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Modelling of house filter for wind turbine noise

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Summary

Wind turbine noise can often be audible inside the residential buildings around wind farms, potentially causing residents' psycho-acoustical annoyance and sleep disturbance. Acoustic measurements inside buildings, however, are very difficult from a physical viewpoint and can invade residents' privacy. Therefore, the noise levels inside houses have to be estimated from the levels measured outdoors. That is, the sound insulation of houses needs to be modelled. The authors have conducted field measurements of wind turbine noise across Japan over the three years from fiscal year 2010, in which simultaneous measurements of outside/inside residential buildings were conducted optionally in cases where the residents were cooperative. Among the data obtained in the measurements, 22 data for ordinary residential buildings were analysed in A-weighted sound pressure level and 1/3-octave-band sound pressure levels from 1 Hz to 500 Hz. Based on those data, the possibility of modelling the "house-filter" according to the classification of window construction was investigated by referring some other data regarding sound insulation performance of general residential buildings.

1. Introduction

Wind turbine noise (WTN) generally has dominant components at low frequencies and is easily transmitted into buildings, causing residents' psycho-acoustical annoyance and sleep disturbance [1]. Therefore, it is essential to assess the noise levels of WTN inside residential buildings, but acoustic measurements inside buildings are very difficult from a physical viewpoint [2,3] and can invade residents' privacy and the levels should be estimated from the levels measured outdoors. To do this, the sound pressure level (SPL) difference between outside and inside a building (sound insulation) needs to be modelled as an acoustic filter (house-filter) which represents the frequency characteristic of sound insulation performance of general houses. Based on the measurement data obtained at wind farm sites in Japan, the possibility of modelling the "house-filter" was investigated by referring some other data regarding sound insulation performance of general residential buildings.

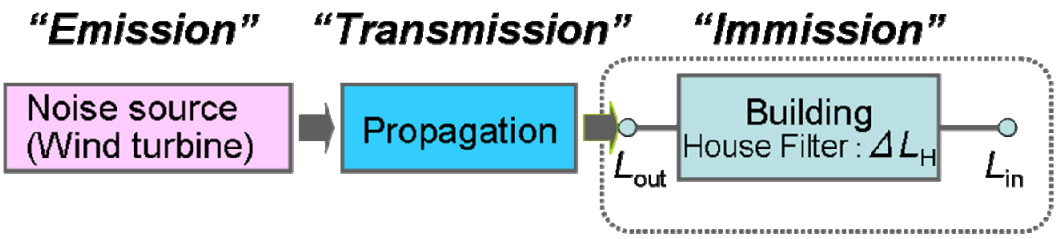

Figure 1: Flow of wind turbine noise problem

2. Field measurements

To investigate the actual condition of WTN in Japan, a research project entitled “Research on the evaluation of human impact of low frequency noise from wind turbine generators” has been conducted over the three years from fiscal year 2010, funded by a grant from the Ministry of the Environment, Japan, in which field measurements at 34 wind farm sites were conducted across Japan [4]. In this field study, simultaneous measurements of outside/inside residential buildings were conducted optionally in cases where the residents were cooperative.

2.1 Measurement instrumentation

In the WTN measurements, a prototype wide-frequency-range sound level meter was manufactured by RION Co. for the requirements of the measurement frequency range from 1 Hz to 20 kHz, with a function for recording the sound pressure signal built into its body (48 kHz sampling, 16 bits, WAVE format). To prevent wind-induced noise, a double-skin-type wind screen set was attached to the microphone of the sound level meter positioned outdoors.

2.2 Measurement results of SPLs outside/inside houses

In the field measurements, 22 data of SPLs outside and inside the residential buildings around wind farms were obtained. All of the houses under measurement are of wooden construction common in Japan and they have various types and areas of windows. The outside measurement point was positioned at a point 1.5 m or more apart from the building façade and 20 cm above the ground, and the inside one was positioned at a point about 1.5 m apart from the window and about 1.2 m above the floor as a representative position in normal use of the room. Since the main purpose of the field survey of this research project was to measure the actual condition of WTN outdoors and enough time could not spare for the indoor measurements.

The time averaged 1/3-octave-band SPLs from 1 Hz to 5 kHz for 10 min analysed from the recordings are shown in Fig. 2. For outside SPLs, insects’ sounds were included in some of the measurement results conducted in summer and autumn seasons. As for the data measured inside, the SPLs in the frequency bands higher than 500 Hz might be influenced by the indoor noises and the internal noise of the measurement instrumentation.

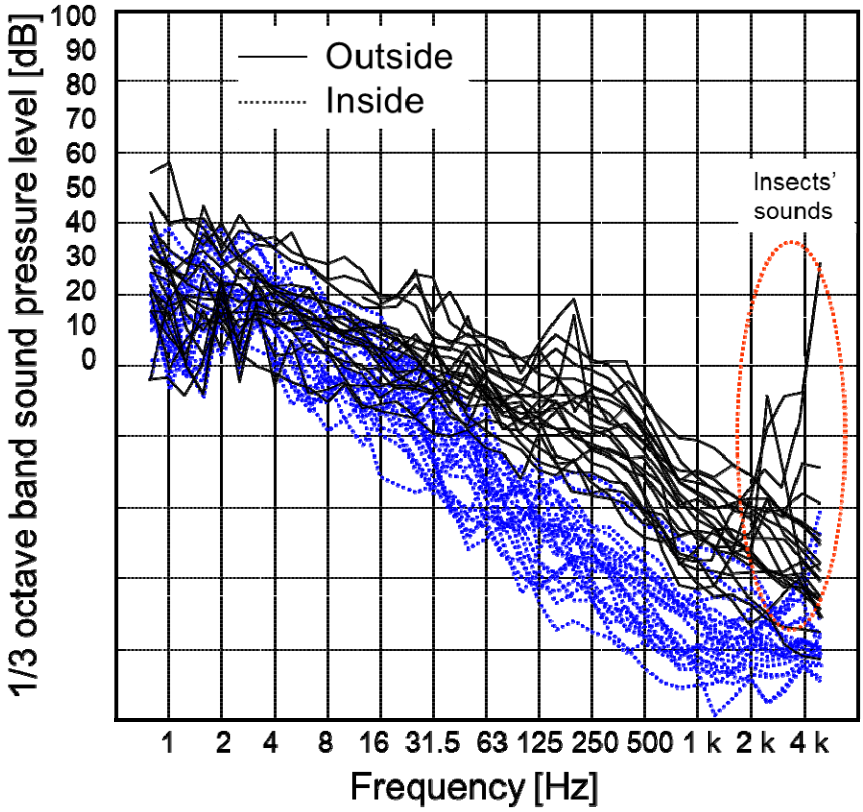

Figure 2: 1/3 octave band sound pressure levels of wind turbine noise measured outside and inside 22 residential buildings

Figure 3 shows the over-all A-weighted SPLs measured outside/inside the 22 houses, in which the window construction was classified into three types: (a) double-pane (aluminium frame) window, (b) single-pane (aluminium frame) window and (c) single-pane (wooden frame) window. In this result, it is seen that the average level difference between the A-weighted SPL outside ($L_{Aeq,out}$) and that inside ($L_{Aeq,in}$) is 17.7 dB on average and a tendency is seen that sound insulation performance is high in order of (a), (b) and (c).

Figure 4 shows the correspondence between the over-all A-weighted SPL ($L_{Aeq,OA}$) and that assessed in the limited frequency bands from 10 Hz to 160 Hz in 1/3 octave bands ($L_{Aeq,LF}$) which is used in the Danish Regulation [5]. The result shows that they are in fairly high correlation with about 7.5 dB difference.

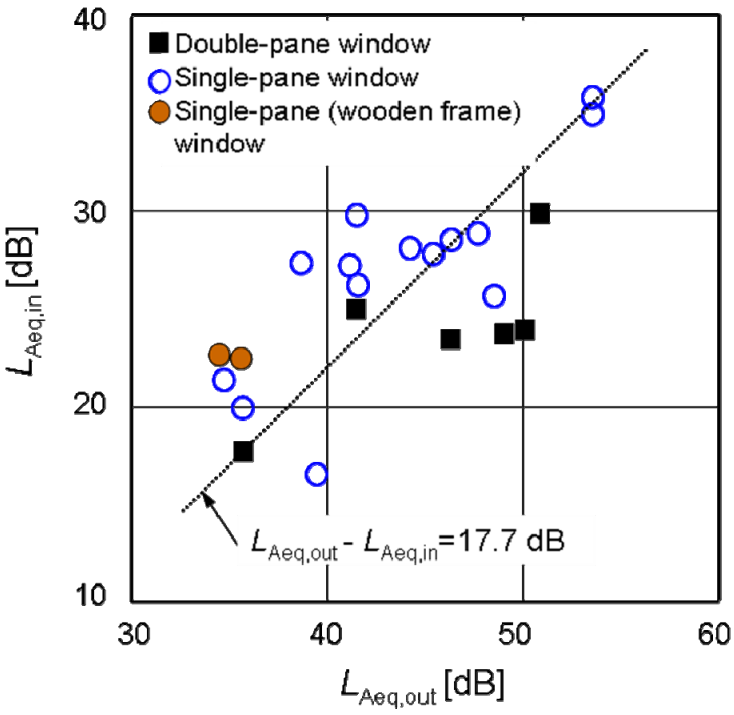

Figure 3: over-all A-weighted SPLs measured outside/inside the 22 houses.

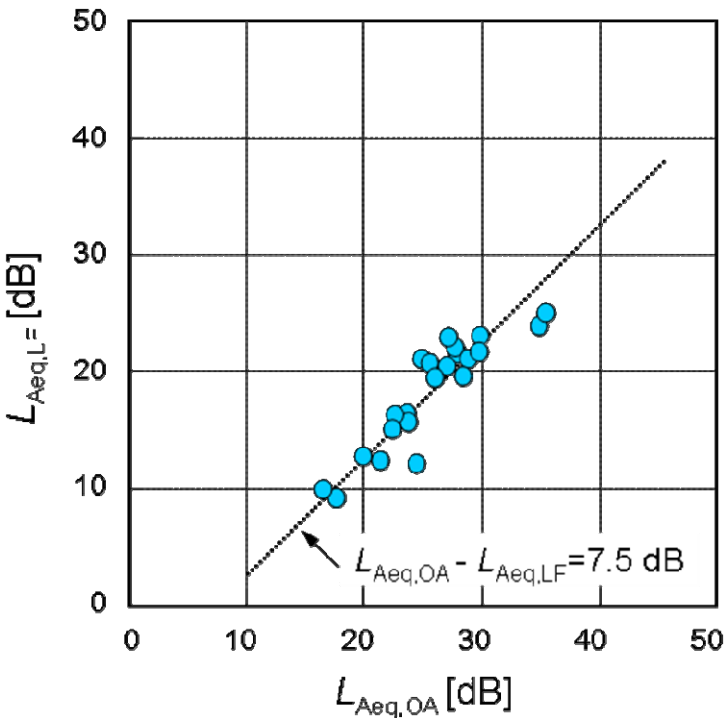

Figure 4: Correspondence between the over-all A-weighted SPL ($L_{Aeq,OA}$) and that assessed in the limited frequency bands from 10 Hz to 160 Hz in 1/3 octave bands ($L_{Aeq,OA}$)

Regarding the 1/3-octave-band SPL difference between outside and inside each house under measurement, four examples are shown in Fig. 5, in which the inside levels in frequency bands higher than 500 Hz might be influenced by the indoor noises and the internal noise of the measurement instrumentation.

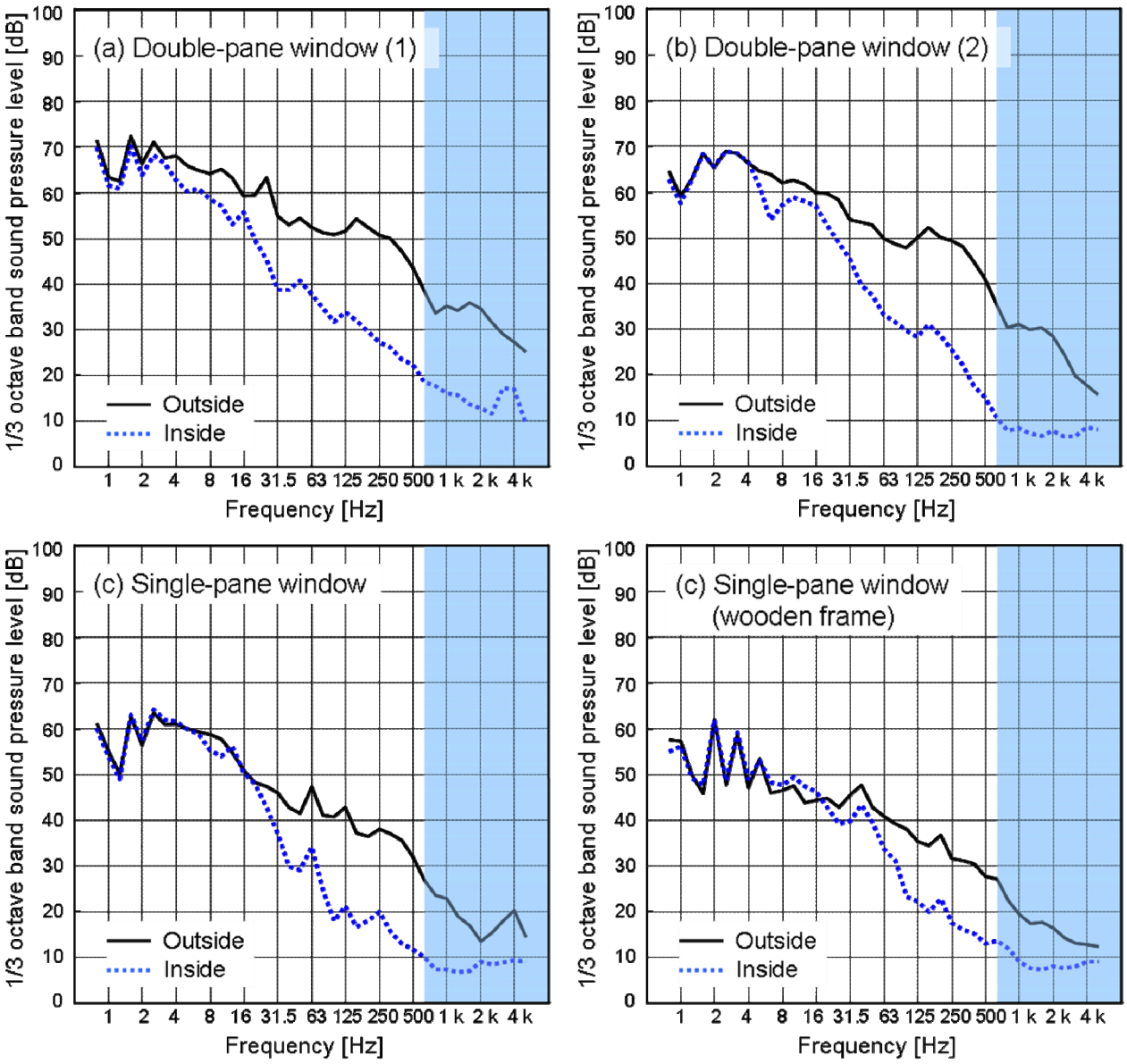

Figure 5: Four examples of the comparison of 1/3 octave band SPLs measured outside and inside the houses.

3. Modelling of the House Filter

From the measurement results of 1/3-octave-band SPLs outside and inside the 22 houses shown in Fig. 2, the SPL difference between outside and inside for each house were obtained for 6 houses with double-pane window, 14 houses with single-pane window, and 2 houses with single-pane (wooden frame) window as shown in Figs 6, 7 and 8. Since the number of the data for each window type is not sufficient for statistical consideration, the simple arithmetic average of the SPL difference was calculated as shown in each figure by the thick line.

Based on the results shown in Figs. 6, 7 and 8 and by simplifying the arithmetic average value for each window type, three kinds of house-filter models were assumed as shown in Fig. 9. They have general frequency characteristics that sound insulation is zero in the infrasound region and increasing at a rate of 4 dB/octave up to 250 Hz. At frequencies higher than 250 Hz, constant values were assumed empirically. Model **C** is based on only two data and is not so reliable.

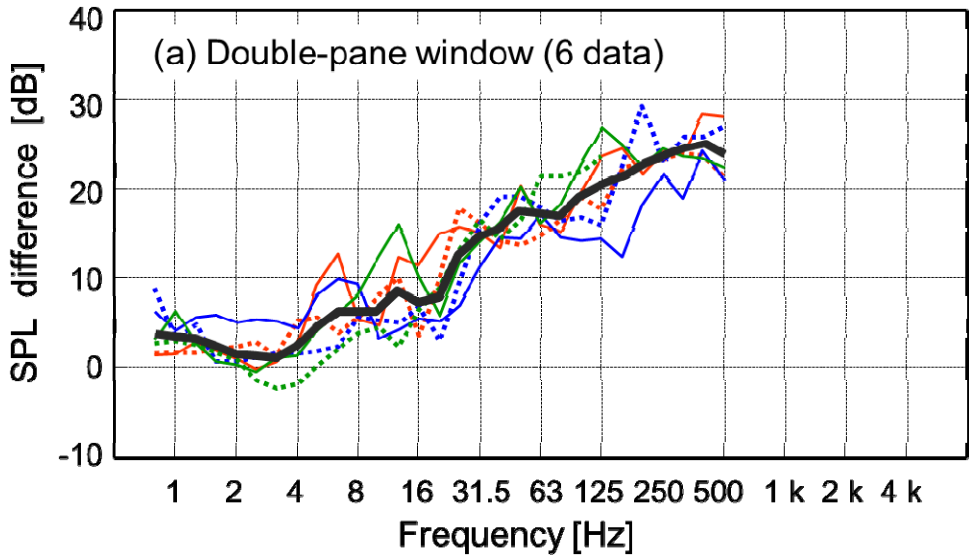

Figure 6: 1/3-octave-band SPL difference for 6 houses with double-pane window

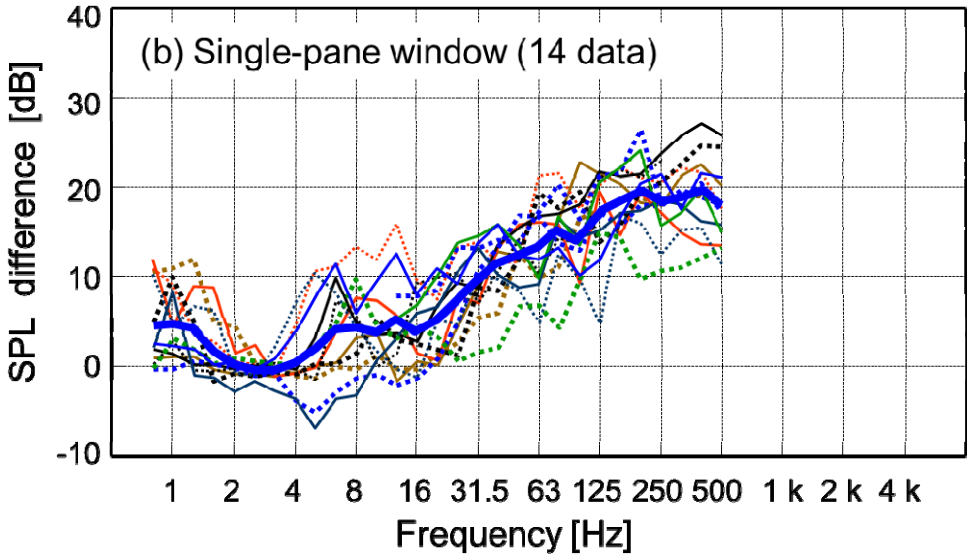

Figure 7: 1/3-octave-band SPL difference for 14 houses with single-pane window

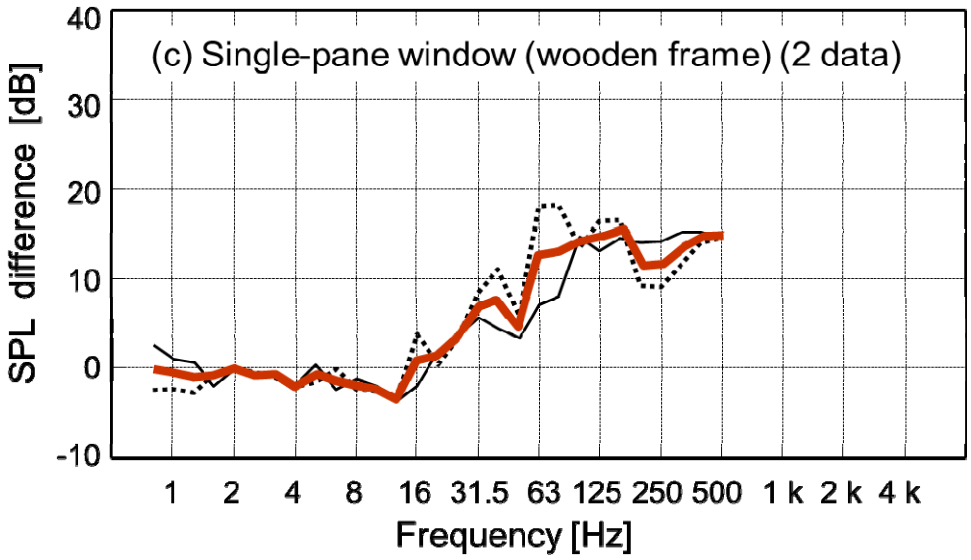

Figure 8: 1/3-octave-band SPL difference for 2 houses with single-pane (wooden frame) window

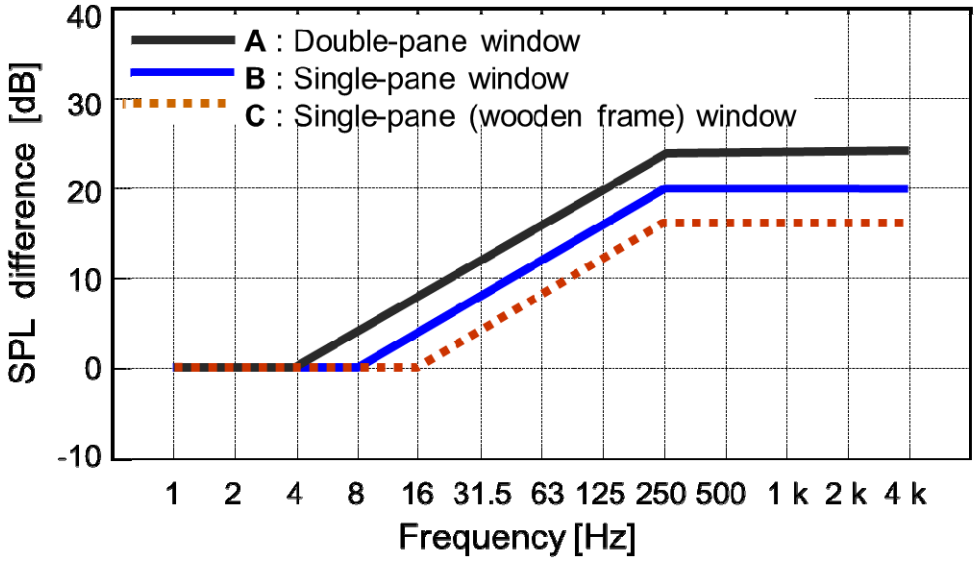

Figure 9: House Filter Models for three kinds of window constructions.

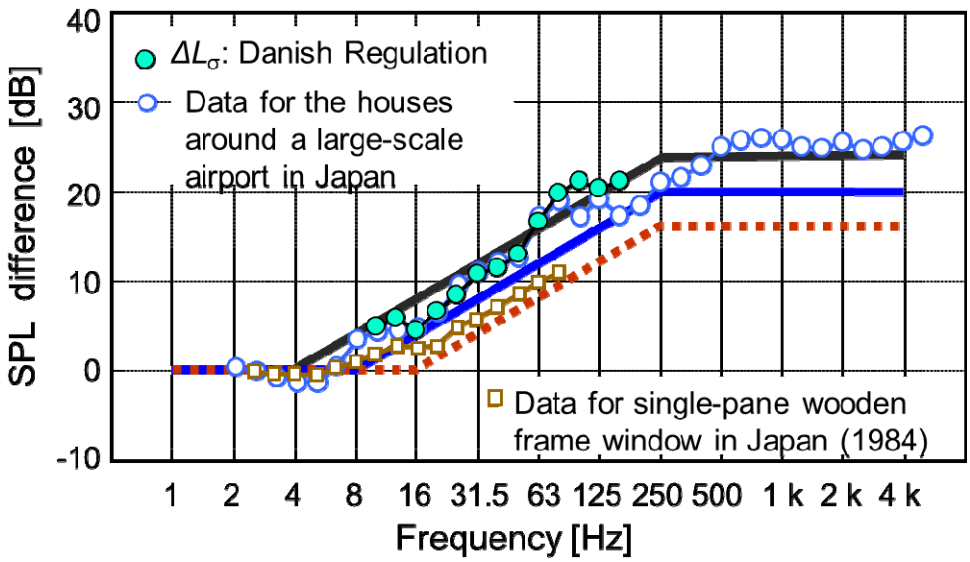

Figure 10: Comparisons between the House Filter Models and the reference data.

To check the house-filter models with other sound insulation data in 1/3-octave-bands, three reference data are introduced as shown in Fig. 10. The first is the outside/inside SPL differences specified in the Danish Regulation for predicting low-frequency sound of WTN in general Danish residential buildings [5]. The data (-●-) well falls on model curve **A**.

The second is the arithmetic average of the outside/inside SPL differences of 9 Japanese wooden houses with single-pane aluminium-frame windows against aircraft noise. The measurements were performed around a large-scale airport in Japan in 2002 using a low frequency sound level meter and a normal sound level meter. The outside measurement microphones with wind-screen sets were positioned at a point 5 m or more apart from building façade and close to the ground and the inside microphones were positioned at a point about 1 m apart from the window and about 1.2 m above the floor as a representative position in normal use of the room. As shown in Fig. 10, the data (-○-) is in fairly good agreement with the Danish data and are plotted between model curves **A** and **B**.

The third is the arithmetic average of the outside/inside SPL differences of 18 Japanese wooden houses with single-pane wooden-frame windows against various kinds of industrial low-frequency sounds [6]. The measurements were performed in Japan about 30 year ago using a low frequency sound level meter. In each measurement, a couple of microphones of low-frequency sound level meters were positioned 1 m outside and inside the window and 1.2 m above the ground (outside) and the floor (inside). As shown in Fig. 10, the data (-□-) is

almost parallel to model curve **C** with a small difference. This old type of window is scarcely used for recent residential buildings in Japan.

4. Conclusions

- In general environmental noise problems, the effect of noise inside houses should be considered. Especially in WTN problem, it often causes residents' sleep disturbance at night. In usual environmental noise monitoring, however, it is rather difficult to measure the noise inside houses by thrusting microphones into them. In the noise impact assessment, it is necessary to predict the noise level inside houses. Therefore, standard model of sound insulation performance of residential buildings (house-filter) is desired to be established.
- As a trial for this aim, simultaneous measurements outside/inside houses were optionally conducted in the field measurements of WTN across Japan and 22 data of outside/inside SPL difference were obtained. All the houses under measurement were of wooden construction common in Japan and they have various types and areas of windows.
- Although the SPL distribution in a room is very much complicated and the way to estimate the representative SPL is still open to argument, the measurement was conducted at only one representative position in normal use of each room (about 1.5 m apart from the window and about 1.2 m above the floor).
- As a result, outside/inside SPL difference in terms of over-all A-weighted SPL was about 18 dB against WTN.
- For respective window types, the arithmetic mean values of outside/inside SPL differences in 1/3-octave-bands from 1 Hz to 500 Hz were calculated and they were approximated using line graphs as the house-filter models. The model curves have general frequency characteristics that the SPL difference is zero in the infrasound region and increasing at a rate of 4 dB/octave up to 250 Hz and constant at frequencies higher than 250 Hz.
- The house-filter models were checked with three reference data: the SPL differences specified in the Danish Regulation for predicting indoor low-frequency sound level of WTN, the measurement data of sound insulation of 9 houses against aircraft noise performed around a large-scale airport in Japan, and the data of 18 wooden houses with single-pane wooden-frame windows against various kinds of industrial low-frequency sounds. As a result, it has been found that these data can be simplified by any of the house-filter models, **A**, **B** or **C**, which were assumed based on the data obtained at wind farm sites.

References

[1] Sonoko Kuwano, Takashi Yano, Takayuki Kageyama, Shinichi Sueoka and Hideki Tachibana, "Social survey on wind turbine noise in Japan," *Noise Control Eng. J.*, 62(6), 503-520 (2015).

[2] Dan Hoffmeyer and Jørgen Jakobsen, "Sound insulation of dwellings at low frequencies," Proc. 14th International Meeting on Low Frequency Noise and Vibration and its Control (2010).

[3] Jonas Brunskog, Finn Jacobsen, "A note on measurement of low-frequency noise in rooms," Proc. 14th International Meeting on Low Frequency Noise and Vibration and its Control (2010).

[4] H. Tachibana, H. Yano, A. Fukushima and S. Sueoka, "Nationwide field measurements of wind turbine noise in Japan", *Noise Control Eng. J.*, 62(2), 90-101 (2014).

[5] Jørgen Jakobsen, "Danish regulation of low frequency noise from wind turbines," Proc. 15th International Meeting on Low Frequency Noise and Vibration and its Control (2012).

[6] Kazuo Shimizu, "Structural response and sound insulation properties of house construction by low frequency sound," Journal of INCE/J, 8(1) (1984) (in Japanese).