Finnish Round Robin Test on Airborne Sound Insulation

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Summary

The Acoustical Committee of the Finnish Association of Civil Engineers RIL organized a round robin test on airborne sound insulation measurements in 2016. The purpose of the test was to offer an opportunity to compare measurement results and to confirm their validity for operators carrying out sound insulation measurements in Finland. In total, 19 measurement groups from 14 different organizations took part in the test which was carried out in an office building made of concrete. Airborne sound insulation between two office rooms was measured vertically in accordance with the standard ISO 16283-1 and single-number quantities were calculated according to the standard ISO 717-1. The participants determined independently apparent sound reduction indices R' and standardized level differences D_{nT} in one-third octave bands and calculated single-number quantities R'_{w} and $D_{nT,w}$ as well as spectrum adaptation terms C, C_{tr}, $C_{50\text{-}3150}$, $C_{50\text{-}5000}$, $C_{100\text{-}5000}$, $C_{tr,50\text{-}3150}$, $C_{tr,50\text{-}5000}$ and $C_{tr,100\text{-}5000}$ from their own results. On the basis of all the results, the weighted apparent sound reduction index R'_{w} was between 57 and 62 dB while the average was 59,9 dB and the standard deviation 1,2 dB. The weighted normalized level difference ranged from 56 to 61 dB while the average was 59,0 dB and the standard deviation 1,2 dB. The deviation of the one-third octave band results was largest in the frequency bands below 100 Hz, which results from the measurement uncertainty of this frequency range. Compared to the standard uncertainties presented in the standard ISO 12999-1 the deviations of the results were mainly larger.

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1. Introduction

The Acoustical Committee of the Finnish Association of Civil Engineers RIL organized a round robin test on airborne sound insulation field measurements in the autumn of 2016. The purpose of the test was to offer an opportunity to compare measurement results and to confirm their validity for operators carrying out sound insulation measurements in Finland.

In total, 19 measurement results were obtained from the groups from 14 different organizations who measured airborne sound insulation between the two rooms. The organizations that took part in the measurements were both educational and research institutes as well as engineering design companies working in the field. The test report is available in Finnish [1].

2. Measurements

The Acoustical Committee of RIL sent a letter of invitation to the round robin test to Finnish organizations carrying out acoustical measurements in August 2016. In September 2016, a more specific information letter was sent to those registered for the test. The measurements were carried out in vertical direction between two office rooms in an office building made of concrete. The participants were directed to carry out the measurements in accordance with the valid standards ISO 16283-1 and ISO 717-1 and by using their respective measuring devices. Each of the participants had to carry out the measurements and to determine the room dimensions and the measurement conditions independently.

The participants determined apparent sound reduction indices R' and standardized level differences D_{nT} in 1/3-octave-bands from their measurements. From these results, the groups calculated the corresponding single-number quantities (SNQ's) R'_w and $D_{nT,w}$, as well as spectrum adaptation terms C, C_{tr}, $C_{50\text{-}3150}$, $C_{50\text{-}5000}$, $C_{100\text{-}5000}$, $C_{tr,50\text{-}3150}$, $C_{tr,50\text{-}5000}$ and $C_{tr,100\text{-}5000}$ (later, the spectrum adaptation terms in general are denoted as C_i). The participants wrote down their results into a predetermined file, which was sent to the office of the test organizer. The organizer anonymized the results before handing them over to the authors. The measurement groups were labelled as A1...A19.

3. Results

All results of the apparent sound level indices R' and the standardized level differences D_{nT} are shown in 1/3-octave-bands in Figure 1. Based on the results, two participants A7 and A8 distinguished from the other groups as outliers. The results of these outlier groups were anomalous in the high-frequency range over the 1250 Hz band. Moreover, the results of the participant A7 were considerably smaller than other results in the 50 Hz frequency band.

The standard deviation of all the apparent sound level indices R' was 1,1–7,7 dB and 0,8–5,7 dB when the results of the outliers were excluded. Furthermore, the standard deviation of the standardized level differences D_{nT} was 1,0–7,6 dB and 0,8–5,8 dB in case of all results and without outliers, respectively. The determined volume of the receiving room varied from 48 to 61.8 m^3 [1].

Tables 1 and 2 show averages, minimum and maximum values, as well as standard deviations of the SNQ's R'_w, $R'_w + C_i$ and $D_{nT,w}$, $D_{nT,w} + C_i$, respectively. Tables show the results for all the measurements and when the outliers were excluded. Based on all results, the average of the SNQ R'_w was 59,9 dB and the standard deviation 1,2 dB. The corresponding results for the SNQ $D_{nT,w}$ were 59,0 dB and 1,2 dB. Without the results of the outliers, the averages and standard deviations of the SNQ's R'_w and $D_{nT,w}$ were 60,0 dB and 1,1 dB, and 59,2 dB and 1,2 dB, respectively. According to the results, the standard deviations of the SNQ's $R'_w + C_{tr,50\text{-}3150}$ and $R'_w + C_{tr,50\text{-}5000}$ were approx. 1 dB lower and the deviations of the SNQ's $D_{nT,w} + C_{tr,50\text{-}3150}$ and $D_{nT,w} + C_{tr,50\text{-}5000}$ 0,8 dB lower when the outliers were excluded. On the basis of the other SNQ's, the corresponding differences were minor.

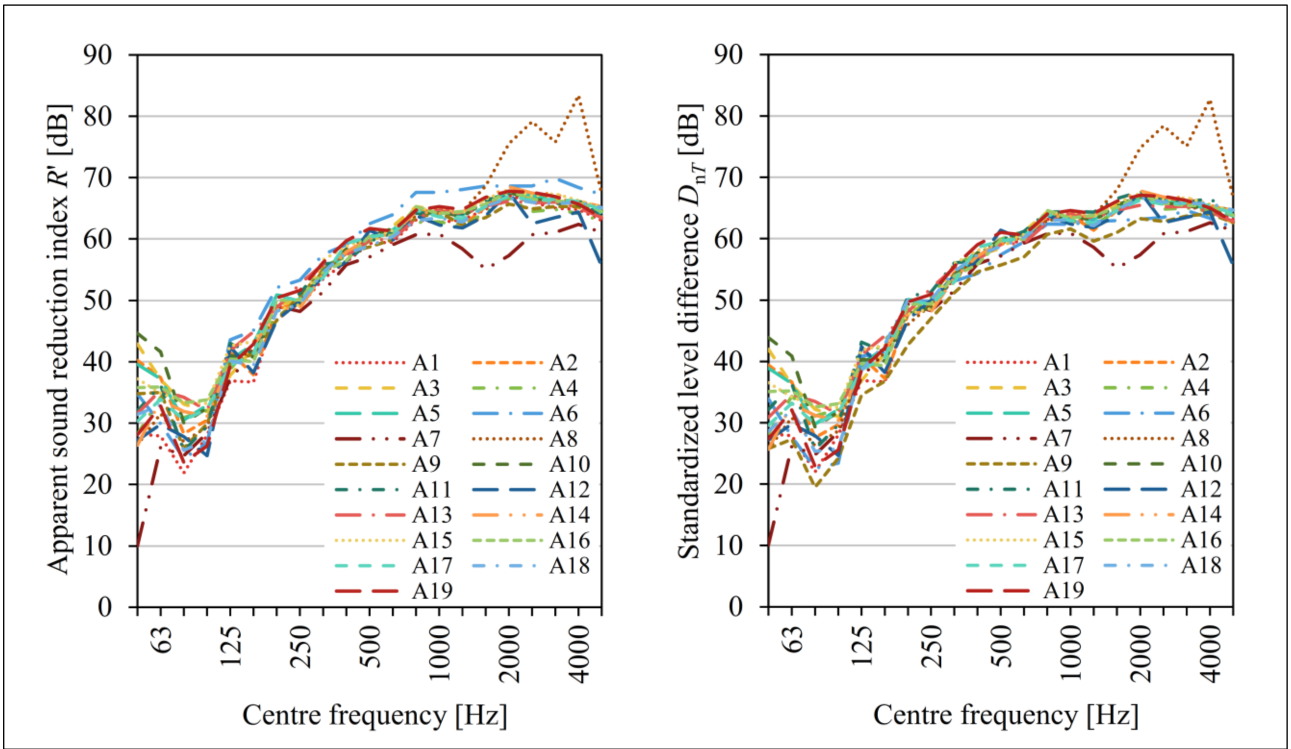

Figure 1. The results of the apparent sound reduction indices R' (left) the standardized sound level differences D_{nT} (right) in 1/3-octave-bands.

Table 1. Averages, Minimum and maximum values, as well as standard deviation of the SNQ's R'_w and $R'_w + C_i$. All the results are included in the results on the left side of the columns; on the right side, the outliers are excluded.

SNQ	Average [dB]	Minimum value [dB]	Maximum value [dB]	Standard deviation [dB]
R'_w	59,9 / 60,0	57 / 58	62 / 62	1,2 / 1,1
$R'_w + C$	55,9 / 56,0	52 / 52	58 / 58	1,8 / 1,7
$R'_w + C_{tr}$	48,8 / 48,9	44 / 44	51 / 51	2,1 / 2,2
$R'_w + C_{50\text{-}3150}$	53,4 / 53,5	44 / 44	58 / 58	3,8 / 3,9
$R'_w + C_{50\text{-}5000}$	54,5 / 54,8	44 / 44	58 / 58	3,6 / 3,5
$R'_w + C_{100\text{-}5000}$	56,1 / 56,2	49 / 49	59 / 59	2,5 / 2,5
$R'_w + C_{tr,50\text{-}3150}$	46,1 / 47,0	34 / 41	54 / 54	4,6 / 3,6
$R'_w + C_{tr,50\text{-}5000}$	45,6 / 46,4	34 / 41	55 / 55	4,4 / 3,5
$R'_w + C_{tr,100\text{-}5000}$	49,0 / 49,1	43 / 43	56 / 56	3,0 / 3,1

Table 2. Averages, Minimum and maximum values, as well as standard deviation of the SNQ's $D_{nT,w}$ and $D_{nT,w} + C_i$, All the results are included in the results on the left side of the columns; on the right side, the outliers are excluded.

SNQ	Average [dB]	Minimum value [dB]	Maximum value [dB]	Standard deviation [dB]
$D_{nT,w}$	59,0 / 59,2	56 / 56	61 / 61	1,2 / 1,2
$D_{nT,w} + C$	54,9 / 55,1	51 / 51	57 / 57	1,9 / 2,0
$D_{nT,w} + C_{tr}$	47,9 / 48,0	43 / 43	51 / 51	2,5 / 2,6
$D_{nT,w} + C_{50\text{-}3150}$	53,1 / 53,4	45 / 45	57 / 57	3,4 / 3,5
$D_{nT,w} + C_{50\text{-}5000}$	54,3 / 54,7	49 / 49	57 / 57	2,8 / 2,6
$D_{nT,w} + C_{100\text{-}5000}$	55,0 / 55,1	42 / 42	58 / 58	3,8 / 4,1
$D_{nT,w} + C_{tr,50\text{-}3150}$	44,6 / 45,5	34 / 38	53 / 53	4,5 / 3,7
$D_{nT,w} + C_{tr,50\text{-}5000}$	44,0 / 44,8	34 / 38	48 / 48	4,0 / 3,2
$D_{nT,w} + C_{tr,100\text{-}5000}$	48,4 / 48,6	43 / 43	54 / 54	2,8 / 2,9

4. Discussion

4.1. The effect of the SNQ's on the results

The standard deviations of the SNQ's R'_w and $D_{nT,w}$ were roughly the same, approx. 1,0 dB. The standard deviations of the sums of the SNQ $D_{nT,w}$ and the spectrum adaptation terms $C_{50\text{-}3150}$, $C_{50\text{-}5000}$, $C_{tr,50\text{-}3150}$, $C_{tr,50\text{-}5000}$ and $C_{tr,100\text{-}5000}$ were lower than the standard deviations of the sums of the SNQ R'_w and the corresponding spectrum adaptation terms. According to the results, the deviation increased 1 to 2 dB, when the frequency bands 50 to 100 Hz were taken into account by the spectrum adaptation terms. This can be seen from the results of the Tables 1 and 2. The reason for this was probably the non-diffusivity of the measured sound field and the deviation caused by it in the low-frequency range [2, 3]. When the frequency range 100 to 5000 Hz was taken into account by the C_i, the standard deviation increased approx. 1 to 2 dB compared to the SNQ's determined based on the conventional frequency range 100–3150 Hz. According to the recent studies, extending the frequency range to the range 3150–5000 Hz has not shown advantage, since neither the value of the SNQ's significantly changes, nor the correlation between the SNQ's and sound level of transmitted living noises increases [4, 5].

4.2. The effect of the receiving room volume

The measurement groups could be divided into two groups based on the volumes determined by them: the participants who determined that the volume of the room was approx. 50 m^3 and to the group which stated that the volume was approx. 60 m^3. The size of the latter group was 6 participants. The rooms under study had a sound absorbing suspended ceiling and the majority of the groups had interpreted the measurement standard so that the volume above the suspended ceiling is excluded from the total volume. The facts that the sound field above the suspended ceiling differs from the sound field below it, and because of the presumption of the diffuse sound field in the room, support this approach. Moreover, the sound pressure levels cannot typically be measured above the ceiling because of the rules concerning the measurements. Furthermore, it is often practically impossible to measure the volume above the suspended ceiling.

4.3. Measurement uncertainty

According to the standard ISO 12999-1 [6], the standard deviation of the measurement results can be used for determining the uncertainty of the measurement results. Since all the participants carried out their measurements independently at the same location using their own equipment, the test corresponded the measurement situation B of the standard. Figure 2 shows the standard deviation of the apparent sound reduction indices *R*' and the standardized level differences D_{nT} for all the results (N = 19) and for the results without the outliers (N = 17). The figure shows also the standard uncertainty of the situation B presented in the standard. Table 3 shows the standard deviations of the results of the SNQ's and the standard uncertainties for single-number values presented in the standard.

From the Figure 2, it can be seen that the standard deviation exceeded the standard uncertainty presented in the standard ISO 12999-1 for all results and when the results of the outliers were excluded. When all the results were included, the exceeding was at largest in the low- and high-frequencies. However, when the results of the outliers were excluded, the exceeding was at largest in the low-frequencies, particularly in the bands 50 and 80 Hz. From the results presented in the Table 3, it can be seen that the standard deviation of all SNQ's was greater than the standard uncertainties for SNQ's presented in the standard ISO 12999-1.

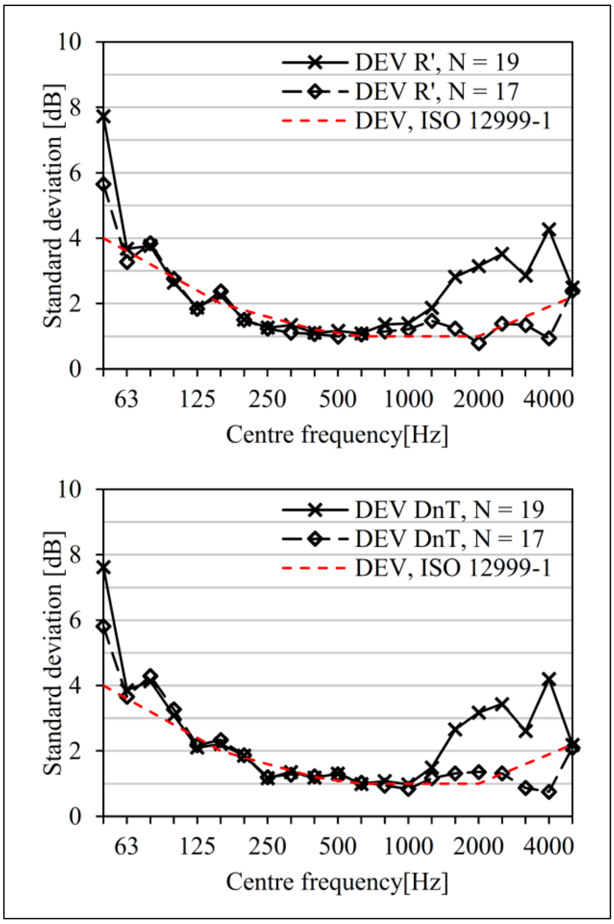

Figure 2. The standard deviations (DEV) of the apparent sound level indices *R*' (above) and the standardized level differences $D_{nT,w}$ (below) for all results (N = 19) and when the outliers were excluded (N = 17). The standard uncertainty is presented as a red dashed line.

Table 3. The standard deviations of the SNQ's for all results and when the outliers were excluded, as well as the standard uncertainties of the SNQ's presented in the standard ISO 12999-1.

SNQ	Standard deviation [dB] all results	Standard deviation [dB] results without the outliers	Standard uncertainty [dB] according to the ISO 12999-1
R'_w	1,2	1,1	0,9
$R'_w + C$	1,8	1,7	0,9
$R'_w + C_{tr}$	2,1	2,2	1,1
$R'_w + C_{50\text{-}3150}$	3,8	3,9	1,0
$R'_w + C_{50\text{-}5000}$	3,6	3,5	1,1
$R'_w + C_{100\text{-}5000}$	2,5	2,5	1,1
$R'_w + C_{tr,50\text{-}3150}$	4,6	3,6	1,3
$R'_w + C_{tr,50\text{-}5000}$	4,4	3,5	1,0
$R'_w + C_{tr,100\text{-}5000}$	3,0	3,1	1,1
$D_{nT,w}$	1,2	1,2	0,9
$D_{nT,w} + C$	1,9	2,0	0,9
$D_{nT,w} + C_{tr}$	2,5	2,6	1,1
$D_{nT,w} + C_{50\text{-}3150}$	3,4	3,5	1,0
$D_{nT,w} + C_{50\text{-}5000}$	2,8	2,6	1,1
$D_{nT,w} + C_{100\text{-}5000}$	3,8	4,1	1,1
$D_{nT,w} + C_{tr,50\text{-}3150}$	4,5	3,7	1,3
$D_{nT,w} + C_{tr,50\text{-}5000}$	4,0	3,2	1,0
$D_{nT,w} + C_{tr,100\text{-}5000}$	2,8	2,9	1,1

4.4. The outliers

The results of the participants A7 and A8 were outliers, since their results deviated significantly from the other results, particularly in the high-frequency range over 1250 Hz.

In case of the group A7, the results for the apparent sound reduction indices R' and the standardized level differences D_{nT} were minor compared to the results of the other participants in the high-frequency range, as well as in the 50 Hz frequency band. In the high-frequency range where the airborne sound insulation between the rooms was high, the floor of the dynamic range of the sound level meter used by the group A7 was probably encountered. In addition, it is possible that the loudspeaker of the group was not able to provide enough power in order to produce a sufficient sound pressure level in the receiving room. In the low-frequency range, in addition to the non-diffusivity of the sound field, the differences could have been caused by the lack of sound power of the loudspeaker, as well.

In case of the group A8, the results in the high-frequency range were significantly greater than on the others. This can refer to a problem occurred during the measurement, but detecting it afterwards is not possible on the basis of the results that were in use. One possible reason for the anomalous results in this frequency range is the lack of sound power used by the group.

5. Conclusions

On the basis of the round robin test results, the averages of the SNQ's R'_{w} and $D_{nT,w}$ were 59,9 dB and 59,0 dB, respectively. The standard deviation of both SNQ's was 1,2 dB, whereas the deviation of the apparent sound reduction indices R' and the standardized level differences D_{nT} was 1,1–7,7 dB and 1,0–7,6 dB, respectively.

Compared to the standard uncertainties presented in the standard ISO 12999-1, the standard deviations of the 1/3-octave-band results were mainly larger, particularly in the ranges under 100 Hz and over 1000 Hz frequencies. The standard deviation of the results was at largest in the frequency range under 100 Hz. When the results of the outliers were excluded, the standard deviations decreased.

The standard deviations of the SNQ's were larger than the standard uncertainties presented in the standard ISO 12999-1. The deviations of the SNQ's R'_{w} and $D_{nT,w}$ were smallest. Based on the results, the deviation increased, when the extended frequency range (compared to the conventional frequency range 100-3150 Hz) was taken into account. This was seen from both the1/3-octave-band results and the SNQ's. This result does not support exceeding the frequency range from the conventional range.

Based on the results, the causes for the measurement uncertainty were differences in low-frequency results and in the receiving room volumes determined by the participants, as well as the results of the outliers. Because the sound field in the low-frequencies is generally non-diffuse, deviation in the low-frequency range is at largest, thus causing deviation of the SNQ's taking this range into account. Based on the test, there was no uniform method for determining the volume of the room, in contrast, a part of the participants included the volume above the suspended ceiling in the determined volume of the room. This was probably caused by the differences in views of the interpretation of the directions given by the measurement standard. However, when determining the SNQ $D_{nT,w}$, such problem is not encountered, because the standardized level differences are determined based on the sound pressure levels and the reverberation time of the receiving room. This supports adopting the standardized SNQ's. When measuring the weighted apparent sound reduction index R'_{w}, a more justified method is to exclude the volume above the suspended ceiling from the total volume of the room.

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