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EUROPEAN ROUND ROBIN TEST FOR THE AIRBORNE SOUND INSULATION OF A STEEL PLATE

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ABSTRACT

To measure the airborne sound insulation of glazing in accordance with Annex D of ISO 10140-1, laboratories must verify their procedure by measuring reference insulating glass units (IGUs) annually. However, it has proved difficult to reproduce the reference IGUs used in the original round robin. A more stable reference sample that can be easily obtained and stored could solve this problem. Within the WG Acoustics of ENBRI (European Network of Building Research Institutes), the use of a steel plate as a reference sample was proposed. This paper presents the result of a round robin test organized by ENBRI with 7 participating laboratories. Each laboratory performed 7 tests on a $2\,\mathrm{mm}$ thick steel plate, fixed to a wooden frame according to clear specifications. Both repeatability and reproducibility standard deviations were overall lower than ISO 12999-1 values. To check the repeatability of the installation in the small test opening, the sample and frame was remounted twice in each laboratory. The mounting affects the repeatability especially at higher frequencies, indicating that careful mounting is necessary to avoid leakage around the perimeter.

Keywords: *sound insulation, laboratory tests, uncertainty, repeatability, reproducibility*

1. INTRODUCTION

The standard series ISO 10140 [1] deals with the laboratory measurement of sound insulation of building elements and was revised in 2021, but a further revision is needed. One of the issues is the verification procedure in Annex D of ISO 10140-1 for the measurement of the airborne sound insulation of glazing. The laboratory must verify its compliance by an annual measurement of two types of reference insulating glass units (IGUs). The measured sound reduction index curves of these IGUs should fall in a range which is determined from a round robin with 22 participating laboratories [2]. It became evident during the revision of ISO 10140 that several laboratories have encountered difficulties to obtain measurement results that fall within the specified range when using reference IGUs produced later. The revised standard points out this problem and recommends to perform measurements with the reference IGUs produced for the round robin. This is an issue for laboratories that did not participate in the original round robin. Furthermore, a lot of the participating laboratories don't possess the original reference IGUs anymore, because glazings are difficult to store without risk of damage over time. Therefore, the revised standard also gives an alternative option where new reference glazings are validated by a laboratory that participated in the round robin. However, no details are given on the validation procedure. Furthermore, such a validation procedure is cumbersome, sending glazings to different laboratories, and it does not solve the problem of storing the reference glazings over long periods of time.

To solve these issues, it is proposed to use a reference sample with well-defined and stable material parameters over time, that can be easily obtained in all countries over the world and that can be more easily stored without risk of damage. A steel plate meets these requirements. The ASTM Specification E1289 [3] uses $0.63\,\mathrm{mm}$ steel sheets as reference specimens for quality control. In this study, a $2\,\mathrm{mm}$ steel plate was chosen, which is more robust to store but still light enough for handling. The critical frequency of a $2\,\mathrm{mm}$ steel plate ($> 5000\,\mathrm{Hz}$) falls outside the building acoustic frequency range ($50\,\mathrm{Hz} - 5000\,\mathrm{Hz}$),

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Table 1. Main characteristics of the participating laboratories

	Rooms		Niche		Loudspeakers		Microphones	
Lab.	V_1 [m^3]	V_2 [m^3]	t_1 [mm]	t_2 [mm]	type	# positions	type	# positions
1	101	73	140	273	moving	2 $^{(a)}$	moving	1
2	52.0	49.2	110	320	fixed	4	moving	1
3	117.7	64.8	155	305	moving	1	moving	1
4	78.7	62.2	145	275	fixed	2 $^{(b)}$	moving	2
5	80.3	64.6	120	238	fixed	4 $^{(b)}$	moving	1 - 2
6	87.6	51.8	N/A	N/A	moving	2 $^{(b)}$	moving	1
7	257	234	120	340	fixed	2	fixed	5

$^{(a)}$ second configuration with source and receiving room interchanged

$^{(b)}$ multiple loudspeakers

making the sound reduction index less dependent on the stiffness and damping of the panel.

To check the repeatability and reproducibility for the airborne sound insulation measurement of the proposed reference sample, a preliminary round robin test was carried out within the WG Acoustics of the European Network of Building Research Institutes (ENBRI) [4]. If the repeatability and reproducibility of the round robin test falls within the limits given in ISO 12999-1 [5], the proposed reference panel could be used as an alternative for the reference IGUs defined in Annex D of ISO 10140-1.

2. MATERIALS AND METHODS

2.1 Participating laboratories

A total of 7 laboratories took part in this round robin test (RRT). All laboratories are a member of ENBRI or appointed by a member of ENBRI. The participating laboratories are located in Belgium, Denmark, France, Poland, Romania, Slovenia and Switzerland.

The main characteristics of each laboratory are given in Tab. 1 (volume of the source room V_1, volume of the receiving room V_2, thickness of the small and large niche at both sides of the panel t_1 and t_2). The laboratories are numbered in a random way to keep the data anonymous. All laboratories meet the requirement of ISO 10140-5 regarding the minimum volume of the rooms ($50\,\mathrm{m}^3$) and the recommendation of a difference of at least $10\,\%$ in room volumes, except for laboratory nr. 2 with a receiving room volume of just below $50\,\mathrm{m}^3$ and a relative difference of $6\,\%$.

The test opening of each of the participating laboratories meets the requirements for small standardized test openings used for glazing, with a maximum deviation of $6\,\mathrm{mm}$ on the recommended dimensions ($1250\,\mathrm{mm} \times 1500\,\mathrm{mm}$) and a maximum depth of $460\,\mathrm{mm}$ ($< 500\,\mathrm{mm}$). All test openings are staggered on both sides and on top by a distance of 60 to $65\,\mathrm{mm}$.

2.2 Test sample

The test sample used in the RRT is a $2\,\mathrm{mm}$ thick, galvanized steel plate with dimensions $1.24\,\mathrm{m} \times 1.49\,\mathrm{m}$ (i.e. $1\,\mathrm{cm}$ smaller then the test opening). Each laboratory used their own test sample. Because the sound reduction index of the steel plate is mostly determined by its surface mass in the frequency range of interest, it was asked to weigh the steel plate (after screwing the holes for fixing). Five laboratories reported the mass of the steel plate, with an average surface mass of $(15.48 \pm 0.12)\,\mathrm{kg/m}^2$.

The steel panels were mounted into the small standardized test opening such that the niches on both sides of the panel have different depths. In most of the laboratories that reported the niche depths on each side of the steel panel, the ratio is approximately 2:1 as prescribed in the standard. For laboratory nr. 2 and nr. 7, the ratio is approximately 3:1. This different niche depth ratio may influence the measured sound reduction index of the steel panel, with theoretical variations of 1 to $2\,\mathrm{dB}$ for single panels below the critical frequency [6].

Clear specifications were given regarding the installation procedure (Fig. 1). First, a timber frame with section $28\,\mathrm{mm} \times 28\,\mathrm{mm}$ - at one corner chamfered - is screwed in

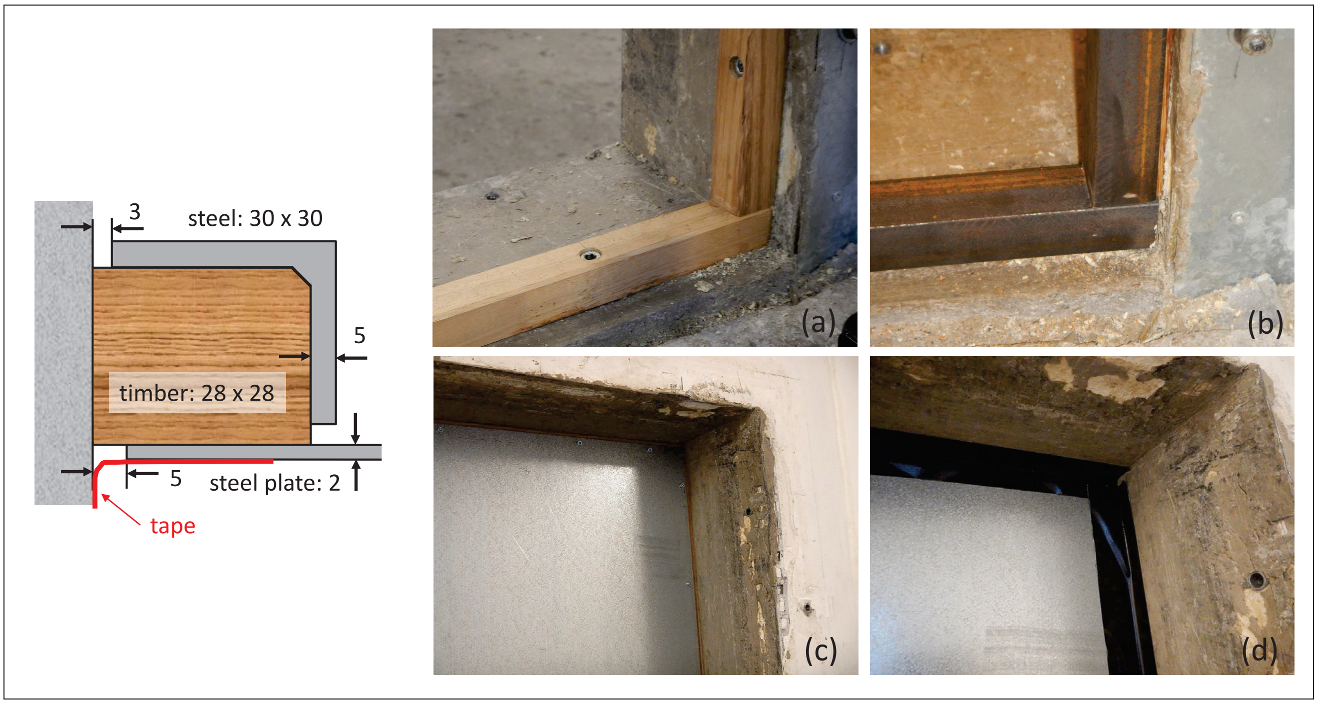

Figure 1. Mounting of the steel plate in the standardized measurement opening for glazing

the test opening with dimensions $1.25\,\mathrm{m} \times 1.5\,\mathrm{m}$ (Fig. 1a). The use of putty between the timber frame and the reveal of the test opening was to be avoided and was only allowed to eliminate any unevenness in the reveal. To avoid leakage between the timber frame and the test opening, the screw center-to-center distance should be small enough (suggested distance between $300\,\mathrm{mm}$ and $350\,\mathrm{mm}$). Next, the timber frame is covered with steel L-profiles with dimensions $30\,\mathrm{mm} \times 30\,\mathrm{mm}$ and thickness $5\,\mathrm{mm}$ (Fig. 1b). The L-profiles are screwed into the timber frame with screws placed between the screws used for fixing the timber frame. Third, the steel panel is screwed into the timber frame with 36 screws (8 on the horizontal frames and 10 on the vertical frames), equally spaced and starting at $60\,\mathrm{mm}$ of the corner (Fig. 1c). Screw holes with a diameter of 4 or $5\,\mathrm{mm}$ are drilled at $9\,\mathrm{mm}$ of the edge of the plate. Finally, tape is applied at the perimeter of the steel plate to cover the gap of approximately $5\,\mathrm{mm}$ between the steel plate and the reveal of the test opening (Fig. 1d). It was decided to not use any putty around the perimeter to avoid additional plate damping which is strongly dependent on the amount of putty applied and thus more difficult to specify.

One of the laboratories used $4\,\mathrm{mm}$ thick steel profiles that didn't cover the corners of the timber frame. However, one comparison measurement with $6\,\mathrm{mm}$ thick L-profiles that also covered the corners of the timber frame, performed in the same laboratory, didn't show any influence on the measured sound reduction index, and thus the results were not discarded.

2.3 Measurement procedure

Each laboratory measured the sound reduction index of the steel plate according to ISO 10140-2. Some details of the test procedure for each laboratory (the type and number of loudspeakers and/or loudspeaker positions and the type and number of microphone positions over which averaging is carried out) are reported in Tab. 1. Three laboratories use moving loudspeakers, two laboratories use multiple fixed loudspeakers and two laboratories use one fixed loudspeaker in different positions. Most of the laboratories use rotating microphone booms, except for laboratory nr. 7. Laboratory nr. 5 uses 1 moving microphone in the source room and 2 moving microphones in the receiving room.
In total, 7 tests were performed by each laboratory. Af-

ter mounting the panel, each laboratory did five tests directly after each other to check the repeatability of the test procedure. It was asked to reposition the sources and microphones after each test (i.e. take them in and out of the rooms). For annual reference measurements, it is important to know that the installation of the panel is repeatable and that small variations in the installation of the panel don't significantly influence the measured sound reduction index. Each laboratory therefore did two additional measurements to check the long-term repeatability. For each measurement, the timber frame and the steel plate had to be remounted completely starting from an empty test opening. The sources and microphones had also to be repositioned for these measurements.

Each laboratory followed their own standardized measurement procedure. Laboratory nr. 1 measured the sound reduction index in both directions, interchanging the source and receiving room and linearly averaging the two measured values. Laboratory nr. 4 interchanged the source and receiving room for the measurement of the sound reduction index at 50 Hz due to modal issues in this frequency band for the standardized measurement direction.

2.4 Statistical analysis

Each laboratory sent a reporting sheet with laboratory data and measurement results for each of the seven tests to the RRT supervisor at Buildwise. The predefined reporting sheet contains:

- details on laboratory characteristics and measurement procedure;
- details on steel plate and frame properties;
- environmental conditions (air temperature, air humidity);
- detailed measurement results (sound pressure levels in source and receiving room, background noise levels, reverberation times);
- single-number values according to ISO 717-1 [7].

The results for the sound reduction index are automatically calculated from the detailed measurement results in the reporting sheet to avoid errors. The single-number values were verified by the RRT supervisor and recalculated to one decimal place according to the latest version of ISO 717-1 [7].

The estimates for the general mean, the repeatability standard deviation s_r and the reproducibility standard deviation s_R have been calculated according to ISO 5725-2 [8] (with the number of laboratories $p = 7$ and the number of replicate tests $n = 7$), without disqualifying any outliers in the results [5]. First, the within-laboratory variance s_i^2 is calculated from the seven test results for each laboratory i. The repeatability variance s_r^2 is then determined as the average of the s_i^2-values. Finally, the reproducibility variance s_R^2 is determined from:

$$s_R^2 = s_L^2 + s_r^2 \tag{1}$$

with s_L^2 the between-laboratory variance.

Some of the laboratories did not meet the room reverberation time requirements of ISO 10140-5 in the lowest frequency bands, with reverberation times smaller than 1 s below 200 Hz for laboratories nr. 2, nr. 5 and nr. 7. The reverberation times in laboratory nr. 7 were also too high between 500 Hz and 1600 Hz. As no reverberation times were reported for the sending room, the criterium could not be checked for the other transmission room.

3. RESULTS

The general mean for the sound reduction index R of the steel plate, estimated from all test results from the seven laboratories, is shown in Fig. 2. The minimum and maximum values of the laboratory average values are also indicated in Fig. 2. The steel plate has a mean weighted sound reduction index R_w of 35.2 dB, with laboratory average values ranging between 33.9 dB and 36.1 dB (Tab. 2). As expected, there is a large spread in the measurement results at low frequencies because the sound reduction index will be influenced by the modal behaviour (see Sect. 4.2).

The sound reduction index is compared with a transfer matrix method (TMM) simulation carried out for a 2 mm steel plate (dimensions 1.25 m × 1.50 m, density $\rho = 7740\,\mathrm{kg/m^3}$, Young's modulus $E = 200\,\mathrm{GPa}$, Poisson's ratio $\nu = 0.28$, loss factor $\eta = 0.025$) assuming a diffuse incident sound field and including a spatial windowing to account for the diffraction effects. In the considered frequency range, the sound reduction index is determined by the surface mass of the panel. The start of the coincidence dip around the critical frequency of the steel panel ($f_c \approx 6125\,\mathrm{Hz}$) is visible at 5000 Hz. Above 1000 Hz, the measured sound reduction indices start to deviate from the predicted values and the spread increases, especially in the minimum values, due to the influence of leakage (see Sect. 4.1). The niche effect can also have a negative effect on the sound reduction index in this frequency range [6]. The deviations below 80 Hz are caused

Table 2. Single-number values: averages for each laboratory, general mean and standard deviation under repeatability and reproducibility conditions

	laboratory							general	method 1		method 2	
	1	2	3	4	5	6	7	mean	s_r	s_R	s_r	s_R
R_w	35.2	35.4	35.3	36.1	35.0	33.9	35.2	35.2	0.3	0.7	0.4	1.3
$R_\mathrm{w} + C_{100-3150}$	33.7	34.2	33.6	34.5	33.2	32.9	34.0	33.7	0.3	0.6	0.4	1.3
$R_\mathrm{w} + C_{100-5000}$	34.5	35.0	34.5	35.3	34.1	33.7	34.8	34.6	0.3	0.6	0.4	1.3
$R_\mathrm{w} + C_{50-3150}$	33.6	34.0	33.6	34.4	33.2	32.9	34.0	33.7	0.2	0.6	0.5	1.3
$R_\mathrm{w} + C_{50-5000}$	34.4	34.9	34.4	35.2	34.1	33.7	34.8	34.5	0.2	0.6	0.5	1.3
$R_\mathrm{w} + C_{\mathrm{tr},100-3150}$	30.7	31.7	30.5	31.4	30.0	30.9	31.4	31.0	0.2	0.6	0.4	1.4
$R_\mathrm{w} + C_{\mathrm{tr},100-5000}$	30.7	31.6	30.5	31.4	30.0	30.9	31.4	30.9	0.2	0.6	0.4	1.4
$R_\mathrm{w} + C_{\mathrm{tr},50-3150}$	29.8	30.6	29.8	30.5	29.8	30.7	30.5	30.2	0.2	0.4	0.5	1.7
$R_\mathrm{w} + C_{\mathrm{tr},50-5000}$	29.8	30.6	29.8	30.4	29.8	30.7	30.5	30.2	0.2	0.5	0.5	1.7

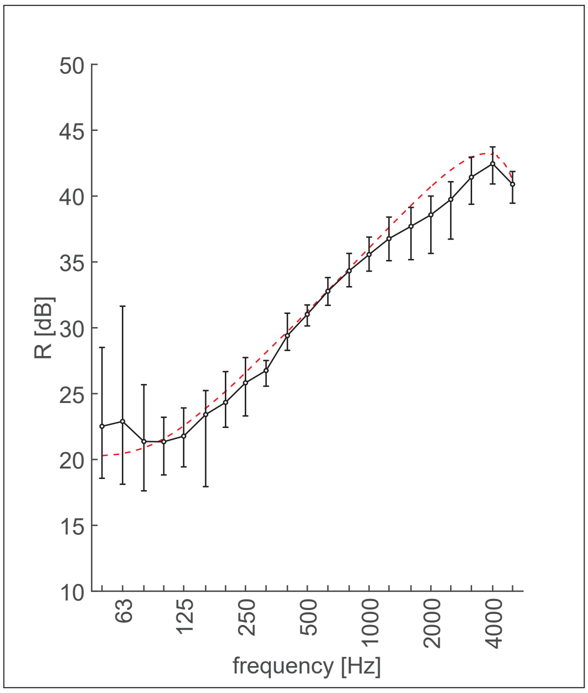

Figure 2. Sound reduction index R of a 2 mm steel plate: general mean and min-max bars of laboratoy average values (full line) and TMM simulations (dashed line)

by the modal behavior of the panel and of the sound fields in the rooms, which is not incorporated in the TMM.

Fig. 3 compares the estimated standard deviation under repeatability and reproducibility conditions with the standard uncertainties for airborne sound insulation of ISO 12999-1 [5]. In most frequency bands, the repeatability standard deviation is significantly lower than the ISO 12999-1 standard uncertainty (Fig. 3a). Only at 1600 Hz, the standard deviation is larger. In this frequency range, the repeatability is strongly influenced by the mounting of the frame and the steel panel (see Sect. 4.1). The reproducibility standard deviation is also lower than the standard uncertainty given by ISO 12999-1, except at 63 Hz (Fig. 3b).

The uncertainty associated with the single-number values determined in accordance with ISO 717-1 [7] is given in Tab. 2 and was determined by two different methods [5]. In the first method, the single-number value is treated as an independent measurand. The standard deviation under repeatability and reproducibility conditions is calculated in the same way as the third-octave band values. In the second method, an upper limit for the uncertainty of the single-number value is calculated assuming full, positive correlation between the one-third octave band values (Annex B of ISO 12999-1 [5]). For all single-number-values, the standard deviations determined with method 1 are smaller than the standard uncertainties reported in ISO 12999-1.

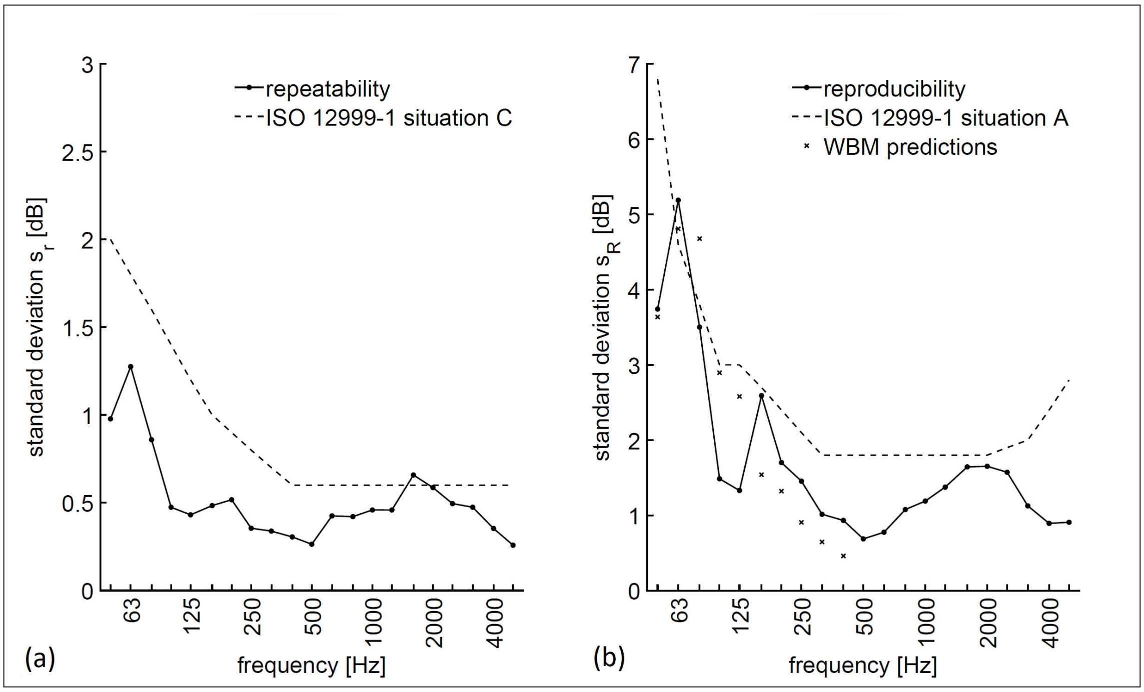

Figure 3. Standard deviation under repeatability and reproducibility conditions for R of the 2 mm steel plate

4. DISCUSSION

4.1 Parameters influencing repeatability

The repeatability standard deviation shown in Fig. 3a is caused by different parameters. The main factor determining the repeatability uncertainty is the mounting of the steel panel (Fig. 4). The standard deviation for the tests on 3 different mountings is larger than the standard deviation for 5 tests on the same mounting in almost all frequency bands, but the influence of the mounting is especially important above 500 Hz. In this frequency range, the measured sound reduction index is sensitive to leakage which may occur between the timber frame and the reveal of the test opening and between the steel panel and the timber frame. One of the laboratories clearly noticed the influence of leakage between the timber frame and the reveal of the test opening, which reduced the sound reduction index above 315 Hz. After two mountings, they decided to repeat all the tests with a new installation procedure applying silicone at the slits between the timber frame and the test opening. The original results without silicone were considered outliers and discarded in the round robin analysis.

For one mounting, the repeatability in all laboratories is good and significantly lower than the limits of ISO 12999-1. The most important parameters influencing the repeatability uncertainty of R are the spatial and temporal averaging of the sound pressure levels in the source room (L_1) and in the receiving room (L_2) and the determination of the room reverberation time (T_r). Above 500 Hz, the repeatability uncertainty is mainly caused by the determination of the sound pressure levels in the rooms (Fig. 4). Below 500 Hz, the uncertainty in R is larger than the uncertainty in the level difference $L_1 - L_2$ due to larger variations in the measurement of the reverberation time. The background noise did not influence the measurement results in most of the laboratories, with only a limited influence (background noise correction < 1.3 dB) below 80 Hz in three laboratories and above 3150 Hz in one laboratory. Because the repeatability measurements for mounting 1 were performed directly after each other, the variations in room temperature and relative humidity were also negligible.

4.2 Parameters influencing reproducibility

The reproducibility uncertainty is influenced by the laboratory characteristics like the room geometry, the posi-

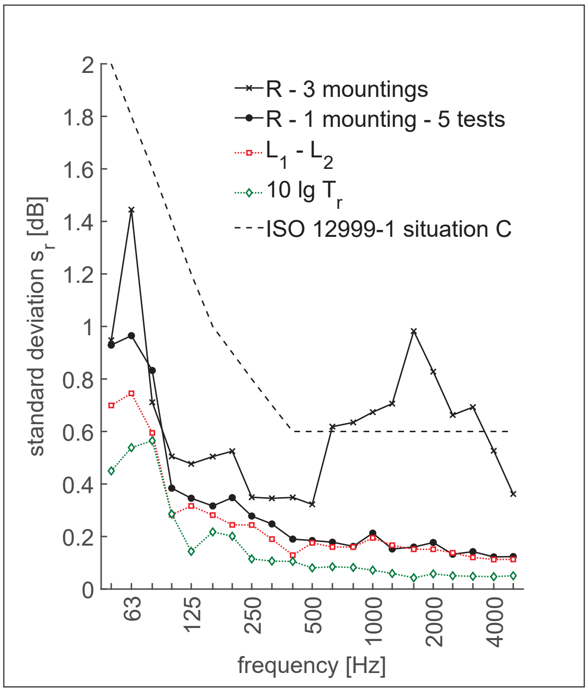

Figure 4. Influence of different measurands and mounting on the repeatability uncertainty

tioning of the test opening and the niche dimensions. The influence is the largest below the Schroeder frequency of the rooms (between 200 Hz and 350 Hz for the participating laboratories) when the sound fields in the rooms are not diffuse [9]. The uncertainty generally decreases with frequency up to 500 Hz (Fig. 3b) because the modal overlap of the room and plate modes increases. Simulations carried out with a wave based model (WBM) confirm that the variations in geometry are the most important factor limiting the reproducibility at low frequencies. In the WBM simulations, five different test facilities, as described in [10], were modelled, using two random source positions. Variations due to the measurement procedure are eliminated in the model by using the exact spatial average of the sound pressure levels in the rooms and the exact reverberation times. The WBM standard deviation is of the same order of magnitude than those obtained in the RRT (Fig. 3b). Above 125 Hz, the WBM systematically underestimates the reproducibility standard deviation, partly because the sampling of the sound field will increase the standard deviation [9].

Above 500 Hz, the reproducibility standard deviation starts to increase again. This inter-laboratory variation is mainly caused by a variability between the test samples. As observed in the repeatability study, small differences in mounting influence the measured sound reduction index in this frequency range due to the influence of leakage around the perimeter in some of the laboratories. The influence of any variation in the properties of the steel plates is assumed to be limited. Below the critical frequency of the plate, the sound transmission is dominated by non-resonant transmission and variations in the Young's modulus and plate damping will hardly influence the sound reduction index. The small variations in the surface mass are also negligible: the standard deviation of $0.12\,\mathrm{kg/m^2}$ for the surface mass leads to an expected standard deviation of $0.13\,\mathrm{dB}$ on the sound reduction index according to the mass law.

4.3 Reference curve

The data from the RRT are used to determine an upper limit and a lower limit for the reference steel plate of $2\,\mathrm{mm}$, mounted following the instructions given in section 2.2. The values of Tab. 3 are determined by taking the average value ± one standard deviation under reproducibility conditions. A criterium - identical to the one described in Annex D of ISO 10140-1 - can then be used to check the reference sound reduction index measured in a laboratory. The criterium states that when the absolute deviations between the numbers in Tab. 3 and the measured values are summed over the frequency bands 100 Hz - 3150 Hz, then the total deviation cannot exceed 6.0 dB. This criterium is met for 6 of the 7 laboratories that participated in the RRT. For laboratory nr. 6, the sum of the absolute deviations is 9.1 dB for the averaged measured sound reduction index over the 7 tests, mainly due to unfavourable deviations from 500 Hz upwards. For two of the three mountings, the test results indicate a problem with leakage. The test results for the third mounting meet the criterium.

5. CONCLUSIONS

This paper presents the result of a European round robin test for the airborne sound insulation of a steel plate with 7 participating laboratories. Each laboratory performed 7 tests on a $2\,\mathrm{mm}$ thick galvanized steel plate, installed in the standardized measurement opening for glazings according to clear specifications. The repeatability and reproducibility of this preliminary round robin test falls within the limits given in ISO 12999-1. Therefore, the proposed reference panel could be used as an alternative

Table 3. Sound reduction index of the reference steel plate with thickness $2\,\mathrm{mm}$

Frequency	Min. value $R_{\mathrm{min},i}$ [dB]	Max. value $R_{\mathrm{max},i}$ [dB]
50	*18.7*	*26.2*
63	*17.7*	*28.1*
80	*18.0*	*25.0*
100	19.9	22.9
125	20.5	23.1
160	20.8	26.0
200	22.6	26.0
250	24.4	27.3
315	25.8	27.8
400	28.4	30.3
500	30.3	31.7
630	32.0	33.6
800	33.3	35.4
1000	34.5	36.8
1250	35.4	38.1
1600	36.0	39.2
2000	36.7	40.0
2500	38.0	41.1
3150	40.2	42.5
4000	*41.5*	*43.3*
5000	*39.9*	*41.7*

for the reference IGUs defined in Annex D of ISO 10140-1. An important point of attention is the mounting of the panel that can significantly affect the repeatability above $500\,\mathrm{Hz}$. To eliminate the effect of any additional plate damping, no putty was used. Therefore, a careful mounting is necessary to avoid leakage around the perimeter.

In the future, it will be studied whether a steel plate could also be considered as a reference sample to validate the test and operating procedure for measuring the airborne sound insulation of walls in large test openings with an area of approximately $10\,\mathrm{m}^2$.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] ISO 10140-x:2021 *Acoustics – Laboratory measurement of sound insulation of building elements*

[2] M. Rehfeld. Handling of uncertainties for CE marking concerning sound transmission loss of glazings In *Proc. of Acoustics '08*, pages 4015–4020, Paris, 2008.

[3] ASTM E1289-08(2022) *Standard specification for reference specimen for sound transmission loss*

[4] http://www.enbri.org/

[5] ISO 12999-1:2020 *Acoustics – Determination and application of measurement uncertainties in building acoustics – Part 1: Sound insulation*

[6] A. Dijckmans and G. Vermeir. A wave based model to predict the niche effect on sound transmission loss of single and double walls. *Acta Acust united Ac*, 98(1):111–119, 2012.

[7] ISO 717-1:2020 *Acoustics – Rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation*

[8] ISO 5725-2:1994 *Accuracy (trueness and precision) of measurement methods and results – Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

[9] A. Dijckmans and G. Vermeir. Numerical investigation of the repeatability and reproducibility of laboratory sound insulation measurements. *Acta Acust united Ac*, 99(3):421–432, 2013.

[10] A. Dijckmans, L. De Geetere and B. Ingelaere. The repeatability and reproducibility of laboratory building acoustic measurements: numerical study. *Proc. Mtgs. Acoustc.*, 30, 015001 (2017); doi: 10.1121:2.0000530.