PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Characterizing Community Noise in Hospital

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ABSTRACT

The present study was conducted in the lobbies of 16 Taiwanese urban hospitals to establish what contributes to the degree of noisiness experienced by patients and those accompanying them. Noise level measurements were conducted by 15 min equivalent sound pressure levels ($L_{Aeq,\ 15m}$, dB). Statistical attribute was better correlated, but the measured data was concerned whether the noise levels are normally distributed or not. According to the correlation between subjective and objective surveys, the 3 independent variables shown to have the largest effects on perceived noisiness were 1) $L_{min} – L_{max}$, 2) effective duration of the normalized autocorrelation function (τ_e, h), of all $L_{Aeq,\ 15\ m}$ over 9 – 17, and 3) gradient of cumulative distribution function (0.3 - 0.7 cumulative rate range). As an advanced approach, we found that the gradient of cumulative distribution function evaluates noisiness with more data statistical integrity than that was easily attained by percentage levels.

Keywords: noisiness, hospital, loudness, autocorrelation function, cumulative distribution function

1. INTRODUCTION

1.1 Noise events in the hospital lobby

The noise in hospitals is detrimental to the recovery of patients, who need an environment quieter than they usually experience in their daily lives. Nevertheless, verbal communications in a hospital lobby constitute a necessary behavior at registration desk, dispensary counters, and outpatient service counters. Those actual procedures that patients undergo normally lasting longer than 20 – 30 min in the hospital lobbies can be an uncomfortable experience in Taiwan. This study focuses on noise-related variables in heavily trafficked hospital lobbies including noise levels at registration desk, at dispensary counters and in emergency departments. The noise sources in hospital lobbies consist primarily of people, machinery, and medical appliances; however, the specific acoustical characteristics of hospital lobbies have not been well established.

The daily activities in hospital have resulted in excessive noise generated from sources such as enormous air-conditioners, medical treatments involving noisy portable carts, conversations, and even TV sounds in lobbies. Recently, many hospitals in Taiwan have opened a convenience store in their lobby, thus greatly increasing the complexity of the noise profile in these places. Furthermore, hospitals run huge mechanical infrastructures, such as the magnetic resonance imaging (MRI) and computerized tomography (CT) medical facilities. For convenience, to dampen their sounds and vibrations, and for the purposes of emergencies, these pieces of equipment have routinely been sited on the first floor (1F) or basement floor (BF). Such facilities, however, drastically augment noise over a frequency range of 500 – 2000 Hz measured in operating rooms and with spectral peaks of 250 Hz (Mcjury, 1995). However, in our previous survey, the noise levels of these magnet facilities were under 49 L_{Aeq} at 1–min intervals measured at the hallway right outside of these examination rooms.

Many studies have provided any information about annoyance and noise perceptions in terms of road-traffic composition (Sandrock *et al.*, 2010; Abo-Qudais, Abu-Qdais, 2005). Those studies concluded that annoyance is highly dependent on the actual noise sources in complex traffic scenarios but provided only limited evaluations regarding the complicated hospital noise disturbances in the lobbies studied. This is an important issue in hospital lobbies because the most of information is transmitted orally (for example, by nurses or other staff members speaking with patients and their families). In this study, we investigated the psychological effects of noise in 16 urban hospital lobbies with the aim of providing complicated noise evaluations based on a variety of independent annoyance descriptors used in previous works.

1.2 Noise Criteria

Previous studies have employed equivalent sound pressure level (L_{eq}) measurements to quantify noise levels according to the WHO guideline recommendations (Berglund *et al.*, 1999, page 7). Some studies have focused on the variation of L_{eq} over a 24-hour period (Bush-Vishniac *et al.*, 2005; Yamada *et al.*, 2003; Orellana *et al.*, 2007; Kracht *et al.*, 2007; Williams *et al.*, 2007). For road-traffic noise, Griffiths, Langdon (1968), proposed using a statistical level of L_N, with $L_{10} – L_{90}$ as the measure of variability. De Coensel *et al.* (2005), used $L_5 – L_{95}$ as an effective descriptor of noise observations since they showed much more variation among statistical levels, while Torija *et al.* (2010), used a sound level variance which was calculated by the standard deviation of the sound levels. However, Torija *et al.* (2010), provided only limited psychological research regarding their models. These indicators provide an idea of the cumulative fluctuation levels from the average background noise. In addition, different noise annoyance ratings for the same L_{Aeq} were caused by different mean percentile loudness in sone (N_{10} or N_5). They concluded that the average loudness, N, better correlates to annoyance ratings than the percentile value of loudness N_5 and that N can be used a noise index for time-varying noise. However, their four traffic noise structures were artificially created in a laboratory from single vehicle pass-by recordings, or we found that their noisiness research subjects were mostly subjected to specific individual noise sources. They do not seem capable of representing community noise, which is defined by WHO (Berglund *et al.*, 1999, page 55) as noise emitted from all sources, including road-traffic, industries, construction, public work, and neighborhoods; i.e., the real noises which occur in our environments surrounding us. Whereas the findings reported by Kaczmarek and Preis (2010) regarding their experiences of the variance in road-traffic noise measures, we believed that statistical levels and percentile loudness of noise measurements would serve as an effective descriptor of the psychological noisiness for the complicated noise sources in hospital lobbies, too. Other measures, meanwhile, such as the maximum and minimum noise levels, octave band levels, and, in particular, the sense of time-varying in noise levels continuity have been investigated by using autocorrelation function analysis (Ando, Chen, 1996; Sato *et al.*, 2007).

In the early stage of measurements, the day-night noise in hospitals, unpredictable impulse noise, which blends into background noise, often poses the biggest difficulties for monitoring background noise in hospitals. However, it was identified that the noise level in general hospital wards is a continuous steady state and varies in daytime (9 -17) are normally distributed. This explains why noise events were averaged at 15-min intervals in this study to detect the noise events without an impulse wave. The frequency of occurrence and the sound pressure level of multiple impulse noise events can easily be assessed through their cumulative percentile sound pressure level. Such impulse noises include ambulance sirens, human screams, and construction noise. In Figures 1, the cumulative percentages of daytime (9 -17) noise events were normally distributed for both indoor and outdoor areas. Sporadic impulse noise events, marked by high decibel levels in the nighttime (17-24), are located on the right side of these distributions (where α > 0.90).

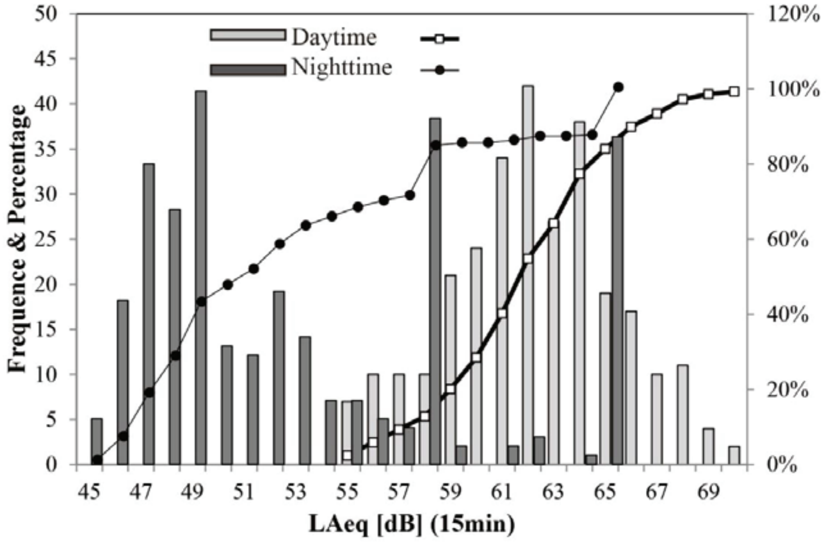

Fig. 1. A comparative cumulative rate of the levels of L_{Aeq} at each 15-min interval over the daytime (9-17) and the nighttime (17-24) in the 16 surveyed hospital lobbies.

1.3 Psychological noisiness

Yamada *et al.* (2003), performed post-occupancy evaluations of subjective responses to sound environments in hospital wards. Their analysis of a questionnaire survey showed that many inpatients pointed out that conversations and noisy medical equipment measured by L_{Aeq} at 15 min intervals were rated as unacceptable noises. To clarify the relationship between the objective measures and the subjective response to complex noise, a questionnaire survey and noise measurements were conducted in the lobbies of 16 urban hospitals in Taiwan. To measure the level of noisiness, visitors in the lobbies were asked to fill out questionnaires, since it would be difficult to evaluate such noisiness via the professional roles of the individuals working in hospitals (Ryherd, 2008; Yamada *et al.*, 2003; Tsiou *et al.*, 2008).

2. METHODOLOGY

2.1 Hospital Survey

16 urban hospitals located in various Taiwanese cities, all of which included service departments such as internal medicine, surgery, orthopedics, cardiology, etc., were selected to participate in the survey. Each of these hospitals had outpatient services, an emergency department, examination rooms, operating rooms connected to their lobbies, and wards with more than 100 beds. However, hospital regulations in Taiwan require that inpatient wards be located as far from the lobbies as possible; hence, those wards were located in different buildings to the extent possible according to the size of the overall hospital site. However, most of the hospitals sited their ward departments in the same building above the lobbies. Meanwhile, hospitals hosting medical schools were excluded from this study, because their service departments, especially their emergency departments, were sited in separate buildings. Each of the hospitals surveyed is confined to a single site; large-sized hospitals consisting of multiple buildings were not included. The main entrance of each surveyed hospital is adjacent to a main road with a width of more than 30 m, and the distance from the hospital façade to the road in each case is less than 6 m. The main entrances open into the lobby, all of which have outpatient registration and dispensary counters. Some of the hospitals surveyed have a drug or convenience store adjacent to the lobby.

2.2 Questionnaire survey of noisiness

Based on the information above, information regarding several subjective responses was requested in the survey. First, do patients or their companions located in the lobby perceive the place to be noisy? And if so, are the noise sources grouped by a factor analysis according to the hospital's routine activities? Also, is it possible for these surveyed lobby visitors to rank the perceived noisiness of one or even all of these activities? A five-point Likert scale was offered in the questionnaire to those surveyed to assess the level of noisiness (Parasuraman *et al.*, 1991). The subjects were asked to evaluate twelve audible events inside the hospital. The total number of subjects was 584. For each hospital, at least 28 people participated in the survey. The subjective responses obtained by this questionnaire survey were classified for noisiness according to definitions established by Berglund *et al.*, (1975). The arithmetic means of noisiness were calculated using the subjective responses from the subjects in each hospital's lobby and averaging the five-point scales for the 12 noise events.

Figure 2 shows the noisiness results with the standard deviation (SD, noted by an error bar). The SD values were calculated for the individual responses at each of the 16 hospital; noisiness variance differed between hospitals, even in those with an equal noisiness rating (e.g. hospital J and K). The results of analysis of variance (ANOVA) tests showed significant differences in mean noisiness between individual subjects across hospitals ($F_{1,\ 15,\ 0.05} = 3.72$, $p < 0.001$). The ANOVA results also showed significant differences between the mean noisiness of the 12 noise events across hospitals ($F_{1,\ 15,\ 0.05} = 4.85$, $p < 0.001$). The mean noisiness of the 12 noise events associate well with factor loading in the factor analysis results ((Kaiser - Meyer - Olkin (KMO) = 0.849, n = 584)). Reliability analysis (Cronbach's alpha = 0.834 in primary noise, PN; 0.746 in accidental noise, AN) were conducted to test the reliability and internal consistency of each factor. The factor loading of 12 individual audible events were construction activity (0.779, AN), children playing (0.774, AN), facility (0.769, PN), board casting (0.761, PN), medical appliances (0.740, PN), roll call (0.696, PN), traffic (0.668, AN), entrance (0.639, PN), conversation (0.572, AN), TV (0.524, AN), ambulance (0.497, PN) and footfall (0.307, AN). These results indicate that the subjective noisiness scale use in this study for the 12 noise events between 16 hospitals was statistically reliable in expressing the experienced annoyance rating.

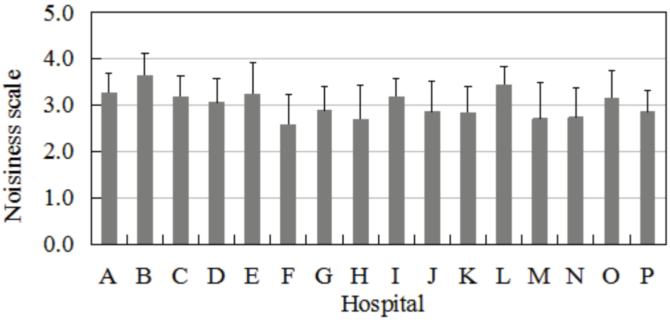

Fig. 2. The noisiness with their standard deviation of each hospital according to the questionnaire responses of patients and those accompanying them measured at that lobbies.

2.3 Noise measurements

To measure the noise levels in the hospital lobbies, A-weighted equivalent sound pressure levels ($L_{Aeq,\ T}$) using time averages at 15-min intervals were obtained over the daytime period of 9 – 17 and nighttime of 17-24. Two microphones (Brüel and Kjær, B&K type 4190) with a fast time constant (0.125 s) were used to record noises at two receiver positions. The first position was in the center of the given lobby's visitor seating area at least 1 m away from the walls and at a height of 1.2 m, with the goal of recording all the sounds that would be experienced by a visitor surrounded by the lobby's soundscape. The other microphone was located outside of the lobby's main entrance and played the role of a road-traffic noise detector. During all the measurements, the patients, staff members, and patients' companions continued with their normal activities. Data were collected with B&K PULSE system and corresponding analysis was conducted using B&K 2-CHs. CPB analyzer software.

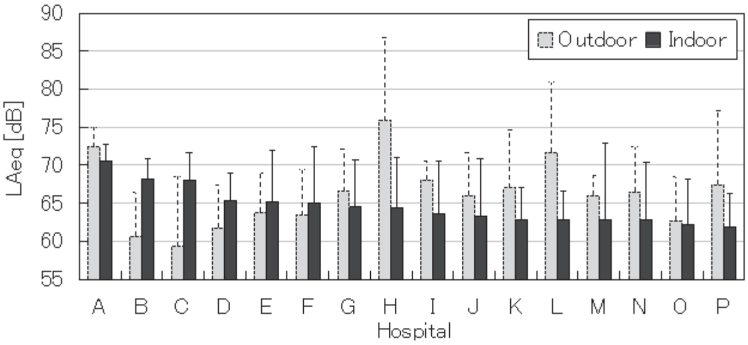

Fig. 3 Logarithmic average L_{Aeq} values for the 16 hospital lobbies (for indoor and outdoor measurements). The vertical bars indicate the respective daily ranges.

2.4 Repetitive feature of noise levels

To evaluate the disturbances caused by the various hospital noises, the normalized ACF (NACF) effective duration of noise levels ($L_{Aeq,\ 15\ m}$), denoted by τe values (*h*), was calculated to detect noise variation in this study. The autocorrelation function (ACF) is defined by

$$\Phi_p(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{+T} p'(t)\, p'(t+\tau)\, dt, \tag{1}$$

Where $p'(t) = p(t)s(t)$, in which $p(t)$ is the sound pressure and $s(t)$ is the ear sensitivity. For convenience, $s(t)$ may be chosen as the impulse response of the A-weighted network. The value τ represents the time delay (*h*), and the value of 2T is the integration interval. The normalized autocorrelation function (NACF) is expressed by

$$\varphi(\tau) = \Phi_p(\tau) / \Phi_p(0), \tag{2}$$

Where Φ(0) represents the ACF at delay time τ = 0 as the maximum Φ(τ). The τe values were defined by the ten-percentile delay (at −10 dB) obtained practically from the decay rate extrapolated in the range from 0 dB to −10 dB of the logarithmic NACF modulus (see **Appendix**). Namely, the τe values (*h*) were calculated with a sampling rate of 0.25 hours against alpha rhythm of the brainwave signals, 0.01 s.

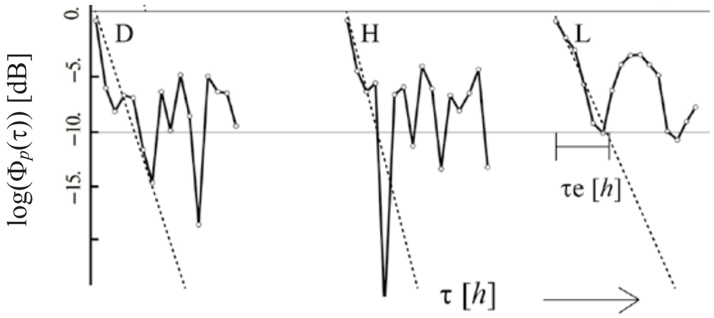

Fig. 4. The noise levels of $L_{Aeq,15m}$ in the hospital lobby (samples in D, H, L) shows an initial decline in the envelope of the normalized autocorrelation function (NACF), and this decline can be fit to a straight line regression in a range of 0 to -10 dB of the power of the NACF. The effective duration of NACF of noise levels (τe, *h*) is defined as it crosses to -10 dB at that of delay.

Calculating τe, NACF of all $L_{Aeq,\ 15\ m}$ over 9 – 17 in this study, only initial part of normalized ACF (approximately 0 to -10dB) showed the clearly decay for all data. As indicated in Figure 4, the value of τe defined at the ten-percentile delay (-10 dB) is obtained by fitting the straight-line regression for ($\log(\Phi_p(\tau))$ > - 10dB) of the ACF envelope for all. This procedure is similar to the manner of measuring the initial reverberation time in room acoustics.

3. RESULTS

3.1 Equivalent sound pressure levels

The insulation loss (IL) value for each building in which the 16 hospital lobbies were located was obtained based on the indoor position and outdoor position measurements of $L_{Aeq,\ 15m}$ for each hospital lobby, which are illustrated in Figure 3. The correlation coefficient between the IL value and the level of psychological irritation was only -0.37, and the mean values of the indoor and outdoor test points were still only 0.43. As indicated in Table 1, $L_{Aeq,\ 15m}$ was correlated with noisiness, but other measures were more closely linked to noisiness, as explained by the correlation coefficient (r) and the statistical reliability between the noisiness scale and the average $L_{Aeq,\ 15m}$ values measured inside of lobbies, which was 0.46 ($p = 0.07$).

On the other hand, no other factor correlated to psychological noisiness could be detected from Table 1. For example, the highest averaged noise levels were measured at hospital A, but the lobby in that hospital has fewer connections with other functional spaces besides outpatient departments. However, the architecture conditions of the hospital lobbies show that multiplications of each lobby's area, ceiling height, number of entrances and number of inpatient beds correlated roughly with the psychological noisiness ($r = 0.64$, $p < 0.01$). We supposed, then, that the architecture conditions of the hospital lobbies would serve as a potential index of psychological noisiness with regard to sound intelligibility. As sound intelligibility was assumed to most affect noisiness, and intelligibility is in turn influenced by T30, the T30 values for each lobby were thus measured according to WHO guideline (Berglund et al., 1999, page 56).

3.2 Statistical levels

It is necessary to move onto measures which relate to the variation of the sound pressure levels. The trend of the correlation coefficients in Table 1 obviously increases as the N% values of the L_N levels rise. The variation of $L_{Aeq,\ 15m}$ for all the measures throughout the daytime period (9 – 17) was found to be more important than the averaged $L_{Aeq,\ 15m}$ in the case of time-varying complicated noise environments. As shown in Table 1, $L_{min} – L_{max}$, $L_{95} – L_5$, $L_{90} – L_{10}$, and the effective duration of the normalized autocorrelation function (τe, NACF) of all the measurements made at 15-min intervals were calculated and used as indices expressing the variation of the noise levels. The correlation coefficients (r) between the noisiness scale and the $L_{min} – L_{max}$, $L_{95} – L_5$, $L_{90} – L_{10}$, and τe values were 0.79 ($p < 0.001$), 0.74 ($p < 0.01$), 0.73 ($p < 0.01$) and 0.76 ($p < 0.01$), respectively. However, the correlation coefficients between the noisiness scale and the $L_{95} – L_5$ in the nighttime was 0.39. Even if the noise levels were not normally distributed, $L_{95} – L_5$ value can be easily conducted. It denotes that the L_N level is not statistical integrity.

The variances in these sets of noise events reflect the noise concentration trend, which is the closeness of the measured levels to the mean sound pressure levels (Figure5 (a)). Therefore, due to similar observation periods, the noise events measured at two different noise level concentration trends can reflect the noise occurring rate in a certain area. The gradient of cumulative distribution function of the daytime noise events measured in 16 hospital lobbies was close to the mean value of 1.12 dB(A)/hr. It is clarifying that a linear curve in the Figure 5 (b) was observed for the results measured in each hospital between the cumulative rate range of 0.3 to 0.7 (4.8hr). The gradient indicates the frequency of similar noise events in a certain space, or, in other words, the continuity of noise. For example, as shown in Figures 5, the difference in the mean noise levels of Hospitals A and F was only 3.25 dB. However, there was a remarkable difference in their gradient of cumulative distribution function, as the gradient of Hospital A was 1.38 times greater than that of Hospital F.

4. CONCLUSIONS

1. The noisiness ratings obtained from the questionnaire cannot be explained only by the average L_{Aeq}. As shown in Table 1, the analysis showed that the noisiness ratings were well correlated with the L_{min} and the 90 percentile L_{Aeq} values. However, if the noise levels were not normally distributed, $L_{95} – L_5$ value can be easily conducted. It denotes that the L_N level is not data statistical integrity.
2. Previous studies found that the τe of brain waves correlates well to the subjective preference of musical

sound fields (Ando, Kageyama, 1977). Similarly, in this study, τe values (*h*) calculated according to the range of noise levels indicated by $L_5 – L_{95}$ showed the highest correlation with noisiness ($r = 0.89$, $R^2 = 0.77$). This means that the initial part of autocorrelation of noise levels persistently reflects the noisiness with regard to the estimation of ACF are almost equal to the real signal.

3. The gradient of cumulative distribution function between the cumulative rate of 0.3 to 0.7 (4.8hr), was defined as the gradient of time of measurement to the distribution of noise levels, as shown in Figure 5 (b). It can serve as guidelines for future laws on the mandatory reduction of noise levels in hospitals. The noise level statistics are strongly correlated with the conditions and activities in a certain space. Therefore, the gradient of cumulative distribution function can be utilized as a condition for the establishment of retail spaces in hospitals (not applicable to admission sections and pharmacies since it is a requirement that they have to be located at the hospital lobby).

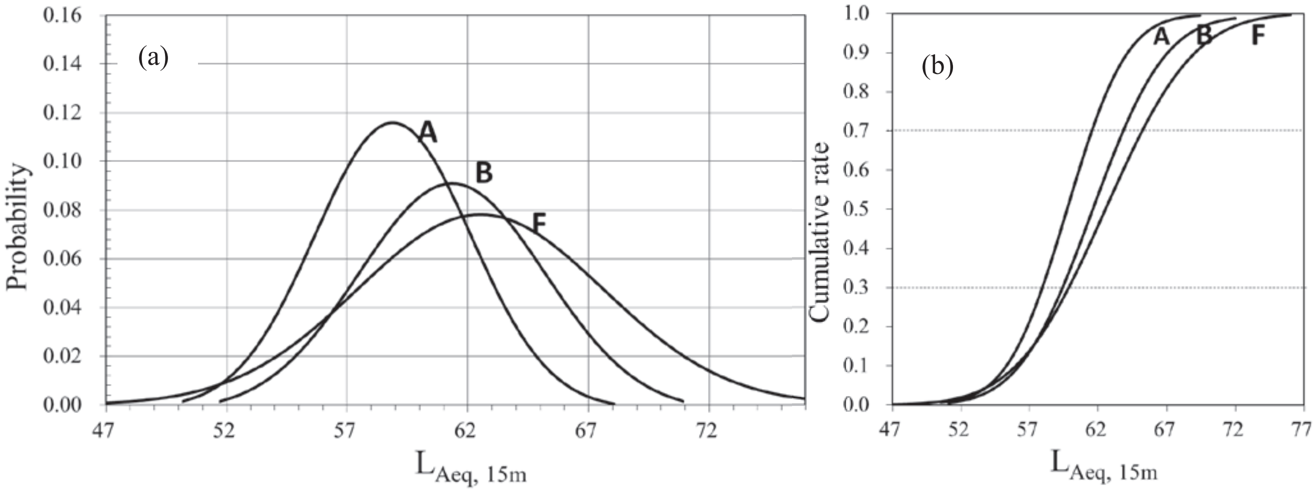

Fig.5 Probability distribution curves of daytime noise events in hospitals, measured hourly from 9 to 17 (comparison of Hospitals A, B and F).

5. APPENDIX

Statistical implication in autocorrelation function of noise levels

The effective duration of NACF of the noise levels, τe, was analyzed as a phenomenon of stationary random processing (SRP). Concerning SRP for noise signal, the estimation of finite length data (2T) for the effect of sound field must discuss a statistical error, and it has two conditions should be considered.

(1) The average values of signal P(t) are constant and independent within arbitrary time domain.

(2) The autocorrelation function (ACF) of signal is also independent in any time span, but only associates with the distance (τ) between two time position (t_1,t_2). And it equals to the expectation of time square average as a definition.

$$\Phi_p(t_1,t_2) = E(P(t_1)P(t_2)) = E(P(t)P(t-\tau)) = \Phi_p(\tau) \qquad (3)$$

Where $\Phi_p(\tau)$ equal to Equation (1)

But for a finite length data (N) will only obtain an estimation of ACF

$$\hat{\Phi}(\tau) = \frac{1}{N}\sum_{n=1}^{N} p_N(n)p(n+\tau) \qquad (4)$$

And the real length of signal for calculation are N-τ, thus

$$\hat{\Phi}(\tau) = \frac{1}{N}\sum_{n=1}^{N-\tau} p_N(n)p(n+\tau) \qquad (5)$$

The expectation of error for estimating are

$$error\left[\hat{\Phi}(\tau)\right] = E\left\{\hat{\Phi}(\tau)\right\} - \Phi(\tau) \qquad (6)$$

Where

$$error\left[\hat{\Phi}(\tau)\right] = \frac{1}{N}\sum_{n=1}^{N-|\tau|}\Phi(\tau) = \frac{N-\tau}{N}\Phi(\tau) \tag{7}$$

Therefore, the expectation of error are

$$error\left[\hat{\Phi}(\tau)\right] = -\frac{\tau}{N}\Phi(\tau) \tag{8}$$

The conclusion are,

(1) When N closes to infinity, error will decrease to 0.

(2) As τ << N, the estimation of ACF are almost equal to the real one.

Table 1. Correlation coefficient (r) with p value results between noise criteria and subjective noisiness in lobbies

Item	*Correlation* (*r*)		*Fit* (r^2)
Noise level [dBA]			
Average $L_{Aeq,\ 15m}$	0.46		0.22
$L_{Aeq,\ 15m}$ standard deviation σ_{LAeq}	**-0.76**	***	0.58
L_{max}	-0.13		0.02
L_{min}	0.69	**	0.48
Insulation of building against traffic noise	-0.37		
Autocorrelation function (ACF) [*h*]			
τ_e of NACF in $L_{Aeq,\ 15m}$	**0.76**	**	0.58
Gradient of cumulative distribution function	**0.76**	*	0.59
Percentile L_{Aeq} values (L_N) [dBA]			
L_5	0.33		0.11
L_{10}	0.56		0.31
L_{50}	0.69	*	0.48
L_{90}	0.71	**	0.51
Compounded indices			
$L_{min} - L_{max}$	0.79	***	0.62
$L_{95} - L_5$	0.74	**	0.55
$\tau_e / (L_5 - L_{95})$	**0.89**	***	0.77
$L_{90} - L_{10}$	0.73	**	0.53
Noise criteria			
NC (Noise criterion) (ANSI, 2008)	0.41		0.17
RC (room criteria)	0.45		0.20
Average loudness, N [sone] (ISO532, 1975)	0.64	**	0.41
Percentile loudness, N_5 [sone]	**0.73**	**	0.53
N_{10} [sone]	0.72	**	0.52
Sharpness (Aure)$_{30s}$	0.45		0.20
Unbiased annoyance (UBA)$_{30s}$ (Zwicker, Fastl, 1999)	0.71	**	0.51
T30 (500Hz) [s]	0.56	*	0.30
Multiplication (architecture conditions)	0.64	**	0.41

Notes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

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