COMPARING RESULTS OF USING ISO 140-4:1998 TO ISO 16283-1:2014

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ISO 140-4:1998 has been replaced by ISO 16283-1:2014. ISO 16283-1 introduces new approaches for source directivity, a limit of 8dB between adjacent 1/3 octave bands within the source room, a means to calculate “level difference”, and distinguishes a Default Procedure and a Low-frequency Procedure for Sound Pressure Level measurement, that are not included in ISO 140-4. For the Default Procedure, ISO 16283-1 introduces the possibility to use a "manually-scanned microphone" method, also not included in ISO 140-4. The main objective of this paper is to compare the results of using the new ISO 16283-1 approaches with results using the old ISO 140-4 approaches. This comparison provides knowledge of the change in results that may occur in the transition from ISO 140-4 to ISO 16283-1, and may be useful to help laboratories in deciding the kind of procedures that are necessary in this transition.

1. Introduction

ISO 140-4:1998 [1] has been replaced by ISO 16283-1:2014 [2], and the main differences/similarities are shown in the next subchapters.

1.1 Source Directivity

In ISO 140-4:1998 and in ISO 16283-1:2014 it is stated that to test the directional radiation of the loudspeaker, the sound pressure levels must be measured around the source at a distance of 1,5 m from the centre of the loudspeaker, in a free-field environment. Both standards state the following equation:

(1) $$DI_i = L_{360°} - L_{30,i} .$$

where *DI* is the Directivity Index, $L_{360°}$ is the energy-average level for the complete arc of 360°, and $L_{30,i}$ is the energy-average value over each arc of 30°.

Both standards state that *DI* values must be within ± 2 dB for the frequency range from 100 Hz to 630 Hz, ± 5 dB for 800 Hz and ± 8 dB for the frequency range from 1,000 Hz to 5,000 Hz.

The differences are: 1) ISO 16283-1:2014 proposes a test periodicity of two years, and ISO 140-4:1998 does not specify any test periodicity. ISO 140-14:2004 [3], that complements ISO140-4:1998, also does not specify a test periodicity for source directivity. In Portugal OEC 013, 2014, [4] specifies an annual periodicity; 2) ISO 16283-1:2014 specifies clearly that the angle step of measurements must be 1º or 5º, and ISO 140-4:1998 does not specify any angle step, so in the worst case an angle step of 30º could be used.

1.2 Emission Spectrum

In ISO 140-4:1998 and in ISO 16283-1:2014 is stated that the emission sound field spectrum must fulfil some requirements. In ISO 140-4:1998 the requirements are that the spectrum, in the source room, shall not have a difference in level of more than 6 dB between adjacent one-third octave bands. In ISO 16283-1:2014 the requirements are that the energy-average sound pressure level in the source room shall not have a difference in level of more than 8 dB between adjacent one-third octave bands, at least above 100Hz.

It must be pointed out that the difference between ISO 140-4:1998 and ISO 16283-1:2014 is not just the change from the 6 dB limit to the 8 dB limit, but also the clarification that the requirement applies above 100Hz, and to the energy-average value not to each microphone measurement position (in the case of fixed microphone positions), as was already clarified in references [5,6]. It should also be pointed out that ISO 16283-1:2014 states that the loudspeaker position should be changed or a graphic equaliser used if necessary to fulfil the 8 dB spectrum rule in the source room. Reference [5] already recommended the use of a graphic equaliser.

1.3 Level Difference Calculation

In ISO 140-4:1998 and in ISO 16283-1:2014 the Level Difference D is defined as:

(2) $$D = L_1 - L_2 \, .$$

where L_1 is the energy-average sound pressure level in the source room and L_2 is the energy-average sound pressure level in the receiving room. When more than one source position is used, the L_1 is normally calculated (for ISO 140-4:1998) from all values (all microphone and all source positions) in source room, and L_2 from all values in receiving room.

Now in ISO 16283-1:2014 it is clearly stated that we must calculate the energy-average sound pressure level for each source position, and calculate for each j source position the D_j Level Difference, and after that calculate the energy-average Level Difference according to the next equation:

(3) $$D = -10 \log \left(\frac{1}{m} \sum_{j=1}^{m} 10^{-0,1 D_j} \right).$$

References [5,6] already recommended energy-average for sound pressure levels for each source position, but recommended an arithmetic average for D_j, instead of a logarithmic average.

1.4 Default Procedure

The Default Procedure of ISO 16283-1:2014 is very similar to the Procedure of ISO 140-4:1998, with just a few changes, as shown in Table 1.

Especial note the new possibility to use a manually scanned microphone, the new rounding rule for background correction, and the new statement of six fixed microphone positions for reverberation measurements with the integrated impulse response method.

Table 1. Comparison between ISO140-4 and ISO 16283-1 Default Procedure.

Type of Procedure	ISO 140-4	ISO 16283-1 Default Procedure
Loudspeaker positions	Positions: For just one loudspeaker: ≥ 2 Distances: room boundaries/loudspeaker: ≥ 0,5 m different positions: ≥ 0,7 m (≥1,4 m for just two positions). Different loudspeaker positions shall not be located within planes parallel to the room boundaries.	Positions: For just one loudspeaker: ≥ 2 Distances: room boundaries/loudspeaker: ≥ 0,5 m (≥1,0 m for separating partition). different positions: ≥ 0,7 m (≥1,4 m for just two positions). Different loudspeaker positions shall not be located within planes parallel to the room boundaries that are less than 0,7 m apart
Microphone distances	0,7 m between microphones. 0,5 m between any microphone position and the room boundaries or diffusers. 1,0 m between any microphone position and the loudspeaker	0,7 m between fixed microphone positions. 0,5 m between any microphone position and the room boundaries. 1,0 m between any microphone position and the loudspeaker
Fixed microphone positions	Way: not specified. Position: ≥ 5 positions. Averaging time: 50 to 80 Hz: ≥15 s; 100 to 400 Hz: ≥6 s; 500 to 5000 Hz: ≥4 s.	Way: Tripod or manually-held. Position: ≥ 5 positions. Averaging time: 50 to 80 Hz: ≥15 s; 100 to 400 Hz: ≥6 s; 500 to 5000 Hz: ≥4 s.
Mechanized continuously-moving microphone	Position: ≥ 1 position. Averaging time: 50 to 80 Hz: ≥60 s; 100 to 5000 Hz: ≥30 s.	Position: ≥ 1 position. Averaging time: 50 to 80 Hz: ≥60 s; 100 to 5000 Hz: ≥30 s.
Manually-scanned microphone	Not specified.	Position: ≥ 1 position. Averaging time: 50 to 80 Hz: ≥60 s; 100 to 5000 Hz: ≥30 s. Velocity constant: ≤ 20º/s and 0,25m/s.
Background noise	The background noise level shall be at least 6 dB (and preferably more than 10 dB) below the level of signal and background noise combined at each frequency band. Rounding: Not specified.	The background noise level shall be at least 6 dB (and preferably more than 10 dB) below the level of signal and background noise combined at each frequency band. Rounding: The values shall be reduced to one decimal place before use in Formula.
Reverberation Time	At least one loudspeaker position shall be used with three fixed microphone positions and two measurements at each position.	Interrupted noise method: at least one loudspeaker position shall be used with three fixed microphone positions and two measurements at each position. Integrated impulse response method: At least one source position and six fixed microphone positions shall be used.

1.5 Low-frequency Procedure

The Low-frequency Procedure in ISO 16283-1:2014 is not included in ISO 140-4:1998. This Procedure establishes, at a glance, the following lines:

- The Low-frequency Procedure shall be used for the 50 Hz, 63 Hz, and 80 Hz one-third octave bands in source and/or receiving room when its volume is smaller than 25 m^3 (calculated to the nearest cubic metre).
- Sound pressure level measurements are taken close to the corners of the room to identify the corner with the highest level in each band: a fixed microphone shall be positioned in room corners (set of four corner measurements, where two corners should be at ground level and two corners should be at ceiling level) at a distance of 0,3 m to 0,4 m from each room boundary that forms the corner. The minimum distance between any microphone position and the loudspeaker shall be 1,0 m.
- When two or more q positions of the loudspeaker are used, the corner sound pressure level (L_{Corner}) is then calculated for each frequency band, from formula (4), where $L_{\mathrm{CornerLS}q}$ is the highest corner sound pressure level for the q loudspeaker position.
- The low-frequency energy-average sound pressure level $L_{\mathrm{LF},j}$ in the 50 Hz, 63 Hz and 80 Hz bands (j band) is calculated by combining $L_{\mathrm{DP},j}$ from the Default Procedure and $L_{\mathrm{Corner},j}$ from the Low-frequency Procedure using Formula (5).
- The reverberation time is measured in the 63 Hz octave band instead of the 50 Hz, 63 Hz, and 80 Hz one-third octave bands, and this single measured value is used to represent the 50 Hz, 63 Hz and 80 Hz bands in the calculation of $D_{\mathrm{n}T}$ and/or R'.

(4) $$L_{\mathrm{Corner}} = 10\log\left(\left(10^{\frac{L_{\mathrm{Corner,LS1}}}{10}} + 10^{\frac{L_{\mathrm{Corner,LS2}}}{10}} + \cdots + 10^{\frac{L_{\mathrm{Corner,LS}q}}{10}}\right)/q\right)$$

(5) $$L_{\mathrm{LF},j} = 10\log\left(\left(10^{\frac{L_{\mathrm{Corner},j}}{10}} + 2\cdot 10^{\frac{L_{\mathrm{DP},j}}{10}}\right)/3\right)$$

2. Equipment

The equipment used during the measurements reported in this paper are: one class 1 sound level meter: SOLO Model, 01dB Brand; one dodecahedral loudspeaker: OmniPower 4292 Model, Brüel & Kjaer Brand; and one amplifier: NOR280 Model, Norsonic Brand.

All this equipment belongs to SONOMETRIA Noise Accredited Lab.

3. Comparison of Measurement Results

In the next section subchapters the results of the measurements are presented, along with the analysis of the results.

3.1 Source Directivity

To analyse the differences between using 5º or 30º angle step, sound level measurements have been performed around the dodecahedral loudspeaker, with 5º step, and calculated the average over each ± 15º arc, and this result (30ºaverage) compared with each 30º singular value (30ºsingular).

Figure 1 illustrates the values obtained for the 1/3 octave bands of 1000 Hz and the maximum and minimum values of *DI* (average and singular) for 1/3 octave bands between 100Hz and 5kHz.

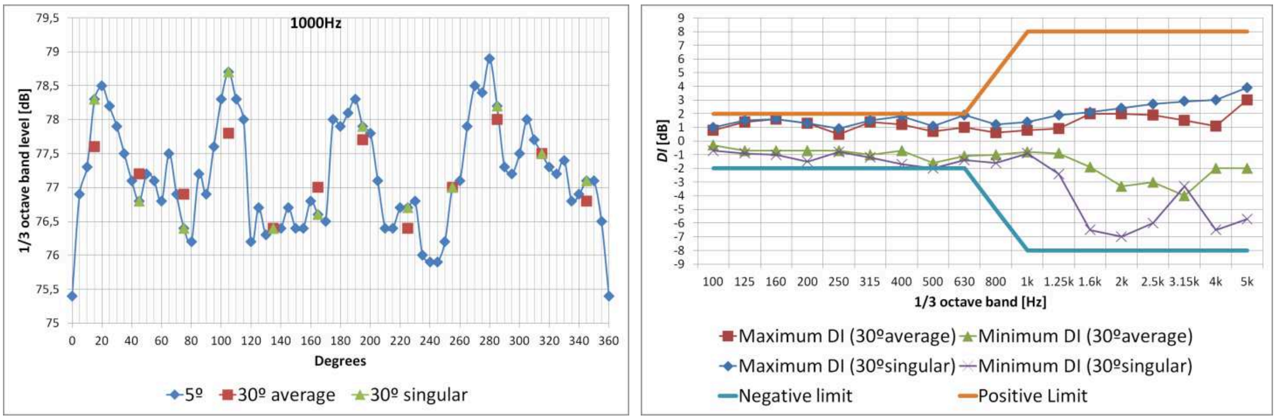

Figure 1. Comparison of source directivity results

The graphics above indicate that the 30º average results, based upon the 5º measurements limit within ISO 16283-1:2014, give a more representative indication of the directivity of the loudspeaker than the 30ºsingular results, based upon the typical use of the old ISO 140-4:1998, and show that the indicated directivity is more reliable. The graphics shows also hat is "easier" to fulfil the directivity requirements using 30ºaverage results.

3.2 Emission Spectrum

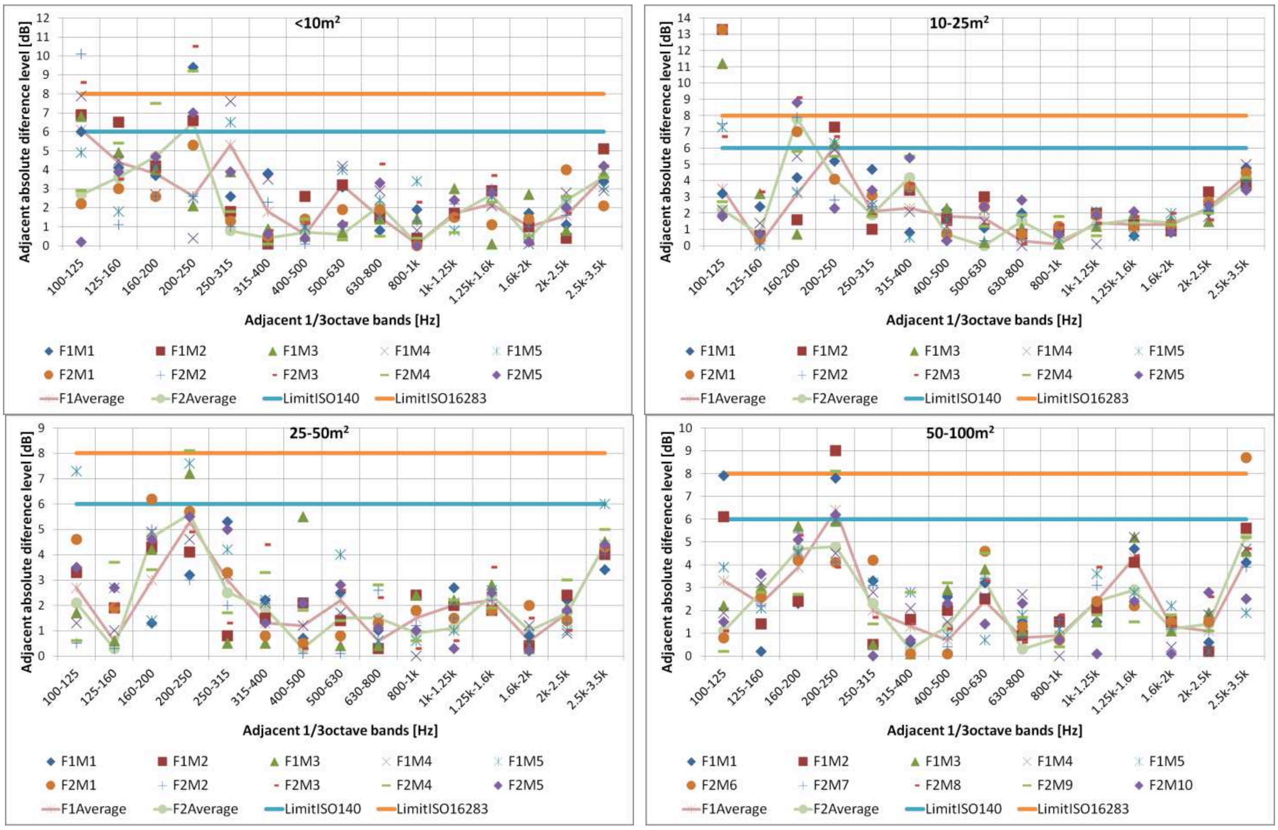

Figure 2. Comparison of emission spectrum results

In order to analyse the differences between using the 6 dB or 8dB emission spectrum 1/3 octave band rules, and energy-average values for each microphone position (fixed microphone), analysis has been undertaken of the emission spectrum related to airborne sound insulation measurements in 12 places (3 places each per floor area group: a) <10 m^2; b) 10-25 m^2; c) 25-50 m^2: d) 50-100 m^2). Figure 2 illustrates the worst case (higher adjacent band levels differences) for each floor area group. In the graphic legend, F*n*M*m* means the Source position *n* and Microphone position *m*.

The graphics show that in all cases at least one singular measurement does not fulfil the 8 dB rule; the energy-average values fulfil the 8 dB rule in all cases; and in just one case the two energy-average values fulfil the 6 dB rule. All the measurements were performed without a graphic equalizer.

3.3 Level Difference Calculation

To evaluate the differences between using the three available approaches for Level Difference calculation (D_1: ISO 140-4:1998; D_2: ISO 140-4:1998 plus references [5,6]); and D_3: ISO 16283-1:2014, the difference between methods was analysed and the results shown in Table 2. The assessment assumes based upon two emission values L_{E1} (energy-average related with source position 1), and L_{E2} (energy-average related with source position 2), and two receiver values L_{R1} (energy-average related with source position 1) and L_{R2} (energy-average related with source position 2):

(6) $$D_1 = 10\log\left(\left(10^{\frac{L_{E1}}{10}} + 10^{\frac{L_{E2}}{10}}\right)/2\right) - 10\log\left(\left(10^{\frac{L_{R1}}{10}} + 10^{\frac{L_{R2}}{10}}\right)/2\right)$$

(7) $$D_2 = \left[(L_{E1} - L_{R1}) + (L_{E2} - L_{R2})\right]/2$$

(8) $$D_3 = -10\log\left(\left(10^{\frac{-(L_{E1}-L_{R1})}{10}} + 10^{\frac{-(L_{E2}-L_{R2})}{10}}\right)/2\right)$$

Table 2. Comparison between the three possible methods of Level Difference calculation

L_{E1}-L_{E2}	L_{R1}-L_{R2}	D_1-D_2	D_1-D_3	Smaller	L_{E1}-L_{E2}	L_{R1}-L_{R2}	D_1-D_2	D_1-D_3	Smaller
1	10	-2,4	-0,4	D_1	1	0	0	0	-
1	5	-0,7	-0,3	D_1	0	1	0	0	-
0	5	-0,7	0	D_1	2	0	0,1	0,2	D_3
2	5	-0,6	-0,3	D_1	5	4	0,2	0,2	D_2; D_3
3	5	-0,4	-0,3	D_1	3	0	0,3	0,6	D_3
0	4	-0,4	0	D_1	4	0	0,4	0,8	D_3
0	3	-0,3	0	D_1	5	3	0,4	0,5	D_3
4	5	-0,2	-0,2	D_1	5	2	0,6	0,9	D_3
0	2	-0,1	0	D_1; D_3	5	1	0,7	1,1	D_3
any	L_{E1}-L_{E2}	0	0	-	5	0	0,7	1,4	D_3
0	0	0	0	-	10	1	2,4	4,4	D_3

The table above shows that, in some cases D_1 is the smaller, in a few cases D_1 and D_3 are the smaller, in some cases D_1, D_2 and D_3 are equal, and in other cases D_3 is the smaller.

The results suggest that when D_1 is the smaller, D_1 and D_3 are very close; however when D_3 is the smaller, D_1 can be very far from D_3, which indicates a more "safe" position (low values of D) using the D_3 approach.

3.4 Default Procedure

ISO 16283-1:2014 states that the fixed-microphone method, and the mechanized continuously-moving microphone method (without operator inside the room), should be considered as reference results, therefore the new manually-scanned microphone method is not a reference result.

A comparison of the six methods in ISO 16283-1:2014 [(1) Circle, (2) Helix, (3) Cylindrical type, (4) Three semicircles, (5) Five fixed positions, and (6) Five fixed positions and Max Corner] has been made by Simmons [7] to obtain a spatial average sound pressure level. In summary the results suggest a preference for method (5) in comparison with methods (1-4):

- Method (5) approximates the mesh average within ±1 dB in the range 50-5000Hz. The moving microphone methods (1-4) deviate more from the mesh average at some frequencies in comparison with method (5);
- The fixed positions were more evenly distributed throughout the permitted space of each room, compared to a moving microphone path that had to be placed more or less in the centre of the small rooms, which may have led to systematic errors;
- The practical findings of the Simmons study [7] indicate that method (5) *Five fixed positions* has advantages. It may even be preferred for all types of room, and it was quicker than first anticipated.

3.5 Low-frequency Procedure

Despite the fact that the Low-frequency Procedure is one of the main differences between ISO 16283-1:2014 and ISO 140-4:1998, its practical importance depends on the parameters used in the building legislation. If the objective of the measurements is to verify the legal requirements, and if the legislation does not apply requirements associated with the spectral adaptation terms for low frequencies, it may not be necessary to use the Low-frequency procedure. According to Rasmussen and Rindel [8] the following parameter is recommended for European harmonization requirements on airborne sound insulation between dwellings: $D_{nT,w} + C_{50\text{-}3150}$.

4. Conclusions

Considering the results presented above, the following conclusions may be drawn:

- Source Directivity: The results presented in section 3.1 show that it is more difficult to verify the standard directivity requirements with 30º angle step measurement, it seems that the transition to ISO 16283-1:2014 (1º or 5º angle step) can be done without major problems and improved reliability in the results. The test periodicity can be two years.
- Emission Spectrum: The results in section 3.2 show that the new 8 dB 1/3 octave band rule applied to energy average values, for each source position, is easier to fulfil than the old 6 dB rule applied to singular values. This also suggests that the transition to ISO 16283-1:2014 could be undertaken without major problems. Since the worst cases analysed fulfil the new 8 dB rule without using a graphic equalizer, it may be possible to continue performing airborne insulation measurements without acquiring a graphic equalizer.
- Level Difference Calculation: The results presented in section 3.3 show that calculation approach D_3 (ISO 16283-1:2014) tends to be the one with higher "safe" position (low values of D). This suggests that it is very important for test laboratories to create new procedures to take into account this Level Difference calculation approach (D_3) instead of ISO 140-4:1998, and references [5,6] approaches (D_1 and D_2).
- Default Procedure: The contents of section 1.4 and 3.4 show that the main changes which may need new laboratory procedures are: a) new rounding rule for the background correction; b) new requirement for six fixed microphone positions for reverberation measurements with the integrated impulse response method. Regarding the possibility of using manually scanned microphone methods, it seems that there may be some advantage to continue using the well-known "fixed microphone" method, widely used by accredited measurement laboratories. The main disadvantage would be the time/number of measurement, but given that the calculation of uncertainty, according to the ISO 12999-1:2014 [9] will not have to calculate the standard deviation of the different measurements, per-

haps it is possible to begin using the fixed microphone method, with just the average values for each source position.

- Low-frequency Procedure: In countries where the building acoustics legislation requirements do not consider the low frequency adaptation terms (e.g. Portugal), it may not be required to use the Low-frequency Procedure in order to meet the legal requirements. According to Helimäki and Rasmussen [10] the Swedish Building Acoustics Legislation takes low frequency adaptations into account.

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