

BARRIER DESIGN STRATEGIES TO CONTROL NOISE INGRESS INTO DOMESTIC BUILDINGS

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ABSTRACT

Noise source for buildings adjacent to streets is traffic-generated predominantly. Where people are mostly spend their time indoors, it is important for buildings to have screening or blocking to control noise intrusion into living spaces. But this blocking should also permit airflow. This is important for middle to low-cost domestic buildings, which do not employ conditioned ventilation. A common feature of Indonesian buildings, fence, is studied to perform noise barrier. The fence -a barrier to be- should obey three factors: position, dimension, and material. All these three factors were studied to seek compromised design for acoustic performance and natural ventilation purpose. Domestic building situated in the urban area of Yogyakarta was studying to see the most possible design of the barrier to be. There are two calculation methods employed to investigate the proposed design. The study shows that it is possible to gain minimum of 10 dB noise reduction by placing windows within the shadow effect of approximately 1.5 height fence-barrier.

Keywords: traffic-generated noise, fence, barrier, noise reduction, natural ventilation.

INTRODUCTION

One of the most complicated problems experienced by developing countries is urban housing. This integrates to environmental issues such as the increase of air and sound pollution. Closing or minimising number of openings, which might reduce pollution intrusion, is not a practical solution for buildings employing natural ventilation.

Indonesian families have not yet addressed any formal complaints in regard to sound pollution. However, this does not indicate that there are no problems. It may be that they -who spend most of their time indoors- are not aware the risks and even if they do, they cannot afford and are not familiar with the solutions. Indonesians very rarely consider designing and building houses in advance to eliminate sound pollution. It is commonly believed that advance design in acoustic is not important for domestic buildings. However, in the increasing use of motorised vehicles, this should not be a reference for today's housing. In a crowded urban area, building will always be close to street with all their attendant problems. Urban traffic pollution is a major concern of those who live and work in this environment. Where it seems impossible to eradicate the source of traffic-generated noise, the receiver buildings should have strategies to attenuate noise intrusion into their living spaces.

GENERAL ISSUE

Apart from environmental issues, it may be easy for high-cost buildings to close all openings and substitute the use of natural ventilation to sophisticated air conditioning system which will eliminate most outdoors noise problem. However, this is not a general and applicable solution for most domestic buildings in warm humid developing countries, especially for those living in middle to low-cost domestic buildings. Regarding this issue and the increasing level of traffic-generated noise, it is then important to seek any possible design strategies to eliminate noise ingress whilst also make natural ventilation possible.

SPECIFIC ISSUE

Residential street that accommodates public transport is the most common noise issue within residential precinct of Yogyakarta. The problem occurs when the narrow and short streets of residential area are in use for short-cut route from and to nearby public street by private vehicles and public transportation. Private vehicles, which mostly are motorcycles, contribute to the major noise source. This encompasses the use of two-stroke motorcycles that generally produce higher noise level, undisciplined drivers, and in some cases the use

of high-noise level muffler types by teenagers. All these turn the private street into noisy street, shifting down the amenity and well being of families living within the zone and local kids playing nearby are also in jeopardy. Having all these complicated noise issue, residential precinct within the urban area of Yogyakarta is selected as a case study. The study postulated that it would be of advantage for other Indonesian middle sized cities which mostly experience similar issue to adopt such findings.

FROM THEORIES INTO APPLICATION

Principles of Sound Attenuation

Sound that travels along a pathway experiences attenuation before it reaches the receivers. As sound waves spread out from a source, their amplitude decreases and the sound level drops. In a free field, the decrease of sound amplitudes are caused by distance, air absorption, temperature gradient, ground absorption, and wind effect. The first two factors usually offer the greatest attenuation. All these are categorised as sound reduction by nature, which in most cases are not significant for warm humid regions where temperature and humidity are mostly at high level. However, there is a strategy to adopt to reduce noise ingress by creating sound shadow using solid and massive obstructions or barriers. Screening the path of sound can create an 'acoustic shadow', which is mostly effective for sound at high frequency. At low frequencies, diffraction will occur at the edge of the barrier, and thus the shadow effect will be slightly blurred. If the dimension of the barrier (in a perpendicular direction to the sound path) is less than the wavelength of the sound, the shadow effect disappears. For example, at 30 Hz the wavelength is over 10 m, any barriers less than 10 m long will be ineffective for sound of such low frequency (Koenigsberger et al, 1973). The attenuation occurs because of barrier absorption as well as the effects of any reflecting or blocking objects in the path.

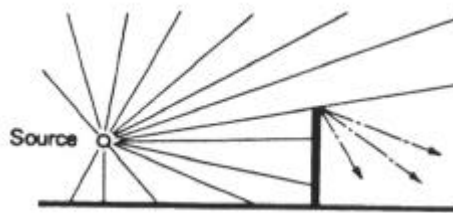


Figure 1. Sound shadow after a solid barrier (After Koenigsberger et al, 1973)

Left: sound shadow of high frequency noise, right: diffracted sound of low frequency noise

Building Improvements to Reduce Noise Intrusion

Learning from the shadow effect of a barrier, there are building vertical elements could perform as barriers, i.e. fences and walls (including windows and doors). These vertical elements receive noise more readily compared to horizontal elements. In order to perform noise blockages, these vertical elements should comply to three acoustical factors (i.e. position, dimension and material) and one non-acoustical factor: aesthetic appearance. Nevertheless, the use of these elements to block noise should be considered as a positive factor in design, equal with other factors, and not as a matter of treatment when the design is finished (Moore, 1967). In the constraint of resources, this study will only be limited to explore design strategies of a fence to perform as a barrier to block noise pathways.

Fence to Perform Noise Barrier

Because of the nature of sound, fences that perform barriers (to be written as fence-barrier at the later) should be solid and massive. These probably differ to common Indonesian fencing that mostly is constructed from steel-frame, timber-frame or brick-frame. As sound transferred even through a very tiny crack of a barrier, barrier which is constructed from solid and massive material will create appropriate sound shadows. The sound shadow will shade openings from noise intrusion through them. However, since the building employs natural ventilation for indoor comfort, dimension of the fence-barrier should not cover the entire airflow to ventilate the living spaces. In details, to create the most effective sound shadow, a fence barrier should comply with factors as follows:

• Position

To achieve effective sound attenuation, a given barrier will be most effective when it is as near to the source as possible. The second best position would be near the building, which is to be protected (Koenigsberger et al, 1973).

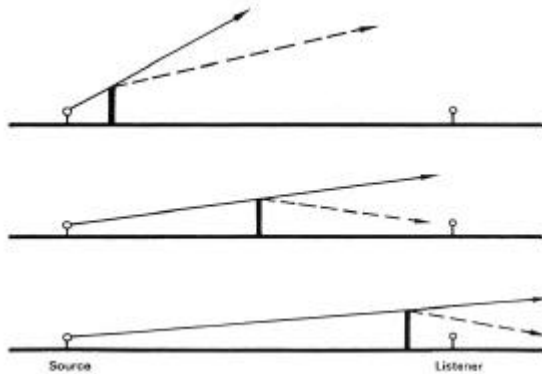


Figure 2. Pathways of noise due to different barrier positions (After Koenigsberger et al, 1973)

• Dimension

Traffic noise generated by motorised vehicles is mostly at low frequency, i.e. 100 Hz to 750 Hz (White, 1982). Refer to formula that sound velocity is a multiply of frequency and wavelength ($V = f \cdot \lambda$), within a constant velocity of a similar medium characteristic, the lower the frequency, the greater the wavelength. Travelling in the air as a medium, sound velocity is constant at 344 m/sec. This means that the low frequencies of traffic-generated noise are identical to great wavelength. Therefore, only barrier with large dimension will be effective to block the sound. The larger the dimension of fence, the greater noise reduction that will be gained. However, it is important to calculate appropriate barrier dimension for reducing noise, permitting natural ventilation and performing aesthetic façade.

• Material

To comply with the massiveness factor a given barrier should obey particular density as is suggested by Freeborn and Turner (1988/1989):

- to provide reduction of 0 to 10 dBA, the minimum density is 5 kg/m²;
- to provide reduction of 10 dBA to 15 dBA, the minimum density is 10 kg/m²;
- to provide reduction of 15 dBA to 20 dBA, the minimum density is 20 kg/m².

Table 1. Weights of some building materials. (After Elridge, 1974)

Material	kg/m ²
asbestos cement sheet 4.8 mm	8.4
lightweight aggregate concrete blocks	7-11
concrete commonly used for floor 25 mm	55-65
gypsum plaster board 9.5 mm	6.5-10
clay tile commonly used for roof	34-40
concrete tile commonly used for roof	34-45

It may not easy to justify building materials that comply with such density whilst still performing aesthetic façade. The appearance of most solid barriers massive barrier is dull and anaesthetic as can be seen in Figure 3. Materials shown on Table 1 with their specific density can be used as references. Some of these may not commonly be used for fencing. However, they may be utilised, either for core materials or for finishing purposes. The thickness of materials show on Table 1 still can be improved to provide better noise reduction. Solid and massive barriers that are aesthetically acceptable and do not detract from the appearance of the house but which can also act as barriers for noise are preferred.

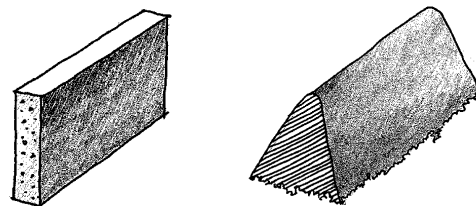


Figure 3. Ordinary physical appearance of solid and massive barriers

DESIGN PROPOSITIONS OF FENCE-BARRIER

Based on the objection of this study which is to seek a compromised design for noise reduction, possibility of air flow and aesthetic appearance if possible, the design propositions for fence to function also as barrier are as follows:

• Dimension:

The proposed fence is to be as long as the house front courtyard including gates for access. Since the receiver within single storey building is standardised at 1.0m height (Sound Control for Homes, 1993), to create the shadow effect, height of fence is proposed

at 1.1m to 1.5m or at least 0.1 m higher than the receiver is. This dimension still permits air to flow over the fence through window, which the upper frame of the window is normally 1.7m to 2.0m above the ground. Some fences could reach up to 2.0m height, however this will only applicable for two storey domestic buildings or more.

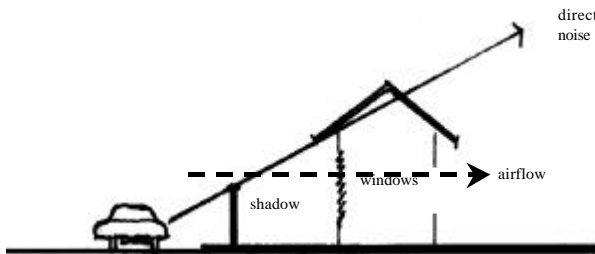


Figure 4. Window heights within the sound shadow (After Koenigsberger, et al, 1973)

- **Position:**
The fence-barrier is proposed to be at the near edge of the kerb (at the outer edge of the front courtyard). This is a common fencing position in Indonesian housing. As it is closer to the receiver (i.e. house), this position gives an opportunity to maximise its function as a noise barrier by creating an appropriate 'sound shadow'. Since buildings in the urban area are mostly built on very limited sites, front courtyard of middle to low cost domestic buildings is normally between 2m to 3m depth. In Yogyakarta, residential streets may vary from 6m to 10m width. According to White (1982) noise source is in the middle of the street. Thus, where streets are between 6 m to 10m, the source is 3m to 5m from the kerb side and is approximately 0.5 m from ground (White, 1982).
- **Materials:**
It is proposed that fence-barrier be built from solid and massive materials. This type of material will create appropriate shadow effect for noise reduction. Examples of solid and massive material commonly be used in Indonesia which comply with the standard are red brick, grey brick or prefabricated concrete.
- **Reduction Offered**
Noise reduction is only significant when the reduction can lower the noise at 10 dB to shift down the Noise Rating Zone (CIBSE Guide, 1986). Therefore, the proposed fence-barrier

is designed to at least offering noise reduction of approximately 10 dB.

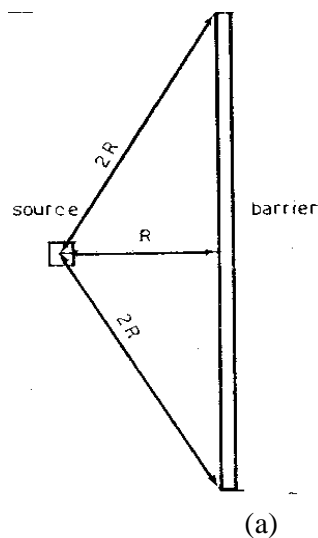
EXAMINING NOISE ATTENUATION OFFERED BY BARRIER

Noise attenuation can be achieved by using barriers. However, to achieve sufficient attenuation, a barrier needs to obey many criteria. The most significant is dimension. The critical dimensions can be found by using the appropriate formulae, chosen from a range of formulae. However, all formulae that have been developed mostly relate to noise conditions in developed countries, where the noise differs from those in developing countries. As traffic in developed countries is smooth, regular, consists of better-maintained vehicles and a limited number of motorcycles, noise levels tend to be lower.

Even though no single existing formula is available for noise measurement in developing countries, it was considered useful to choose the most suitable formulae for the proposed design to predict noise reduction that might be offered by certain barrier dimensions. Once the noise reduction offered by certain barriers is determined, the reduction values to be achieved by housing adjacent to traffic-generated noise can be predicted. The range of the formulae considered for the calculation are given below:

1. Lawrence's Formula (Lawrence, 1967)

Lawrence suggests the use of large barriers in comparison to the wavelength (λ) of the sounds. The detailed dimensions are calculated using the following formula:



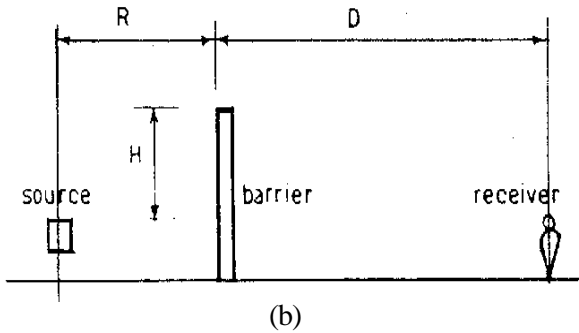


Figure 5. Lawrence's calculation for barrier dimensions (After Lawrence, 1967)

$$N = 10 \log_{10} 20X$$

Where N is the attenuation, dB re 2×10^{-5} N/m² and X is found from :

$$X = \frac{2[R(\sqrt{1+(H/R)^2}-1)+D(\sqrt{1+(H/D)^2}-1)]}{\lambda[1+(H/R)^2]}$$

(if $D \geq R \geq H$ this may be reduced to $X = H^2/\lambda R$)

2. Egan's Formula (Egan, 1976)

Egan's formula is an improvement of Lawrence's formula. This formula seems more suitable for houses with longer yards. This is obvious from the requirement that D be at least 4R. The first step in Egan's calculation is to determine the ratio of H²/R by using barrier attenuation curves, which then will show the attenuation values.

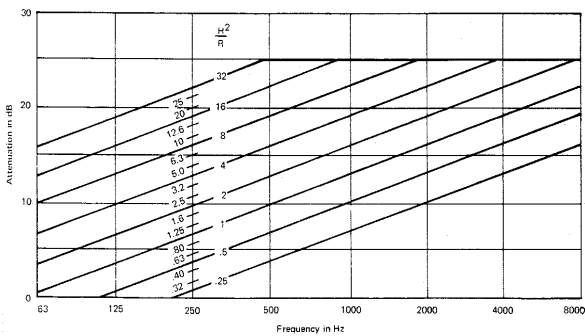


Figure 6. Charts to calculate sound attenuation given by barriers using ratio of H²/R (After Egan, 1976)

Similar attenuation values can also be found by using Egan's formula (without using the curves):

$$A = 10 \log H^2/R + 10 \log f - 17$$

Where A is the attenuation value in dB and f is frequency of the sound in Hz.

2. Barrier correction charts or the normalised charts (Welsh Office, 1975)

One method used to calculate barrier attenuation by a series of charts, is employed by The Department of the Environment (Welsh Office, UK). These charts allow the users to calculate L₁₀ and other L values on street traffic noises. In order to fully utilised this formula, users should provide data of traffic flow rates over 18 hours per day, mean traffic speeds, proportions of heavy vehicles, road gradient, distance correction, soft ground correction, angle of view corrections, reflection effect of building façade, and a scenario of barrier position and dimension (including height of noise source and height of receiver). The required data may slightly be complicated for research with constraint resources, however, within a very limited data, noise reduction offered by a series of scenario of barrier position and dimension could be calculated. The first stage of the calculation is to seek a path difference using Phytagoras method of triangles. Using the barrier correction chart, the path difference will show the reduction gained by the proposed designs. Users do not required to provide data of sound frequency and wavelength as this chart has been normalised from a series of frequencies.

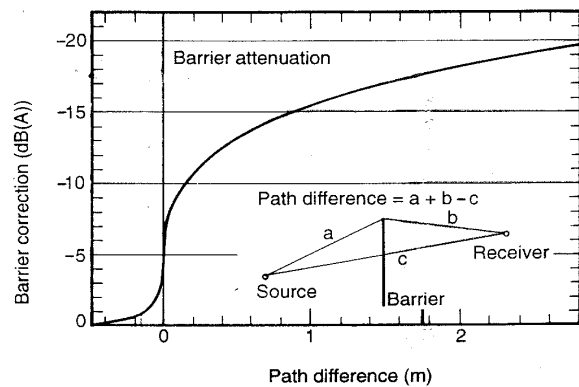


Figure 7. Barrier correction curve which has been normalised from a series of frequencies (Source BRE/CIRIA Report, 1993)

In using the curve, it is possible for users to calculate a series of proposed designs. Considering several factors of the actual conditions as it is discussed in Section 4, this study proposed a series of design to be investigated as is presented on Table 2.

Table 2. Detailed design of the proposed fence-barrier

	Fence barrier 1.1 m height (H*=0.6)	Fence barrier 1.2 m height (H=0.7)	Fence barrier 1.3 m height (H=0.8)	Fence barrier 1.4 m height (H=0.9)	Fence barrier 1.5 m height (H=1.0)
Street 6m width (R=3), distance from fence to building 2m (D=2)	Calculation No. 1	Calculation No. 2	Calculation No. 3	Calculation No. 4	Calculation No. 5
Street 8m width (R=4), distance from fence to building 2m (D=2)	Calculation No. 6	Calculation No. 7	Calculation No. 8	Calculation No. 9	Calculation No. 10
Street 10 m width (R=5), distance from fence to building 2 m (D=2)	Calculation No. 11	Calculation No. 12	Calculation No. 13	Calculation No. 14	Calculation No. 15
Street 6m width (R=3), distance from fence to building 3m (D=2)	Calculation No. 16	Calculation No. 17	Calculation No.18	Calculation No. 19	Calculation No. 20
Street 8m width (R=4), distance from fence to building 3m (D=2)	Calculation No. 21	Calculation No. 22	Calculation No. 23	Calculation No. 24	Calculation No. 25
Street 10 m width (R=5) distance from fence to building 3 m (D=2)	Calculation No. 26	Calculation No. 27	Calculation No. 28	Calculation No. 29	Calculation No. 30

*) H is the difference between barrier height and source height from ground, where source height is 0.5m

Table 2 shows that from the proposed design scenarios there are 30 calculation to be made apart from partial calculation of each determined frequency between 100 Hz to 1000 Hz, i.e. 125 Hz, 250 Hz, 500 Hz and 750 Hz. This set of frequencies is sufficient to represent series of frequencies between 100 Hz to 750 Hz (Egan, 1976).

This study employs two formulae to investigate the proposed design in order to seek the most possible design. At the first stage, Lawrence’s calculation is carried out. These then to be validate using the barrier correction chart. An example of using Lawrence’s calculation with a scenario of distance between source and barrier (R) is 3 m (for street 6m width), source at 0.5 m (White, 1982) and barrier at 1.1 m height, thus H is 0.6m, distance between barrier and receiver (D) is 2.0 m, and the incoming noise is at frequency of 125 Hz (identical to $\lambda=2.752m$), is as follows:

$$X = \frac{2[R(\sqrt{1+(H/R)^2-1})+D(\sqrt{1+(H/D)^2-1})]}{\lambda[1+(H/R)^2]}$$

$$X = \frac{2[3(\sqrt{1+(0.6/3)^2-1})+2(\sqrt{1+(0.6/2)^2-1})]}{2.752[1+(0.6/3)^2]}$$

$$X = \frac{2[0.06+0.088]}{2.752 (1.04)}$$

$$X = 0.1$$

Where $N = 10 \log_{10} 20X$

Thus $N = 10 \log_{10} 2$

$N = 3.1 \text{ dB}$

RESULT

The first calculation using Lawrence’s formula is of important to calculate noise reduction offered by barrier in regard to a series of frequencies, whilst the second calculation using barrier correction chart considered useful to validate the first calculation. Using similar calculation process as is shown in Section 6, other proposed design scenarios in regard to such frequencies are calculated. All the calculation that has been processed is shown on Table 3.

Table 3. Result of calculation using Lawrence Formula of all proposed design scenarios

Calculation Number	Reduction at frequency 125 Hz (dB)	Reduction at frequency 250 Hz (dB)	Reduction at frequency 500 Hz (dB)	Reduction at frequency 750 Hz (dB)	Mean
1 (H=0.6, R=3, D=2)	3.1	6.2	9.2	10.9	7.35
2 (H=0.7, R=3, D=2)	4.4	7.4	10.4	12.2	8.60
3 (H=0.8, R=3, D=2)	5.5	8.5	11.5	13.2	9.68
4 (H=0.9, R=3, D=2)	6.4	9.0	12.4	14.2	10.50
5 (H=1.0, R=3, D=2)	7.2	10.2	13.2	14.9	11.38
6 (H=0.6, R=4, D=2)	2.8	5.8	8.8	10.5	6.98
7 (H=0.7, R=4, D=2)	4.0	7.1	10.1	11.8	8.25
8 (H=0.8, R=4, D=2)	5.1	8.1	11.2	12.9	9.33
9 (H=0.9, R=4, D=2)	6.1	9.1	12.1	13.9	10.30
10 (H=1.0, R=4, D=2)	6.9	9.9	12.9	14.7	11.10
11 (H=0.6, R=5, D=2)	2.5	5.5	8.5	10.3	6.70
12 (H=0.7, R=5, D=2)	3.8	6.8	9.8	11.6	8.00
13 (H=0.8, R=5, D=2)	4.9	7.9	10.9	12.7	9.10
14 (H=0.9, R=5, D=2)	5.9	8.9	11.9	13.6	10.08
15 (H=1.0, R=5, D=2)	6.7	9.7	12.7	14.5	10.90
16 (H=0.6, R=3, D=3)	2.2	5.2	8.2	10.0	6.40
17 (H=0.7, R=3, D=3)	3.5	6.5	9.5	11.2	7.68
18 (H=0.8, R=3, D=3)	4.5	7.6	10.6	12.3	8.75
19 (H=0.9, R=3, D=3)	5.5	8.5	11.5	13.2	9.68
20 (H=1.0, R=3, D=3)	6.3	9.3	12.3	14.1	10.50
21 (H=0.6, R=4, D=3)	1.7	4.7	7.7	9.5	5.90
22 (H=0.7, R=4, D=3)	3.0	6.0	9.0	10.8	7.20
23 (H=0.8, R=4, D=3)	4.1	7.1	10.1	11.9	8.30
24 (H=0.9, R=4, D=3)	5.1	8.1	11.1	12.8	9.28
25 (H=1.0, R=4, D=3)	5.9	8.9	11.9	13.7	10.10
26 (H=0.6, R=5, D=3)	1.4	4.4	7.4	9.1	5.58
27 (H=0.7, R=5, D=3)	2.7	5.7	8.7	10.4	6.88
28 (H=0.8, R=5, D=3)	3.8	6.8	9.8	11.6	8.00
29 (H=0.9, R=5, D=3)	4.8	7.8	10.8	12.5	8.98
30 (H=1.0, R=5, D=3)	5.6	8.6	11.6	13.4	9.80

The second calculation using the barrier correction chart is presented on Table 4.

Table 4. Result of calculation using barrier correction chart of all proposed design scenarios compared to those calculated using Lawrence's Formula

Calculation Number	Barrier Reduction Offered (calculated using normalised chart) (dB)	Mean of Barrier Reduction Offered (calculated using Lawrence Formula) (dB)
1 (H=0.6, R=3, D=2)	7.0	7.35
2 (H=0.7, R=3, D=2)	8.5	8.60
3 (H=0.8, R=3, D=2)*	9.5	9.68
4 (H=0.9, R=3, D=2)**	10.0	10.50
5 (H=1.0, R=3, D=2)**	11.0	11.38
6 (H=0.6, R=4, D=2)	6.5	6.98
7 (H=0.7, R=4, D=2)	8.5	8.25
8 (H=0.8, R=4, D=2)*	9.0	9.33
9 (H=0.9, R=4, D=2)**	10.0	10.30
10 (H=1.0, R=4, D=2)**	10.5	11.10
11 (H=0.6, R=5, D=2)	6.5	6.70
12 (H=0.7, R=5, D=2)	7.5	8.00
13 (H=0.8, R=5, D=2)	8.0	9.10
14 (H=0.9, R=5, D=2)*	9.5	10.08
15 (H=1.0, R=5, D=2)**	10.0	10.90
16 (H=0.6, R=3, D=3)	8.0	6.40
17 (H=0.7, R=3, D=3)	8.5	7.68
18 (H=0.8, R=3, D=3)	9.5	8.75
19 (H=0.9, R=3, D=3)*	10.5	9.68
20 (H=1.0, R=3, D=3)**	11.0	10.50
21 (H=0.6, R=4, D=3)	7.0	5.90
22 (H=0.7, R=4, D=3)	8.5	7.20
23 (H=0.8, R=4, D=3)	9.0	8.30
24 (H=0.9, R=4, D=3)*	9.5	9.28
25 (H=1.0, R=4, D=3)**	10.5	10.10
26 (H=0.6, R=5, D=3)	6.5	5.58
27 (H=0.7, R=5, D=3)	8.0	6.88
28 (H=0.8, R=5, D=3)	8.5	8.00
29 (H=0.9, R=5, D=3)*	9.0	8.98
30 (H=1.0, R=5, D=3)**	10.0	9.80

*) Reduction offered nearly 10 dB

**) Reduction offered exactly at or above 10 dB

Letter in bold = the difference between two reduction offered is more than 1.0 dB

DISCUSSION

Table 4 shows both results between calculation using Lawrence's formula and the barrier correction chart. Both results report similar reduction values offered by the proposed design (i.e. most result shows differences of less than 1.0 dB which is determined as insignificant (Moore, 1966)), excluding value in bold which differences are quite significant. This is due to difficulties in determining reduction value using barrier correction chart where the path-difference scale is far too small in regard to the reduction curve. There is also part of the curve within grey area between reduction of 3 dB to 7 dB, which causing difficulties to determine the exact value. Any significant differences appeared can be excluded from discussion since the proposed design should at least offering noise reduction of approximately 10 dB. Calculation using

Lawrence's formula is more comprehensive, therefore, this become the main consideration in selecting the most effective design. As can be seen on Table 4, there are some designs that offer noise reduction nearly 10 dB. However, since 10 dB is the minimum noise reduction that should be provided by the design (CIBSE Guide, 1986), only design offering 10 dB or more will really be suggested. For housing with 2m front courtyard depth adjacent to 6m to 8m street width, the fence-barrier is suggested to be at least 1.4m height, placed just at the kerbside. Whilst, similar housing adjacent to 10m street width, the fence-barrier is suggested be at least 1.5m height. Where the front courtyard is 3m depth, housing adjacent to street of 6m to 10m width should has fence- barrier of at least 1.5m height placed just at the kerbside.

When the position and dimension of fence-barrier is determined, the next stage is to consider possibility of using solid and massive material as suggested in Section 5, without distracting the façade of the house. This never has been an easy design proposition, since there is no formula to be adopted for calculation. Moreover, in some cases, aesthetic appearance can be subjective. Thus, the author could only suggest the use of slightly unusual solid and massive material but considered aesthetic as can be seen on Figure 8.

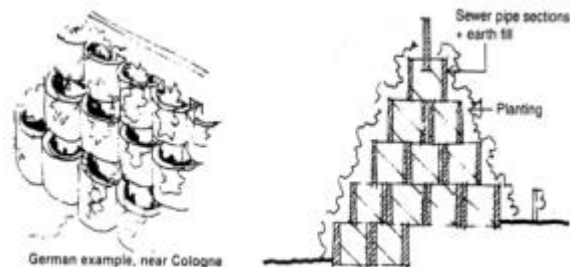


Figure 8. Examples of slightly unusual appearance of solid and massive barrier

CONCLUSION AND RECOMMENDATION

This study shows that using theoretical calculation, it is possible to use a compromised design for both reducing the ingress of traffic-generated noise but still permitting airflow for natural ventilation. The suggested design is by using fence to perform barrier that complies to standard of solid and massive material, standard of position and standard of minimum dimension. The minimum height of fence of middle to low-cost domestic buildings to perform an effective barrier is approximately 1.5 m. This design offers a quite significant traffic-generated noise reduction of 10 dB as the minimum.

This study also recommends further research to validate the finding of theoretical calculation by carrying investigation of laboratory-experimental research and or field-experimental research.

Acknowledgment

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REFERENCES

- Attenborough, Keith, *Noise Abatement*, The Open University Press, Buckinghamshire, UK, 1972, pp. 21-24.
- Baerwald, John E., *Traffic Engineering Handbook*, Third Edition, Institute of Traffic Engineers, Washington DC, 1965, pp. 142-221.
- Calculation of Road Traffic Noise*, Department of the Environment Welsh Office, Her Majesty's Stationery Office, London, 1975, pp. 2, 3, 7, 16, 19, 27, 31.
- CIBSE Guide Volume A: Design Data*, CIBSE, London, 1986, pp. A1-4, A4-6.
- Chunnif, Patrick F., *Environmental Noise Pollution*, John Wiley and Sons, New York, 1977, pp. 57-58, 66, 128-146.
- Croome, D.J., *Noise, Buildings and People*, Pergamon Press, UK, 1977, pp. 286-287, 365-369.
- Data Sistem Arus Lalu Lintas, DLLAJ*, Kodya Yogyakarta, Indonesia, 1990.
- Egan, M. David, *Concepts in Architectural Acoustic*, Prentice-Hall Inc., New-Jersey, 1976, pp. 91-93.
- Eldred, K., "Noise at the Year 2000", *Proceedings of the 5th International Congress on Noise as a Public Health Problem*, Volume 5, Swedish Council for Building Research, Stockholm, 1990, pp. 363-365.
- Eldridge, H.J., *Properties of Building Materials*, MTP Construction, Lancaster, UK, 1974, pp. 28, 36, 40, 44, 52, 58, 88, 106, 108.
- Ford, RD., *Introduction to Acoustic*, Elsevier Publishing Company Limited, England, 1970, p. 142.
- Freeborn and SW. Turner, "Environmental Noise Vibration", *Noise Control in the Built Environment*, edited by John Roberts and Diane Fairhall, Gower Technical, US, 1988/1989, pp.54, 60.
- Kinsler, Lawrence, *Fundamentals of Acoustics*, John Wiley and Sons, New York 1982, p. 279.
- Koenigsberger, O.H, et al, *Manual of Tropical Housing and Building*, Orient Longman, Bombay, India, 1973, pp. 51, 129, 190, 198.
- Lawrence, Anita, *Architectural Acoustic*, Applied Science Publishers Ltd., London 1967, pp. 62-65.
- Moore, JE., *Design for Good Acoustic*, second edition, Architectural Press, London, 1967, pp. 23, 50.
- Moore, JE., *Design for Noise Reduction*, Architectural Press, London, 1966, pp. 130-131.
- Rettinger, Michael, *Acoustic Design and Noise Control*, Volume 1 (Acoustic Design), Chemical Publishing Co., New York, 1977, p. 155-159.
- "Roadside Noise Abatement", *Road Transport Research*, OECD, 1995, pp. 37, 45, 105-123

"Sound Control for Homes", *BRE and CIRIA Report*, 1993, pp.8, 10, 30-31, 43, 96-96, 112-113

Templeton, D. and D. Saunders, *Acoustic Design*, The Architectural Press, London, 1987, p. 11, 33, 61, 64, 72, 89

Watkins, L.H., *Environmental Impact of Roads and Traffic*, Applied Science and Publishers, England, UK, 1981, pp.7, 16, 148-149, 152-153, 168-171

White, R.G. and J.G. Walker, *Noise and Vibration*, Ellis Horwood Ltd., England, 1982, pp. 389-399