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Reduction of heavy-weight impact sounds with sound absorbers for renovation of a box-type building with 120 mm-thick concrete slab

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ABSTRACT

In this study, effects of low frequency sound absorbers on reduction of heavy-weight impact noise were investigated in a box-type test building to improve sound isolation performances against impact noises. Two types of sound absorbers were prepared: frame type plane absorber using wood wool boards and corner bass trap using PU foam. Sound absorption properties of the absorbers were measured in a reverberation chamber in accordance with ISO 354. Then, the absorbers were installed in a box-type test building with concrete slab of 120 mm. Bang machine was employed as a heavy-weight sound source. In receiving room, maximum levels were measured at 54 points spacing by width 500 mm and length 600 mm. The experiment consists of 6 cases according to combination of the installed sound absorbers. As results, the case adding bass trap on top and side corners of receiving room showed maximum 3 dB reductions in terms of single number quantity based on KS F 2810-2 and KS F 2863-2. These sound absorbers were helpful to reduce room modes at 50 to 63 Hz. In addition, practical design approach of sound absorbers was discussed for further study.

Keywords: Sound absorbers, Heavy-weight impact noise, Retrofitted apartment building
I-INCE Classification of Subject Number: 45

1. INTRODUCTION

In South Korea, mandatory use of floating floor structure with resilient materials is a common solution to guarantee an acceptable level of impact sounds transmitted from upstairs[1-2]. However, improvement of floor structure is not easy in case of renovation of the existing deteriorated apartment buildings due to reuse of concrete structures with the d height of 2.4 m around[3].

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For that reason, retrofitting approaches of receiving room have been tried to increase room absorption in wall and ceiling[4-5]. Several studies reported the amplification of heavy-weight floor impact sounds especially in low frequency bands since room modes in box-type living rooms could occur due to surrounding parallel walls[6-9]. Moreover, 63 Hz sounds showed the maximum values at the fixed microphone height of 1.2 m in KS F 2810-2[10]. Some previous studies reported that increases of reverberation time in the receiving room could affect reducing heavy-weight impact sounds[11-12]. However, low-frequency specialized sound absorbers such as bass trap were not employed in the previous studies.

In this study, effects of low frequency sound absorbers on reduction of heavy-weight impact noise were investigated to improve sound isolation performances against impact noises for box-type apartment buildings to be renovated. Sound absorbing performances of the bass trap profiles were evaluated in a reverberation chamber. Then, it was verified in a box-type test building with slab thickness of 120 mm.

2. METHODS

2.1 Sound absorber profiles and measurements in a reverberation chamber

Four types of sound absorber profiles were selected for bass trap: a wall panel with wood wool board, a triangular prism with slit-shaped medium-density-fibreboard (MDF), a triangular prism with polyurethane (PU) foam, and a triangular prism with perforated gypsum board (GB). Twelve test cases were prepared to find out the effective sound absorber profiles as shown in Figure 1.

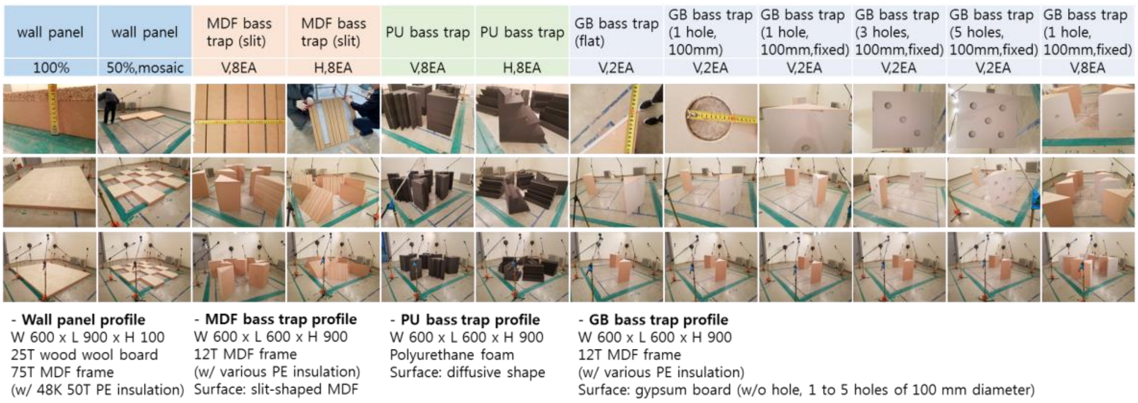


Fig. 1. Test configurations for sound absorber profiles in a reverberation chamber

The reverberation chamber employed in this study was located in Ochang, South Korea. It has a room volume of 209.7 m^3. Sound absorber specimen was installed in centre of the reverberation chamber floor. Two omni-directional sound sources and six microphones with different positions were employed to measure reverberation time of each test case. Equivalent sound absorption area per object (A_{obj}) was derived using reverberation time measured with and without specimen according to ISO 354[13].

2.2 Measurements in a box-type test building

The box-shaped test building employed in this study was located in Chungju, South Korea. It consists of two stories with slab thickness of 120 mm (Sample room #3). On the concrete slab, a floating floor structure with 30 mm-thick ethylene-vinyl acetate (EVA), 40 mm-thick light-weight aerated concrete and 40 mm-thick finishing mortar was installed. Ceiling was finished by 9.5 mm-thick gypsum board with air cavity of 180 mm and non-hanger type metal frame. Dimension of the receiving room was 3.5 m width, 5.9 m length and 2.4 m height.

Figure 2 shows six test configuration according to combination of sound absorbers in the receiving room based on the measurements in the reverberation chamber. The first case (c0) is empty room with impacts on centre (S1) and corner (S2) of the sound source room. The second case (c1) is with the maximum use of sound absorbers. The third and fourth cases (c2 and c3) used wall panel shaped sound absorbers. The fifth and sixth cases (c4 and c5) used PU bass trap shaped sound absorbers. For measuring heavy-weight impact sounds, bang machine was employed to measure the maximum impact sound pressure level with fast property (L_{iFmax}) in accordance with KS F 2810-2[10]. Single number quantity (SNQ) was derived using inverse-A weighting filter in accordance with KS F 2863-2[14]. Basically five fixed receiver positions including centre and 4 corners of 75 cm off from adjacent wall surfaces were employed according to Korean legal guideline[15]. In addition, 54 points of grid measurements were carried out with spacing of 500 to 600 mm. Receiver height was fixed as 1.2 m. In the grid measurement, reverberation time (T_{20}) in the receiving room was measured using omni-directional loudspeaker.

Case	c0		c1	c2	c3	c4	c5
	empty		wall + side corner	wall	both walls	side corner	upper corner
Sound absorbers	none		wall panel x 16 PU bass trap x 8	wall panel x 16	wall panel 8+8	PU bass trap x 8	PU bass trap x 8
Source position	S1	S2	S1	S1	S1	S1	S1

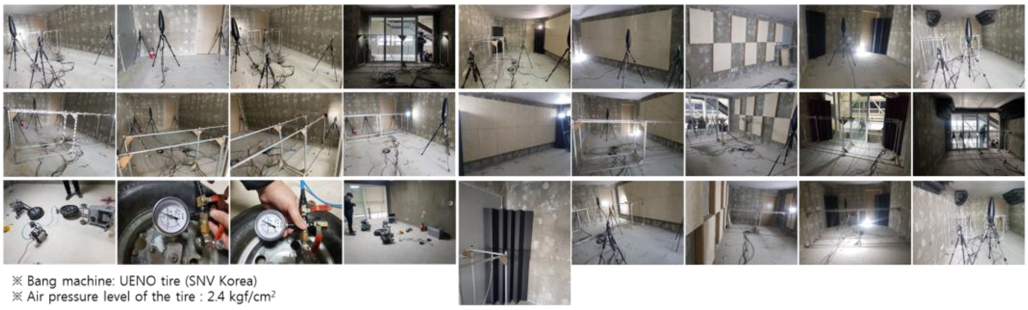


Fig. 2. Test configurations of the box-shaped test building with combination of sound absorbers

3. RESULTS

3.1 Sound absorption in a reverberation chamber

Figure 3 shows the measurement results for each test specimen in terms of equivalent sound absorption area per object in the reverberation chamber. The triangular shaped PU bass trap showed the highest sound absorption over all frequency bands. Wall panel made of wood wool board showed sound absorption mainly over 250 Hz area. 50% arrangement of the wall panel sound absorbers showed higher performance than 100% arrangement. The specimens of MDF and GB bass traps did not show high performance of low-frequency sound absorption. In case of PU bass trap, vertical arrangement showed a little higher sound absorption below 250 Hz area, whereas horizontal arrangement showed higher sound absorption over 250 Hz.

In this study, wall panel and PU bass trap were selected as shown in Figure 4 for the experiments in a box-shaped test building. Wall panel shaped sound absorber can be applied to lateral walls in a living room of apartment buildings. Although the shape and size of the PU bass trap is not proper to use practically, it was selected due to its high performance of sound absorption.

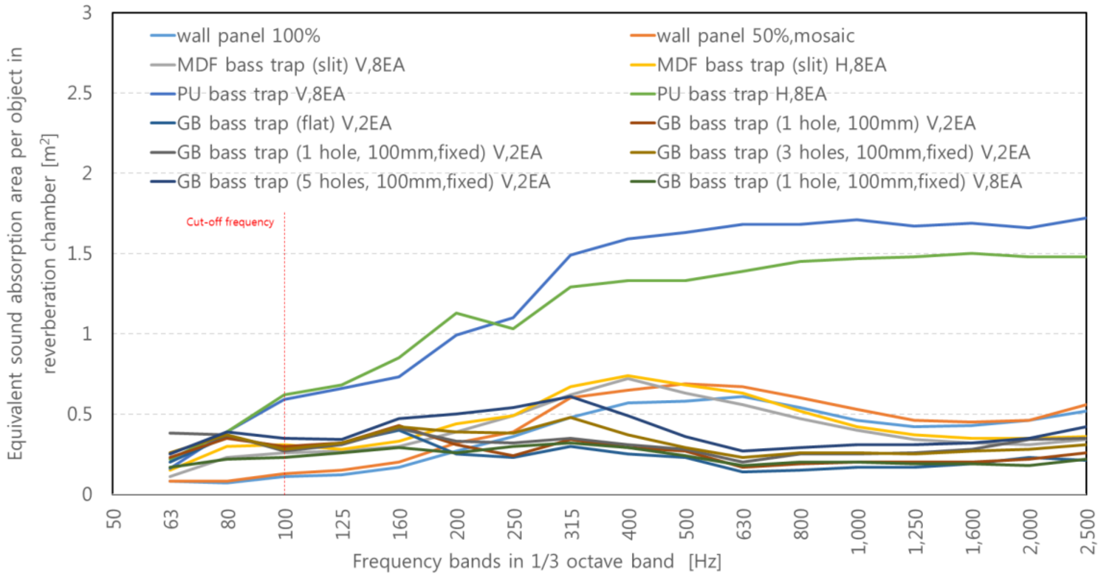


Fig. 3. Equivalent sound absorption area per object of the sound absorber profiles measured in the reverberation chamber

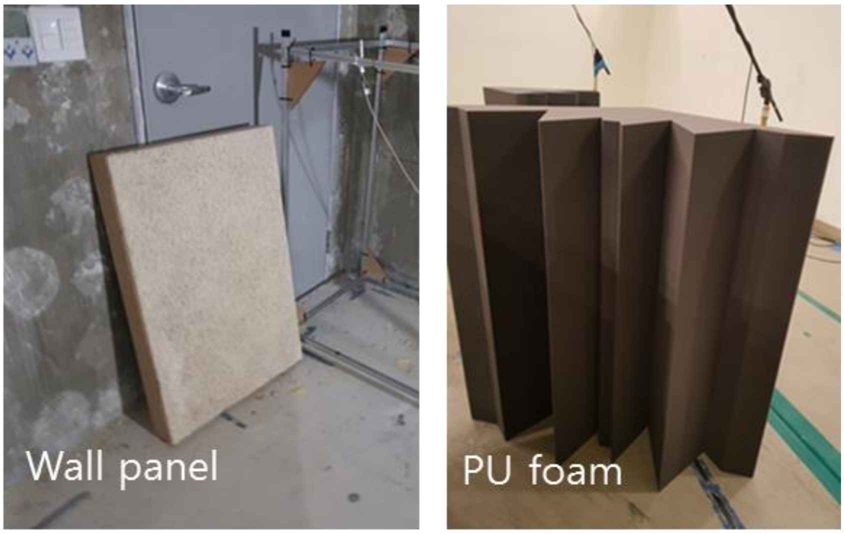
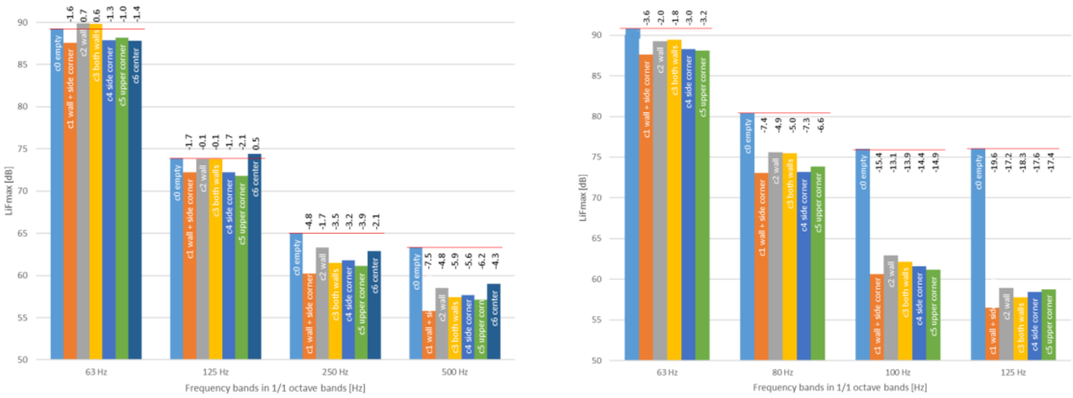


Fig. 4. Selected sound absorber profiles based on the measurements in the reverberation chamber

3.2 Heavy-weight floor impact sounds in a box-type test building

Figure 5 shows the measurement results of L_{iFmax} values for each case. In case of the measurement using 5-fixed points, an additional configuration (c6) to arrange PU bass trap randomly in centre is considered. As shown in Figure 5(a), use of PU bass trap yielded decrease of 63 Hz sound levels by 1 to 1.6 dB for the measurement of 5-fixed points. However, 63 Hz sound level of the cases using wall panels was rather increased. Sound levels over 250 Hz were all decreased after adding sound absorbers. On the other hand, the measurement of 54-grid points showed clear decrease of sound levels for all frequency bands after adding sound absorbers as shown in Figure 5(b). At 63 Hz in 1/1 octave bands, sound levels were decreased by 1.8 to 3.6 dB by sound absorbers. PU bass trap showed better performance than wall panels in terms of low-frequency sound absorption below 125 Hz. At 125 Hz, it was decreased by 4.9 to 7.4 dB. There was little difference between the measurement cases when use of PU bass trap.



(a) Results of 5-fixed points *(b) Results of 54-grid points*

Fig. 5. Results of L_{iFmax} values in 1/1 octave bands by different averaging methods measured in the box-type test building with 120-mm thick concrete slab

Table 1 shows the single number quantity values of each test case. Similar to the previous study[12], SNQ values of heavy-weight floor impact sounds using bang machine were decreased up to 3 dB measured by the Korean regulation using 5-fixed points. Especially use of PU bass trap showed 58 to 59 dB, whereas use of wall panels showed 60 dB. In case of the measurement using 54-grid points, empty room showed very high level of 70 dB due to room modes. In case of the corner impact (S2), SNQ of the empty room was 65 dB which is 4 dB higher than the centre impact (S1).

Table 1. Single number quantity of heavy-weight floor impact sounds at centre impact (S1) measured in the box-type test building with 120-mm thick concrete slab

Case No. with sound absorber application		SNQ of 5-fixed points	SNQ of 54-grid points
0	Empty room	61 (corner impact: 65)	70
1	Sound absorbers on wall and side corner	58	59
2	Sound absorbers on one side of wall	60	61
3	Sound absorbers on both sides of wall	60	61
4	Sound absorbers on side corner	59	59
5	Sound absorbers on upper corner	58	59

3.3 Sound absorption in a box-type test building

Reverberation time was measured at the 54-grid points. Two different sound source positions were considered to maintain minimum distance of 1 m between sound source and receivers. Figure 6 shows frequency characteristics of the measured reverberation time for each case. Empty room condition showed a reverberation time of 2 s around. In cases of wall panel sound absorbers, reverberation time in low frequency bands below 125 Hz was 1 to 1.5 s. Staggered arrangement of both side walls using wall panel sound absorber showed shorter reverberation time by about 0.7 to 0.8 s at 500 Hz around than the arrangements in single side wall even with the same amount of sound absorbers. PU bass trap effectively decreased reverberation time at low frequency bands below 250 Hz up to 0.5 s around. Figure 7 compared the equivalent sound absorption area per object of wall panel and PU bass trap sound diffusers. Low frequency absorption characteristics of the PU bass trap was revealed in the box-type test building results. However, the wall panel sound absorbers showed low sound absorption performance at lower frequency bands in both reverberation chamber and box-type test building.

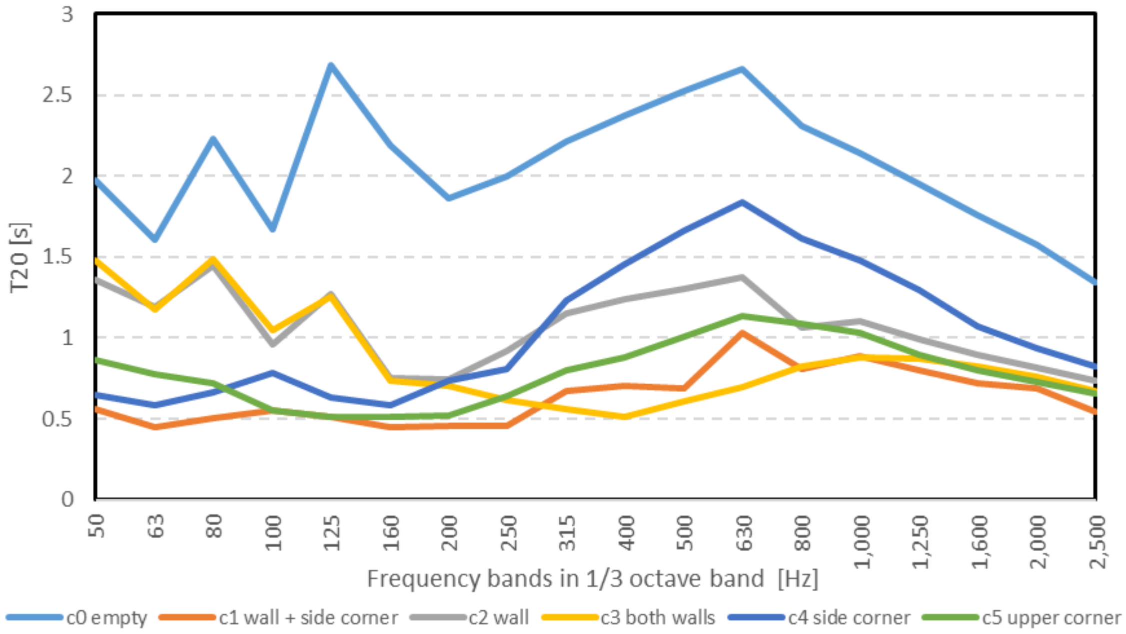
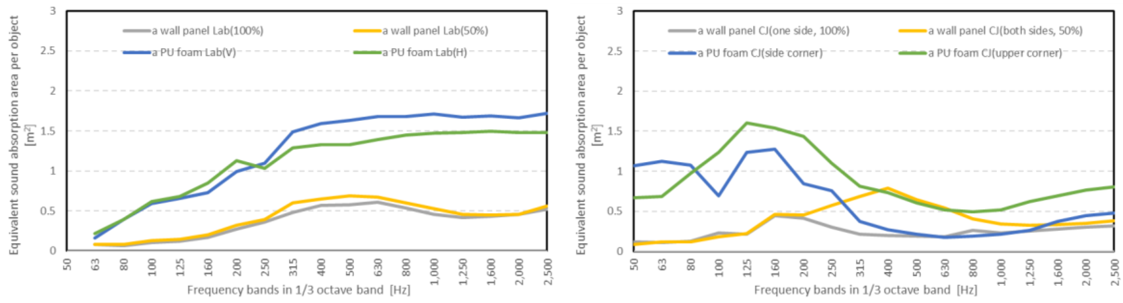


Fig. 6. Frequency characteristics of reverberation time measured in the box-type test building with 120-mm thick concrete slab



(a) Results in the reverberation chamber *(b) Results in the box-type test building*

Fig. 7. Comparison of equivalent sound absorption area per object of the wall panel and the PU bass trap between the reverberation chamber and box-type test building

3.4 Spatial distribution of floor impact sounds and reverberation time in a box-type test building

Figures 8 to 10 showed spatial distribution of L_{iFmax} levels and reverberation time in terms of T_{20} of each measurement case for 63 Hz, 125 Hz and 500 Hz, respectively. In case of 63 Hz, amplifications of the sound levels were clearly disappeared as shown in Figure 8. Reverberation time with the PU bass trap is also clearly decreased by almost 1 s. However, wall panels were not so effective to decrease reverberation time at 63 Hz.

In case of 125 Hz, the sound levels in longitudinally-middle area were amplified in the empty room condition as shown in Figure 9. However, the sound levels with sound absorbers were to be more uniformly distributed. In cases of the vertically-installed PU bass trap (c1 and c4), dramatic decrease of sound levels at corner area were observed.

In case of 500 Hz, the sound level distribution showed the similar tendency with the 125 Hz results as shown in Figure 10. After adding sound absorbers, the sound levels were clearly decreased up to 50 dB around for all cases. In cases of the wall panels on one side (c2) and PU bass trap at side corners (c4), large spatial deviations of reverberation time were observed.

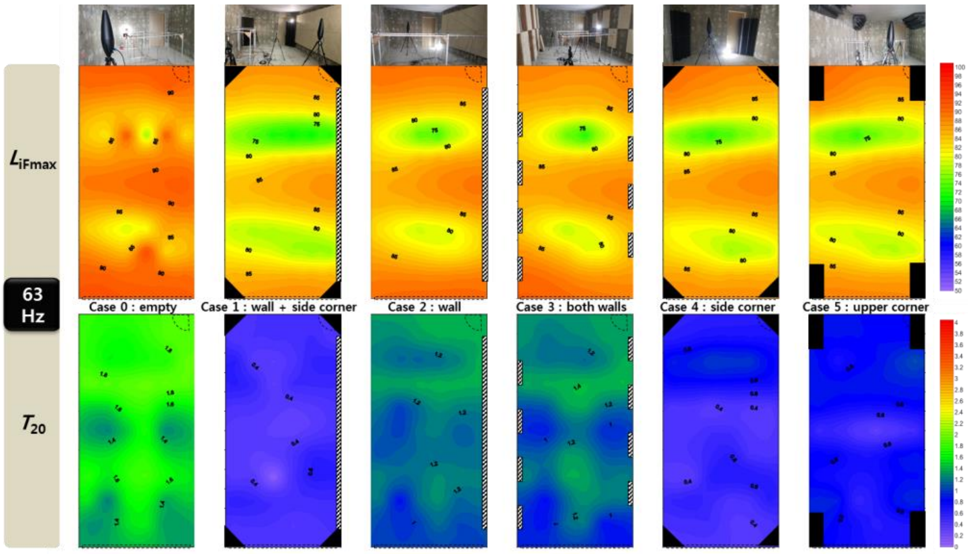


Fig. 8. Spatial distribution of L_{iFmax} and T_{20} at 63 Hz of 1/3 octave bands

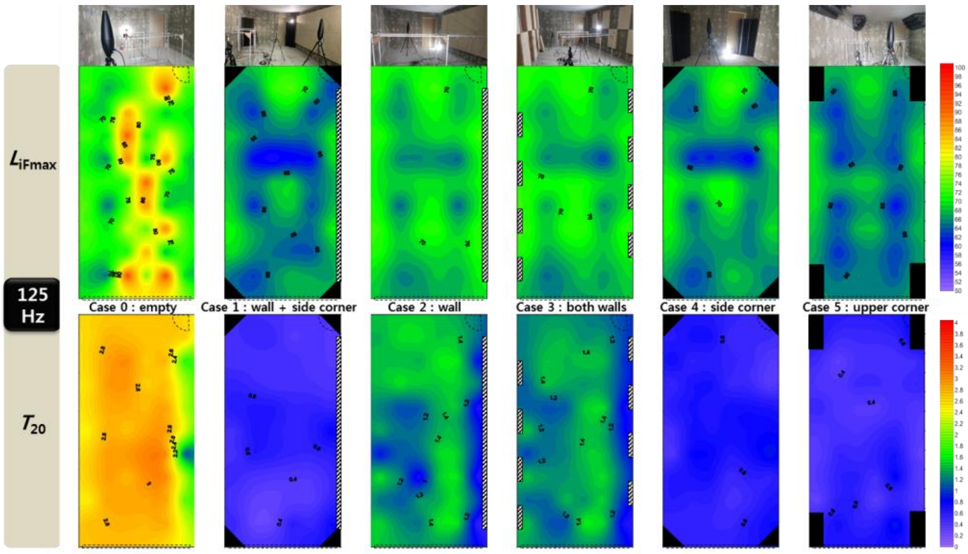


Fig. 9. Spatial distribution of L_{iFmax} and T_{20} at 125 Hz of 1/3 octave bands

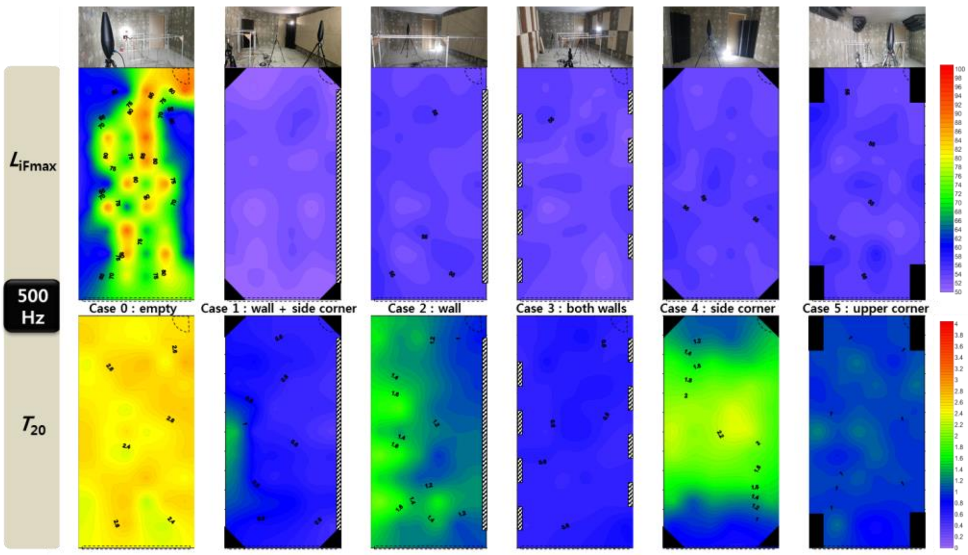


Fig. 10. Spatial distribution of L_{iFmax} and T_{20} at 125 Hz of 1/3 octave bands

4. CONCLUDING REMARKS

In this study, the low-frequency sound absorbers showed up to 3 dB reduction of heavy-weight floor impact noise using bang machine and 5-fixed points in a box-type test building. To extend 54-grid positions which covers almost all receiving room, the low-frequency sound absorbers could partly suppress the amplification of sound pressure levels by room modes. Accordingly, it leads to reduce about 3 to 6 dB of maximum sound pressure level at 63 Hz, about 6 to 9 dB at 125 Hz, and about 20 to 30 dB at even 500 Hz in 1/1 octave bands. Since measurements of low-frequency sound absorption in a reverberation chamber are lack in differentiation of sound absorber profiles, a practical evaluation under *in situ* condition is required to find out effective bass trap.

As a further study, *in situ* application to the actual apartment building to be renovated will be carried out. In addition, it is needed to develop more acceptable design of bass traps with high performance of low-frequency sound absorption.

5. ACKNOWLEDGEMENTS

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