. Empirical research by Lazarus (1966) and others has revealed two major determinants of stress: perceived threat and perceived control. As described by Maarten (2008), Stallen (1999) argued that the perceived disturbance (i.e., annoyance) and the perceived threat basically form equal concepts. Subsequently, noise annoyance as a form of psychological stress is determined by the extent to which a person perceives a threat (i.e., perceived disturbance) and the possibilities or resources that a person has with which to face this threat (i.e., perceived control) (Stallen, 1999). Stallen's conceptual model is shown in 2.

According to Maarten (2008), Stallen (1999) argued that if the perceived threat (i.e., noise) is larger than the perceived resources to face the threat (i.e., perceived control and coping capacity), psychological stress (i.e., noise annoyance) will arise. In addition, even though the perceived disturbance may be very high, no noise annoyance will arise if there are sufficient coping resources. Lastly, since the process of coping is in a constant flux, the theoretical framework includes multiple reciprocal relationships between variables.

Based on the noise annoyance model by Stallen (1999), it is assumed that acoustic comfort is dependent on the perceived disturbance and behavioural responses (perceived control) towards the perceived disturbance. It is also assumed that a decrease in perceived disturbance shall increase level of acoustic comfort. Acoustic comfort is conceptualized as long term evaluation of an indoor acoustic environment. The other relevant assumptions pertaining to proposed acoustic comfort model are: a) Perceived disturbance and behavioural responses related to acoustic comfort can be evaluated through the evaluation of 'Attitude'; b) The theoretical framework of acoustic comfort model includes multiple reciprocal relationships between several acoustical and non-acoustical variables.

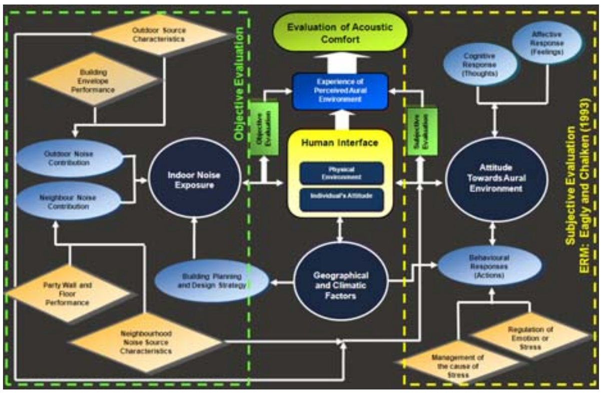

Figure 3. Proposed acoustic comfort evaluation framework

To investigate acoustic comfort among high-rise dwellers in the tropics, for the development of a comfort model, a conceptual framework is proposed as illustrated in Figure 3. The proposed conceptual evaluation framework is an integration of objective and subjective evaluation of acoustic comfort. Objective evaluation is based on the quantitative evaluation of noise exposure and the relevant acoustical factors. Subjective evaluation is based on the Evaluative Response Model (ERM) proposed by Eagly and Chaiken (1993).

The proposed acoustic comfort evaluation framework is a novel approach which is rooted in Stallen's (1999) theory of noise annoyance. The framework is founded on the humans' nature for evaluation of environmental disturbance and the profound theory of evaluation response model, ERM by Eagly and Chaiken (1993). According to the ERM model, "Attitude" is a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour.

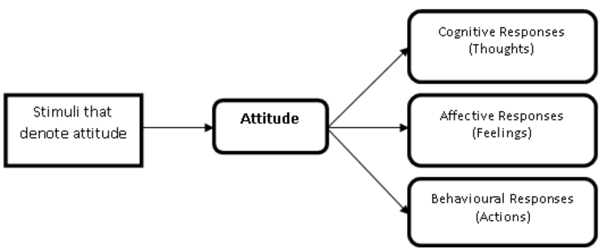

Figure 4. Eagly and Chaiken's (1993) model of attitude

As shown in Figure 4, Eagly and Chaiken identified three response types that form the cornerstone of the ERM. These response types are (a) cognitive, (b) affective and (c) behavioural. These three main response types are similar to the tripartite model of attitudes and also referred to as the structural approach to attitudes (Lyons, 1998). Eagly and Chaiken suggested that each one of these response types can be defined as follows.

Cognitive responses: Eagly and Chaiken suggested that cognitive response reflects the thoughts and ideas people have about the attitude object (i.e. noise), which are often conceptualized as beliefs but more often referred to as knowledge, opinions, information and inferences about an attitude object. These conceptualizations form the links between the attitude object and the various attributes of the attitude objects. Therefore, favourable evaluations are likely to be linked with positive attributes. Both positive and negative beliefs about the attitude objects may be shared.

Affective responses: Affective response refers to emotions, feelings and moods that are experienced with regard to the evaluation of the attitude object and are thus a way of responding to the attitude object. Eagly and Chaiken stated that people who evaluate an attitude object favourably are generally also likely to experience a positive affective reaction, contrary to what others might experience, which may range from extremely positive experiences to extremely negative experiences.

Behavioural responses: Behavioural response refers to the intentions to act or to the overt action associated with the attitude objects. People who evaluate an attitude object favourably tend to engage in behaviours that support such an attitude, while others might resort to opposite behaviour.

According to the proposed conceptual acoustic evaluation framework, human interface, which is built up on relevant physical environmental conditions and individual's attitude, is subjected to noise from outdoor and immediate neighbous. The physical environment influence the noise exposure at dwellings which in turn depends on the type and characteristics of noise sources, their proximity to dwellings, level of noise exposure, acoustical performances of the building components, the geographical and the climatic requirements for building design. Therefore, the evaluation of aural comfort in dwelling is not limited to the individual's attitude towards noise environment, it also requires the evaluation of the physical environment related to noise exposure at indoor which in a way or other influence the acoustic comfort of an individual at dwelling. A comprehensive evaluation of the aural comfort thus necessitates an integrated evaluation approach which is founded on an objective evaluation of the physical environment and subjective evaluation of the individual's attitude towards the objective noise exposure that influence acoustic comfort among the dwellers in the tropics.

Data collected through such investigation shall undergo factor analysis and regression for development of acoustic comfort model. A Structural Equation Modeling (SEM) technique shall be used to investigate the relationship among several variables related to acoustic comfort and establish the critical path leading to acoustic comfort.

OBJECTIVE EVALUATION OF ACOUSTIC COMFORT

According to the proposed conceptual framework for the evaluation of acoustic comfort, the objective evaluation of acoustic comfort requires characterization of various environmental and community noise sources, establish apartments' noise exposure levels due to outdoor noise sources and evaluation of sound transmission loss performances of different types of facades. All these are required to establish the indoor noise exposure levels of the apartments which shall be used in evaluating subjective comfort responses of the respondents during noise survey.

As there are no established model for road traffic noise, Mass Rapid Transit (MRT) train noise and different community noise sources (e.g. waste disposal truck, children playground, food centre etc) in Singapore for prediction of the noise exposure levels of high-rise apartments subjected to these sources, CadnaA software has been used to model these noise sources and predict the noise exposure levels of buildings at different elevation. The predicted data are verified with measured noise levels data on the same buildings. With the validation of the predicted results, CadnaA software is used to simulate facade noise exposure levels for different source to buildings distances. A number of charts have been established for quick estimation of the noise exposure levels of buildings subjected to different source to building distances. This part of the study is not include in this paper and can be found in the published papers by Lee et. al. (2008, 2009). Measurements for noise isolation of different types of facades are also carried out and it was found that with 'one window opened' conditions, the mean NIC rating of the facades is 11 dB (Alam et al, 2009). Considering the natural ventilation requirements in the high-rise residential buildings in Singapore, the indoor noise exposure level is computed considering that there is only one window open for natural ventilation in the room subjected to the particular noise source. The established charts for prediction of noise exposure for buildings subjected to different noise sources are used along with the mean facade noise isolation rating to compute the indoor noise exposure levels of the apartments surveyed to evaluate subjective responses about acoustic comfort.

SUBJECTIVE EVALUATION OF ACOUSTIC COMFORT

A preliminary investigation (Lee et. al. 2008) by a noise survey among 522 households in cluster sampling showed that the large systemic noise sources like Road Traffic and MRT train are the major sources of environmental noise and are associated with noise disturbance in dwellings. As road traffic and MRT train buildup the backbone network of land transport system and are widespread in every parts of Singapore, these noise sources form the background noise in the living environment. Therefore, evaluation of acoustic comfort among the high-rise dwellers, in the presence of such background noise becomes a key concern of this research investigation.

For evaluation of acoustic comfort among the high-rise dwellers, in accordance to the proposed acoustic comfort evaluation framework, a noise survey using stratified sampling technique was conceived. The stratification criteria included different noise exposure levels of buildings subjected to different category of road traffic and different distances from MRT train tracks. A total of 604 households (302 households near different categories of roads and another 302 households at different distances from MRT tracks (at different sites) were surveyed at 20 different locations in Singapore. Both major environmental and neighbour noise were investigated.

The questionnaire consisted of 21 questions and was categorized into 4 sections. The first section of the questionnaire focused on the general rating of noise in the outdoor living environment, indoor apartment and rating of long term acoustic comfort in apartment. The second section of the questionnaire involved subjective evaluation of the noise from immediate neighbouring apartments. Respondents were asked to rate the subjective 'loudness' of the noise heard from their immediate neighbours instead of the sound performance of the separating elements for a more accurate and consistent result. The third section investigated the subjective evaluation of different outdoor environmental and community noise sources. The final section of the questionnaire consisted of an objective noise measurement inside the resident's apartment together with the subjective rating of the exposed noise level during the measurement. Indoor noise exposure levels of the individual apartments surveyed were computed from the established charts for predicted noise exposure levels of the apartments and the measured mean sound insulation performance of facades. The computed indoor noise exposure levels of the apartments were then correlated with the subjective responses of the respondents with respect to environmental and neighbour noise.

Analysis of Acoustic Comfort with respect to Environmental Noise

Among the entire cohort, 78.3% of the sample population found the overall noise level in the indoor environment as 'very quiet' and 'acceptable' while the rest 21.7% felt as 'noisy' and 'very noisy'. Though 78.3% of the respondents felt the indoor noise level was acceptable, a significantly lesser proportion of them (60.3% of the total sample) felt aurally 'comfortable' and 'very comfortable' and the rest felt 'neither' and 'uncomfortable'. Therefore, rating of indoor noise environment as 'acceptable' was found not a direct indicator of acoustic comfort among the high-rise dwellers.

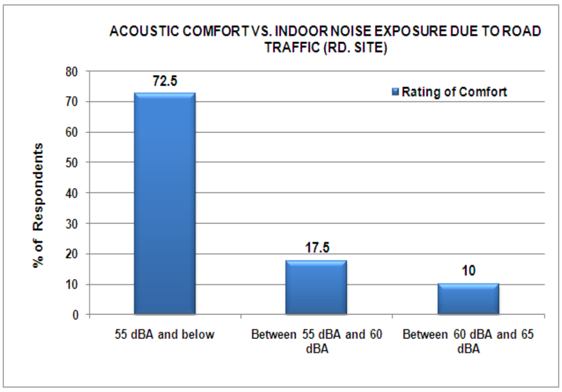

Figure 5. Acoustic comfort with respect to indoor road noise exposure level (Lday)

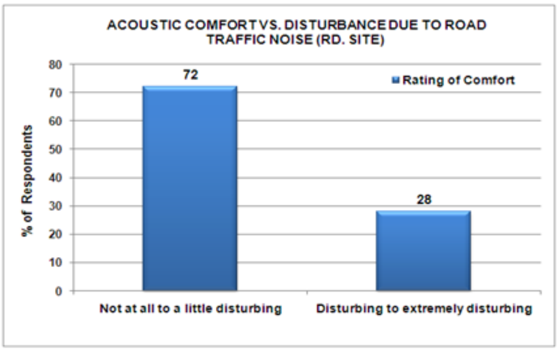

Figure 6. Acoustic comfort with respect to disturbance due to road traffic noise

The analysis of survey data showed that among the respondents who were aurally comfortable, the rating of long term indoor acoustic comfort increases appreciably with the decrease in indoor background noise exposure level (Lday) due to road traffic noise as illustrated in Figure 5. It was found that (Figure 6) the rating of acoustic comfort appreciably increases when the subjective noise disturbance due to road traffic noise is limited to 'not at all loud' and 'little loud'. The similar phenomenon was observed among the respondents who were aurally comfortable and exposed to MRT train noise.

Analysis of Acoustic Comfort with respect to Neighbour Noise

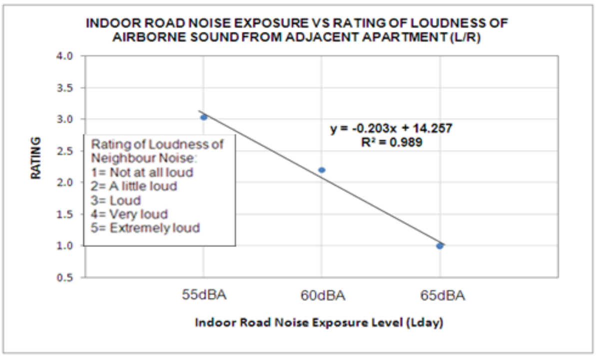

Figure 7. Rating of subjective 'loudness' of neighbours airborne transmitted noise with respect to indoor road noise exposure level (Lday)

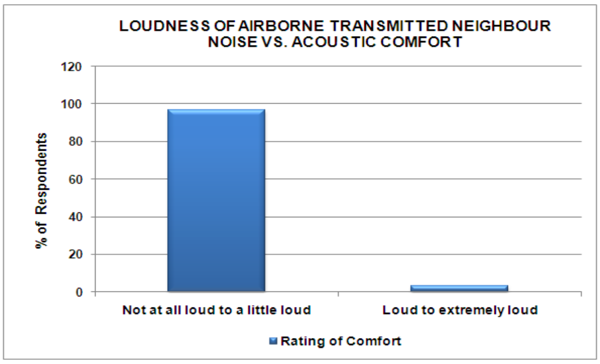

Figure 8. Acoustic comfort with respect to subjective rating of 'loudness' of neighbours' airborne transmitted noise

The analysis of the neighbour noise with respect to indoor daily average road noise exposure level (Lday) showed that (Figure 7) the subjective rating of 'loudness' of the immediate adjacent neighbours' airborne transmitted noise is inversely related to the indoor noise exposure level due to road traffic noise. As such the rating of 'loudness' is appreciably lower when the indoor noise exposure level (Lday) is higher. Figure 8 illustrates that acoustic comfort is considerably higher when the subjective rating of neighbours' air-borne noise 'loudness' is rated as 'not at all loud' and 'little loud'. Similar observations are established from subjective 'loudness' of neighbours' impact transmitted noise with respect to indoor daily average road noise exposure level. This is illustrated in Figure 9 and Figure 10.

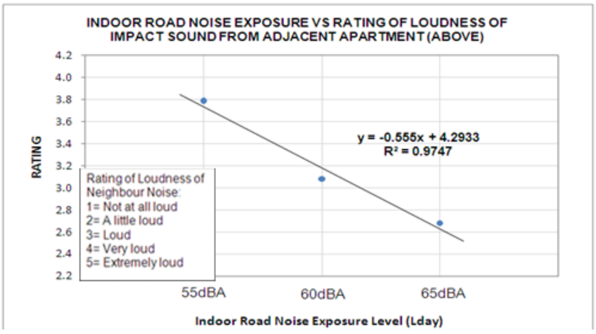

Figure 9. Rating of subjective 'loudness' of neighbours impact transmitted noise with respect to indoor road noise exposure level (Lday)

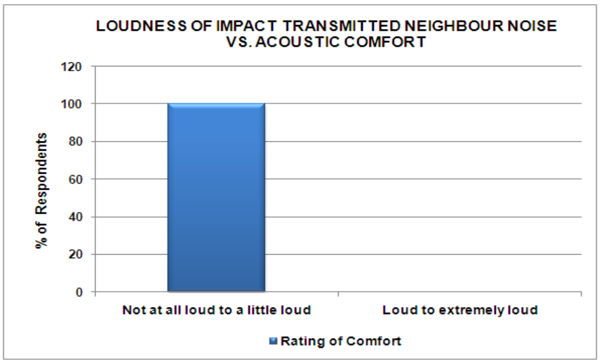

Figure 10. Acoustic comfort with respect to subjective rating of 'loudness' of neighbours' impact transmitted noise

ESTABLISHMENT OF A SUBJECTIVE ACOUSTIC COMFORT MODEL

To investigate the relationship between acoustic comfort and several acoustical and non-acoustical factors, spearman rank correlation tests were carried out and the results are presented in Table 1. It was found that the rating of acoustic comfort in the apartment was significantly correlated to the rating of noise in surrounding living environment, rating of noise level within the apartment, rating of disturbance by road traffic and MRT train noises. The other factors are weakly correlated to acoustic comfort and are significant. One way ANOVA test showed that rating of indoor acoustic comfort is not influenced by age, gender, education level, level of the apartment the respondents reside in, length of residence, type of apartment, type of noise source (road traffic or MRT train) but influenced by the noise sensitivity of the respondents.

A factor analysis was then carried out to establish the different components that explain acoustic comfort. All the five components extracted from PCA explained over 70% of the total variance in all of the variables. From the rotated component matrix, presented in Table 2, it can be observed that the most important factors related to the 1st component are: rating of indoor noise level in apartment, rating of noise level in surrounding living environment, sensitivity to noise, consideration of noise as an important aspect in living environment and rating of disturbance due to road traffic noise. The second component is mostly related to the neighbour noise: the disturbance by the neighbours' noise and personal activities disturbed by the neighbours' noise. The third and fourth components depend on the adaptive behaviour of individuals. The third component is mostly related to the management of the cause of stress (noise) to achieve aural comfort. It includes closing windows and doors to achieve aural comfort at indoor environment. On the other hand, the fourth component is related to the regulation of emotions (e.g. playing music and watchig TV) to achieve acoustic comfort. The fifth component was found to be related to indoor noise exposure level (Lday) and rating of disturbance due to MRT train noise exposure.

Table 1. Correlations between acoustic comfort and other factors

CORRELATIONS BETWEEN ACOUSTIC COMFORT AND OTHER FACTORS		
Factors	Correlation Coefficient	Level of Significance
Rating of indoor noise level in apartment	0.673	0.01
Rating of noise level in surrounding living environment	0.575	0.01
Rating of sensitivity to noise	0.178	0.01
Consideration of noise as an important aspect in living environment	0.175	0.01
Rating of disturbance due to neighbour noise	0.129	0.01
Personal activities disturbed by neighbour noise	-0.134	0.01
Rating of disturbance by road traffic noise	0.414	0.01
Rating of disturbance by MRT train noise	0.244	0.01
Rating of likeliness of closing window	-0.174	0.01
Rating of likeliness of closing door	-0.15	0.01
Rating of likeliness of playing music	-0.165	0.01
Rating of likeliness of watching TV/Video	-0.139	0.01
Calculated indoor noise exposure level, Lday (dBA)	0.154	0.01

Table 2. Results of factor analysis

ACOUSTIC COMFORT IN APARTMENT					
Rotated Component Matrix					
	Component				
	1	2	3	4	5
	% of Variance Explained				
	17.5	15.2	13.5	13.2	13.1
	Cumulative % of Variance Explained				
	17.5	32.7	46.2	59.4	72.5
	Component Loading				
Rating of indoor noise level in apartment	.655	-.036	.053	-.209	.319
Rating of noise level in surrounding environment	.769	-.067	-.050	-.088	.351
Rating of sensitivity to noise	.539	-.131	-.317	.001	-.249
Rating of consideration of noise as an important aspect in living environment	.525	-.076	-.290	.093	-.183
Rating of disturbance due to Neighbour Noise	-.062	.987	.027	.020	-.009
Personal Activities Disturbed by Neighbourhood Noise	-.071	.986	.038	.012	-.014
Rating of disturbance due to Traffic noise	.761	.032	-.062	-.046	.121
Rating of disturbance due to MRT noise	.227	.000	-.145	-.047	.785
Rating of likeliness of closing window	-.155	.040	.868	.129	-.155
Rating of likeliness of closing door	-.114	.006	.859	.207	-.128
Rating of likeliness of listening to music	-.047	.006	.152	.895	.002
Rating of likeliness of watching TV/Video	-.087	.024	.131	.886	-.022
Computed indoor noise exposure level	.017	-.019	-.087	.032	.841

The findings from factor analysis have strong agreement with the fundamental two assumptions of acoustic comfort model based on Stallen (1999) theory of noise annoyance. These shows that perceived disturbance (disturbance by road, train and neighbour noise and their relation to cognitive thoughts and feelings about noise) and the behavioural responses i.e. perceived control (management of the cause of stress by closing windows and doors and regulation of emotion by playing music and watching television) are significantly related to acoustic comfort and explain over 70% of the total variance in all of the variables.

Table 3. Results of multiple regressions

1st Regression Statistics				
Multiple R	**R Square**	**Adjusted R Square**	**Standard Error**	**Observations**
0.977993232	**0.956470762**	0.953894872	0.573273115	604
Regression Summary				
Variables	*Description*	*Coefficients*	*Standard Error*	*P-value*
X Variable 1	APARTMENT RATING	0.608	0.036	0.00000
X Variable 2	LIVING ENVIRONMENT	0.201	0.042	0.00000
X Variable 3	SENSITIVITY	0.003	0.028	0.90014
X Variable 4	NOISE IMP ASPECT	0.011	0.013	0.39845
X Variable 5	DIST BY NEIGHBOUR	0.219	0.196	0.26274
X Variable 6	ACTIVITIES DIST	-0.062	0.038	0.10113
X Variable 7	RAT RD	0.089	0.026	0.00056
X Variable 8	RAT MRT	0.059	0.023	0.00964
X Variable 9	CLOSE WINDOW	-0.006	0.021	0.79354
X Variable 10	CLOSE DOOR	0.023	0.022	0.30132
X Variable 11	PLAY MUSIC	-0.047	0.032	0.14053
X Variable 12	WATCH TV	0.034	0.029	0.23195
X Variable 13	Predicted Indoor NE	-0.007	0.004	0.07687
2nd Regression Statistics				
Multiple R	**R Square**	**Adjusted R Square**	**Standard Error**	**Observations**
0.977301217	**0.955117668**	0.95322659	0.577732585	604
Regression Summary				
Variables	*Description*	*Coefficients*	*Standard Error*	*P-value*
X Variable 1	APARTMENT RATING	0.584	0.033	0.00000
X Variable 2	LIVING ENVIRONMENT	0.141	0.035	0.00006
X Variable 3	RAT RD	0.099	0.025	0.00008
X Variable 4	RAT MRT	0.047	0.021	0.02914
3rd Regression Statistics				
Multiple R	**R Square**	**Adjusted R Square**	**Standard Error**	**Observations**
0.976679478	**0.953902802**	0.952085507	0.585012046	604
Regression Summary				
Variables	*Description*	*Coefficients*	*Standard Error*	*P-value*
X Variable 1	APARTMENT RATING	0.689	0.021	0.00000
X Variable 2	RAT RD	0.150	0.022	0.00000
X Variable 3	RAT MRT	0.069	0.021	0.00103

Multiple regressions using least square method was then applied to the data to establish an acoustic comfort model. The test statistics and the regression summary are presented in Table 3. It can be noted that during the first regression, only four variables (rating of noise in apartment, rating of noise in general surrounding living environment, disturbance by noise exposure due to road and MRT train) are found significantly related to acoustic comfort. It was therefore decided to reduce the number of variable to four and carryout a second regression. The summary of the second regression showed an excellent goodness of fit with R^2 0.955 and the four factors being significantly related. Among the four variables, the first two variables were related to the rating of noisiness within the apartment and outside the apartment in general surrounding living environment. As both of these variables are related to the similar noise exposure information (one is within apartment and the other is outside the apartment) with the former having a computed indoor noise exposure level for each apartments surveyed, it was decided further to reduce the number of variables to three. A third regression was then carried out to finally derive the acoustic comfort model. The regression statistics showed an excellent goodness of fit with R^2 0.954 and the three factors being significantly related with a 95% confidence level. With the reduction of one variable, the goodness of fit was found not compromised. The derived acoustic comfort model is:

$$\textbf{Indoor Acoustic Comfort Index (IACI)} = 0.689\ X\ \text{Rating of Indoor Noise Exposure Level} + 0.15\ X\ \text{Rating of Road Noise Disturbance} + 0.069\ X\ \text{Rating of Train Noise Disturbance} \quad \text{[Eq. 1]}$$

Equation 1 illustrates that rating of indoor acoustic comfort depends on the perception of noise at indoor environment and perceived disturbance by the noise exposure due to road traffic and MRT train noise. The developed subjective acoustic comfort model demonstrates the fundamental assumption of acoustic comfort, based on Stallen's (1999) theory of noise annoyance, that the perceived disturbance is significantly related to acoustic comfort.

As general multiple linear regression does not analysis the reciprocal relationships between factors which might have an influence on the overall evaluation of acoustic comfort, Path analysis by Structural Equation Modeling (SEM) technique was then applied to establish the causal relations between acoustic comfort and other factors. AMOS 18 statistical software package was used for the analysis.A preliminary model for acoustic comfort was created in AMOS based on the thirteen factors used in the multiple linear regressions. Path analysis was then carried out. The model tests and parameters estimates were based on the covariance matrix and used maximum likelihood estimation.

Table 4. Direct, indirect and total effects of all factors affecting acoustic comfort in the SEM model

Factors	Direct Effect	Indirect Effect	Total Effect
Sensitivity to noise	-0.002	0	-0.002
Consideration of noise as an important aspect in living environment	0.009	0	0.009
Rating of noise in surrounding living environment	0.194	0	0.194
Rating of indoor noise level in apartment	0.605	0	0.605
Computed indoor noise exposure level	-0.013	0	-0.013
Rating of disturbance due to Road traffic noise	0.09	0	0.09
Rating of disturbance due to MRT train noise	0.069	0	0.069
Rating of Disturbance due to neighbour noise	0.152	0	0.152
Personal activities disturbed by neighbour noise	-0.052	0	-0.052
Closing of windows	-0.009	0	-0.009
Closing of doors	0.023	0	0.023
Listening to music	-0.051	0	-0.051
Watching television	0.032	0	0.032

Table 4 presents the direct and indirect effects of all factors on acoustic comfort for the preliminary model. Four factors were identified from the analysis as significantly correlated with the rating of acoustic comfort namely: rating of noisiness in apartment, rating of noise in surrounding living environment, disturbance due to road traffic and MRT train noise.Acoustic comfort is clearly strongly influenced by perception of indoor noise environment in apartment. The perception of noise level in surrounding living environment and the disturbance due to road traffic and MRT train noise also influence the perceptions of acoustic comfort. All these factors significantly influence the perception of acoustic comfort directly and there is no indirect influence observed.

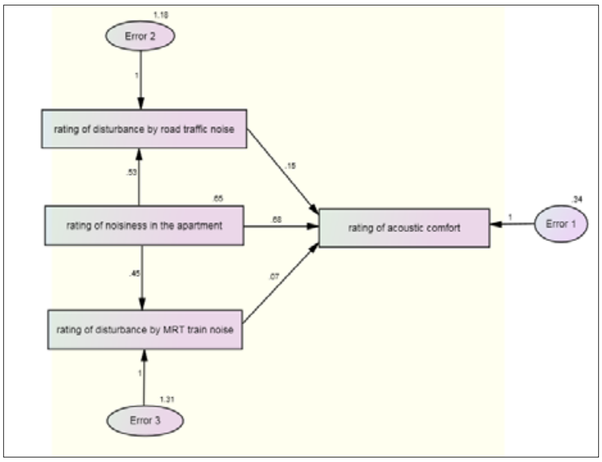

Figure 11. Primary model for acoustic comfort

Based on the path analysis of the preliminary model, the insignificant paths were deleted and the model was re-estimated which yielded a general model for acoustic comfort as presented in Figure 11.

The goodness of fit of the developed statistical acoustic comfortmodel is assessed based on a number of indices as commonly used in SEM applications and are presented in Table 4. The chi-square value for the model was found statistically significant (Chi-square = 6.452, p=0.01), which means that the model implied covariance matrix is significantly different from the observed covariance matrix. In essence a statistical significance test Chi-Square statistic is sensitive to sample size which means that the Chi-Square statistic nearly always rejects the model when large samples are used (Bollen and Long, 1993). However, since this statistic is very sensitive for large sample sizes (N>500), the review of other fit indices is recommended (Bollen and Long, 1993; Hu and Bentler, 1995; Schermelleh-Engel et al., 2003).

Table 4. Goodness of fit of the model

Goodness of Fit Indices	Goodness of Fit Criteria	Calculated Value for the Model
Goodness of Fit Index (GFI)	> 0.9	0.995
Adjusted Goodness of Fit Index (AGFI)	> 0.9	0.947
Normed Fit Index (NFI)	> 0.9	0.990
Relative Fit Index (RFI)	> 0.9	0.941
Incremental Fit Index (IFI)	> 0.9	0.992
Tucker Lewis Index (TLI)	> 0.95	0.950
Comparative Fit Index (CFI)	> 0.9	0.992
Root Mean Square Error of Approximation (RMSEA)	0.06 - 0.1	0.090

Goodness of fit index (GIF) calculates the proportion of variance that is accounted for by the estimated population covariance (Tabachnick and Fidell, 2007). By looking at the variances and covariances accounted for by the model it shows how closely the model comes to replicating the observed covariance matrix (Diamantopoulos and Siguaw, 2000). The computed GIF value for the model is well above tbe recommended value of 0.9. Related to GFI, the adjusted goodness of fit index (AGFI) is also well above the recommended value of 0.9. Incremental fit indices, also known as comparative (Miles and Shevlin, 2007) or relative fit indices (McDonald and Ho, 2002), are a group of indices that do not use the chi-square in its raw form but compare the chi-square value to a baseline model. These are Normed fit index (NFI), Relative fit index (RFI), Increamental fit index (IFI), Tucker Lewis index (TLI) and Comparative fit index (CFI). All the computed values of these indices for the established acoustic comfort model are well above the recommended value as shown in table 4. Root mean square error of approximation (RMESA) measures the discrepancy between the models implied and observed covariance matrix per degree of freedom. The computed RMSEA of the established statistical model is 0.9 which is considered as an indication of fair fit (MacCallum et al, 1996). Meeting the criteria of a number of goodness of fit indices demonstrates that the established subjective acoustic comfort model is a ‘good fit’ model.

The developed acoustic comfort model using SEM technique is indeed exactly the same model as the developed model through multiple linear regressions (Eq 1). As SEM analyse the inter-relationships among variables, the established acoustic comfort model using SEM illustrates that acoustic comfort is significantly depended on the rating of noisiness of indoor noise environment and disturbance due to Road traffic and MRT train noise. The SEM model also illustrates that it is the perception of noisiness of the indoor environment which influences the disturbance due to exposure to Raod traffic noise and MRT train noise which in turn affects the perception of indoor acoustic comfort. This study reveals that when high-rise apartments in the tropical climatic conditions are subjected to Road traffic and MRT train noise of different exposure levels, the perception of indoor acoustic comfort is not sifnificantly influenced by the noise sensitivity, the belief of noise as important aspect in living environment, disturbance due to neighbour noise and the adaptive behaviour to achieve aural comfort. It rather depends on the perception of the noisiness of indoor aural environment and associated sisturbance due to Road traffic and MRT train noise.

CONCLUSION

In this study, a subjective acoustic comfort model is developed for the dwellers in high-rise residential environment in tropical Singapore. The established acoustic comfort model is founded on a sound theoretical framework based on Stallen’s (1999) theory of noise annoyance. The acoustic comfort evaluation is carried out in accordance to the proposed evaluation framework which relies on the subjective and objective evaluation of acoustic comfort and their integration. The final model established through a SEM technique provides a good model fit. The model demonstrates that among the high-rise dwellers in tropical Singapore, exposed to road traffic and MRT train noise, the perception of indoor acoustic comfort is largely dependent on the subjective perception of the noisiness of indoor aural environment which in turn influence the noise disturbance due to Road traffic and MRT train noise. Acoustic comfort in such environment was found not influenced by the noise sensitivity, the belief of noise as important aspect in living environment, disturbance due to neighbour noise and the adaptive behaviour to achieve aural comfort. Further investigations is recommended to establish relationships between subjective comfort indices and objective acoustical quantities of the exposed sounds.

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