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Revision of ISO 717: Why Not Use Impact Sound Reduction Indices Instead of Impact Sound Pressure Levels?

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Summary
In the current edition of ISO 717 airborne and impact sound insulation are described in an oppositional way: airborne sound insulation is expressed in terms of a 'sound reduction index', impact sound insulation, however, as an 'impact sound pressure level'. The fussiness of two different approaches for comparable properties of building elements is furthermore increased by the duality or mixture of reference curve comparison and A-weighting methods. The implicit and exclusive application of the tapping machine for the impact sound pressure level prevents any flexibility in the impact source characteristics, other than with airborne sound reduction indices, where traffic noise and 'living' noise from the neighbour can be used likewise for building element characterisation. This paper proposes to replace the impact sound pressure level by a new quantity called "impact sound reduction index". A detailed introduction into the background of this paper is given in [1].

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1. Introduction

At present, the international standard series ISO 717 [2] is under revision. ISO 717 has the task to specify calculation procedures, how to condense measured spectra of sound insulation values into so-called single-number results. The ISO 717 series deal with airborne as well as with impact sound insulation. However, both are treated so far in a different or even opposite way, making things more difficult than necessary. E.g. impact sound insulation is characterised by a sound pressure level which must be excited by a standard tapping machine, whereas airborne sound insulation is expressed by a sound reduction index. Thus the scales for impact and airborne sound are oriented contrariwise. Other than with sound reduction indices for airborne sound, the characterising impact sound pressure level does not contain a reference to the strength of the applied tapping machine, thus excluding a priori any flexibility with respect to the choice of impact sources. Furthermore in the current issue of ISO 717, two concepts of single-number evaluation are mixed: the concept of comparing the frequency spectrum of sound insulation values with a given reference curve and the concept of comparing the available total sound power of a source with the total sound power transmitted into the receiving room of interest. "Total" means here the sum of all contributing frequency bands. So on the occasion of the revision of ISO 717, the idea arose to replace the 'old' impact sound pressure level by a 'new' impact sound reduction index which fully conforms to the approach for airborne sound. The concept is explained subsequently in detail. As this paper here highlights only one particular section of the single-number evaluation discussion, it is strongly recommended to take note of the introducing paper [1], where background information, many examples and further interpretation of the new quantities are presented.

The author of this paper is fully aware that in the present situation a compromise had to be made: On the one hand there is a kind of 'historical' chance to essentially improve the statement of impact sound insulation characteristics of building elements on the occasion of the ongoing revision of ISO 717. This time window will not be open very long. On the other hand, not all aspects of describing the (maximum) available sound power of the impact sources like the standard tapping machine are yet fully discussed, in particular when regarding a full independence of this power from the mechanical properties of the receiving structure. In order not to miss the chance, it was not attempted to answer all open questions. Nevertheless the system proposed here is consistent in itself and can completely be traced back to the existing single-number evaluation for impact sound. It is completely applicable in practice from the first beginning without any need to make further assumptions by the user, it simplifies drastically the evaluation procedures (in particular with respect to sound reduction improvement measures), and it provides a clear framework for any subsequent change to accommodate alternate impact sources. [1]

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2. The basic idea of sound reduction indices

The sound reduction index R of a building element is defined as the ratio of sound power arriving at this building element (called "source power" P_S here) divided by the power transmitted through this element into the receiving room (P_R), expressed as a level,

$$R = 10 \lg \left(\frac{P_S}{P_R} \right). \quad (1)$$

Referring to a separating element between two closed rooms, and to diffuse airborne sound coming in and radiated through the element, the powers can be expressed by the sound pressure level on the source side of the element as

$$P_S = \frac{p_S^2 S}{4 \rho c}, \quad (2)$$

and on the receiving side as

$$P_R = \frac{p_R^2 A}{4 \rho c}, \quad (3)$$

where p_s^2 and p_R^2 mean the average of the squared sound pressures on the respective element side, S the power receiving area of the element, A the equivalent absorption area in the receiving room, and ρ and c the density resp. wave speed in air. Thus equation (1) becomes

$$R = 10 \lg \left(\frac{p_S^2 S}{p_R^2 A} \right) = L_S - L_R + 10 \lg \left(\frac{S}{A} \right). \quad (4)$$

It is important to keep in mind, that the source power here is the power 'offered' to the element (or 'incident sound power' or 'available sound power') and not the fraction of the power 'accepted' by the element (or in other words: transmitted into the element). The sound 'rejection' (or 'reflection') by the element is clearly a part of its sound insulation capacity, which must not be eliminated by referring the transmitted power to only the accepted power.

3. Impact sound reduction index

At present impact sound insulation is expressed in terms of the normalised impact sound pressure level in a room when a standard tapping machine acc. to ISO 140-6 [2] acts on the floor above that room,

$$L_n = L + 10 \lg \left(A/A_0 \right), \quad (5)$$

where A = the equivalent absorption area in the receiving room, $A_0 = 10\,\mathrm{m}^2$, and L = the space and time averaged sound pressure level in the receiving room, or in terms of the standardised impact sound pressure level

$$L_{nT} = L - 10 \lg \left(T/T_0 \right), \quad (5a)$$

with T = the reverberation in the receiving room, and T_0 = the reference value, $T_0 = 0.5\,\mathrm{s}$ in living rooms.

Unfortunately this type of characterising impact sound insulation is completely restricted to the use of the standard tapping machine as a source, although this doesn't appear explicitly in the definition (5) or (5a). Furthermore it may be confusing, that the use of a received sound pressure level for impact sound on the one hand and the use of the reciprocal of the received sound pressure level for airborne sound on the other hand express the insulation efficiency of an element in exactly opposite directions. This involves different wording ('improvement' versus 'reduction') as well as different procedures to average or add the effect of different transmission paths, to calculate single-number values, or determine uncertainty.[2]

So it seems to suggest itself to express impact sound insulation just as well in terms of an impact sound reduction index according to equation (1):

$$R_{\mathrm{impact}} = 10 \lg \left(\frac{P_S}{P_R} \right), \quad (6)$$

where P_S = the impact power provided by the standard tapping machine according to [5], P_R = the radiated sound power into the receiving room, and R_{impact} = the impact sound reduction index.

The impact power, provided by the tapping machine, is given by the potential energy of its hammers times the number of beats per second,

$$P_S = mgh\,n, \quad (7)$$

and with $m = 500\,\mathrm{g}$ (mass of a tapping machine hammer), $g = 9.81\,\mathrm{m/s}^2$ (gravitational acceleration), $h = 0.04\,\mathrm{m}$ (falling height of the hammers), and $n = 10\,\mathrm{s}^{-1}$ (hammer beats per second) the impact power becomes

$$P_S = 1.962\,\mathrm{Watt}. \quad (8)$$

The airborne sound power radiated into the receiving room was already given by equation (3).

[1] Other descriptors for the available incident power of an impact source than the one presented here are thinkable, e.g. the characteristic source power introduced by Moorhouse [3] or defined in EN 12354-5 [4]. But these quantities are based on sinusoidal action, expressed by 'free velocity' and 'source mobility', and it is not obvious, how to transfer this to a falling hammer without further assumptions about the receiver mobility. However, this problem will not occur before new impact sources with different mobilities are taken into account and one additionally requires to compare the available incident powers of the sources directly. This should be dealt with in future.

[2] In the American Standard ASTM 989-6 [11] there is a single-number value to characterise the impact sound insulation, called "Impact Insulation Class (IIC)", which corresponds to the $L_{n,w}$ value of ISO 717 but with the exception, that the dB-scale is turned upside down, and that there is an additional 8-dB rule. Apart from the reversed scale, there are no further similarities with the R_{impact} approach presented here.

4. Third octave band values of the impact sound reduction index

To be able to replace the tapping machine total impact power according to equation (7) by its third octave band values, the following assumptions are made:

- the whole power is concentrated in the 18 third octave bands from 50 to 2500 Hz, and
- it is equally distributed over frequency according to the hit character of the source (for one single hit this would be exact, for the line spectrum of a tapping machine with 2 Hz distance [6] between the lines of comparable height this is an approximation).

For the i-th third octave band the corresponding fraction $P_{S,i}$ of the total impact power P_S then follows from

$$P_{S,i} = \frac{P_S\, B_i}{B}, \tag{9}$$

with B = the frequency bandwidth comprising all the third octave bands considered (= 2784 Hz for third octave bands from 50 to 2500 Hz), B_i = the frequency bandwidth of third octave band i.

B_i can be calculated for the third octave band with centre frequency f_i from

$$B_i = \left(2^{1/6} - 2^{-1/6}\right) f_i \approx 0.232 f_i. \tag{10}$$

The source sound power level of the third octave band i then becomes

$$L_{P,S,i} = 10\lg\left(\frac{P_{S,i}}{P_0}\right) = 10\lg\left(\frac{P_S B_i}{B P_0}\right) \tag{11}$$

$$= 10\lg\left(\frac{1.96 \cdot 0.232 f_i}{2784 \cdot 10^{-12}}\right),$$

$$L_{P,S,i} = 82.1 + 10\lg\left(\frac{f_i}{1\,\text{Hz}}\right). \tag{12}$$

The power $P_{R,i}$ transmitted into the receiving room follows from equation (3), here written for third octave bands,

$$P_{R,i} = \frac{p_{R,i}^2 A_i}{4\rho c}, \tag{13}$$

thus yielding the impact sound reduction index R_i at third octave band i:

$$R_i = 10\lg\left(\frac{P_{S,i}}{P_{R,i}}\right) = 10\lg\left(\frac{P_{S,i}}{P_0}\right) - 10\lg\left(\frac{P_{R,i}}{P_0}\right)$$

$$= L_{P,S,i} - 10\lg\left(\frac{p_{R,i}^2 A_i}{4\rho c\, P_0}\right), \tag{14}$$

with $P_0 = 10^{-12}$ Nm/s or Watt, the reference value for sound power, and $\rho c = 400\,\text{Ns/m}^3$, the characteristic acoustic impedance of air.

Expanding and rearranging equation (14) yields

$$R_i = L_{P,S,i} - \left(L_{R,i} + 10\lg(A_i/A_0)\right)$$

$$- 10\lg\left(\frac{A_0 p_0^2}{4\rho c\, P_0}\right), \tag{15}$$

where $p_0 = 2 \cdot 10^{-5}\,\text{N/m}^2$, the reference value for sound pressure levels, $L_{R,i}$ = the time and space average sound pressure level in the receiving room, and $A_0 = 10\,\text{m}^2$.

A comparison with equation (5) shows, that

$$\left(L_{R,i} + 10\lg(A_i/A_0)\right) = L_{n,i}, \tag{16}$$

with $L_{n,i}$ being the normalised impact sound pressure level at frequency band i, so that equation (15) simplifies to

$$R_i = L_{P,S,i} - L_{n,i} - 4.0, \tag{17}$$

or after insertion of $L_{P,S,i}$ from equation (12):

$$R_i = 78.2 + 10\lg\left(\frac{f_i}{1\,\text{Hz}}\right) - L_{n,i}. \tag{18}$$

5. Single-number evaluation of the impact sound reduction index

In general practice third octave band spectra of sound insulation quantities are merged into a single result, called a 'single-number value'. Following the present discussion going along with the revision of the corresponding standard ISO 717 ("Acoustics – Rating of sound insulation in buildings and of building elements") [7], the single-numbers will consist of the energetic sum of the transmitted third octave band sound powers, when applying a particular source spectrum (possibly including further frequency shaping like e.g. the so-called A-weighting). Mathematically expressed in the case of the impact sound reduction index this results in

$$R_{\text{impact}} = 10\lg\left(\frac{\sum_i 10^{L_i/10}}{\sum_i 10^{(L_i - R_i)/10}}\right), \tag{19}$$

where L_i = the assumed source spectrum level at third octave band i. Rearranging equation (19) and inserting R_i from equation (18) yields

$$R_{\text{impact}} = 10\lg\left(\sum_i 10^{L_i/10}\right) \tag{20}$$

$$- 10\lg\left(\sum_i 10^{(L_i - 10\lg(f_i) - 78.16 + L_{n,i})/10}\right).$$

Now reference source spectrum values L_i have to be chosen. Although this is arbitrary in principle, here the attempt is made to find a reference spectrum that allows to express R_{impact} in terms of the old and most closely related single-number value ($L_{n,w} + C_{I,50-2500}$), which is constituted essentially by the energetic sum Ln,sum of the normalised impact sound pressure levels, namely [8]

$$L_{n,w} + C_{I,50-2500} = L_{n,sum} - 15\,\text{dB}, \tag{21}$$

where $$L_{n,sum} = 10\lg\left(\sum_i 10^{L_{n,i}/10}\right). \tag{22}$$

Comparing equations (22) and (20) suggests, that frequency dependent terms within the second sum in equation

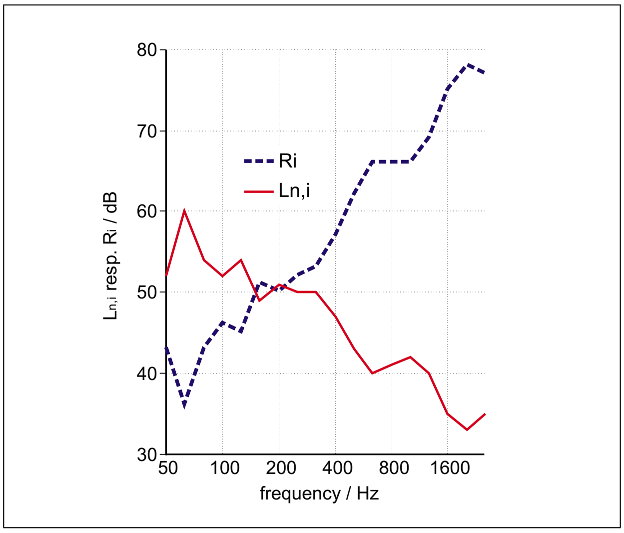

Figure 1. Impact sound pressure level values $L_{n,i}$ and impact sound reduction index values R_i of an arbitrarily chosen floor as an example. The single-number values are: $L_{n,w} = 46\,\text{dB}$, $C_{I,50-2500} = 3\,\text{dB}$, $R_{\text{impact}} = 55\,\text{dB}$.

(20) should be removed to get a sum like in equation (22). So, simply the tapping machine spectrum from equation (12) was taken for the reference spectrum values L_i,

$$L_i = L_{P,S,i} = 82.1 + 10\lg\left(f_i\right). \quad (23)$$

With the intermediate result

$$10\lg\left(\sum_i f_i\right) = 40.8$$

for the third octave bands i from 50 to 2500 Hz then follows

$$R_{\text{impact}} = 119.0 - 10\lg\left(\sum_i 10^{L_{n,i}/10}\right) = 119.0 - L_{n,sum}, \quad (24)$$

or in old terms from equation (21):

$$R_{\text{impact}} = 119.0 - \left(L_{n,w} + C_{I,50-2500} + 15\right). \quad (25)$$

This means, that the considered old single-number quantity can directly be converted into the new single-number R_{impact} without the detour via third octave band values, if the reference source spectrum is chosen according to equation (23).

In the long run, of course, it would be desirable for the single-number evaluation, not to have the impact sound pressure levels $L_{n,i}$ as an input from the measurement standards but directly the third octave band values of the impact sound reduction index, R_i.

Figure 1 illustrates the relation between the 'old' impact sound pressure level and the 'new' impact sound reduction index by means of the example of an arbitrarily chosen floor.

6. Normalised and standardised impact sound pressure level differences

In groups dealing with building acoustics and related requirements, there is a discussion going on, as to whether single-number values for sound insulation purposes should refer to receiving room levels which are normalised to the equivalent sound absorption area of the receiving room (called 'normalised' levels) or rather to its reverberation time (called 'standardised' levels for some reason).

Thus in airborne sound insulation e.g. two sound pressure level differences exist besides the sound reduction index: the 'normalised' sound pressure level difference

$$D_n = L_S - L_R - 10\lg\left(A/A_0\right), \quad (26)$$

and the 'standardised' sound pressure level difference

$$D_{nT} = L_S - L_R - 10\lg\left(T/T_0\right). \quad (26a)$$

For the simple sound pressure level difference without any reference to room absorption one often abbreviates

$$D = L_S - L_R. \quad (26b)$$

L_S and L_R are the room average sound pressure levels in the source and receiving rooms respectively. Reverberation time T and equivalent absorption area A represent the receiving room characteristics.

In impact sound insulation, expressed so far as impact sound pressure levels, also two such quantities exist, the 'normalised' impact sound pressure level and the 'standardised' impact sound pressure level, as given in equations (5) and (5a). To be able to express requirements in the new system via the existing standardised and normalised impact sound pressure levels, L_{nT} and L_n, one can use the following relations, derived from equations (5), (5a), and (15):

$$R_i = L_{P,S,i} - 10\lg\left(\frac{A_0 p_0^2}{4\rho c P_0}\right) - L_{n,i} \quad (27a)$$

and $$R_i = L_{P,S,i} - 10\lg\left(\frac{A_0 p_0^2}{4\rho c P_0}\right) + 10\lg\left(\frac{A_0 T_0}{0.16V}\right) - L_{nT,i}, \quad (27b)$$

where V is the receiving room volume in m^3, $T_0 = 0.5\,\text{s}$ the reference value of reverberation time, and $A_0 = 10\,\text{m}^2$ the reference value for the equivalent sound absorption area.

When installing a sound reduction index system for impact sound it might be desirable to define also normalised and standardised sound pressure level differences analogous to airborne sound, as given in equations (26). A sound pressure level in the sense of excitation in the source room, however, does not exist, but could be defined via the following question: Which (space averaged) sound pressure level L_S in the source room would offer the same sound power to the receiving building element as the impact source does? This equivalent source room sound pressure level L_S can be deduced in a room with a diffuse sound field from the relation between the sound pressure and the sound power incident on the building element surface S,

$$p_{S,i}^2 = P_{S,i}\, 4\rho c/S, \tag{28}$$

or in terms of a sound pressure level:

$$L_{S,i} = 10\lg\left(\frac{p_{S,i}^2}{p_0^2}\right) = 10\lg\left(\frac{P_{S,i}4\rho c}{p_0^2 S}\right). \tag{29}$$

When assigning to S the typical reference area value of $S = 10\,\mathrm{m}^2$ ([3]) and to $P_{S,i}$ the impact sound power of a standard tapping machine according to equation (12), one obtains

$$L_{S,i} = 78.2 + 10\lg\left(\frac{f_i}{1\,\mathrm{Hz}}\right), \tag{30}$$

and hence from equations (26) the corresponding 'impact sound pressure level difference' at third-octave band i,

$$D_i = 78.2 + 10\lg\left(f_i/1\,\mathrm{Hz}\right) - L_{R,i}, \tag{31}$$

the corresponding 'normalised impact sound pressure level' at third-octave band i pressure level

$$D_{n,i} = 78.2 + 10\lg\left(f_i/1\,\mathrm{Hz}\right) - L_{R,n,i}, \tag{31a}$$

and the corresponding 'standardised impact sound pressure level' at third-octave band i

$$D_{nT,i} = 78.2 + 10\lg\left(f_i/1\,\mathrm{Hz}\right) - L_{R,nT,i}. \tag{31b}$$

7. Impact sound reduction improvement

The single-number quantity of the improvement of the impact sound reduction index R_{impact} of a bare floor by a floor covering is called "impact sound reduction improvement" and is denoted by ΔR_{impact}. Its third octave band values ΔR_i are determined from a measurement on one of the available standard laboratory floors acc. to [9] or [10]. The single-number value ΔR_{impact} then is calculated as the improvement of R_{impact} of the corresponding standardised reference floor, when applying the measured third octave band improvement values of the flooring to this reference floor. The calculated improvement of the reference floor at third octave band i is

$$\Delta R_i = R_{i,\text{ref,with}} - R_{i,\text{ref,without}}, \tag{32}$$

where $R_{i,\text{ref,without}}$ = the impact sound reduction of the reference floor without floor covering on it, $R_{i,\text{ref,with}}$ = the impact sound reduction of the reference floor, improved by the floor covering by ΔR_i.

The relation between the 'old' third octave band values of the "reduction in impact sound pressure level", ΔL_i, and the 'new' "impact sound reduction improvement" ΔR_i simply is

$$\Delta R_i = \Delta L_i. \tag{33}$$

The single-number value of the impact sound reduction index of the floor covering hence can be obtained from

$$\Delta R_{\text{impact}} = 10\lg\frac{\sum_i 10^{(L_i - R_{i,\text{ref,without}})/10}}{\sum_i 10^{(L_i - R_{i,\text{ref,with}})/10}}\ \mathrm{dB}, \tag{34}$$

where L_i is again the supposed impact source reference spectrum, which for the ISO standard tapping machine can be taken from equation (23).

8. Conclusions and summary

Replacing the 'old' characterisation of impact sound insulation in terms of impact sound pressure levels by the 'new' impact sound reduction indices results in one single harmonic system for the characterisation of airborne and impact sound. This makes it clearer and more logical. However, the greatest advantage is that the impact source is now included in the definition of the sound insulation and is thus made visible. This allows us to make (careful) attempts to introduce impact sources other than the tapping machine for comparison, and – even easier – to introduce different source spectra (via frequency shaping of the reference source spectrum, c.f. [1]), which enable an improved consideration of psychoacoustic effects such as e.g. annoyance due to impact sound.

Of course, R_{impact} does not answer all of the existing open questions or delete all disadvantages which are (invisibly) associated with the impact sound pressure levels. The ranking of floors will still not be transferable from one impact source to another one having a different source mobility. And the impact sound reduction improvement of a floor covering will still depend on the mechanical characteristics of the bare floor and the impact source, so that the values cannot simply be transferred either. But these are no drawbacks caused newly by the sound reduction index definition of impact sound insulation, so that finally the advantages remain.

And, last but not least, there is a simple link between the old and the new quantities, in all cases on the basis of third octave band values, and, partially, even on the basis of single-number values. This means: existing measurement results can – as long as they cover the required frequency range – be used to determine the new single-number quantities without any extra effort. Of course requirements in terms of the proposed impact sound reduction index will have to be adjusted to the new approach. A large survey

[3] As the maximum available impact sound power of the tapping machine is independent of the receiving building element area, S has to be a fixed number and not the actual area of the receiving element, e.g. a floor. Although the choice is arbitrary in principle, $10\,\mathrm{m}^2$ have the advantage to be approximately typical in buildings und thus yield 'realistic' values of the sound pressure level in the source room.

of ‘old’ and ‘new’ single-number values for heavy and lightweight floors is presented in [1].

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