DELTA Test Report

TEST Reg. no. 100

Measurement of acoustic properties of lightweight concrete SL-Deck

Performed for Abeo A/S

DANAK 100/2431 Revision 1
Project no.: 118-24971

14 November 2018

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Title
Measurement of acoustic properties of lightweight concrete SL-Deck

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Client
Abeo A/S
Beredskabsvej 12
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Client ref.
Morten S. Rasmussen

Summary
Laboratory measurements of impact sound pressure level and sound reduction index per one-third octave were carried out according to the test method of:

Application rules for specific products:	EN ISO 10140-1:2016
Measurement of airborne sound insulation	EN ISO 10140-2: 2010
Measurement of impact sound insulation:	EN ISO 10140-3:2010/Amd 1:2015
Measurement procedures and requirements:	EN ISO 10140-4:2010
Requirements for test facilities and equipment:	EN ISO 10140-5:2010

Test results evaluated according to EN ISO 717-2:2013:

The weighted impact sound pressure level for the floor	$L_{n,w}$ (C_I)	= 79 (-13) dB
The weighted sound reduction index for the floor	R_w (C; C_{tr})	= 54 (-1; -6) dB

Measurements of structural reverberation time are according to EN ISO 10848-1:2017.

This report contains a description of the test specimen according to the client's specifications, a description of the mounting in the laboratory and the test results.

The test results per one-third octave are shown in tabular form and graphically on the graph sheet.

Descriptions of test rooms, test procedure, and evaluation methods are found in the Appendix.

DELTA – a part of FORCE Technology, 14 November 2018

Rasmus Stahlfest Holck Skov
Specialist, Acoustics & Vibration

Leif Ødegaard
Senior Specialist, Acoustics & Vibration

Remarks

This report is a revision and replaces previously issued report dated 26 September 2018. The changes in this report: The table in graph sheet 1 and 2 has been replaced due to one incorrect frequency.

The test results apply only to the objects tested.
The measurements of structural reverberation time are not a part of the accreditation.
The test has been carried out by Rasmus Stahlfest Holck Skov.

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1. Introduction

At the request of Abeo A/S building acoustic laboratory measurements were carried out on the lightweight concrete deck type SL-Deck. The measurements comprise of the following:

- Measurements of the impact sound pressure level
- Measurements of airborne sound insulation
- Structural reverberation time (Loss factor measurements).

2. Description of the flooring based on the client's specifications

The design of the SL-Deck is based on Abeo's technology, Super-Light Structures, which is based on a combination of ordinary concrete and lightweight concrete. The SL-Deck consists of arched shaped blocks made of light aggregate concrete (850 kg/m^3). These are covered with a completely traditional concrete (2400 kg/m^3).

The under surface of light aggregate concrete gives an area with improved sound absorbing properties than traditional concrete.

In the gaps between the light aggregate blocks, reinforcement is put across the deck which in combination with the pre-stressing that runs lengthwise gives a grid-like reinforcement structure.

Figure 1
Construction of SL-Deck.

3. Mounting in the laboratory

The two test elements (approx. 10 m²) were mounted in a 2.99 m × 3.37 m test opening between two reverberant rooms. The two elements were casted together with concrete after mounting in the test opening. The gap between the test specimens and the mounting frame in the test opening was partly filled with mineral wool and sealed with approx. 50 mm concrete on the top.

The floor consists of two elements each of dimensions (lengths x width x height) 2968 x 1658 x 180 mm. The weight of the slab is 310 kg/m^2 corresponding to a total weight of 3318 kg for the test elements.

The mounting of the test specimens was carried out by DELTA.

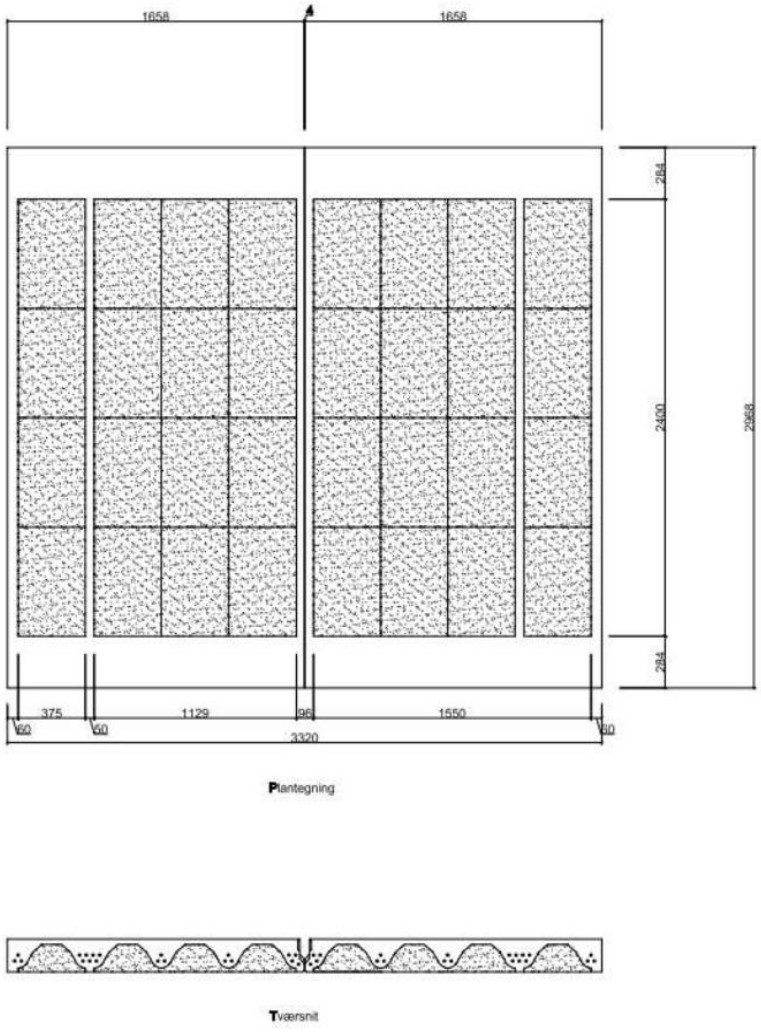


Figure 2
Construction of the test floor.

4. Test method

The impact sound pressure level and the sound reduction measurements were carried out according to the test method of EN ISO 10140 – part 1, 2, 3, 4 and 5: "Acoustics – Laboratory measurement of sound insulation of building elements".

The measurements were performed in Rooms 004 and 904, Building 355 at the Technical University of Denmark in Kgs. Lyngby. A brief description of the test rooms and test methods is found in Appendix 1 and Appendix 2.

The measurement of the structural reverberation time is made as stated in section 4.7 in EN ISO10140:4:2010. However, it is chosen that the results for these measurements are reported outside the accreditation sections.

4.1 Impact sound pressure level

The normalized impact sound pressure level was measured at the bare concrete deck.

The measurements were performed using a standardized tapping machine. The sound pressure level in the receiving room was measured using one-third octave band filters.

4.2 Sound reduction index

The measurement of sound reduction index was carried out using two loudspeaker positions in the source room (the lower room with the test specimen has the most absorbing surface). One receiver position was placed in the receiver room. Rotating microphones were used in all positions. The sound pressure level in the source and in the receiving room was measured using one-third octave band filters.

5. Instrumentation

The following instruments were used for the impact sound pressure level and sound reduction tests.

Instrument	Type	DELTA No.	Calibration	
			Last	Next
Sound Level Meter / Analyser	B&K 2270	1498L	2017-07-18	2019-07-18
Tapping Machine	B&K 3207	1250L	2014-05-20	2019-05-20
Measuring Microphone	B&K 4144	1256L	2017-09-21	2019-09-21
Measuring Microphone	GRAS 40EN 1”	1616L	2017-09-21	2019-09-21
Microphone Preamplifier	B&K 2619	719L	2017-09-22	2018-09-22
Microphone Preamplifier	B&K 2619	464T	2018-01-03	2019-01-03
Microphone Power Supply	B&K 5935	1040L	2018-04-16	2020-04-16
Microphone Power Supply	B&K 5935	1392L	2018-04-16	2020-04-16
Sensor for Temperature and Humidity	EBRO EBI 20-TH1	1617L	2017-12-08	2019-12-08
Sensor for Temperature and Humidity	EBRO EBI 20-TH1	1618L	2017-12-08	2019-12-08
Acoustic calibrator	B&K 4231	1158L	2018-04-19	2018-10-19

6. Measurement conditions

Date of tests and temperature and relative humidity in the source room during measurements.

Date of tests: 22 June 2018, 21,2 °C, 52 % RH

The tapping machine was placed in six positions on the floor under test.

7. Test results

7.1 Sound reduction index

The sound reduction insulation is determined to according to EN ISO 10140-2:2010. The single-number quantity R_w and the corresponding spectrum adaptation terms are determined according to EN ISO 717-1:2013.

The weighted sound reduction index for the deck: R_w = 54 dB.

The corresponding spectrum adaptation term: C = -1 dB, C_{tr} = -6 dB.

The sound reduction index, R, per one-third octave from 100 Hz to 5000 Hz is shown in tabular form and graphically on Graph Sheet 1.

Description of the evaluation method is found in the Appendix 2.

7.2 Impact sound pressure level

Impact sound pressure level is determined according to EN ISO 10140-3:2010. The single-number quantity $L_{n,w}$ and the corresponding spectrum adaptation term is determined according to EN ISO 717-2:2013.

The tapping machine was placed in six positions on the floor under test.

Description of the evaluation methods is found in the Appendix 2.

The weighted impact sound pressure level for the deck: $L_{n,w}$ = 79 dB.

The corresponding spectrum adaptation term: C_I = -13 dB.

The test results, L_n, per one-third octave from 100 Hz to 5000 Hz are shown in tabular form and graphically on Graph Sheet 2.

8. Measurement uncertainty

According to DS/ISO 140-2:1992 precision of laboratory measurements expressed as the reproducibility of single-number quantities, including ΔL_w, as follows (as a two-sided 95 % confidence interval and k = 1.96):

Value	U (k =1.96, two-sided)
R_w	± 2.4 dB
R_w + C	± 2.5 dB
R_w + C_{tr}	± 2.9 dB
$L_{n,w}$	± 3.0 dB
$L_{w,w}$ + C_I	± 3.0 dB

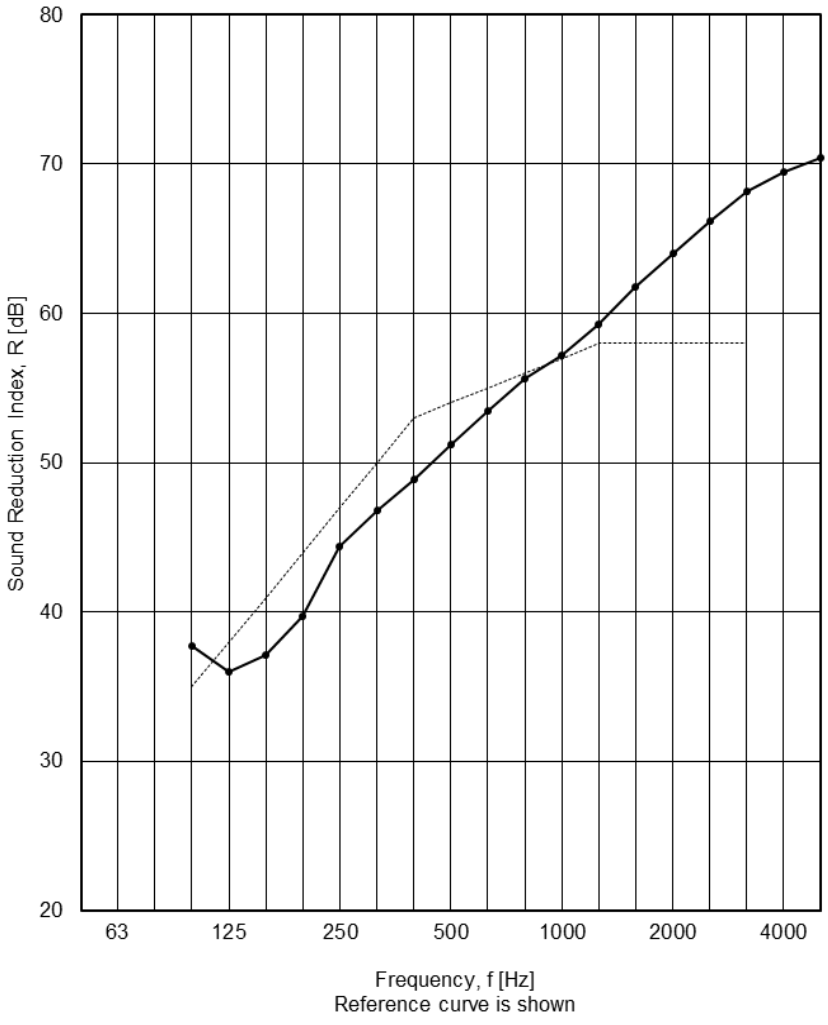
Laboratory measurement of sound reduction index according to EN ISO 10140

Client: Abeo A/S, Beredskabsvej 12, 2640 Hedehusene, Denmark
Date of test: 22 June 2018

Description of the test specimen: 180 mm lightweight concrete SL-Deck. Description of the test specimen and mounting in the laboratory appear in section 2 and 3 in this report.
Test specimen mounted by: DELTA – a part of FORCE Technology

Area of test opening: 10.0 m^2
Air temperature: 21 °C
Air humidity: 52 % RH
Source room volume: 243 m^3
Receiving room volume: 230 m^3

Frequency f [Hz]	R One-third octave [dB]
100	37.7
125	36.0
160	37.1
200	39.7
250	44.4
315	46.8
400	48.9
500	51.2
630	53.5
800	55.6
1000	57.2
1250	59.3
1600	61.8
2000	64.0
2500	66.2
3150	68.2
4000	69.5
5000	70.4



Weighted sound reduction index according to EN ISO 717-1:2013:

R_w (C; C_{tr}) = 54 (-1; -6) dB

Evaluation based on laboratory measurement results obtained by an engineering method EN ISO 10140 part 1, 2, 4 and 5

DELTA – a part of FORCE Technology, 14 November 2018

Leif Ødegaard, Acoustics & Vibration

Laboratory measurement of normalized impact sound pressure level according to EN ISO 10140

Client: Abeo A/S, Beredskabsvej 12, 2640 Hedehusene, Denmark

Date of test: 22 June 2018

Description of the test specimen: 180 mm lightweight concrete SL-Deck. Description of the test specimen and mounting in the laboratory appear in section 2 and 3 in this report.

Test specimen mounted by: DELTA – a part of FORCE Technology

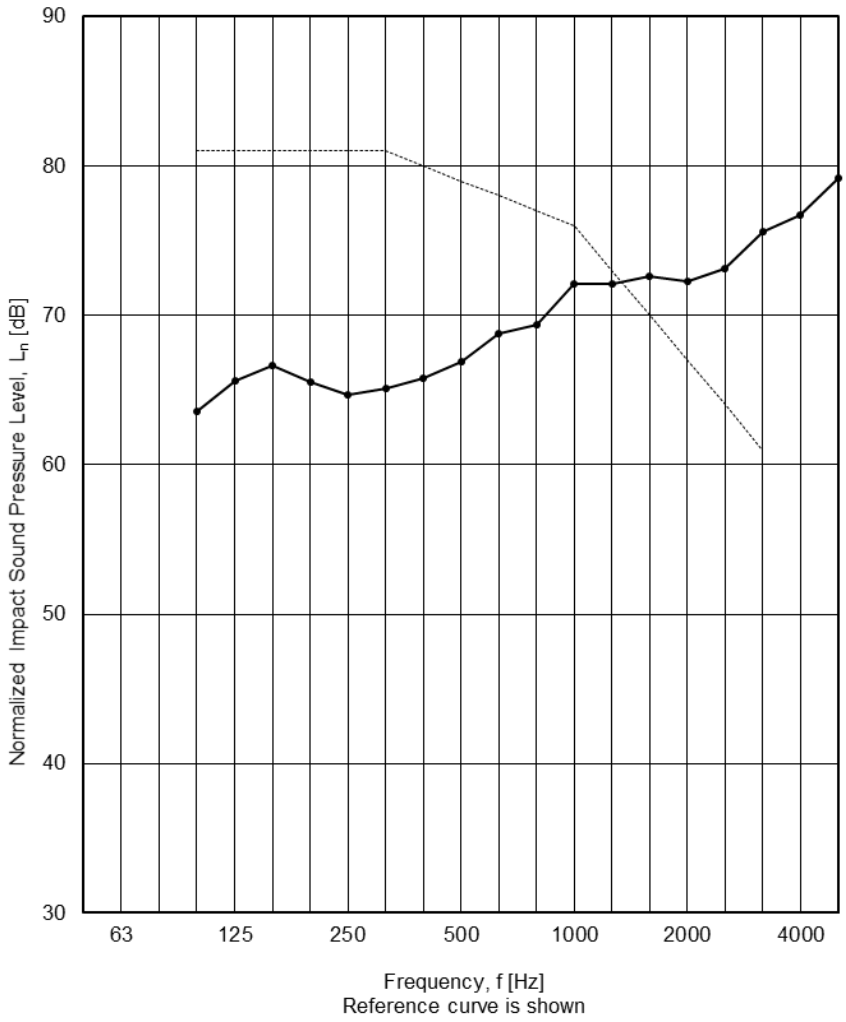
Area of test opening: 10.0 m^2

Air temperature, source room: 21 °C

Air humidity, source room: 52 % RH

Receiving room volume: 243 m^3

Frequency f [Hz]	L_n One-third octave [dB]
100	63.6
125	65.6
160	66.6
200	65.5
250	64.7
315	65.1
400	65.8
500	66.9
630	68.8
800	69.4
1000	72.1
1250	72.1
1600	72.6
2000	72.3
2500	73.1
3150	75.6
4000	76.7
5000	79.2



Weighted impact sound pressure level according to EN ISO 717-2:2013

$L_{n,w}$ (C_I) = 79 (-13) dB

Evaluation based on laboratory measurement results obtained by an engineering method EN ISO 10140 part 1, 3, 4 and 5

DELTA – a part of FORCE Technology, 14 November 2018

Leif Ødegaard, Acoustics & Vibration

9. Evaluation and interpretations

The following sections are not a part of the accreditation.

9.1 Structural reverberation time

The structural reverberation time has been measured using vibrator excitations according to EN ISO 10848-1:2017. The vibrator applied is type Brüel & Kjær (B&K) 4809. The response of the deck is measured with an accelerometer type B&K 4381 in connection with charge amplifier type B&K 2635.

The exciter is fed with three different signals: MLS signal (Maximum Length Sequence), e-sweep signal and linear sweep signal. The structural reverberation time has been determined using the B&K software Dirac, version 6. The integrated impulse response method has been used with backward integration of the squared impulse response. The vibration signal used for input for the impulse response function has been as a velocity signal. The number of measuring positions has been 6-8 for each exciter positions. The exciter has been placed in 4 positions. The measuring positions are randomly distributed over the test element. In Figure 3 is shown the test setup for the structural reverberation measurements.

Figure 3
Mounting of exciter on test deck for the structural reverberation time.

The relation between the total loss factor η_{total} and the structural reverberation time T_S of the element is:

$$\eta_{total} = \frac{2,2}{f\ Ts}$$

where f is the frequency.

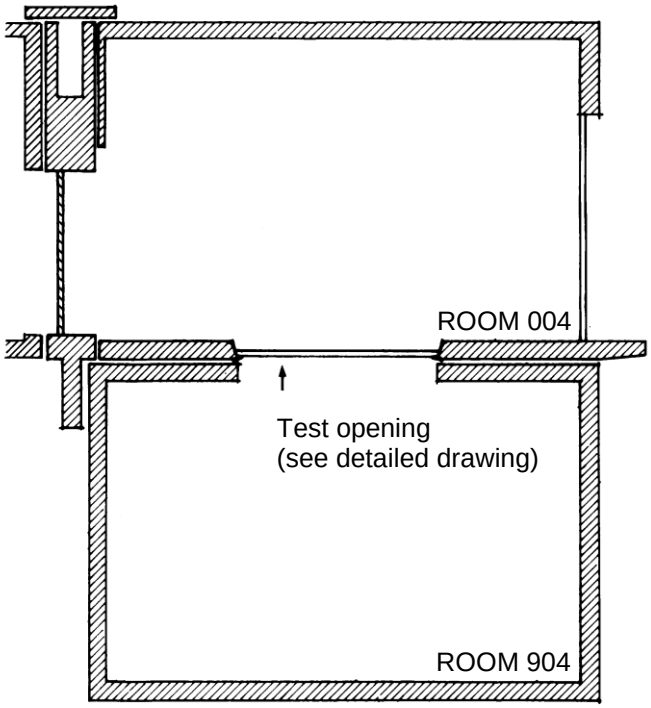
The results of the structural reverberation time measurements are given in Table 1.

Frequency f [Hz]	**Reverberation time T_S [sec.]**	**Total loss factor**
100	0.464	0.047
125	0.298	0.060
160	0.281	0.052
200	0.292	0.039
250	0.215	0.042
315	0.195	0.036
400	0.184	0.030
500	0.173	0.026
630	0.137	0.025
800	0.103	0.026
1000	0.101	0.022
1250	0.098	0.019
1600	0.085	0.018
2000	0.081	0.015
2500	0.066	0.014
3150	0.053	0.014
4000	0.049	0.012
5000	0.045	0.010

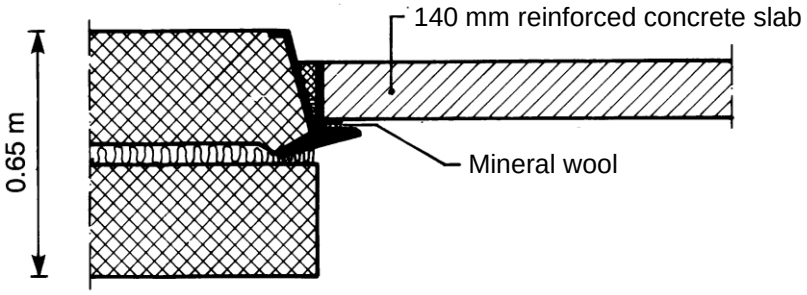
Table 1
Results of the structural reverberation time measurements.

Description of test rooms

The measurements are performed in two reverberant rooms (004 and 009), one placed on top of the other. The length, width, and height of the rooms are 7.85 m, 6.25 m and 4.95 m, respectively. The test opening between the rooms is 2.99 m × 3.37 m and has a depth of 0.65 m. In the upper room (004) sound diffusing elements of concrete and of damped steel plate are situated on two of the walls and on the ceiling. The volume of the room is approx. 230 m³. In the lower room (009) the volume is approx. 245 m³, 20 sheets of 10 mm acrylic (dimensions 0.90 m × 1.2 m) are used as sound diffusing elements.



Test rooms.
Vertical section.
Scale 1:125.



Test opening with standard floor.
Vertical section.
Scale 1:20.

Test method – Impact sound pressure level

The normalized impact sound pressure level is defined as the sound pressure level in the receiving room when the floor under test is excited by the standardized tapping machine increased by a correction to a reference equivalent absorption area (10 m²) of the receiving room.

The measurements of the normalized impact sound pressure level are performed using a standardized tapping machine provided with steel hammers and meeting the requirements of EN ISO 10140-5:2010 Annex E. The tapping machine is adjusted in such a way that the falling height of the hammers on an even surface corresponds to a free fall from a height of 40 mm.

The tapping machine is placed in six positions on the floor under test, and the sound pressure level in the receiving room is measured using a moving microphone with a sweep radius of approx. 1.25 m and with an inclined plane of the traverse. The measurement is carried out using a real-time frequency analyzer with one-third octave band filters. The averaging time is 32 seconds corresponding to two traverses of the moving microphone. The total electrical and acoustic background noise level in the receiving room is measured. The sound pressure level in the receiving room is corrected for background noise, if affected. If the sound pressure level in the receiving room is less than 6 dB above the background noise level, this will be stated in the report together with an indication of the validity of the test results.

The equivalent absorption area of the receiving room is determined by means of Sabine's formula by measuring the reverberation time of the room in three microphone positions with two decays in each. The measurement of the reverberation time is performed with pink noise emitted by a loudspeaker system placed in a corner of the receiving room. The one-third octave filtered microphone signal is registered during the decay and evaluated in the range approx. 5 dB to approx. 25 dB below the steady-state level.

The normalized impact sound pressure level is determined within frequency bandwidths of one-third octave at the following standardized center frequencies: 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, and 5000 Hz.

$$L_n = L_M + 10 \log_{10} \cdot \frac{A_M}{A_O} \text{ and } A_M = \frac{0.163 \cdot V_M}{T_M}$$

where L_n = Normalized impact sound pressure level with a reference equivalent absorption area of 10 m² [dB re 20 μPa]

L_M = Sound pressure level in the receiving room when the floor under test is excited by the standardized tapping machine [dB re 20 μPa]

A_M = Equivalent sound absorption area in receiving room [m²]

A_0 = Reference equivalent sound absorption area (10 m²)

V_M = Volume of receiving room [m³]

T_M = Reverberation time in receiving room [s]

Evaluation method – Impact sound

To evaluate the normalized impact sound pressure level of a floor the single-number quantity $L_{n,w}$ is used. The value is determined according to EN ISO 717-2:2013.

When determining the evaluation value, $L_{n,w}$, the measured results of the normalized impact sound pressure level per one-third octave from 100 Hz to 3150 Hz are compared with a reference curve, which has a constant value from 100 Hz to 315 Hz, while it falls by 1 dB per one-third octave from 315 Hz to 1000 Hz, and by 3 dB per one-third octave from 1000 Hz to 3150 Hz. The values of the reference curve at the one-third octave centre frequencies are integers. An unfavourable deviation occurs at a certain frequency when the test result exceeds the value of the reference curve. The reference curve is shifted in steps of 1 dB until the sum of unfavourable deviations is as large as possible, but not more than 32.0 dB.

The $L_{n,w}$-value is determined from the shifted reference curve as the value in dB at 500 Hz.

As an additional evaluation method based on a summation of the unweighted linear impact sound level the spectrum adaptation terms C_I for the normalized impact sound pressure level is defined in EN ISO 717-2:2013, Annex A.

Test method – Sound reduction index

The sound reduction index, R, is defined as the ratio in decibel between the sound power incident on the test specimen and the transmitted sound power radiated from the other side of the test specimen.

When measuring the sound reduction index, R, according to EN ISO 10140-2:2010 and EN ISO 10140-4:2010 the test specimen is placed between a source room and a receiving room meeting the requirements of EN ISO 10140-5:2010, and the sound reduction index is determined by means of the formula below presupposing diffuse sound fields in the rooms.

The measurement was carried out with a broadband noise signal emitted by a loudspeaker in the source room. The loudspeaker is fed through an equalizer and a power amplifier. Two loudspeaker positions established according to the qualification method in EN ISO 10140-5:2010 are used in the source room.

The sound pressure levels of the source room and the receiving room were averaged for each loudspeaker position within a period of 32 seconds corresponding to two revolutions of a rotation microphone system with sloping path and a radius of approx. 1.25 m. The sound pressure level is measured using a real-time frequency analyser with one-third octave band filters. The total electrical and acoustic background noise level in the receiving room is measured. The sound pressure level in the receiving room is corrected for background noise, if affected.

The equivalent absorption area of the receiving room was determined by means of Sabine's formula by measuring the reverberation time of the room in tree microphone positions with two decays in each. The measurement of the reverberation time was performed with a broadband noise signal emitted by a loudspeaker system placed in a corner of the receiving room. The one-third octave filtered microphone signal was registered during the decay and evaluated in the range approx. 5 dB to approx. 25 dB below the steady-state level.

The sound reduction index was determined within frequency bandwidths of one-third octave at the following standardized centre frequencies: 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, and 5000 Hz.

$$R = L_1 - L_2 + 10 \log_{10} \frac{S}{A} \text{ and } A = \frac{0.16 \cdot V}{T} \text{ [dB]}$$

where R = Sound reduction index of test specimen [dB]

L_1 = Sound pressure level in source room [dB/20 µPa]

L_2 = Sound pressure level in receiving room [dB/20 µPa]

S = Area of test specimen [m²]

A = Equivalent sound absorption area in receiving room [m²]

V = Volume of receiving room [m³]

T = Reverberation time in receiving room [s]

Evaluation method – Sound reduction index

To evaluate the airborne sound insulation of the test specimen, the weighted sound reduction index, R_w, is used. The value is determined according to EN ISO 717-1:2013.

When determining the evaluation value, R_w, the measured results of the sound reduction index, R, per one-third octave from 100 Hz to 3150 Hz are compared with a reference curve. The reference curve is shifted in steps of 1 dB towards the measured curve until the sum of unfavourable deviations is as large as possible but not more than 32.0 dB. An unfavourable deviation at a particular frequency occurs when the test result is less than the value of the reference curve.

The evaluation value, R_w, is determined from the shifted reference curve as the value in dB at 500 Hz.

Additionally, the spectrum adaptation terms, C and C_{tr}, for A-weighted pink noise and A-weighted urban traffic noise are calculated. These adaptation terms are stated in the report in brackets after the R_w-value.