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Façade sound insulation of residential houses within 5–5000 Hz

Jukka Keränen,
Jarkko Hakala,
Valtteri Hongisto
Turku University of Applied Sciences, Indoor Environment, Finland.

Summary

Health-based regulations for indoor sound pressure level (SPL) within 20–200 Hz presuppose that the planners of industrial sites shall estimate the indoor SPL of environmental noise in nearby dwellings. However, data about typical façade sound insulation is not available in Finland. The aim of the study was to determine façade sound insulation of typical Finnish residential houses. Level difference between outdoor and indoor sound pressure level was measured in 1/3-octave bands 5–5000 Hz using special loudspeakers as sound sources. The measurements were made for 26 façades in 13 different houses. The apparent sound reduction index for the façades was determined according to ISO 16283-3 in 50–5000 Hz. The weighted apparent sound reduction indices, $R'_w + C_{tr}$ (ISO 717-1), varied between 31 and 51 dB. The level differences were from 3 to 40 dB within 20–200 Hz, and from -3 to 30 dB within 5–16 Hz. The results depended strongly on frequency, building materials, window area, and measurement positions. The 84% percentile value of the 26 measured level differences can be used to estimate the indoor SPL caused by environmental noise which is usually determined outdoors by sound propagation models.

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1. Introduction

Sound insulation of residential houses at low frequencies has received increasing interest recently. E.g. industrial plants, ships, wind turbines, and aircraft produce low frequency sound involving infrasound. Limits for sound pressure level (SPL) indoors are given in one-third octave band values within 20–200 Hz in Finland [1]. However, current standard for sound insulation measurements ISO 16283-3 (2016) [2] does not consider frequencies below 50 Hz.

Only a few authors have published measurement data on sound insulation at low frequencies [3–5]. Their measurement arrangements have followed more or less the guidelines presented in ISO 140-5 (1998) [6]. The results have been presented as level difference between outdoor and indoor SPL. The statistical level difference reported in DSO 1284 [7] is applied in Finland to estimate the indoor SPL of wind turbine noise within 20–200 Hz. However, the representativeness of the Danish data has been questioned in Finland.

The aim of our study was to produce measured data on sound insulation within frequencies 5–5000 Hz for research and design purposes. The first purpose was to measure level difference between outdoor and indoor SPL within 5–200 Hz in various residential houses. The second purpose was to determine the sound reduction index within 50–5000 Hz according to ISO 16283-3 which replaced ISO 140-5 very recently. The measured data can be used in determination of indoor SPL when the outdoor SPL is known by measurements or simulations.

2. Residential houses

Modern Finnish residential houses have relatively thick layers (>225 mm) of thermal insulation materials, insulating glass windows, and airtight structures. On the other hand, older houses have significantly thinner (<180 mm) thermal insulation layers. Old timber log walls do not involve thermal insulation layers at all. Therefore, Finnish houses offer a good platform to survey constructions with varying thermal and sound insulation. Our study incorporated 26 façades of 13 houses with both heavy and light façade constructions, both with and without windows (Table I). Our results are expected to have broader applications than previous studies [3–5].

The sample included houses with concrete, brick, log and wood constructions in the bear loading façade wall. The details of façade constructions were collected from the building drawings and examined visually. The dimensions of the windows, walls and rooms were measured and the number of glass panes was inspected. The density of the building materials were obtained from the building drawings, building descriptions or relevant literature. The surface mass was calculated using the collected information.

3. Measurement methods

Three sound sources were used in the measurements (Figure 1). A dodecahedral loudspeaker (A) and power amplifier were used in the measurements according to ISO 16283-3. Two subwoofers were used for the measurements in the low frequency range 20–80 Hz (B) and the infrasound range 5–20 Hz (C). Uncorrelated pink noise signals were produced for the three sound sources, simultaneously, using three signal generators. The sound sources were located near each other at the distance of five metres from the center of the façade wall. The locations were selected in agreement with ISO 16283-3.

The SPL was measured using a sound analyzer (NOR 150) equipped with a condenser microphone (NOR 1225) and wind screen (diameter 90 mm). The device was calibrated before and after each measurement using a sound level calibrator (B&K 4231). The SPL measurements were made within 5–5000 Hz. The measurement time of all measurements was 30 seconds which was twice the time required for fixed measurement points in the low frequencies 50–80 Hz according to ISO 16283-3.

Table I. The studied houses and façades, thickness of the wall *t*, façade surface area *S*, surface mass *m*, percentage of window area in the façade *W* and the room volume *V*.

Façade	*t* [mm]	*S* [m^2]	*m* [kg/m^2]	*W* [%]	*V* [m^3]
1A	290	8.5	144	18	26
1B	290	7.1	174	0	26
2A	195	9.2	115	41	29
2B	195	7.8	175	0	29
3A	250	10.6	87	24	29
4A	435	11	432	15	37
5A	680	8.5	271	15	25
5B	330	12.2	43	18	109
5C	330	12.2	43	18	48
6A	210	10	94	0	26
6B	210	10	81	20	26
7A	125	8.9	101	24	27
8A	175	5.4	61	13	22
8B	175	17.6	54	24	82
9A	240	9.4	41	24	61
9B	240	8.2	40	28	65
9C	200	10	31	48	25
10A	270	16.2	207	0	98
10B	215	15.9	32	52	98
10C	315	8.1	163	40	29
11A	250	8.8	67	17	33
11B	250	7.1	76	0	33
12A	190	9	60	0	45
12B	190	11	54	14	45
13A	315	7.6	131	0	26
13B	315	9	66	64	98

Figure 1. The three sound sources located in front of the façade of house 13. **A**: dodecahedral loudspeaker. **B**: ordinary subwoofer. **C**: infrasound subwoofer.

The measurement points were selected in agreement with ISO 16283-3. The outdoor SPL was measured in five fixed points at the distance of 5 cm from the façade wall while the three sound sources produced pink noise.

The indoor SPL was measured in four corner points and in five fixed points in the middle area of the room. The points were selected in agreement with ISO 16283-3 so that the distance was 30 cm from the room boundaries in the corner points. Distance of 10 cm was not used since both distances produce the same results below 50 Hz [8]. The SPL was measured in all points while the three sound sources were on. The background noise level was measured in the same indoor points immediately after the three sound sources were switched off. The indoor SPL was corrected for background noise.

The reverberation time, T [s], in the room was measured within 50–5000 Hz using the dodecahedral loudspeaker (A) and the ordinary subwoofer (B). The reverberation times were not measured below 50 Hz, since they were supposed to be very short and, therefore, not reliably measurable by the sound analyser [9].

Apparent sound reduction index was determined using equation

$$R'_{45} = L_{1,s} - L_2 + 10\log_{10}(S/A) - 1.5 \text{ dB}, \quad (1)$$

where $L_{1,s}$ [dB] was the mean outdoor SPL measured on the façade, L_2 [dB] was the mean indoor SPL measured in the middle of the room and A [m^2] was the equivalent absorption area that was determined using equation

$$A = 0.16\, V/T, \quad (2)$$

where V [m^3] was the room volume.

The weighted apparent sound reduction index $R'_{45,w}$ with a correction C_{tr}, was determined according to ISO 717-1 [9] within 100–3150 Hz. This quantity is mainly applied in Finland to characterize the sound insulation performance of façades against environmental noise [10].

The level difference between outdoor SPL and indoor SPL was determined in one-third octave bands 5–200 Hz for all the indoor measurement points: four corner points, C1 – C4, and five middle area points, M1 – M5. The level difference was determined using equation

$$DL_{\text{XY}} = L_{1,s} - L_{2,\text{XY}} - 6 \text{ dB}, \quad (3)$$

where $L_{2,\text{XY}}$ was the indoor SPL in measurement point and –6 dB was the correction to express the free field SPL of the incident sound. X refers to either corner point C or middle area point M. Y refers to the corresponding microphone position. DL_{M} and DL_{C} are the mean level differences based on middle and corner positions, respectively.

Statistical methods were used to determine 84% percentile levels of the mean level differences $DL_{\text{M}\sigma}$ and $DL_{\text{C}\sigma}$. A polynomial function was fitted to the mean of 84% percentile levels of both $DL_{\text{C}\sigma}$ and $DL_{\text{M}\sigma}$. The values of the function at one-third octave bands were rounded to nearest whole numbers. This statistical descriptor, DL_{σ}, represents the expected level difference exceeded by 84% of the studied houses.

Using the same statistical methods, 84% percentile level, R'_{σ}, was determined for sound reduction index R'_{45} within 50–5000 Hz.

4. Results

An example of measured SPLs for façade 13A is presented in Figure 2.

The maximum and minimum R'_{45} are presented together with R'_{σ} in Figure 3. The results of $R'_{45,w} + C_{tr}$ varied between 31 and 51 dB.

A comparison of $DL_{C\sigma}$ and $DL_{M\sigma}$ to the ΔL_{σ} values of DSO 1284 [7] is presented in Figure 4.

The expected level difference exceeded by 84% of the façades, DL_{σ}, within 5–200 Hz is presented with ΔL_{σ}-values of DSO 1284 [7] in Table II.

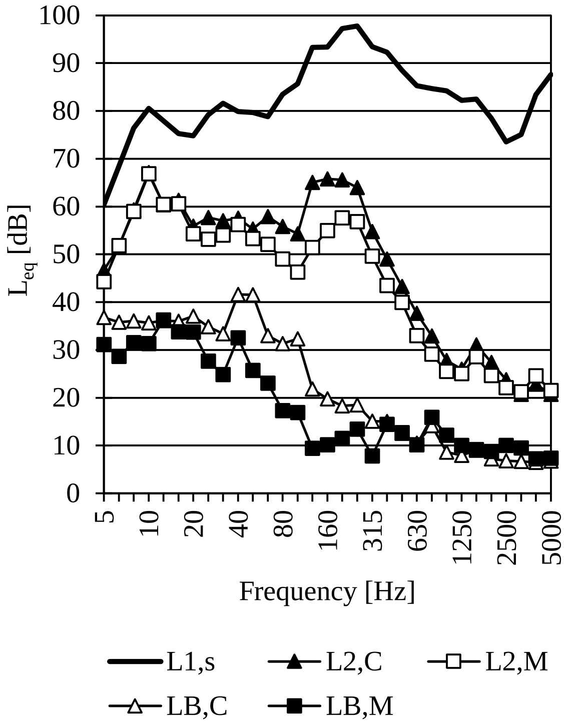

Figure 2. An example of measurement results of façade 13A. $L_{1,s}$ is the SPL on the outer surface of the façade. $L_{2,C}$ is the SPL in the corners of the room. $L_{2,M}$ is the SPL in the middle area of the room. $L_{B,C}$ is the SPL of the background noise in the corners of the room. $L_{B,M}$ is the SPL of the background noise in the middle area of the room.

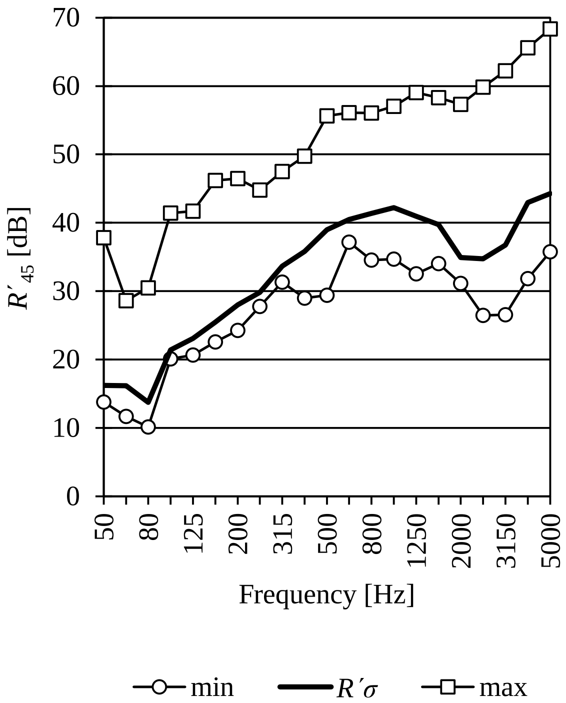

Figure 3. The minimum, the maximum, and the 84% percentile level of R'_{45}, R'_{σ}, measured for the 26 façades.

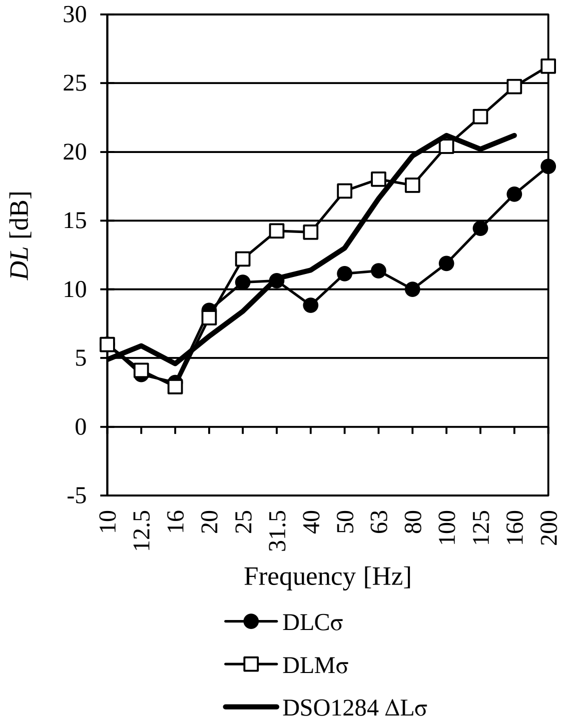

Figure 4. The 84% percentile levels of level difference measured for the 26 façade walls in corners $DL_{C\sigma}$ and in the middle area $DL_{M\sigma}$. The statistical level difference ΔL_{σ} (DSO 1284) is presented for comparison.

Table II. The expected level difference exceeded by 84% of the houses, DL_σ, within 5–200 Hz in our study. The ΔL_σ of DSO 1284 [7] is presented for comparison.

f [Hz]	DL_σ [dB]	ΔL_σ [dB]
5	6	
6.3	6	
8	6	
10	7	4.9
12.5	7	5.9
16	7	4.6
20	8	6.6
25	9	8.4
31.5	10	10.8
40	11	11.4
50	12	13.0
63	14	16.6
80	15	19.7
100	17	21.2
125	19	20.2
160	21	21.2
200	21	

The values of Table II can be applied to estimate the indoor SPL in 1/3-octave bands when the outdoor SPL, L_{out} [dB], is determined by measurement or simulation. The indoor SPL, L_{in} [dB], is

$$L_{in} = L_{out} - DL_\sigma \tag{4}$$

5. Conclusions

Our study implied that it is possible to make field measurements of sound level difference between outdoor and indoor SPL in the low frequency range down to 5 Hz using a special infrasound loudspeaker.

An expected level difference, DL_σ, which is exceeded in 84% of Finnish residential houses was derived (Table II).

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