Soundscape elaboration from anthrophonic adaptation of community noise

FX Teddy Badai Samodra
Department of Architecture, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

E-mail: fxteddybs@arch.its.ac.id

Abstract. Under the situation of an urban environment, noise has been a critical issue in affecting the indoor environment. A reliable approach is required for evaluation of the community noise as one factor of anthrophonic in the urban environment. This research investigates the level of noise exposure from different community noise sources and elaborates the advantage of the noise disadvantages for soundscape innovation. Integrated building element design as a protector for noise control and speech intelligibility compliance using field experiment and MATLAB programming and modeling are also carried out. Meanwhile, for simulation analysis and building acoustic optimization, Sound Reduction-Speech Intelligibility and Reverberation Time are the main parameters for identifying tropical building model as case study object. The results show that the noise control should consider its integration with the other critical issue, thermal control, in an urban environment. The 1.1 second of reverberation time for speech activities and noise reduction more than 28.66 dBA for critical frequency (20 Hz), the speech intelligibility index could be reached more than fair assessment, 0.45. Furthermore, the environmental psychology adaptation result "Close The Opening" as the best method in high noise condition and personal adjustment as the easiest and the most adaptable way.

1. Introduction
Global warming has affected in an urban environment where noise would be one of a critical issue in affecting the indoor environment. Therefore, a reliable approach is required for evaluation of the community noise as one factor of anthrophonic in an urban acoustic environment. The noise source from traffic area has a greater contribution to the global acoustic energy rather than any other sources [1]. However, the community noise could be generated from various source and induced noise by human activities classified as anthrophonic and it results in a high contribution to the room acoustics. Moreover, community noise is managed as a waste and focus is on sounds of discomfort and its background noise would be potentially generated as a soundscape, a preference perceived sound [2,3].

Atmospheric absorption, diffraction and ground effect are various attenuation factors that an effect on noise propagation [4]. Those factors have importance aside from the sound pressure level of the noise source and distance from the receiver which is still the main factors. Moreover, that beside receiver position, the setting such as urban, suburban, rural and the available space for site barrier are also considered as important factors [5].

The noise environment of traditional houses as representative of the tropical architecture in the present time is affected by the growth of occupant population. In this situation, the higher building and
transportation densities contribute to large risk to annoyance [6]. Moreover, non-acoustical factors have an important role in the prediction of noise annoyance as reaction indicator [7].

Indonesia is located in the tropical climate which is represented by geographical altitude; lowland and highland (Figure 1.). In fact, it does not affect the noise propagation directly, but by the difference in air movement, while the site or building design for wind acceleration may affect the noise control. The noise condition is also indicated by the thermal contour because transportation and human movement comprise the largest component of the heat source.

![Figure 1. Research location of noise assessment study](image)

2. Method
Investigation on the level of noise exposure from different community noise sources and elaborates the advantage of the noise disadvantages for soundscape innovation are conducted in this research. A similar method with Oh [8], the aim of this study was to evaluate the occupant's perception and adaptation in the present time noise condition. Integrated building element design as the protector for
noise control and speech intelligibility compliance using field experiment and MATLAB programming and modeling are also carried out. Meanwhile, for simulation analysis and building acoustic optimization, Sound Reduction-Speech Intelligibility and Reverberation Time are the main parameters for identifying tropical building model as case study object.

In general, this study consists of 4 steps as follows: (1). Analysis of noise source: to observe the character of the amplitude and signal, (2). The noise of adaptation method: to analyze the adaptation of user or community in the urban environment related to the source, (3). Analysis for noise criteria and optimization of noise control, and (4). Soundscape elaboration: Speech intelligibility from consideration of reverberation time and background noise.

In most Javanese houses as traditional building, this study observes the building model (see also Figure 1.). The building material and orientation have had many variations, but the study uses the most commonly used or found at present time. The traditional Javanese houses have many variations of acoustical properties of a material, depending on the location and time factor. Recently, wood, the Transmission Loss in average: \( TL_{wood} = 18 \text{ dB} \), has been used for walls.

The study conducts traditional building outdoor (noise source) and indoor (occupant receiver noise) locations of measurements. The sound level meter with real time analyzer was set in human reference height in order to check the effect of frequency bands (Table 1.). The sample of LAeq,1h was also taken at the peak of the transportation density in daytime and conducted to evaluate the noise assessment of occupants. The sound level meter was also used for road and indoor at the same time in order to analyze the direct effect of noise from source to the receiver. The interview was performed in critical (daytime noise) and additional measurement at night-time condition without interfering the routine activities. General time is the condition that is felt by the occupant at all time of throughout the year. In current or survey time condition, the tool of measurement was used simultaneously with the occupant interview in order to cross check with the real or measured condition (Table 2.). In the urban environment, as explained in the previous section, the limited number of remaining traditional buildings, 19 buildings, was appointed as representation number both in lowland and highland with 71 occupants for the noise environment survey.

| Tools                | Function                          | Range                          | Measurement Location                  | Measurement Time                  |
|----------------------|-----------------------------------|--------------------------------|--------------------------------------|-----------------------------------|
| Sound Level Meter    | To Measure Sound Pressure Level    | - Weighting: A                 | Road or Noise Source and Indoor:     | 24 hours (1 day in Weekday and     |
|                      | (with Frequency Extraction/Real    | - Single dynamic range: 30-137 | - 0.6 m to 1.5 m of height            | Weekend), and sample for LAeq,1h   |
|                      | Time Analysis)                    | dB(A) in class 1 and class 2   | (occupant sitting/standing).         | at peak time (14:00)              |
|                      |                                   | - Real-time frequency analysis:|                                      |                                   |
|                      |                                   | 1s average 1/1 or 1/3 octave   |                                      |                                   |
|                      |                                   | (from 12.5 Hz to 20 kHz)        |                                      |                                   |

| Table 2. Vote setting of noise assessment |
|-------------------------------------------|
| General Condition                         |
| Very Quiet (-3)                           |
| Quiet (-2)                                |
| Slightly Quiet (-1)                       |
| Neutral (0)                               |
| Slightly Noisy (1)                        |
| Noisy (2)                                 |
| Very Noisy (3)                            |
| Current (Survey Time) Condition           |
| Indoor Sound Pressure Level: ......dBA    |
| Very Quiet (-3)                           |
| Quiet (-2)                                |
| Slightly Quiet (-1)                       |
| Neutral (0)                               |
| Slightly Noisy (1)                        |
| Noisy (2)                                 |
| Very Noisy (3)                            |
3. Results and Discussions

3.1. Noise Source

In this section, the analysis for noise source is calculated using MATLAB Programming. As results of field study, its sources consist of outdoor (traffic/road noise) and indoor (talking people and electric appliances). Basically, indoor noise source, due to the shorter distance, the magnitude of sound pressure level could be higher than the outdoor. However, if the noise is mainly about volume control, then the outdoor noise is often felt as unpredictable and annoyance noise. Furthermore, by recording the *.wav audio file captured from field study and compared with digital references, the calculation of MATLAB code expected can explain the phenomena of noise by the source.

Given its predictable magnitude and frequency, the traffic noise is determined as the most critical source. Traffic noise results continuing effect on the of sound pressure level. As shown in Figure 2, at the high frequency, the traffic noise propagates high magnitude of sound pressure level. At the most sensitive frequency for human, 1000 Hz, the noise is calculated in about 70-75 dBA. As recorded in 15 s, the Figure 3, shows the traffic noise is fluctuating in every 2 s even low amplitude, not more than 0.8 (Figure 4). It indicates that the traffic noise is continued noise. However, the unpredictable and shocking effect still occurred and caused more annoying noise. Traffic noise in the study is dominated by light vehicle (motorcycle). Its noise is jerking, makes the shocking effect as indicated by high spectrogram of the signal and its amplitude for short time. However, the distance of the source by traffic has advantage contribution in reducing airborne transfer. Therefore, it should pay attention to the closer distance as indoor noise source as background noise also resulted by user activities (taking people and electronic or electric appliances).

![Amplitude spectrum of signal of traffic noise](image1)

**Figure 2.** Amplitude spectrum of signal of traffic noise

![Spectrogram of the signal of traffic noise](image2)

**Figure 3.** Spectrogram of the signal of traffic noise
Figure 4. Signal in the time domain of traffic noise

Different from the outdoor source, as predicted before, talking people noise affects directly to the high of noise magnitude (Figure 5.). In 1000 Hz as the example (Figure 6.), the sound pressure level could be more than 80 dBA. As consequence, as shown in Figure 7., the 60 s of the sample shows the high of a stable value of noise magnitude in all frequency. Nevertheless, this source could be controlled by user and effects better on background noise both physically and psychologically.

Figure 5. Amplitude spectrum of signal of talking people

Figure 6. Spectrogram of the signal of talking people
In the case of electric appliances, like searching TV signal, the captured sound shows very un-
continued sound (very fluctuating). In lower magnitude in all frequencies (Figure 8. and Figure 9.), the
noise has dropped amplitude in every 1 s from 35 s of the sample (Figure 10.). Both occupancy
activities and electronic appliances noise have the higher result but predictable. As shown in the field
study, the vehicle, element of traffic noise is the most significant factor that affects occupant's noise
annoyance.

Figure 7. Signal in the time domain of talking people

Figure 8. Amplitude spectrum of signal of electric appliances

Figure 9. Spectrogram of the signal of electric appliances
The higher frequencies (>1 kHz) of the road gave the significant effect on the noise propagation that was received by the room (Figure 11.). The lowest frequency (125 Hz) has the highest effect on the sound transmission in the road, but less to the room. The room receives fewer fluctuations than source or outdoor after being reduced by distance and wall. Because of shorter expanse than lowland, the direct effect of instability and minimum reduction is occurring. However, about 25% of highland conditions are in comfort. The higher frequencies (>1 kHz) of the road or noise source have a little effect on the noise spread received by the room. The highest frequency (4 kHz) has least effect on the street and room. The room receives fewer fluctuations than source/outdoor after being reduced by the distance and the wall.

In the peak density of transportation at daytime, the field observation conducted the sample of an hour measurement (L.Aeq,1h) of lowland and highland road noise is. Although the highland
environment has a lower sound pressure level, the fluctuating value in various frequency bands affects the noise annoyance, and there is shocked noise magnitude. Both of 2 locations have indoor noise that was directly caused by outdoor (road noise) indicated by the same pattern of the propagation. In the most sensitive frequency for human, 1000 Hz, the lowland building has around 10 dBA of noise reduction when the highland has around 14 dBA at the same distance. It was caused by the door opening schedule of the lowland, which is more often than highland because of occupants' requirement for ventilation.

3.2. Adaptation Method

In the lowland, the respondents vote ascended trend (Figure 12.). On the other hand, in highland, the distributed votes were found. The highest vote (3=very noisy) is the dominant option for lowland. Psychologically, higher sound pressure level triggers occupants to vote higher index and average vote for lower ones. The "very noisy" as the dominant vote is affected by denser environment and more crowded transportation movement. Lowland has closer index-percentage relationships than highland. Sound Pressure Level, SPL, in lowland has more constant and monotone grades in all time and the average both lowland and highland approaches to a neutral vote. In any condition of noise (high or low), generally, the occupants feel the tolerable noise. The results indicate not more than 50% of vote percentage. Scattered results occur because of the fluctuating condition of the source, various objects or building location, and occupants adaptability. A small number of lower part of votes (quiet group, vote -3 to 0) appears to be because of the long distance from the source to the receiver for several buildings. Moreover, the density of several buildings gives an environmental noise barrier.

![Figure 12. Noise perception in general condition](image)

The character of critical condition, daytime, is indicated by none votes for lower part (-3 to 0), which is different from the general condition (Figure 13.). The higher noise source does not always result in upper noisy sensation and vice versa. Some occupants vote to neutral noise index. Besides lower SPL of the source, the distance from the road as the foremost source is the most cause. It is more than WHO Standard (will be discussed in next section). They have sufficient capability in noise adaptation as Indonesian Standard of the noise level. Base on trend line linear equations: For lowland, if x=0, y=49.9 dBA, and highland, if x=0, y=47.8 dBA, and those values can be determined as daytime noise limits. Different altitude with different urban growth (results different terrain roughness or building density) has the different preference. Furthermore, higher SPL results in advanced adaptation and noise limit. In the most critical condition (very noisy vote=vote 3): For Lowland, if x=3, y=62.5 dBA, and Highland, if x=3, y=63.4 dBA. In lowland, the occupants are more sensitive than in highland. Although they have higher noise limit, they vote lower when it is in very noisy condition. It
may be caused by the noise accumulation, worse adaptation, and expectation.

Noise perception by occupants in nighttime shows that both in the lowland and in highland, the vote is lower than daytime (Figure 14.). The noise limits (vote = 0) are 45.9 dBA and 40.0 dBA for lowland and highland, respectively. It indicates that highland environment has a high amplitude, with fluctuation between daytime and nighttime of road noise movement as the key indicator. With a little difference of daytime and nighttime, 5 dBA, lowland noise indicates the constant noise exposure; it results in high risk of health or adaptation to the non-shocking noise source.

Figure 13. Noise perception and measurement check in critical condition (daytime)

Figure 14. Noise perception and measurement check in night-time

The acceptable noise is not preferred, but several methods of adapted occupants could adjust in various condition. If slightly noise is assumed as a tolerable vote (+1), the noise limits move to 54.1
dBA and 53 dBA for lowland and highland daytime, respectively. Meanwhile, in the night-time, it changes to 50.5 dBA for lowland and 44.9 dBA for highland.

A sound could be categorized the ambient sounds as traditional, traffic noise, regional vitality sound, nature sound, construction work sound, rural environment sound, and train or mechanical sound [9]. By similar noise source of a sound, this study offered noise adaptation analysis. Normally, a vehicle is the leading source for noise. However, for lower noise source in highland, the percentages are distributed more evenly. The noise from slow or static movement of the vehicle is perceived as a similar problem with another source. When lowland has less various sources (noise factors), the highland has more complex ones. The lowland has a critical condition on volume effect, whereas the highland on frequency effect.

The capability in noise prediction as the way of environmental psychology adaptation results "Close The Opening" is the best way for higher noise (lowland) and self-control for highland (Figure 15.). Source control in zero vote means that the occupants have an inability for source interruption. "Close The Opening" is the simplest way when self-control is the easiest and adapted capability. An inability interruption means that vehicle as the core of unexpected noise source. In relationships with noise factor, the internal electric appliance is also one of the noise factors. However, the occupants can control it anytime they want to. Including regular noise source, vehicle, results in higher adaptation capability. In lowland, when the adjustable method is dominated by "Close The Opening", the highland it has more various ways as consequences of several noise factors.

![Figure 15. Noise adaptation method](image)

Although the occupant votes closing door ("Close The Opening") as the method for adaptation, the higher source noise do not always result in closing the door response (Table 3.). It may be affected by the combined response to the heat control (ventilation needs) and circulation time. In line with Samodra, Samodra and Yoon [10,11], the total opened door (100%) by the occupant in the morning–afternoon occurs when the road SPL is at the peak. The requirement of heat control with ventilation is considered more important than noise control. Total response to close the door (100%) in the night-time happens when the SPL is lower in the lowland. More than noise control, security is the main reason of lowland in a larger area of the city than highland.
### Table 3. Outdoor SPL and opening schedule relationships

| Time     | Lowland | Highland |
|----------|---------|----------|
|          | Average Road SPL (dBA) | Response | Average Road SPL (dBA) | Response |
|          | Open The Door (%) | Close The Door (%) | Open The Door (%) | Close The Door (%) |
| Weekday  | Night: 67.5 | 0.0 | 100.0 | 46.9 | 33.3 | 66.7 |
|          | Morning: 73.7 | 33.3 | 66.7 | 60.1 | 66.7 | 33.3 |
|          | Afternoon: 71.7 | 33.3 | 66.7 | 62.8 | 66.7 | 33.3 |
|          | Evening: 73.4 | 0.0 | 100.0 | 62.1 | 33.3 | 66.7 |
| Weekend  | Night: 66.5 | 0.0 | 100.0 | 54.2 | 33.3 | 66.7 |
|          | Morning: 74.3 | 100.0 | 0.0 | 63.9 | 100.0 | 0.0 |
|          | Afternoon: 72.5 | 100.0 | 0.0 | 63.4 | 100.0 | 0.0 |
|          | Evening: 70.3 | 0.0 | 100.0 | 62.7 | 33.3 | 66.7 |

### 3.3. Noise Criteria and Noise Control

WHO standard in Berglund et al [12] has the lowest noise limits because WHO considered the health risk than just acoustical comfort from noise annoyance as almost all countries guideline or regulation adopted (Figure 16.). Actually, occupants of the tropical building have sufficient capability in noise adaptation as the Indonesian Standard on Noise Level. Base on trend line linear equations, the lowland has limits of noise in 49.9 dBA where in highland is 47.8 dBA for daytime and for night-time, 45.9 dBA for lowland and 40 dBA for highland. Both of them are lower than 55 dBA of Indonesian Standard [13].

![Figure 16. Comparison of field study noise limits to existing standard](image)

The characteristic of the tropical environment is that the occupants have no consideration of daytime or night-time acoustical comfort. Thus, as Indonesian standard, both daytime and night-time have the same value of noise limits in existing. One of the reason is, traditionally, the tropical people occupy a house at the shorter time, and they have more outdoor activities than indoor. Most the cities of Indonesia have lower traffic densities as developing country compared to the developed one.
Nevertheless, this study adopts WHO consideration for proposing the better future noise control, integrated with the thermal problem.

Based on Equation 1. taken from De Salis et al [14], noise simulation by Sound Reduction Index (SRI) or Transmission loss of wall material as the base of integration on improvement shows that by existing material (wood, 24.8 kg/m$^2$, thickness 30 mm), all frequency condition (20 Hz - 20 kHz), location and time meet the Indonesia Standard and field study noise limits (Figure 17. and Figure 18.). However, in lowland night-time, the lowest frequency (20 Hz) does not comply the WHO Standard (>30 dBA). Therefore, the modification of material by adding the existing material thickness (44.2 mm) as the easiest way is conducted. Modifying by adding the thickness of wood results that by its mass at minimum 36.5 kg/m$^2$, the lowland building (especially for night-time) meets with the standard of WHO noise limits. In line with Janusevicius et al [15], changing the material method by full modification of wood to a brick wall as popular material in Indonesia, the 20 Hz gets 28.66 dBA (meets the WHO Standard).

![Figure 17. Lowland noise simulation by Sound Reduction Index (SRI) or Transmission loss (TL) of existing material (wood) and brick walls](image-url)
Figure 18. Highland noise simulation by Sound Reduction Index (SRI) or Transmission loss (TL) of existing material (wood) and brick walls

\[
SRI_{W+A}(dB) = -10 \log \left[ \frac{A_W 10^{(-SRI_W/10)} + A_A 10^{(-SRI_A/10)}}{A_W + A_A} \right]
\]

\[\text{(1.)}\]

Sound reduction index (SRI) of a composite panel consisting of an aperture area, \(A_A\) and sound reduction index \(SRI_A\) in a wall area, \(A_W\) and sound reduction index \(SRI_W\) (for opened condition, \(SRI_W = 0\)).

For integrated design, the improvement for noise control should integrate with thermal control. Thermal environment adopts the SRI of acoustical improvement using conduction heat flow analysis. Thermal simulation conducts the calculation of Conduction Heat Flow Rate (Equation 2.), where \(A\) is Area, Thermal Transmittance is \(U\), and the Temperature difference is \(\Delta T\), between the indoor and outdoor effect on simulation. Temperature difference implements the upper and lower limits of field...
study temperature of comfort (28.60-30.00°C for lowland and 28.55-30.05°C for highland) compared to the maximum and minimum outdoor temperature.

By modifying material as proposed by noise simulation, Simulation 1 (wood Wall with 36.5 kg/m², thickness 44.2 mm) has better performance than both existing and brick wall (Figure 19.). Higher and thicker material, brick wall (220 kg/m², 110 mm) has a little worse than modified wood wall. It has higher \( \lambda \), a Conductivity (W/mK) than wood (0.711 compared to 0.209 W/m K).

\[
Qc = A \cdot U \cdot \Delta T \tag{2}
\]

Simulation 1: Modified Wood Mass by Changing wall thickness from 30 mm in existing into 44.2 mm (36.5 kg/m²) as the minimum requirement for noise control.

Simulation 2: Material Change by Brick Wall (110 mm, 220 kg/m²)

Figure 19. Thermal simulation by Conduction Heat Flow (Qc) of existing material (wood), mass material modification of wood, and brick

Living in an urban environment, the best way to reach noise criteria is to fill complement building material for noise and heat control simultaneously and to optimize the integration. As shown in Figure 20. and Figure 21., in the optimization of integrated analysis by conduction heat flow and noise control for different material, in addition to \( t \) (thickness), conductivity effects on the thermal transmittance of material (\( U \)-value material = \( \lambda / t \), W/m²K). However, for the same material, a thickness that effects on material mass is important for both thermal and noise control, the higher thickness has higher SRI and lower Qc.

Based on the noise control strategy above, it could be defined that traditional potency, material role, has developed for elaborating the translation from noise to soundscape. The method is how to produce speech clarity for community among background noise and think that noise as part of their life. This would be new mindset forming for urban people or urban design paradigm that is potentially conducted for supporting and creating a friendly city. Therefore, in the following section, reverberation time and speech intelligibility are analyzed as part of room acoustics to accommodate the sustainability for an urban environment.
Figure 20. Optimization of material mass for controlling noise propagation

Figure 21. Integrating of conduction heat flow with noise control
3.4. Soundscape Elaboration: Reverberation time and speech intelligibility

In line with Kang et al [2], environmental noise management focuses on sound as a waste, and on reducing the extent and intensity of its adverse effects on people [16]. Meanwhile, soundscape design, planning, and management are a useful augmentation to environmental noise management approaches, potentially expanding the scope of application of the tools of room acoustic. The two fields require quite different approaches to acoustic measurement.

Based on the standard, the Reverberation time (RT) is 0.8-1.2s for intimate speech [17]. For the object of study, the building reaches 1.1 s as the base of determining Speech Transmission Index (STI) for a fair requirement and it should be more than 0.45 [18]. As shown in Figure 22., SI (Speech Intelligibility) is targeted 50% as a minimum, the building could meet by 83 through RT path. Another way, comparing to background noise between the signal of speech activity compared to the electrical appliances or traffic noise, it results in Signal (S), 0.3 and Noise (N), 0.5, based on the field sound recording (see Figure 2 to 10.). It means that STI results at 0.5 or 73% of SI. All indicate that noise control as background noise does not affect significantly to the soundscape and requirement for Reverberation Time.

![Figure 22. Analysis of RT and SI](image)

4. Conclusions

Modifying material by adding the thickness of wood results mass minimum at 36.5 kg/m² (thickness = 44.2 mm), the lowland buildings as the critical buildings meet the strict standard of WHO. In addition to Huang et al and Schnell et al [19,20], the noise control should consider its integration with the other urban critical issue, thermal environment control. With reverberation time, 1.1 seconds, for speech activities and noise reduction more than 28.66 dBA for critical frequency (20 Hz), the speech intelligibility index could be reached more than fair assessment, 0.45. Therefore, background noise does not affect significantly to the soundscape and requirement for Reverberation Time. Meanwhile, the capability in noise prediction as an environmental experience of soundscape and the environmental
psychology adaptation result "Close The Opening" as the best method in high noise condition and personal adjustment as the easiest and the most adaptable way.

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