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INTEGRATING AND HARMONIZING AIRBORNE SOUND INSULATION DESCRIPTOR IN EUROPE - WHAT IS THE DIFFERENCE IN R'_w AND $D_{nT,w}$?

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A descriptor for airborne sound insulation used in Europe are the weighted apparent sound reduction index R'_w and secondly the weighted standardized level difference $D_{nT,w}$. The metrological determination is conducted according to the rules described in EN ISO 16283 Part 1. There are two main differences between both quantities, namely R'_w uses a separation surface S standardised with the equivalent sound absorption area A_0 whereas $D_{nT,w}$ uses the reverberation time T standardised with a standard reverberation time T_0. Both quantities exhibit some differences which are not immediate obvious. This paper evaluates the difference based on the geometrical relation between the weighted apparent sound reduction index R'_w and the weighted standardized level difference $D_{nT,w}$. It will be shown that R'_w is only equal $D_{nT,w}$ for a certain geometrical relation between separation surface and room volume (S/V) and on the other hand R'_w is biased by using a equivalent sound absorption area A.

1. Introduction

In [1] it is reported that in Europe mainly the weighted apparent sound reduction index R'_w and secondly the weighted standardized level difference $D_{nT,w}$ are used in regulatory requirements. Although it has long been known that the weighted apparent sound reduction index R'_w does not do justice to subjective perception [2], the weighted apparent sound reduction index remains in the application of sound insulation requirements. Furthermore, it is confirmed in [3] that R' has compared to D_{nT}, a weaker connection to the subjective impression of airborne sound insulation. In addition, it is shown in [4] that the calculation routine to determine R' is flawed because A, the equivalent absorption area, is an unknown quantity and can only be determined approximately. On the other hand, although the weighted standardized level difference $D_{nT,w}$ correlates better with subjective perception, it is still not uniformly taken into account in regulatory requirements. Both quantities are determined based on the same measured sound level differences and measured reverberation times and thus basically describe the same sound insulation effect. Nevertheless, there are differences due to the different calculation algorithms. The differences that arise when determining these two values are presented and discussed below.

2. Basic equations

The sound reduction index R is defined as ten times the decadal logarithm of the ratio of the sound power incident on a test object to the sound power transmitted into a room. If all transmission paths involved in sound transmission are included, the apparent sound reduction index *R'* results and is calculated according to equation (1):

$$R' = L_1 - L_2 + 10log\frac{S}{A} \tag{1}$$

There is:

L_1 is the energetically averaged sound pressure level in the source room, in dB
L_2 is the energetically averaged sound pressure level in the receiving room, in dB
S is the area of the test object, in m²
A is the equivalent sound absorption area in the receiving room, in m².

The calculation of the equivalent sound absorption area (*A*) in the receiving room is based on the measured reverberation time (*T*) using Sabine's equation. If the apparent sound reduction index (*R*') is weighted according to EN ISO 717-1 [5], the weighted apparent sound reduction index (R'_w) is obtained. This value is a single-number rating of the airborne sound insulation between rooms and is component-related.

The standardized sound level difference (D_{nT}) on the other hand, is defined as the difference in sound level between two rooms, in a stated frequency band and standardized to the internationally agreed reference reverberation time of 0.5 seconds and is calculated according to equation (2):

$$D_{nT} = L_1 - L_2 + 10log\frac{T}{T_0} \tag{2}$$

There is:

L_1 is the energetically averaged sound pressure level in the source room, in dB
L_2 is the energetically averaged sound pressure level in the receiving room, in dB
T is the reverberation time in the receiving room, in seconds
T_0 is the reference reverberation time, in seconds.

The standardized sound level difference takes account of all sound transmission paths between the rooms and provides a direct correlation to the subjective impression of the airborne sound insulation [3]. If the standardized level difference (D_{nT}) is weighted according to EN ISO 717-1, the weighted standardized level difference ($D_{nT,w}$) is obtained. This value is a single-number rating of the airborne sound insulation between rooms and is room-related and directional.

3. Differences between R'_w and $D_{nT,w}$

The differences are obvious. Both quantities describe the same sound level difference between the rooms ($D = L_1 – L_2$). The difference between the two dimensions (R'_w, $D_{nT,w}$) is represented by the difference in references, i.e. between the size of the room and the absorption taken into account:

$$D + 10\log T = \begin{cases} -10\log\left(\frac{S}{0{,}16\,V}\right) & \rightarrow \quad R'_w \\ +3\,dB & \rightarrow \quad D_{nT,w} \end{cases} \tag{3}$$

To compare these two sound insulation properties, the area of the dividing partition (*S*), the room volume of the receiving room (*V*), the sound absorption properties of the receiving room (*A*), the reverberation time of the receiving room (*T*), respectively, need to be considered.

The general difference between both sizes R'_w and $D_{nT,w}$ is then:

$$10 \log \left(\frac{S}{V}\right) + 5\ dB \quad (4)$$

Equation (4) gives a zero sum for a ratio (S/V) of 0.32.

According to equation (3) a direct link between both quantities $D_{nT,w}$ and R'_w is only possible depending on the ratio (S/V). A general equivalence of both quantities cannot thus be conducted. As shown in [6], the geometric ratio of room volume to separating surface (S/V) can basically be resolved in such a way that this results in either a functional dependence on the room width (w), the room length (l) or the room height (h). If a floor area of $S_G \geq 8$ m² and room heights between 2.40 m and 3.0 m is assumed, the following results for the case distinction: $R'_w = D_{nT,w}$, i.e., the numerical uniformity of both measures, shown in Figure 1 below.

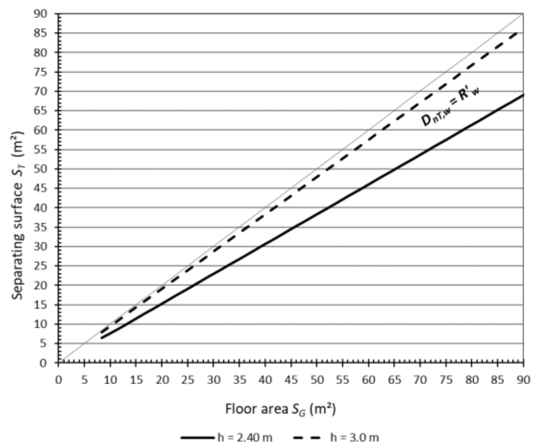

Figure 1: Depicted is the difference: R'_w - $D_{nT,w}$ = 0 depending on the geometric ratios: separating surface S_T and floor area S_G. The minimum floor area is 8 m². The room height is between 2.40 m and 3.0 m. The diagonal drawn in grey indicates the equality of $S_T = S_G$.

Figure 1 shows that mathematically based on equation (3) the equality of R'_w and $D_{nT,w}$ is always given if the floor area (S_G) is not larger than the separating surface (S_T). If the separating surface deviates from the floor area, there are differences between R'_w and $D_{nT,w}$. If a difference (R'_w - $D_{nT,w}$) of ±1 dB and of ±2 dB is allowed, the graphical representation results as shown in Figure 2.

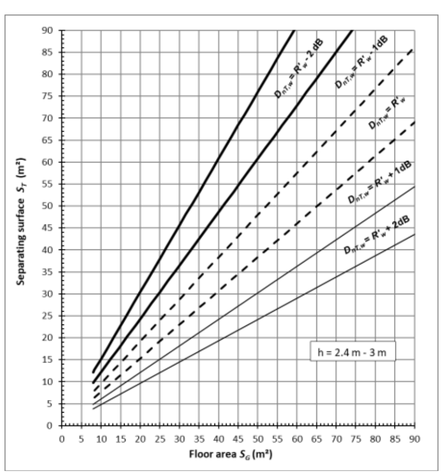

Figure 2: Difference: R'_w - $D_{nT,w}$ depending on the geometric ratios of separating surface S_T and floor area S_G.

If the separating surface (S_T) deviates from the floor area (S_G), the difference increases, and deviations of several decibels occur. These deviations result from the geometric conditions and are not "acoustically" conditioned. From Figure 2 it is seen that a floor area, e.g., rooms between 10 m² and 20 m², the difference between $D_{nT,w}$ and R'_w is mathematically not greater than +2 dB. The standard sound level difference only becomes smaller when the separating surface (S_T) becomes larger than the floor area (S_G). From Equation (3) it follows that with a ratio of (S/V) = 0.32 both quantities are equal. In other words, this means that if there is any deviation from this ratio, there is no equality between $D_{nT,w}$ and R'_w.

3.1 Absorption

In general, the sound absorption properties of the receiving room (A) are not known. Fortunately, the sound absorption and reverberation time are mathematically related, so if the reverberation time is measured in the receiving room, then both properties are established, and the sound insulation measurements are standardised to the reference reverberation time (T_0) and the sound absorption value (A). However, the equivalent sound absorption area (A) is not that easy to determine. It cannot be determined exactly theoretically nor by measurement in rooms with medium and high absorption in the room, such as those found in normal apartments [7]. To avoid the difficulty of determining sound absorption, it has been internationally agreed to use Sabine's equation to determine the sound absorption area. In [8] it is shown that there are many approaches to calculate the reverberation time, although no calculation method is exact. A reverberation time web application that is striving to be complete in features and theory of reverberation is presented in [9]. The calculator currently supports seven different reverberation times, which shows how different theories attempt to correctly predict the reverberation time in rooms. Furthermore, even to measure reverberation time is limited in accuracy. In [10] several methods of determining the reverberation time have been investigated and compared. The measurement procedure of the reverberation time is standardized in [11, 12]. It is well known that Sabine's reverberation formula for calculating the equivalent sound absorption area is only sufficiently accurate for small equivalent sound absorption areas, i.e. small sound absorption coefficients ($\alpha << 1$), and reasonably rectangular rooms [13, 14]. In addition, an at least semi-diffuse sound field is generally assumed [3]. For rooms with large equivalent sound absorption areas, the use of Eyring's reverberation formula has generally proven and is commonly accepted. The reverberation formula of Sabine and Eyring are in case of neglect of air absorption reproduced below [x]:

$$\frac{V}{S_{tot}}\left(\frac{55{,}26}{C_0\,T_{60}}\right) = \begin{cases} \bar{\alpha} & Sabine \\ -\,ln(1-\bar{\alpha}) & Eyring \end{cases} \tag{5}$$

There is:

T_{60} is the reverberation time, in s
V is the room volume, in m³
S_{tot} is the total of the room's surface area, in m²
$\bar{\alpha}$ is the average sound absorption coefficient
c_0 is the speed of sound in air, in ms^{-1}

The functional relationship is depicted in Figure 3.

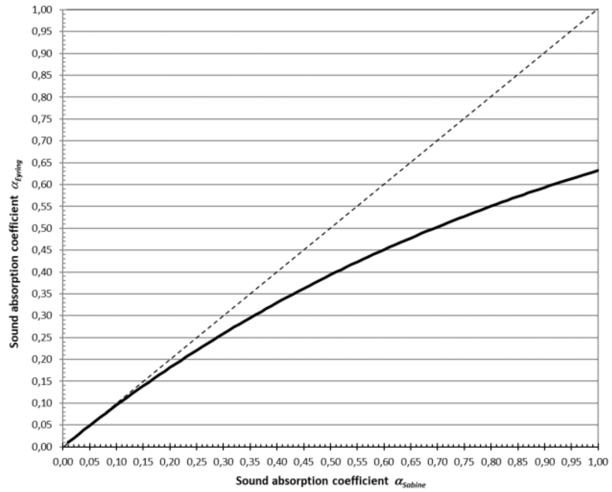

Figure 3: Comparison of sound absorption coefficients according to Sabine and Eyring. The dashed line indicates the equality of the results ($\bar{\alpha}_S - \bar{\alpha}_E$).

The graph in Figure 3 shows that both sound absorption coefficients are only approximately the same in a small area ($\bar{\alpha}$ < 0.10), they are never identical. The deviation between the two approaches for calculating the sound absorption coefficients according to Sabine and Eyring can be immediately recognized by the doted line in Figure 3. If a deviation of less than 10% is required or accepted, the average sound absorption coefficient ($\bar{\alpha}$) must not be greater than 0.2 [4]. This can be observed in Figure 4.

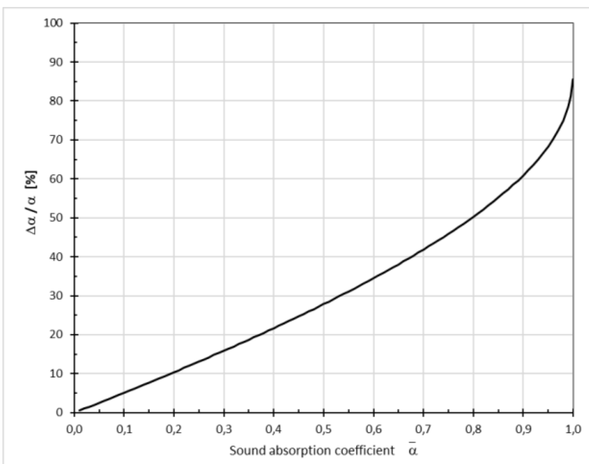

Figure 4: Relative error of the derived quantities ($\bar{\alpha}$) and ln (1 – $\bar{\alpha}$).

In [4] it was shown that the equivalent sound absorption area calculated according to Eyring's reverberation time formula is always smaller than the equivalent sound absorption area calculated according to Sabine's reverberation time formula. With reference to Eq. (1), the apparent sound reduction index (R') becomes larger. The difference in the reverberation time formulae therefore has a direct influence on the weighted apparent sound reduction index (R'_w). For the calculation of this sound insulation value, the equivalent sound absorption surface is required, which is from the measured reverberation time. If the equivalent sound absorption area is determined according to Sabine (A_{Sab}) and according to Eyring (A_{Eyr}). the functional relationship results as shown in Figure 5. Where it is immediately apparent that with increasing interior surface area (S_{tot}) and with the same mean sound absorption coefficient ($\bar{\alpha}$), the deviation between the results according to Sabine and Eyring increases.

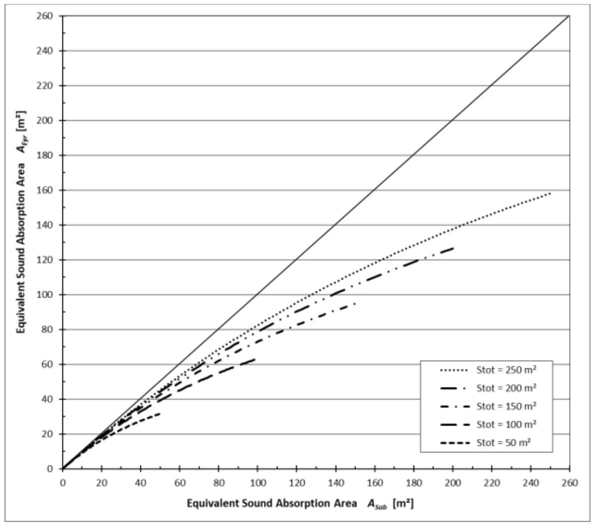

Figure 5: Comparison of the calculated equivalent sound absorption area (*A*) according to Sabine's and Eyring's reverberation time theory. The solid line (diagonal) indicates the equality of both results.

The study presented in [4] on the application of the reverberation formula according to Sabine, as prescribed in EN ISO 16283-1, shows that when applying Eyring's reverberation formula in the determination of the apparent sound reduction index R'_w a deviation of +1 dB may occur. The calculated equivalent sound absorption area according to Eyring is always smaller or, in the borderline case, equal to the calculated equivalent sound absorption area according to Sabine. In the light of this realization, the reference to an equivalent sound absorption area to determination the sound insulation must be critically questioned.

3.2 Measurements

To determine the airborne sound insulation of 194 apartment partitions measurements according to EN ISO 16283-1 were conducted. The results are shown in Figure 6 and exhibits the difference of both descriptors for the same partition (construction).

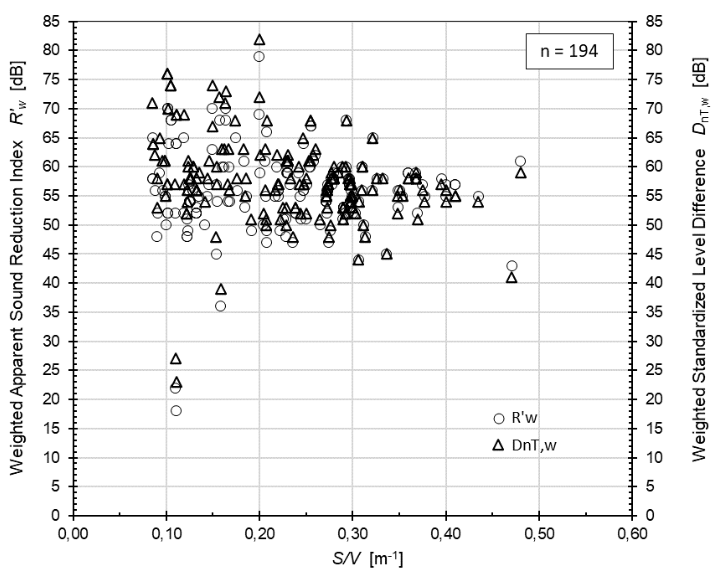

Figure 6: Measured sound insulation values R'_w and $D_{nT,w}$ depicted over the ratio (*S*/*V*)

The ratio of (S/V) for this data set (n = 194 measurements) is between around 0,05 m^{-1} and 0,5 m^{-1}. The determined weighted apparent sound reduction index R'_w and the weighted standardized sound level difference $D_{nT,w}$ are compared and depicted in Figure 7.

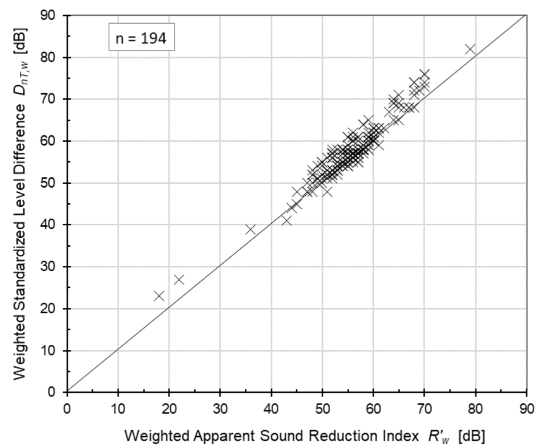

Figure 7: Measured sound insulation values R'_w and $D_{nT,w}$. The solid line shows the equality of both sizes.

From Figure 7 it is seen that the values fluctuate significantly. For the presented data set (n = 194), the fluctuation range of the differences (R'_w - $D_{nT,w}$) is equal to -6 dB to +2 dB. If the difference values of R'_w and $D_{nT,w}$ from the measurements of the data set are directly related to the corresponding (S/V) ratios, the representation shown in Fig. 8 results.

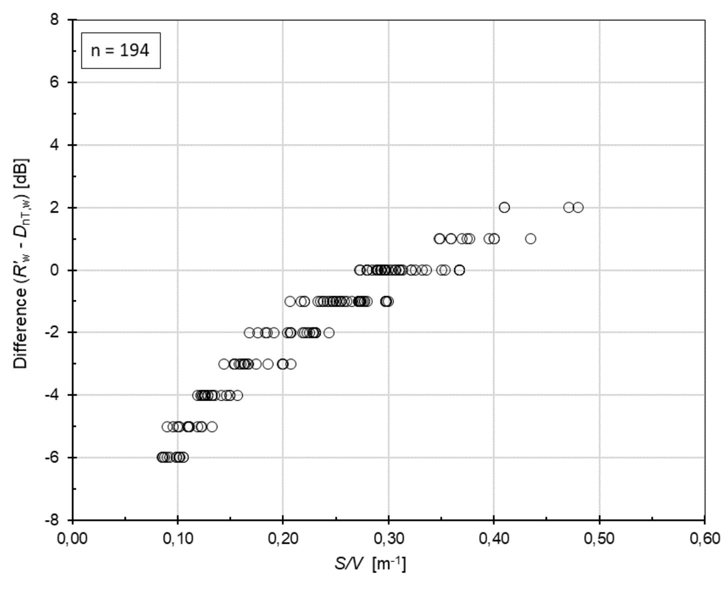

Figure 8: Relationship of the difference (R'_w - $D_{nT,w}$) and the ratio (S/V) of the measurement data set (n = 194).

It is seen in Figure 8 that the ration (S/V) for this data set does not exceed 0,5 m^{-1}. The minimum ratio is 0.053 m^{-1}. In this data set, the deviation of the differences is from -6 dB up to +2 dB. If a deviation of ±1 dB is tolerated, then the ratio (S/V) is between 0.20 m^{-1} to 0.43 m^{-1}.

4. Conclusion

The presented results show that sound insulation, expressed with the weighted apparent sound reduction index R'_w is not equal to the sound insulation, expressed with the weighted standardized level difference $D_{nT,w}$. A direct comparison of R'_w and $D_{nT,w}$ is only agreed with a fixed (S/V) ratio and always leads to a difference (dispersion), except for (S/V) = 0.32 m²/m³. Depending on the size of the parting surface and the room volume, the spreading width can be -6 dB to +2 dB.

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