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Experimental study on low-frequency averaging of indoor sound pressure level in façade sound insulation measurement

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ABSTRACT

In the ISO 16283 series for field measurement of sound insulation, a low-frequency procedure is specified for determining indoor average sound pressure level, which is the so-called corner method. In the procedure, additional measurements are required in the corners in addition to the default measurements in the central zone, and the indoor average level is corrected with the highest level in the corners. However, this procedure was empirically proposed, and its validity is not fully examined for various cases. In this paper, façade sound insulation measurements were performed above 20 Hz for two rooms of a mock wooden house, where sound pressure levels were measured at five default points and eight corner points in each room. The low-frequency procedure was tested in comparison with the default procedure, in particular, observing the deviation among the corner points. In addition, the influences of the microphone position in the corners were examined with varying the distance from each corner.

Keywords: Sound insulation, Low-frequency sound, Façade, Wooden house

1. INTRODUCTION

In the field measurement of airborne sound insulation, indoor average sound pressure level is usually determined with five microphone positions placed in a room, which could lead to adverse significant deviation at low frequencies due to low-order normal modes. Thus, in the ISO 16283 series [1, 2], a low-frequency procedure has been specified for determining the indoor average sound pressure level, based on the study by Hopkins [3]. In the low-frequency procedure that is the so-called corner method, additional microphone positions are required in the corners in addition to the default positions in the central zone, and the indoor average level is corrected with the highest level in the corners. In the ISO series, the low-frequency procedure is applied for the 50 Hz, 63 Hz, and 80 Hz 1/3-octave bands, and also for rooms with a volume of smaller than 25 m^3. However, this procedure was empirically proposed, and its validity is not fully examined for various cases although measurements of insulation between rooms were intensively done [3, 4]. Regarding façade insulation, we have recently performed a 1/4-scale model measurement using a small house model installed in a semi-anechoic room [5], and the low-frequency procedure was roughly validated using the measured sound pressure levels at multiple grid points [6].

In this paper, façade sound insulation measurements are performed above 20 Hz for two rooms with different window systems of a mock wooden house. In the measurements, two loudspeakers for lower and higher frequency ranges are used as outdoor sound sources, and sound pressure levels are measured at five default points and eight corner points in each room. In comparison with the default procedure, the low-frequency procedure is tested, in particular, observing the deviation of sound pressure levels among the corner points. Furthermore, the influences of the microphone position in the corners were examined with varying the distance from each corner.

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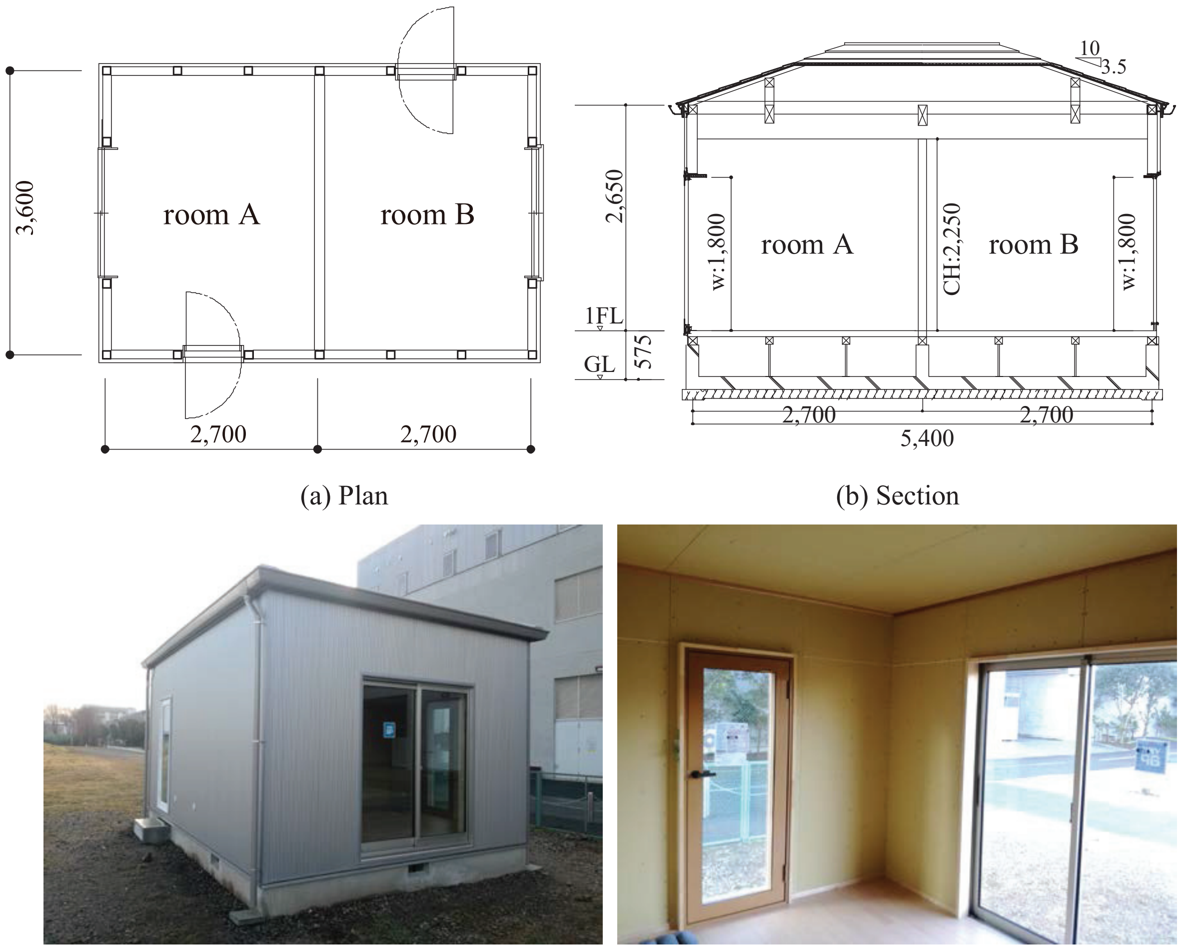
2. EXPERIMENTAL SETUP

2.1 Mock Wooden House

Figure 1 shows the mock wooden house constructed by the traditional timber framework method in the field without obstacles nearby. This house has two rooms (Rooms A and B) with a volume of about 20 m^3, of which plan layout is rotationally symmetrical, and the windows of the two rooms are aluminum sliding terrace windows with different sound transmission losses. For Room A, a regular sash with 5 mm thick single glazing is installed, while a soundproof sash with double glazing of a total thickness of 10 mm is installed for Room B. The façade wall and the roof/ceiling are light structures with a surface density of about 25 kg/m^2 (including studs), the partition wall is a hollow double wall, the floor is wooden flooring, and a double door with high sound transmission loss is installed for each room. In the four sides of the concrete foundation (h = 575 mm), four underfloor ventilations (w = 275 mm, h = 155 mm) are installed under the windows and on the opposite side of the doors. The roof is a hipped roof, and no ventilation is installed for the attic space. The detailed components of the house are shown in Table 1.



(a) Plan (b) Section

(c) Exterior view (d) Interior view

Figure 1 – Mock wooden house

2.2 Measurement Setup

Façade airborne sound insulation measurements are conducted in Rooms A and B, where a number of microphones and two loudspeakers are set for each room as shown in Figure 2. For generating broad-band noise from 25 Hz to 160 Hz 1/3-octave bands, a subwoofer (Electro-Voice EKX18SP) is set on the round, and another loudspeaker (JBL EON15 G2) is set over the subwoofer for noise from 200 Hz to 5 kHz bands, both of which are placed at a distance of 8 m away from the center of the window in the direction of 45 degrees.

Table 1 – Compositions of the mock wooden house: unit [mm]

Façade wall	Metal siding (16) + Furring strips (18) + Windproof/moisture-permeable sheet + Plywood (9) + Glass wool 16K (100) + Gypsum board (9.5)
Partition wall	Gypsum board (9.5) + Air (100) + Gypsum board (9.5)
Floor	Composite flooring (12) + Plywood (12) + Polystyrene foam (25)
Ceiling	Gypsum board (9.5) + Glass wool 16K (100)
Roof	Metal roofing + Asphalt roofing + Plywood (12)
Window	Aluminum double sliding sash (h = 1,800, w = 1,600) Glazing: FL5 (Room A), FL6+A6+FL4 (Room B)
Door	Resin door (h = 1,800, w = 720) Glazing: W6.8+A11+FL4 (exterior), FL6+A8+FL4 (interior)

In outdoors, 14 receiving points (S1~S13, F) are set at a height of 1.2 m above the floor (1.8 m (+GL)), where S1~S13 are at a distance of 4 cm from the three façade walls around the house, and F is at a distance of 2 m in front of the center of the window according to the global method in ISO 16283-3. In the room, 5 default points (R1~R5) and 8 corner points (C1~C8) are arranged. According to the default procedure, R1~R5 are set in the center zone at least 0.6 m away from the inner walls, with different heights of 0.8 m to 1.6 m above the floor. The corner points are set at a distance of 0.4 m from each boundary that forms the corner, in which C1~C4 are near the floor, and C5~C8 are near the ceiling.

At all receiving points, equivalent continuous sound pressure levels are measured in the 1/3-octave bands from 25 Hz to 5 kHz with an averaging time of 20 seconds. Moreover, as a reference, sound pressure level on the ground without obstacles, L_{free}, is measured at a distance of 8 m in front of the loudspeakers, at the same height as the outdoor receiving points. The measurements were conducted under windless condition, and it was confirmed that the signal-to-noise ratio is greater than 10 dB at all frequency bands.

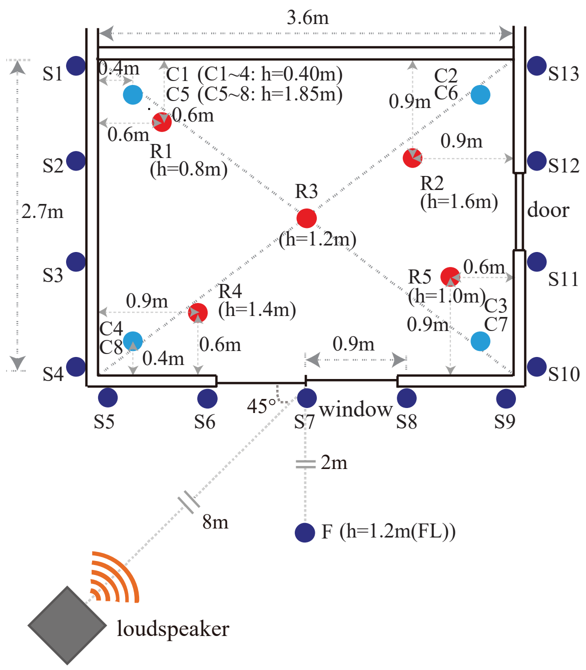


Figure 2 – Arrangement of microphones and loudspeakers

3. EXAMINATION ON THE CORNER METHOD

In the low-frequency procedure specified in ISO16283-3, indoor sound pressure levels are determined in 50, 63 and 80 Hz bands, by combining the energy-average level for the five default points in the central zone, $L_{in,5}$, and the maximum level among the eight corner points, $L_{cn,max}$, using the following equation:

$$L_{LF} = 10\lg\left(\frac{2}{3}\cdot 10^{L_{in,5}/10} + \frac{1}{3}\cdot 10^{L_{cn}/10}\right) \text{ [dB]} \quad (1)$$

where L_{cn} is a general representation of sound pressure level related with corners. However, the use of the maximum value for the corner level is not necessarily reasonable in the aspect of uncertainty, and also, the proportion of 2 to 1 seems to be empirically given.

So then, as a possible value that was tested in the previous scale model experiment [6], the energy-average level over all the corner points, $L_{cn,ave}$, is also tentatively used for the corner level. In the following examination, the two kinds of low-frequency indoor sound pressure levels, $L_{LF,max}$ and $L_{LF,ave}$ are calculated from the measured values at R1~R5 and C1~C8, and these differences from the default average level are quantitatively compared.

According to the recent paper by Hopkins [7], he originally proposed a corner microphone position at a distance of 0.3 m to 0.6 m, but the upper distance was reduced to 0.4 m in ISO 16283-3 because the distance of 0.6 m is used for the default procedure. Moreover, it is noted in the ISO that the distance from each boundary that forms the corner does not have to be identical, giving an example of the combination of 30 cm, 35 cm and 40 cm from the three boundaries. However, considering that the wavelength below 100 Hz is greater than 3 m, the limitation of the near distance and the additional note seems to be needless. Therefore, in the latter examination, sound pressure levels are measured around the corner by varying the distance from each boundary from 2 cm to 60 cm identically, and also at the ISO recommendation point. In each room, two corner zones near the floor are selected: one is around C2 in the far corner from the source, and the other is around C4 in the near corner.

4. RESULTS AND DISCUSSION

4.1 Outdoor Sound Pressure Levels

Figure 3 shows the distributions of the outdoor sound pressure levels measured at S1~S13 and F for Room A, relative to L_{free} the reference level in the free field. Below 500 Hz, the relative levels are 5 to 8 dB at S6~S8 on the front façades, and 2 to 5 dB at S1~S3 on the side façade facing to the source. On the other hand, at F in front of the window, the levels are greatly fluctuating between -3 and +5 dB, which is due to the interference with reflected wave. On the back side façade, the levels are at least 10 dB lower than those on the front façade due to the diffraction attenuation.

According to the global loudspeaker measurement specified by ISO 16283-3, outdoor-to-indoor level difference is evaluated from the sound pressure level at a distance 2 m in front of the façade. However, it is not necessarily suitable for investigating the frequency characteristics of sound insulation of the house. Accordingly, in the following, outdoor-to-indoor level difference is evaluated considering L_{free} as the outdoor sound pressure level.

4.2 Outdoor-to-Indoor Level Difference by the Default Procedure

As a global index of sound insulation of the house, sound pressure level difference, $D_{free} = L_{free} - L_{in,5}$, is calculated with the default procedure. Figure 4 shows the calculated results of D_{free} for Rooms A and B. Generally, D_{free} is about 15 dB at 500 Hz in both rooms, and Room B has higher D_{free} below 100 Hz and above 1 kHz than Room A. The increase of D_{free} below 100 Hz may be caused by the doubling of total surface density of glazing, while that above 1 kHz must be due to the positive effect of double layers. On the other hand, this double glazing has a resonance frequency, which causing the significant drop between 250 and 500 Hz. In addition, a rise of D_{free} is seen at 25 Hz in both rooms, which may be due to stiffness control of the whole structure of the house. On the whole, the influence of the window system will be small at low frequencies because the surface density of the façade wall is relatively comparable to those of glazing.

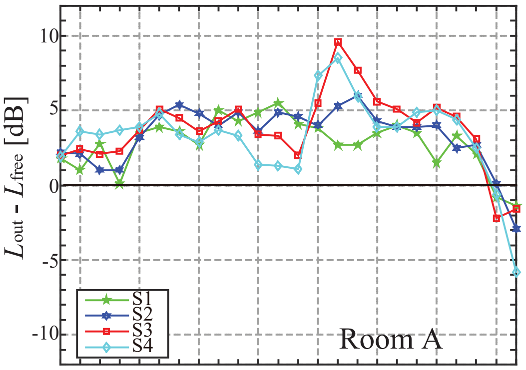


Figure-3 (a)

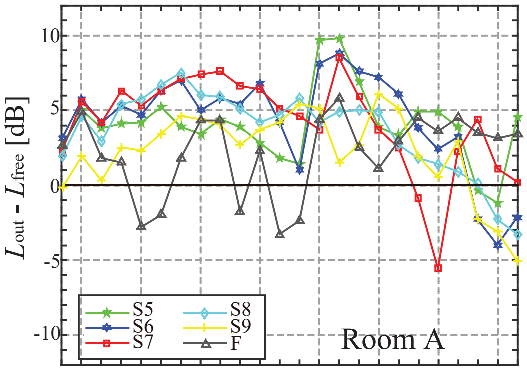


Figure-3 (b)

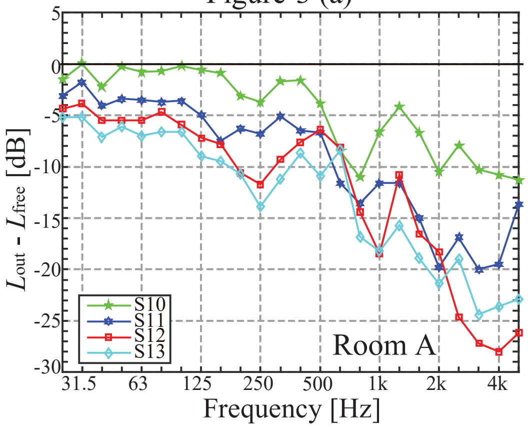


Figure-3 (c)

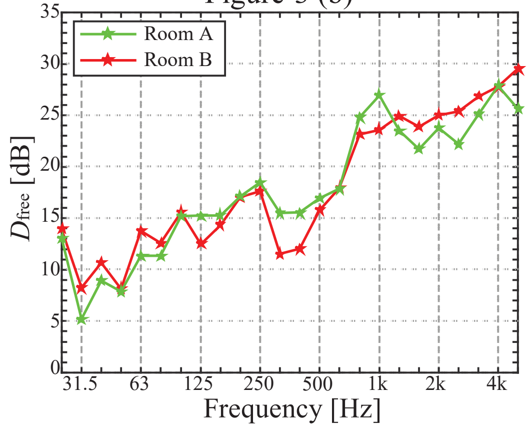


Figure-4

Figure 3 – Outdoor sound pressure levels around Room A, relative to the reference level in the free field: (a) S1~S4, (b) S5~S9, (c) S10~S13

Figure 4 – Outdoor-to-indoor level difference of Rooms A and B, calculated by the default procedure

4.3 Correction Level by the Corner Method

In the previous section, outdoor-to-indoor level difference was calculated with the default procedure regardless of frequency range. Although the ISO applies the low-frequency procedure in 50 to 80 Hz bands, the corner method is tentatively applied over all frequency bands, and the behavior of the correction value is observed. As is mentioned in Chap. 3, the two kinds of values, $L_{\mathrm{LF,max}}$ and $L_{\mathrm{LF,ave}}$, are calculated by Eq. (1), and used as indoor sound pressure level of the room. Corresponding to those values, the outdoor-to-indoor level differences, $D_{\mathrm{LF,max}}$ and $D_{\mathrm{LF,ave}}$, are calculated with the free-field reference level in the same way as D_{free}.

Figure 5 shows the differences of D_{LF} and D_{free} for the two rooms, that is, the correction levels by the corner method using the maximum or average level of corner. It is seen that $D_{\mathrm{LF,ave}}$ is approximately 0 dB above 500 Hz, which means that the effect of room boundaries is negligible at the receiving point 0.4 m away from each boundary. In the lower frequency range, a positive peak appears around 250 Hz, and a remarkable negative dip appears around 100 Hz. The former peak will be due to the destructive interference with reflected wave from the boundaries, which is confirmed in details in the last experiment. In the low-frequency range below 100 Hz, the correction value is negative and tends to approach 0 dB with decreasing frequency, and moreover, $D_{\mathrm{LF,max}}$ is about 1 dB lower than $D_{\mathrm{LF,ave}}$.

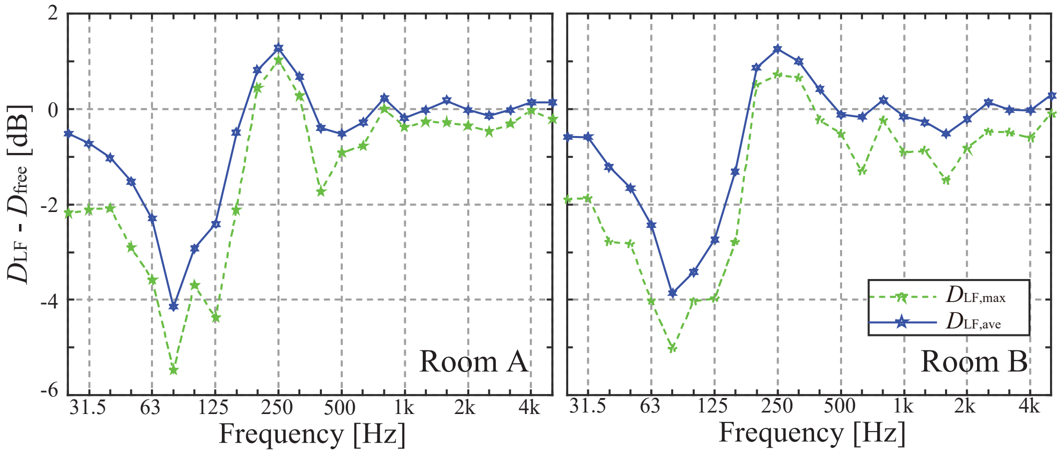


Figure 5 – Correction levels by the corner method using $L_{cn,max}$ and $L_{cn,ave}$ for Rooms A and B.

4.4 Sound Pressure Levels in Corners

In order to examine the variation of sound pressure level in eight corners (C1~C8), the maximum ($L_{cn,max}$), the average ($L_{cn,ave}$), and the minimum ($L_{cn,min}$) levels, relative to the average level in the central zone ($L_{in,5}$) in each 1/3-octave band are shown in Figure 6. It is seen that the range between $L_{cn,max}$ and $L_{cn,min}$ is less than 4 dB above 500 Hz, whereas it tends to significantly increase up to 10 dB with decreasing frequency. Furthermore, a great peak and a sharp dip are seen around 100 Hz and 250 Hz, respectively, both for $L_{cn,max}$ and $L_{cn,min}$. Below 100 Hz, the highest sound pressure level occurred in the far corners (C2, C6) to the sound source, and on the contrary, the lowest occurred in the near corners (C4, C8). This tendency is consistent with the results for the field measurement of airborne sound insulation between rooms by Hopkins [3]. Hence, for the corner method, the highest sound pressure level in eight corners could be identified by measuring in the four corners opposite to the sound source, instead of all corners.

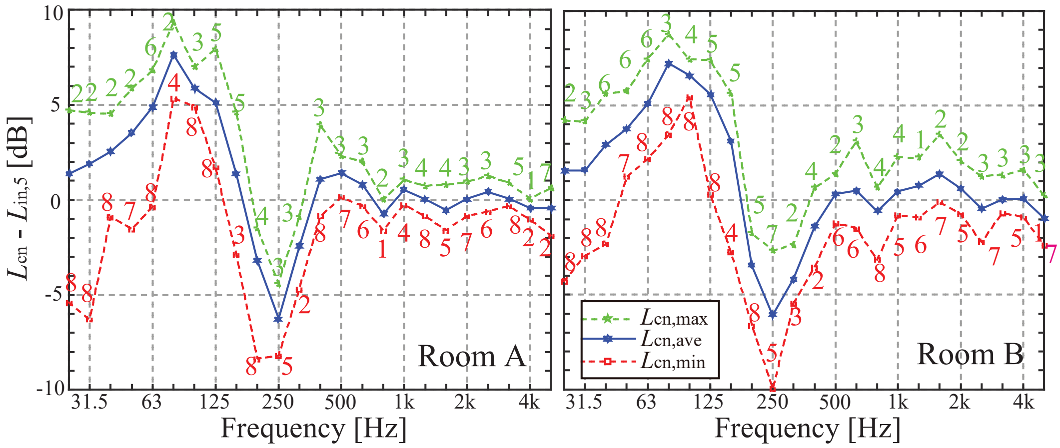


Figure 6 – Maximum/minimum and average sound pressure levels in eight corners, relative to the average level in the central zone. Green/red numbers represent the numbers of corners for maximum/minimum levels, respectively.

4.5 Sound Pressure Level around Corners

In order to investigate the effect of the position of the corner receiving point, sound pressure levels were measured around the corner by varying the distance from each boundary from 2 cm to 60 cm identically, and also at the ISO recommendation point. Figure 7 shows the sound pressure levels around the two near and far corners, C4 and C2, in Room A, relative to those at the nearest point 2 cm away ($L_{cn,2cm}$). It is seen that, as the distance from the corner increases, a remarkable dip shifts to lower frequency, which gradually lowers the level below 100 Hz. Thus, it was confirmed that this dominant dip is due to the destructive interference, which occurs when the distance from the boundaries roughly corresponds with 1/4 of the wavelength.

Figure 8 shows the levels around C4 and C2 in Room B, relative to the average level in the central zone ($L_{in,5}$). Regardless of the distance from the corner, a significant peak is seen around 100 Hz, which will be caused by the decrease of $L_{in,5}$ due to normal modes in the room. Moreover, below 100 Hz, the levels around the far C2 are obviously greater than the near C4, as is observed in Figure 6.

Regarding the range of 30 to 40 cm specified in the ISO, the reduction level relative to the point at the distance of 2 cm is within 2 dB below 100 Hz, in both rooms. Furthermore, no considerable difference is observed at the point with unequal distances from the three boundaries. Finally, it was suggested that the limitation for near distance and the avoidance of identical distance are not necessarily required.

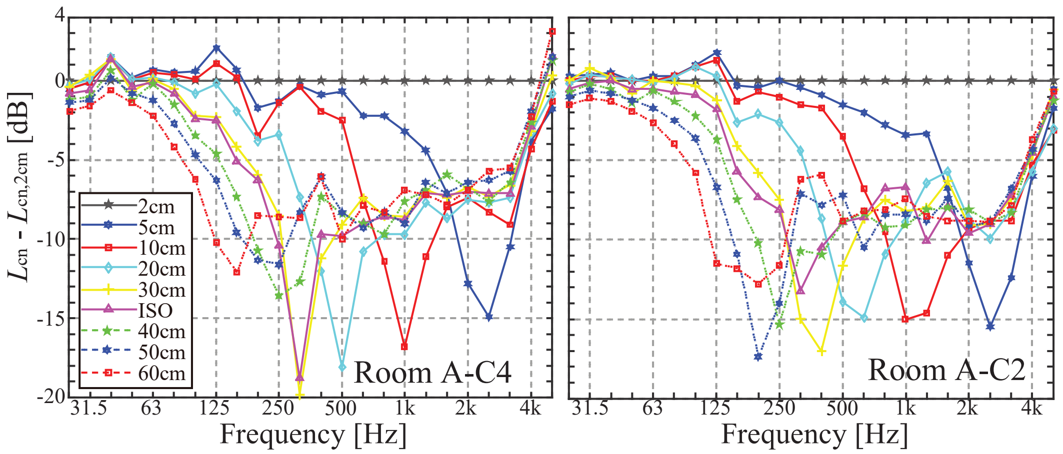


Figure 7 – Change in sound pressure level with varying the distance from the corner, relative to the level at the nearest point ($L_{cn,2cm}$), around C4 and C2 in Room A.

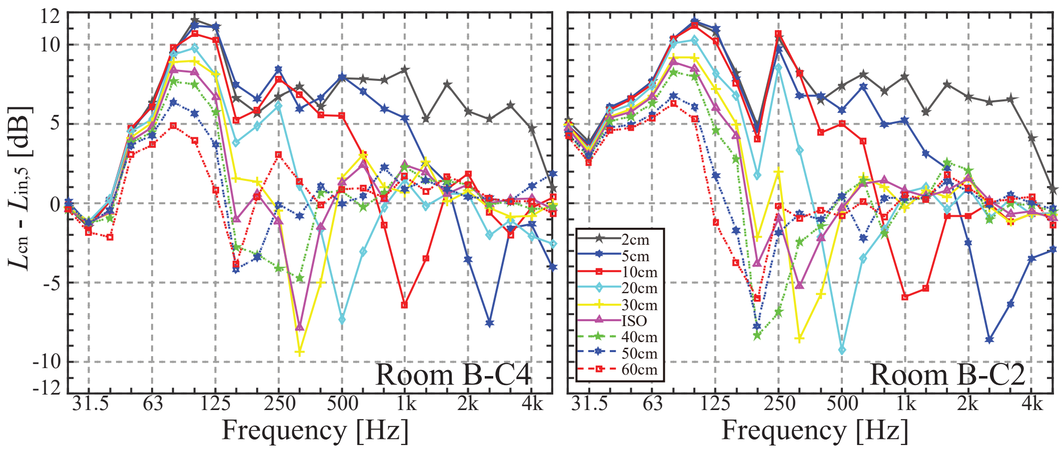


Figure 8 – Change in sound pressure level with varying the distance from the corner, relative to the average level in the central zone ($L_{in,5}$), around C4 and C2 in Room B

5. CONCLUSIONS

In order to verify the validity of the low-frequency procedure (corner method) specified for determining indoor average sound pressure level in ISO 16283 series, façade sound insulation measurements were performed for two rooms in a mock wooden house using a loudspeaker as outdoor sound source. Regarding the 5-point average level in the central zone for the default procedure as a reference, the deviation of sound pressure levels among all corners, and the influence of microphone position in the corner were examined.

Regarding the deviation among the corners, it was considerably great in the low-frequency range, and the far corners from the outdoor sound source tend to have higher levels up to 10 dB than the near corners. If the highest level among the corners is to be determined, four corners opposite the sound may be enough for the measurement. However, it should be noted that the obtained results are in the case of a wooden house having light façade walls with low sound insulation.

Regarding the influence of microphone position, it was confirmed that the ISO specification, that is, 0.3 to 0.4 m from each room boundary, is valid to determine the sound pressure level in the corner. However, it was suggested that the limitation for the near distance and the avoidance of identical distance from each boundary are not necessarily required.

In the corner method, the above two aspects for receiving points will be related with the empirical weighting factors in Eq. (1). As a future work, a test measurement using indoor multiple grid points will be done to examine the certainty of the sound insulation measurement.

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REFERENCES

1. ISO 16283-1:2014, Field measurement of sound insulation in buildings and of building elements, Part 1: Airborne sound insulation.
2. ISO 16283-3:2016, Field measurement of sound insulation in buildings and of building elements, Part 3: Façade sound insulation.
3. Hopkins C, Turner P. Field measurement of airborne sound insulation between rooms with non-diffuse sound fields at low frequencies. Appl. Acoust..2005;66(12):1339-82.
4. Simmons C. Measurement of sound pressure levels at low frequencies in rooms - Comparison of available methods and standards with respect to microphone positions. Proposal for new procedures. Nordtest Project No. 1347-97. SP Report 1997:27.
5. Sakuma T, Inoue N, Kami K. Numerical simulation and scale model experiment of low-frequency noise transmission into house. Proc Inter-Noise 2017; Hong Kong, China 2017. p. 413-20.
6. Liu J, Sakuma T. Experimental study on the low-frequency measurement of average sound pressure level in room. Proc Acoust Soc Jpn Spring Meet; Tokyo, Japan 2019. p. 683-4.
7. Hopkins C. Revision of international standards on field measurements of airborne, impact and façade sound insulation to form the ISO 16283 series. Build Environ. 2015;92:703-12.