A method for design of sound insulation of glazed balconies against traffic noise

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ABSTRACT

The maximum allowed values of the noise levels for outdoor residential areas issued by the government in 1992 are applied to balconies in several cities in Finland. There are no generally agreed design methods to determine whether a balcony meets these requirements. The object of this work was to develop such method. The basis lies on the use of the laboratory measurement values of airborne sound insulation of the glazing. The method also takes into account the noise field inside the balcony (sound absorption), balustrade and its slit-shaped apertures and the surface areas of these building elements. The design method was validated by comparing the calculated A-weighted sound level difference of balconies with corresponding field measurements. Measurements were done in 5 new buildings from which 10 glazed balconies were measured (2 balconies each). The average difference between measurement and design values was found to be around -5 dB, which is used as a correction term in the final design method. After the introduction of the correction term, the differences between calculated and measured single-number values were found to be 1 dB for traffic noise and 2 dB for railway or air traffic noise.

Keywords: glazed balcony, sound insulation, traffic noise
I-INCE Classification of Subjects Number(s): 51.1, 51.2, 51.4, 52.3

1. INTRODUCTION

Around 45 % of building stock in Finland consists of apartment buildings (1). There are balconies in over 60 % of the dwellings (2). New apartment buildings tend to have balconies in nearly all dwellings because they have proven to increase occupants' satisfaction, which further increases when balcony glazing is added. According to few Finnish survey studies, the most important benefit of the glazing for dwellers seems to be the protection against snow, rain and dirt. Glazing also increases the lifespan of the balcony structures. (3, 4, 5)

The maximum allowed values of the noise levels in outdoor residential areas have been issued by the government in 1992 (6). The allowed A-weighted equivalent levels are 55 dB and 45 dB (or 50 dB for old building areas) for daytime and nighttime, respectively. Several Finnish cities have started to require that these levels are met on balconies. This agrees with WHO recommendations (7). There are also indications that Finnish dwellers are annoyed by traffic noise on balconies (4), which makes the guideline justified. In Finland, the sound insulation requirement of facades is described as the A-weighted sound level difference ΔL_A between the sound incident to the façade and the acceptable sound level inside. This definition shall be used for the balcony façade as well.

In Finland, the building regulations define balconies as follows: balcony is a cold or a half-cold space; there should be a balustrade; at least 30 % of the balcony façade surface should be openable; the balcony façade should not resemble an outer wall of an apartment; balcony is not counted in the total floor area of a building. Typical Finnish balconies are shown in Figure 1. If these conditions are not met, the space is usually counted as a conservatory, which in turn is counted in the total floor area of a building. Because of the restrictions, an openable glazing seems to be the only effective way to insulate traffic noise.

To the author's knowledge, there is very little research about the sound insulation and noise levels

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of glazed balconies. Usually balcony-related acoustical research concerns the screening advantages achieved to façade sound insulation of apartments (8). This means that if there are sound insulation requirements for balconies, these requirements can only be verified through measurements and not by calculations. The aim of this study was to define a design method which can predict the A-weighted sound level difference ΔL_A of a balcony façade with sufficient accuracy. The design method was compared to field measurements performed on newly built glazed balconies.

Figure 1 – Typical Finnish balconies where the upper portion of glass is made of openable panes (glazing). The lower part is usually made of larger non-openable glass panes (balustrade).

2. MEASUREMENTS

2.1 Method

The measurements were done according to the global method in standard ISO 140-5:1998 (9) with a dodecahedron sound source. The sound levels outside were taken 2 m away from the glazing and inside the balcony. The reverberation time of the balcony was also measured. Typically one source position outside was used since balconies tend to be rather small in surface area and the sound level variation over the surface is quite small. In the cases where shadowing of a balcony corner could be important, the source position and/or number of source positions was taken accordingly. Reverberation time measurements were done with a single source position and 3 receiver positions with a total number of 6 measurements. This corresponds to the minimum requirement given in the standard.

With the measurement setup described above, sound level differences $D_{ls,2m}$ between outside and inside levels were measured from which normalized and standardized sound level differences, $D_{ls,2m,n}$ and $D_{ls,2m,nT}$ respectively, can be calculated. These two latter quantities take into account the sound field inside the balcony by the use of either sound absorption area or reverberation time. From these quantities, weighted sound level difference index values $D_{ls,2m,w}$, $D_{ls,2m,n,w}$ and $D_{ls,2m,nT,w}$ and their corresponding spectral weighted (C and C_{tr}) were calculated.

Low-frequency procedure measurements were done in four balconies according to the draft of ISO 16283-3 (10). The low-frequency procedure was, however, questioned in our study since the standards assume the receiving room as a closed space which the balcony is not. Most corners in the balcony façade have apertures due to partial sealing and structural junctions which leak sound inside. The leaking sound may dominate the local sound pressure level in the corner in a way which does not represent the sound field inside the balcony.

2.2 Measured balconies

Five newly-built buildings with 2 balconies per each were measured. All 10 balconies had a glass balustrade and a rectangle-shaped floor plan. At the time of the measurement, the balconies were empty excluding the measurement equipment and the person performing the measurements. This was considered to correspond to the worst case or room acoustics of an occupied balcony of a finished apartment building. The basic structure of balconies ON1, ON2, ON3 and ON4 was similar. Also the balconies N2 and N3 were similar. The basic dimensions of these balconies are given in table 1.

Table 1 – Balcony parameters. A half of a glazed side means a situation where one side is only partly glazed.

Balcony	Glazed sides	Length, m	Width, m	Height, m	Volume, m^3
S1	1	3.19	2.24	2.72	19.4
S2	1	4.48	2.23	2.72	27.2
ON1	1 ½	4.13	2.04	2.73	23.0
ON2	1 ½	4.13	2.04	2.74	23.0
S3	1	6.52	2.17	2.74	38.7
N1	2	6.64	2.16	2.74	39.3
ON3	1 ½	4.14	2.00	2.74	22.7
ON4	1 ½	4.14	2.01	2.74	22.8
N2	2	2.54	1.90	2.77	13.4
N3	2	2.55	1.89	2.77	13.4

2.3 Correction for façade reflection

Since we were interested in the sound incident to the façade, one should account for the façade reflection which is normally included in the measurements. Façade sound reflection has been quite widely studied (11, 12, 13, 14, 15), but the results have only confirmed that the effect on the measured sound level near the façade is complex and varies from site to site. A few examples of the effect of façade reflection has been calculated with the method shown by Hopkins and Lam (14) where only 4 specular reflections and source and façade orientations are considered. Following variables have been used in the calculation:

1. Height of the point source 1.5 m (on a stand)
2. Height of the receiver 1.5 m, 4.5 m or 7.5 m
3. Angle between source and façade middle point 45 degrees
4. Horizontal distance between the receiver and façade 2 m

The effects of façade reflection on the incident sound are shown in Figure 2 (point source on a stand). Results are shown up to 1000 Hz after which turbulence and diffraction start to affect the overall sound pressure level (14).

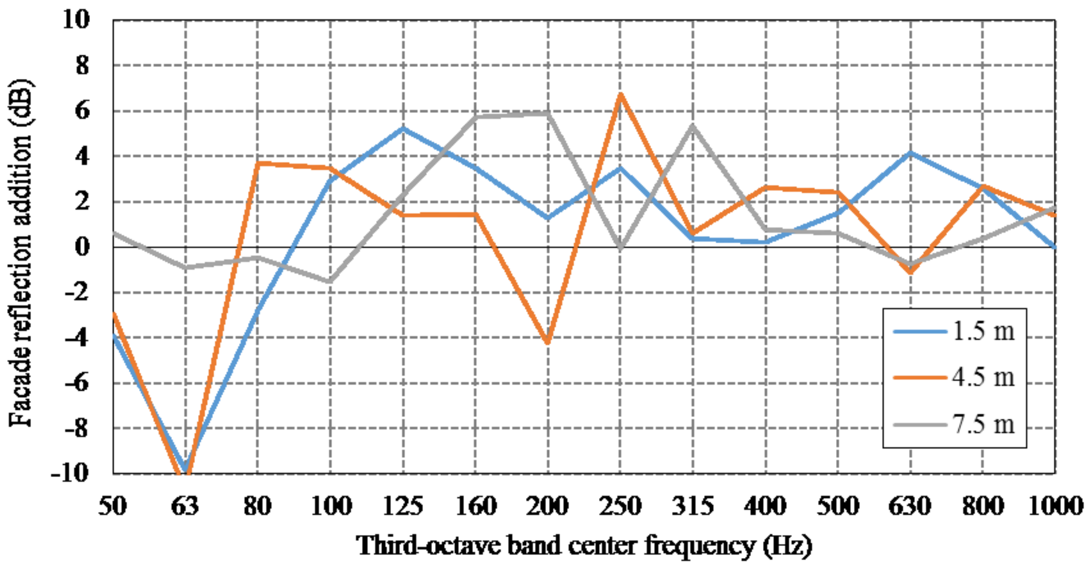
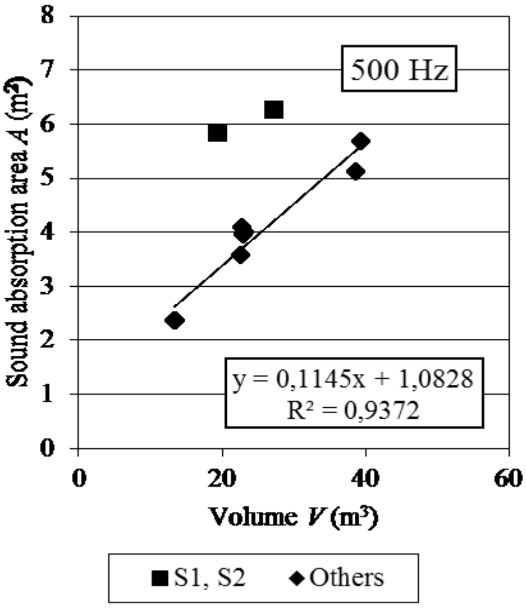


Figure 2 – The effect of façade reflection on the incident sound on different floor levels when the sound source is on a stand (source height point at 1.5 m).

Even with a quite simple evaluation it is seen that the sound pressure level is highly affected by the positioning of instruments. Even more, the height points of both source and receiver change the nature of the correction. Therefore the correction can be sensitive to individual parameters and could cause unnecessary inaccuracy without further improvement. Since there is not yet a generally agreed method to calculate this correction, an ideal value of 3 dB has been used (16).

2.4 Results

A balcony corresponds poorly to a room in terms of sound absorption (Figure 3) and façade sound insulation (Table 2). Hence, the reference absorption areas or reference reverberation times given in the standards (9, 10) are not relevant in the measurements of balconies. The reference situation should be an empty balcony occupied by one person since all balconies are not necessarily furnished. The absorption of measured balconies was found to be linearly dependent on volume (Figure 3). Balconies S1 and S2 differed from others by having more sound absorption area than what volume would indicate. because of a separating lightweight wall against the next balcony. The measurement results for the weighted sound level difference $D_{ls,2m,w}$ (not normalized or standardized), the sums of $D_{ls,2m,w}$ and spectrum adaptation terms and the sound level difference ΔL_A for traffic noise are given in table 2.



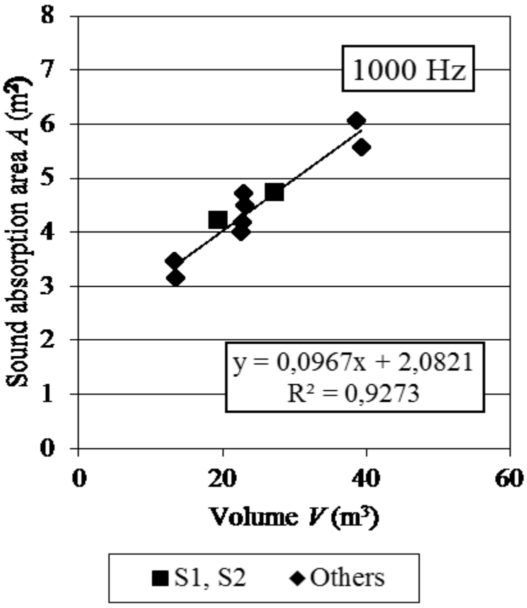


Figure 3 – Measured sound absorption areas at third-octave bands 500 Hz (left) and 1000 Hz (right). Balconies S1 and S2 differ clearly from the other sample at 500 Hz.

Table 2 – Measurement results.

Balcony	$D_{ls,2m,w}$, dB	+ C, dB	+ C_{tr}, dB	ΔL_A, dB
S1	16.9	15.9	15.1	12.1
S2	16.9	15.4	14.0	11
ON1	12.4	11.7	10.8	7.8
ON2	13.1	12.2	11.0	8
S3	11.2	10.6	9.7	6.7
N1	12.4	11.5	10.4	7.4
ON3	14.5	13.6	11.7	8.7
ON4	13.2	12.4	10.8	7.8
N2	15.0	14.0	12.3	9.3
N3	12.9	12.0	10.4	7.4

3. DESIGN METHOD

3.1 Basis

The key factor affecting the sound insulation of a balcony glazing is its apertures instead of glazing thickness. The apertures are mainly located between the glass panes, but there are also gaps in the corners and in the metal profiles to which the glass panes are fixed. Due to the variability between manufacturers and the complexity of sound insulation calculation of structures with apertures of different sizes and shapes it was not desirable to try to define the sound insulation of an openable balcony glazing theoretically. Instead, the design method is based on laboratory measurements of the elements. Different uncertainties dealing with apertures and differences of sound in laboratory and field conditions are taken into account by using a correction term *K* which is derived on the basis of measurements.

3.2 Calculation

Since the laboratory measurements usually correspond to a diffuse sound field, the calculation is done accordingly. The sound level difference ΔL_{A} of a balcony item *i* (e.g. glazing or balustrade) is calculated as follows:

$$\Delta L_{\mathrm{A,i}} = X_{\mathrm{i}} - 10\log_{10}\left(\frac{S_{\mathrm{i}}}{A}\right) + K \tag{1}$$

where X_{i} is the weighted apparent sound reduction index (e.g. $R_{\mathrm{w}}+C_{\mathrm{tr}}$)
S_{i} is the surface area
A is the sound absorption area of an empty balcony
K is the correction term derived from the measurements

A linear fit between balcony volume and measured sound absorption area at third-octave band frequency 1000 Hz (Figure 3) has been taken as the reference value of sound absorption area. Balconies S1 and S2 have not been included in this fit since they differed from the sample. Since the sound level inside the balcony is of interest and not solely the sound insulation of the balcony façade, absorption material with a primary purpose of noise reduction inside the balcony is included in the total absorption area of an empty balcony:

$$A = 0.10V + 2.10 + A_{\mathrm{abs}} \tag{2}$$

where V is the balcony volume
A_{abs} is the added sound absorption area intended to reduce noise inside the balcony

Different building blocks are combined as follows assuming even sound exposure over the balcony facade:

$$\Delta L_{\mathrm{A,tot}} = -10\log_{10}\left(\sum_{i=1}^{N} 10^{-\Delta L_{\mathrm{A,i}}/10}\right) \tag{3}$$

3.3 Comparison to measurements

3.3.1 Derivation of the correction term K

First the calculation was performed for measured balconies. Laboratory measurement values were used for balcony glazing. Values for typical glass from standard EN 12758:2011 were used by thickness for glass balustrades. Slit-shaped apertures were added to the balustrade according to the theory presented by Mechel (17). All balconies also had indefinite apertures and gaps which have not been taken into account because their geometry was too complex to calculate with sufficient accuracy. The difference between the calculated value $\Delta L_{\mathrm{A,calc}}$ and measured value $\Delta L_{\mathrm{A,meas}}$ was derived with 1 dB rounding.

The average difference between calculation and measurement was found to be around 5 dB for both $D_{\mathrm{ls,2m,w}} + C$ and $D_{\mathrm{ls,2m,w}} + C_{\mathrm{tr}}$ (after reducing the measurement by 3 dB due to the façade reflection) with measurement being less than the calculated value. After introducing -5 dB as the correction term *K*, the differences between measurements and calculations are shown in figure 4 (with 1 dB rounding).

The effect of including slits seems to be significant according to figures 4 and 5, but in reality and with 0.1 dB rounding the benefit is much smaller. This is mostly due precision associated with rounding. The accuracy for air and railway traffic weighted (C) index seems to be around ± 2 dB and for traffic noice (C_{tr}) around ± 1 dB if balconies S1 and S2 are disregarded (since the absorption area differed from the other sample).

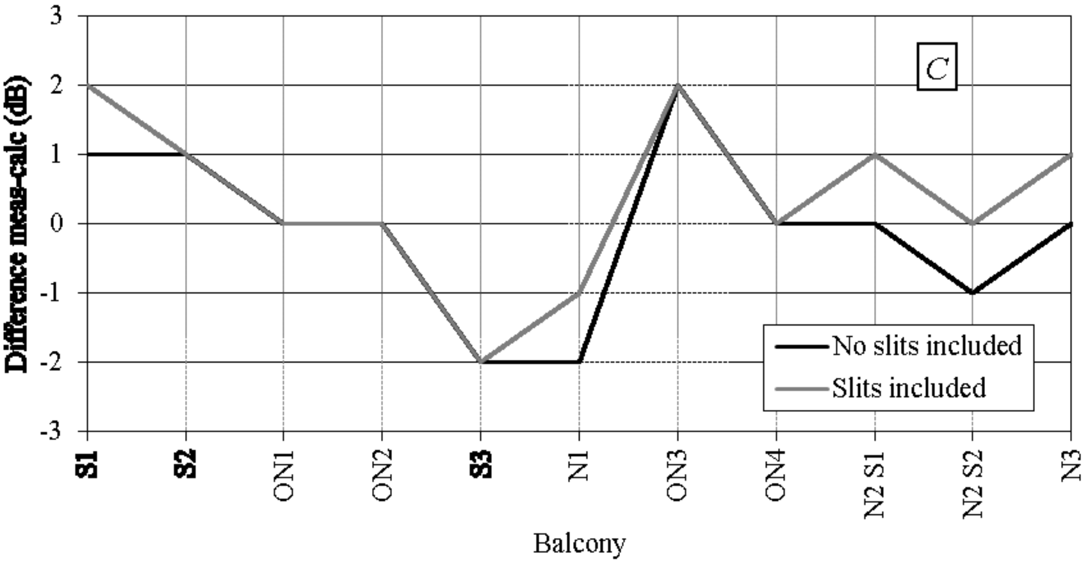


Figure 4 – The difference between measurement and calculation rounded to 1 dB for C.

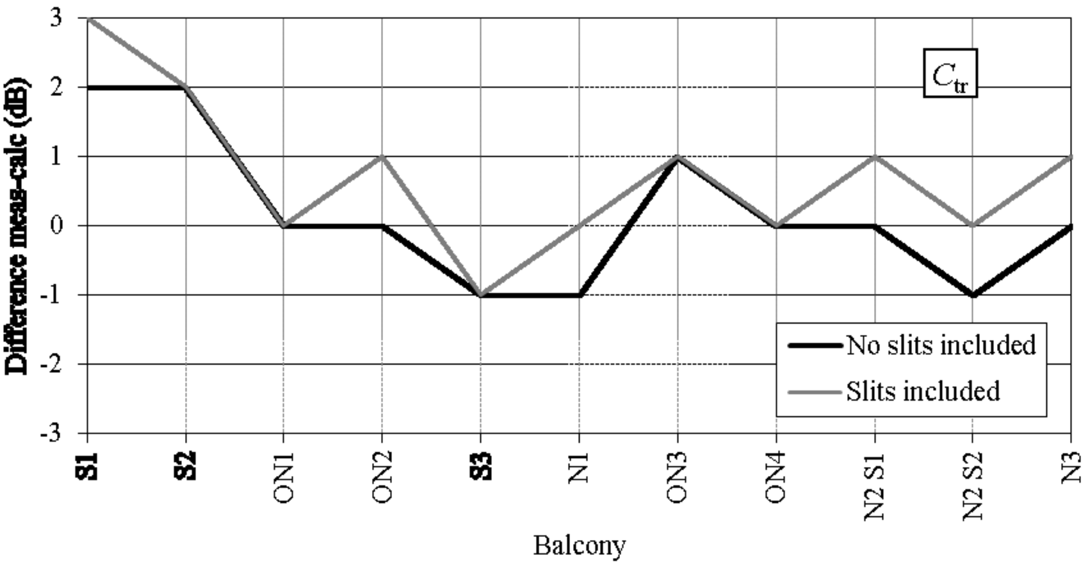


Figure 5 – The difference between measurement and calculation rounded to 1 dB for C_{tr}.

3.4 Calculation example

Let us consider a typical balcony with following parameters:

- Dimensions: 4 x 2 x 2.7 = 21.6 m^3
- Glazing: Height 1.6 m, $R_w + C_{tr}$ = 15 dB
- Glass balustrade: Height 1.1 m, $R_w + C_{tr}$ = 21 dB

Weighted apparent sound reduction index of the glass balustrade is a combination of an ideal 8 mm thick glass pane and slit-shaped apertures which contribute for 0.2 % of the balustrade's surface area. This was the general case for the measured balconies. The A-weighted sound level differences L_A are calculated for both building blocks:

$$\Delta L_{\mathrm{A,glazing}} = 15\mathrm{dB} - 10\log_{10}\left(\frac{4\cdot 1.6}{0.1\cdot 21.6 + 2.1}\right) - 5\mathrm{dB} = 8.2\mathrm{dB}$$

$$\Delta L_{\mathrm{A,balustrade}} = 21\mathrm{dB} - 10\log_{10}\left(\frac{4\cdot 1.1}{0.1\cdot 21.6 + 2.1}\right) - 5\mathrm{dB} = 15.9\mathrm{dB}$$

Combining the two sound level differences results in a sound level difference of $\Delta L_{\mathrm{A,tot}}$ = 7.5 dB, or rounded down to 7 dB . If we add 2 more glass sides to the shorter edges we get a total of 5.7 dB, or rounded down to 5 dB.

4. CONCLUSIONS

In Finland, glazed balconies are treated as residential outdoor areas to which regulatory noise level limits are applied. Measurements have usually been needed to verify that the requirements are met but they are quite expensive and impractical to carry out. Therefore a research was carried out in order to develop a simple design method to predict the sound level difference of a glazed balcony. After the introduction of the correction term, the accuracy was found to be sufficient.

ACKNOWLEDGEMENTS

This study was funded by the Finnish Transport Agency and the Ministry of the Environment. The authors would like to thank Mr Erkki Poikolainen and Mr Ari Saarinen for their valuable comments during the work. The measurements were carried out by the engineering office A-Insinöörit Suunnittelu Oy which is also acknowledged.

REFERENCES

1. Building stock 2014. Statistics Finland. Available (in Finnish): http://www.stat.fi/til/rakke/2014/rakke_2014_2015-05-28_tau_001_fi.html
2. Kummala, I. The current state of balcony construction in Finland (in Finnish). Bachelor’s thesis. Tampere University of Technology. Tampere 2014.
3. Aro, P., Tuononen, T., Åkerblom, S. The balconies of sheltered homes (in Finnish). Sotera and Helsinki University of Technology. Espoo, Finland 2006.
4. Heikkilä, J. Balcony as an apartmental outdoor space of Finnish apartment buildings (in Finnish). Dissertation University of Oulu. Oulu, Finland 1996.
5. The refurbishment trial of Putaa’s apartment houses (in Finnish). VTT. Finland 1989.
6. Government decree on values for allowable noise levels 993/1992 (in Finnish). Helsinki, Finland 1992.
7. Berglund, B., Lindvall, T. Community noise. World Health Organization, Geneva 1995.
8. Kim, M.J., Kim, H.G. Field measurements of facade sound insulation in residential buildings with balcony windows. Building and Environment 2007:42:1026-1035.
9. ISO 140-5: Acoustics – Measurement of sound insulation in buildings and of building elements – Part 5: Field measurement of airborne sound insulation of facade elements and facades. International Organization for Standardization, Genève,1998
10. Committee Draft ISO/CD 16283-3: Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 3: Façade sound insulation Draft 19.12.2013, International Organization for Standardization, Genève.
11. Berardi, U., Cirillo, E., Martellotta, F. Interference effects in field measurements of airborne sound insulation of building facades. Noise Control Engineering Journal 2011:49(2):165-176.
12. Bradley, J.S., Chu, W.T., Errors when using façade measurements of incident aircraft noise, Inter-Noise 2002, Dearborn 19.-21.8., USA, 2002, s. 10.
13. Hall, F.L., Papakyriakou, M.J., Quirt, J.D. Comparison of outdoor microphone locations for measuring sound insulation of building facades. Journal of Sound and Vibration 1984:92(4):559-567.
14. Hopkins, C., Lam, Y. Sound fields near building facades – comparison of finite and semi-infinite reflectors on a rigid ground plate. Applied Acoustics 2009:70:300-308.
15. Ismail, M.R., Oldham, D.J. A scale model investigation of sound reflection from building facades.

Applied Acoustics 2005:66:123-147.

16. ISO 1996-2: Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels, International Organization for Standardization, Genève 2007.
17. Mechel, F.P. Formulas of Acoustics, 2nd edition: Springer-Verlag Berlin Heidelberg. New York, USA 2008.