

Acoustic classes - Airborne sound insulation

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ABSTRACT

In building acoustics, sound insulation classes are used to characterise a certain sound insulation quality. The corresponding classes specify different levels of acoustic conditions in dwellings. If a sound insulation class is stated, this is typically done by specifying a certain level of sound insulation, expressed as for example a weighted apparent sound reduction index R'_w or a weighted standardized level difference $D_{nT,w}$. Both sizes describe a quality that is not necessarily comparable. In this paper, the difference between R'_w and $D_{nT,w}$ is discussed, and it is shown that if a class formation with both quantities is to be characterized in a linked manner, it is possible if certain boundary conditions are fulfilled or if a certain deviation between the two quantities is accepted.

Keywords: building acoustics, sound insulation class, airborne sound insulation, soundproofing.

1. INTRODUCTION

In building acoustics, sound insulation classes are often used to characterize a certain sound insulation quality, e.g., for doors and windows. If a sound insulation class is presented, this is usually done by specifying a certain height of sound insulation, expressed as a weighted apparent sound reduction index R'_w , or by specifying a certain weighted standard sound level difference $D_{nT,w}$. Both quantities describe a quality that is not necessarily equivalent [1]. Soundproofing as a parameter has a subjective meaning, namely the perceived protection against disturbing noise immissions. As protection, a perceptual quantity is described as opposed to a physical quantity. In Europe, various classification systems have been established, partly as parameters of soundproofing (e.g. $D_{nT,w}$) and partly as parameters of sound insulation (e.g. R'_w) [2]. In this paper, the difference between the component-

related size: R'_w and the spatial size: $D_{nT,w}$ is discussed, and it is shown that class formation with both quantities is possible if certain boundary conditions are met or if a certain deviation between the two quantities is accepted.

2. SOUNDPROOFING AND SOUND INSULATION

In this context one must discriminate between soundproofing and airborne sound insulation. The main difference is that soundproofing is a process of a heard sound while airborne sound insulation is related to the process of blocking airborne sound by entering a room [3]. Sound Insulation is the ability of components to reduce sound transmission.

2.1 Standardized level difference D_{nT} , $D_{nT,w}$

The standardized sound level difference D_{nT} is defined by the sound pressure level difference (ΔL) between the source and receiving rooms using a reference reverberation time T_0 . The sound level difference is measured by spatial and temporal averaging of the respective sound pressure levels depending on the frequency. The frequency dependent reverberation time (T) determined in the receiving room is normalized to the reference reverberation time (T_0) and thus considers the room acoustic properties of the receiving room. The standardized sound level difference is calculated according to Eqn. (1).

$$D_{nT} = L_1 - L_2 + 10 \log\left(\frac{T}{T_0}\right) [dB] \quad (1)$$

The weighted standardized level difference ($D_{nT,w}$) is the frequency dependent standardized level difference (D_{nT}) weighted to a single number according to ISO 717-1 [4].

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2.2 Sound insulation measure R' , R'_w

The apparent sound reduction index R' is defined by ten times the decadal logarithm of the ratio of the sound power that is incident on a partition of area S in m^2 under test to the total sound power transmitted into the receiving room. If all transmission paths involved in the sound transmission are included, and under the assumption that there are sufficiently diffuse sound fields in the two rooms the apparent sound reduction index R' results. Instead of measuring the incident and transmitted sound power, the level difference is measured by the sound pressure level difference (ΔL) between the source (L_1) and receiving (L_2) rooms. The apparent sound reduction index R' is calculated according to Eqn. (2).

$$R' = L_1 - L_2 + 10 \log \left(\frac{S}{A} \right) [dB] \quad (2)$$

The weighted apparent sound reduction index (R'_w) is the frequency dependent apparent sound reduction index (R') weighted to a single number according to ISO 717-1 [4].

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 assuming a diffuse sound field [5]. The formula for the equivalent sound absorption area A is given in Eqn. (3).

$$A = \frac{0.16 V}{T} [m^2] \quad (3)$$

where V is the volume of the receiving room, in m^3 , and T is the reverberation time in the receiving room, in s.

The result obtained for the sound insulation value R' strictly depends on the validity of Sabine's formula, i.e., the applicability of the Equation 3. Therefore, two important requirements must be fulfilled when determining the sound insulation value R' : On the one hand, the validity of the statistical reverberation time theory according to the formula of Sabine and, on the other hand, the correct measurement of the reverberation time in the receiving room.

Introducing Eqn. (3) in Eqn. (2), yield:

$$R' = D + 10 \log \left(\frac{S}{V} \right) + 10 \log(T) + 8 \text{ dB} [dB] \quad (4)$$

with D denoting the level difference of L_1 and L_2 of the energy-average sound pressure levels measured in the source and receiving rooms, in dB.

The reciprocal value of the ratio (S/V) reflects the room height (h) for ceilings and either the room width (w) or the room length (l) for partition walls. When examining partition walls, the assignment of the spatial dimension is therefore not determined. The numerical value of 8 dB results from the application of Sabine's equation from the ratio ($24 \ln 10/c_0$), where c_0 represents the speed of sound in air. For the quantity 0.16 in Eq. (3), the speed of sound is assumed to be 345.6 m/s [6]. R' is frequency dependent. To obtain a single number, the weighted apparent sound reduction index R'_w is

determined with the help of a reference curve according to ISO 717-1.

ISO 16283-1 [7] describes the fact that the sound reduction index R' has a weaker connection to the subjective impression of air-borne sound insulation compared to the standardized sound level difference D_{nT} .

3. CLASSES OF AIRBORNE SOUND INSULATION

A class formation of both quantities (D_{nT} and R') is possible separately for each parameter singly without any problems. For example, Austria [8] has defined sound insulation classes from A to E and assigned a specific $D_{nT,w}$ to each class. Spain [9], on the other hand, has a classification system from A to F. ISO/TC 19488 [10] also assigns so-called "class limits" from A to F to the standard sound level difference. In all classification scheme, certain singular values corresponding to a certain class are always required. Fixed class boundaries and class widths are given.

The classes or intervals are always divided in such a way that the boundaries between two classes are directly adjacent to each other. The detection of a certain class is therefore always assigned to the same parameter. However, there are difficulties when calculating a parameter, i.e., a descriptor from another descriptor. Combining Eqn. (1) and Eqn. (2) yield Eqn. (5):

$$D_{nT,w} = R'_w + 10 \log \left(\frac{0.32 V}{S} \right) \quad (5)$$

The relationship between the component-related measure R'_w and the reverberation time-related measure $D_{nT,w}$ is shown in detail in [1]. There, it is shown that a flat-rate conversion without reference to the geometric ratios of room volume (V) and separating element area (S) is not possible. R'_w and $D_{nT,w}$ agrees numerically if the ratio of room volume (V) to separating element area (S) corresponds to the value of $3.125 \text{ m}^3/\text{m}^2$ [1].

In the literature [11-13] it is shown that with the same weighted construction, the single values R'_w can deviate from the perceived sound insulation. On the one hand, this is due to the different frequency curves of the sound insulation or to the inherent properties of the component characteristic "sound insulation" [1]. Due to the assignment of the parameters $D_{nT,w}$ and R'_w according to Eqn. (5), a direct link is only possible as a function of the ratio of (V/S). There is no general conformity between the two numerical values. As shown in [1] [3] [14], the geometric ratio of room volume to parting surface (V/S) can basically be resolved in such a way that either a functional dependence on the room width (w), the room length (l) or the room height (h) results. Assuming a minimum floor area of $S_F \geq 8 \text{ m}^2$ and room heights between 2.40 m and 3.0 m, the dependencies shown in Fig. 1 result in: $R'_w = D_{nT,w}$, i.e., the numerical equality of both parameters.

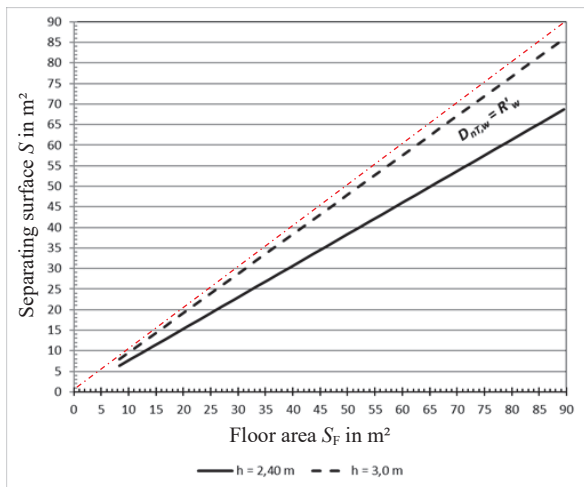


Figure 1. Depiction of the difference: $R'_w - D_{nT,w} = 0$, as a function of the geometric conditions: separation surface S and floor area S_F . The minimum floor area is 8 m^2 . The room height is between 2.40 m and 3.0 m . The point-dashed line (diagonal) represents the equality: $D_{nT,w} = R'_w$ if $h = 3.125 \text{ m}$, i.e., $S_F = S$.

Fig. 1 shows that according to Eqn. (5), the equality of R'_w and $D_{nT,w}$ is given if the floor area (S_F) is greater than the parting area (S) at the assumed room heights. At exactly the room height $h = 3.125 \text{ m}$, the floor area is then equal to the parting surface and $D_{nT,w} = R'_w$ applies. If the parting surface deviates from the floor area, there are differences between R'_w and $D_{nT,w}$. If a difference ($D_{nT,w} - R'_w$) of $\pm 1 \text{ dB}$ and e.g. $\pm 2 \text{ dB}$ is allowed, Fig. 2 shows the result.

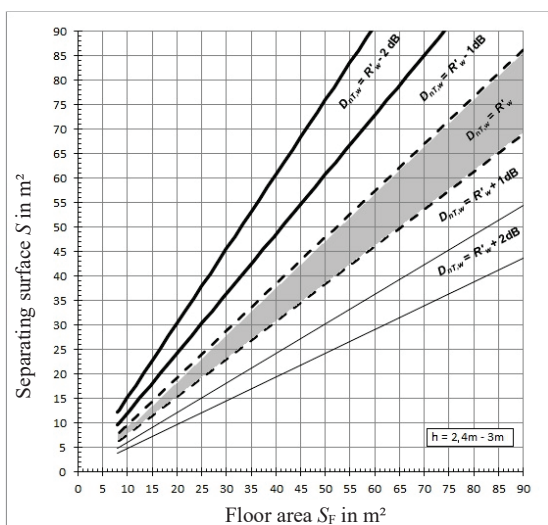


Figure 2. Depiction of the differences; $D_{nT,w} - R'_w$, as a function of the geometric relationships: separation surface S and floor area S_F . The minimum floor area is 8 m^2 . The room height is between 2.40 m and 3 m .

3.1 Computational analysis

For a computational analysis of the characterizing quantities, the following boundary conditions are assumed [14].

- The minimum floor area is $S_F = 8 \text{ m}^2$
- The minimum room height is $h = 2.4 \text{ m}$, resulting in a minimum room volume of $V = 19.2 \text{ m}^3$
- The minimum parting area is $S = 10 \text{ m}^2$ and remains constant. This results in a lower limit for the ratio from parting surface to room volume of $V/S = 1.92 \text{ m}^3/\text{m}^2$
- There is an idealized curve of the sound level difference adopted
- The frequency dependent reverberation time is $T = 0.5 \text{ s}$ and remains constant.

With variation of volume and a constant parting surface, the theoretically expected parameters are calculated depending on frequency and an evaluation of the frequency-dependent quantities is plotted graphically as a function of the ratio (V/S) using the evaluation method according to [4] and the difference ($D_{nT,w} - R'_w$). The ideal frequency response of the sound level difference was iteratively subjected to several variations. Fig. 3 summarizes the theoretically expected difference values ($D_{nT,w} - R'_w$) as a function of the ratio (V/S) including the tolerance limits [14].

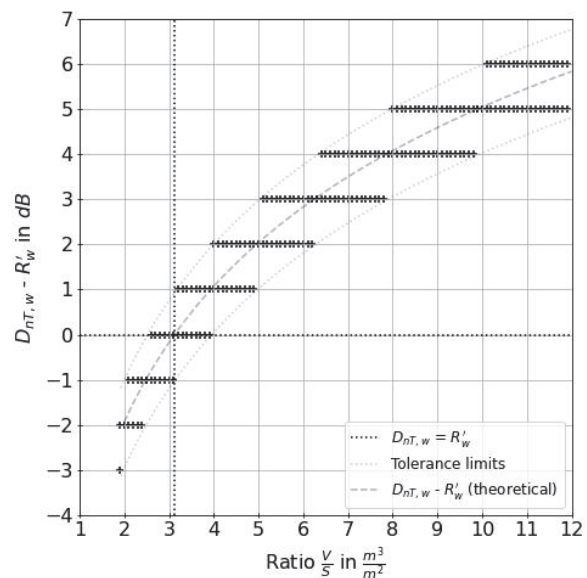


Figure 3. Theoretical differences ($D_{nT,w} - R'_w$) for the ratio (V/S). (Graphic from [14]).

The dashed vertical line shown in Fig. 3 represents the ratio of $V/S = 3.125 \text{ m}^3/\text{m}^2$, where the numerical values of the two parameters R'_w and $D_{nT,w}$ are equal. Accordingly, for ratios smaller than this threshold, the weighted apparent sound reduction index R'_w is always greater than the weighted standard sound level difference $D_{nT,w}$ and always smaller for larger

ratios. From Fig. 3 it can be further deduced that with a maximum permissible difference of +2 dB, the V/S ratio is 5 and with the assumed minimum parting component area of $S_{\min} = 10 \text{ m}^2$, the permissible volume is then 50 m^3 . Thus, a delimitation of the volumes with a minimum volume of $V_{\min} = 8 \text{ m}^2 \times 2.40 \text{ m} = 19.2 \text{ m}^3$ and a "threshold volume" in which the numerical values of the difference are equal to 31.25 m^3 , as well as a "limit volume" of 50 m^3 , where the maximum deviation is +2 dB, can be specified. The resulting volume intervals are then:

$$19.2 \text{ m}^3 \leq V \leq 31.25 \text{ m}^3 \text{ and } 31.25 \text{ m}^3 < V \leq 50 \text{ m}^3.$$

In this context, volume classes and separating surface classes can be derived and are discussed in detail in [14] [15-16]. A graphical summary is shown in Fig. 4 and Fig. 5.

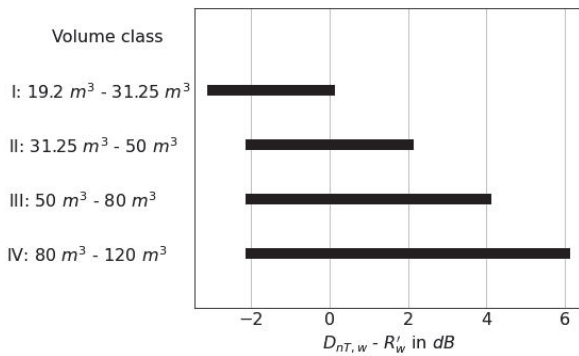


Figure 4. Volume classes and dispersion of the difference ($D_{nT,w} - R'_w$) [14].

The differences depicted in Fig. 4 show that the deviations are greater for growing volumes. The number equality of R'_w and $D_{nT,w}$ is a singularity that applies only to a volume of $V = 31.25 \text{ m}^3$. Under- and overshoots of this volume cause an increasing dispersion. From the theoretical consideration, valid for the assumed boundary condition, a scattering width of -3 dB to +6 dB results.

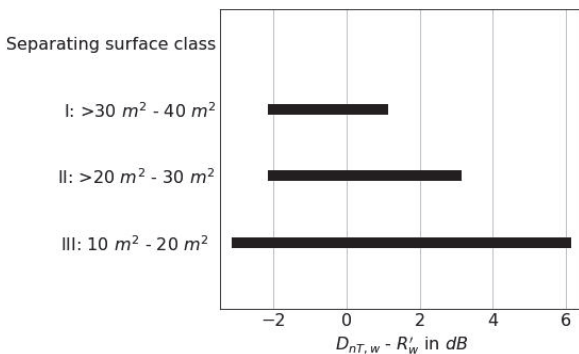


Figure 5. Separating surface classes and dispersion of the difference ($D_{nT,w} - R'_w$) [14].

Fig. 5 shows that the deviations are becoming smaller for growing separating surfaces. The number equality of R'_w and $D_{nT,w}$ is a singularity that occurs volume-dependent at a separating surface of $S = (V/3.125) \text{ m}^2$. Under- and overshoots of this separating surface cause a decreasing dispersion. From the theoretical considerations, valid for the assumed boundary conditions, a scattering width of -3 dB to +6 dB results.

3.2 Measurement

Measurements in-situ were carried out on 71 separation components (ceilings and walls) in accordance with ISO 16283-1 to determine R'_w and $D_{nT,w}$. The results are shown graphically in Fig. 6.

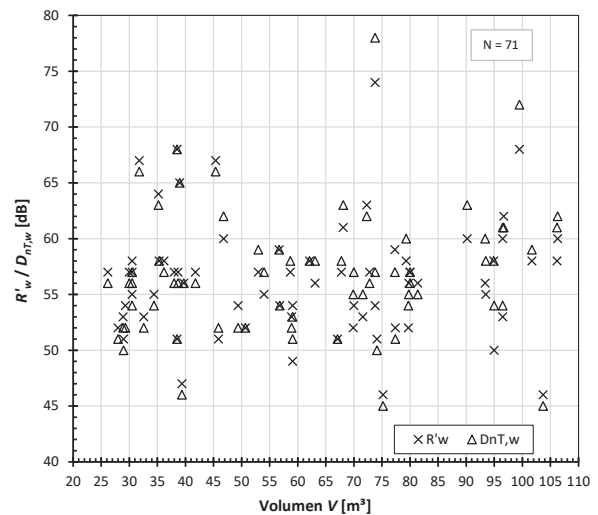


Figure 6. Measured values R'_w and $D_{nT,w}$ of 71 separation components (ceilings and walls).

Fig. 6 illustrates the distribution of the measurement results for the data $D_{nT,w}$ and R'_w . The fluctuation range of $D_{nT,w}$ is 45 dB to 78 dB and of R'_w equal to 46 dB to 74 dB. From Fig. 6 it is seen that the values fluctuate significantly. For the presented data set ($N = 71$), the fluctuation range of the differences ($D_{nT,w} - R'_w$) is equal to -2 dB to +4 dB. If the difference values of $D_{nT,w}$ and R'_w from the measurements of the data set are directly related to the corresponding (V/S) ratios, the representation shown in Fig. 7 results.

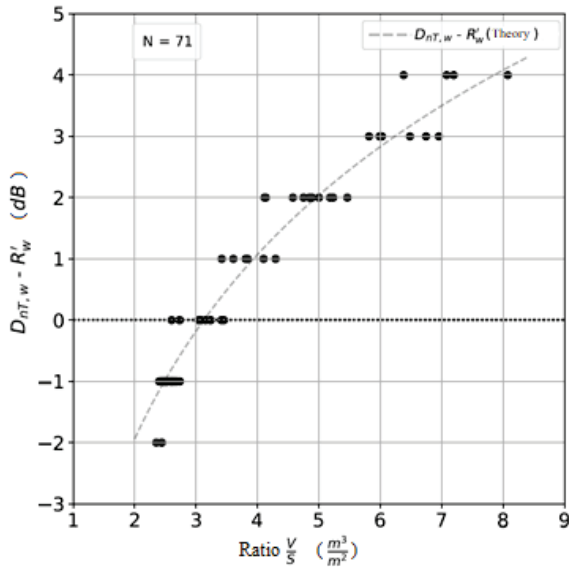


Figure 7. Shown is the relationship of the difference ($D_{nT,w} - R'_w$) and the ratio (V/S) of the measurement data set ($N = 71$) [14].

The comparison of Fig. 7 with Fig. 3 reveals excellent agreement of the measured and calculated results. The investigated measurement data set results in a spread of -2 dB to +4 dB, the theoretical consideration results in a spread of -3 dB to +6 dB.

3.3 Example of a classification scheme

To show a classification as an example, the following conditions are assumed:

- Room height: 2.40 m - 3.0 m
- Room volume: 20 m³ - 120 m³
- Separating surface: 10 m² - 40 m²

Eqn. (5) shows that $D_{nT,w}$ is equal to R'_w only if the ratio V/S is equal to 3.125 m³/m². Deviating ratios result in more or less large scatterings in the difference between $D_{nT,w}$ and R'_w (see Fig. 3). In a first step, an area must be selected in which a certain deviation is accepted. For example, if a deviation of ± 2 dB is allowed, the permissible ratio of V/S can be determined according to Fig. 3. If the V/S ratio is divided into a certain interval where a deviation of ± 2 dB is accepted, two ranges results:

$$\begin{aligned} &V/S [1,9; 5,0] \text{ m} \\ &V/S [5,1; 12,0] \text{ m} \end{aligned}$$

The following classification is based on ISO/TC 19488 [10], where the classes are categorized from A to F and an additional "NPD class", i.e., NPD stands for: "no performance is determined" has been introduced. Where class A is the highest class and class F is the lowest class. The indication "NPD" can be used for dwellings where acoustic power is not

required or intended, or where the performance does not meet the requirements of Class F. With the knowledge gained, particular with respect to results presented in Fig. 2 and Fig. 3, sound insulation classes with an accepted deviation of for example ± 2 dB, can be designed. The smallest value for $D_{nT,w}$ is freely selectable and the R'_w values result from this. In Tab. 1 and Tab. 2 classes in dependance of the V/S ratio are presented.

Table 1. Classes of V/S at intervals [1.9; 5.0] m

Sound insulation criterion	Sound insulation classes						
	V/S [1.9 - 5.0] m						
	NPD	F	E	D	C	B	A
Airborne sound insulation	≤ 45 dB	46 48 dB 50	51 53 dB 55	56 58 dB 60	61 63 dB 65	66 68 dB 70	> 70 dB
Nominal value $D_{nT,w}$							
Design value R'_w [dB]	43	48	53	58	63	68	70

NPD: No performance determined.

Table 2. Classes of V/S at intervals [5.1; 12.0] m

Sound insulation criterion	Sound insulation classes						
	V/S [5.1 - 12.0] m						
	NPD	F	E	D	C	B	A
Airborne sound insulation	≤ 45 dB	46 48 dB 50	51 53 dB 55	56 58 dB 60	61 63 dB 65	66 68 dB 70	> 70 dB
Nominal value $D_{nT,w}$							
Design value R'_w [dB]	39	44	49	54	59	64	66

NPD: No performance determined.

The two tables Tab. 1 and Tab. 2 show that a jump of 4 dB occurs between the weighted apparent sound reduction index R'_w in a class (e.g., between classes F with $R'_w = 44$ dB and 48 dB). This jump can also be deduced from Fig. 3 and results from the specified spread of ± 2 dB. If a different deviation or spread width is specified, there are other "jumps" in the determination of the value for the weighted apparent sound reduction index R'_w . For clarification, this is shown graphically in Fig. 8.

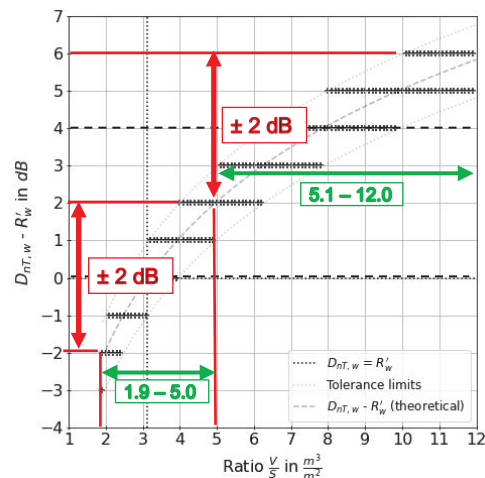


Figure 8. Depiction of the grouping of the class as a function of the accepted difference (deviation ± 2 dB).

3.3.1 Calculation example of the application of the classes

The required weighted apparent sound reduction index R'_w for a certain sound insulation class is determined based on the V/S ratio. For example, if it is intended that a room with volume V and a separation surface S ($V = 4.85 \text{ m} \times 3.60 \text{ m} \times 2.50 \text{ m}$; $S = 4.85 \text{ m} \times 2.50 \text{ m}$) should ensure a sound insulation class C, the V/S ratio must first be determined.

The V/S ratio is: 3.6 m.

With a $V/S = 3,6 \text{ m}$ it follows from Tab. 1 for a chosen class C: $D_{nT,w}$ is 63 dB ($\pm 2 \text{ dB}$)

The required R'_w value is either taken from Tab. 1 or it is determined by use of Eqn. (5).

Using Eqn. (5): $D_{nT,w} = R'_w + 10 \lg(0.32 \times V/S)$

yield: $R'_w = D_{nT,w} (\text{class}) - 10 \lg(0.32 \times V/S)$

i.e.: $R'_w = 63 \text{ dB} - 10 \lg(0.32 \times 3.6) = 62.4 \text{ dB}$

And Tab. 1 shows a required weighted apparent sound reduction index of $R'_w = 63 \text{ dB}$ for class C.

Since the class width is $\pm 2 \text{ dB}$, class C is maintained with a $D_{nT,w} = 61 - 65 \text{ dB}$. If the room volume were twice as large for the same partition area, the V/S ratio would be 7.2 m (application of Tab. 2). This would result in a required weighted apparent sound reduction index of $R'_w = 59.4 \text{ dB}$ for class C. Tab. 2 shows a required weighted apparent sound reduction index of $R'_w = 59 \text{ dB}$ for class C.

Class C is complied with a $D_{nT,w} = 61 - 65 \text{ dB}$.

3.3.2 Measurement example of the application of the classes

In practice a separating component may be measured, and the class may be determined in dependence of the result. For example, if a partition is measured it is either the weighted apparent sound reduction index R'_w or a weighted standardized level difference $D_{nT,w}$.

If from measurement a $D_{nT,w}$ is determined the class may directly be read from Tab. 1 or Tab. 2 depending on V/S ratio. If from measurement a R'_w is determined the class may be determined in accordance with the V/S ratio.

If the measured result for example is $R'_w = 52 \text{ dB}$, and the V/S ratio is 2.1 m, the resulting class is F.

Proof: It applies Eqn. (5), yielding: $D_{nT,w} = 50.3 \text{ dB}$.

Since 50.3 dB is 50 dB according to the rounding rule, class F must be used with a $D_{nT,w}$ of 46 dB – 50 dB.

4. CONCLUSION

The presented results show that sound insulation, expressed with the weighted standardized level difference $D_{nT,w}$, is not equal to the sound insulation, expressed with the weighted apparent sound reduction index R'_w . A classification of sound insulation can be a clear help to be able to make quick and targeted divisions. The advantage of a representation in classes is a simpler estimation of the expected differences of the two parameters $D_{nT,w}$ and R'_w . However, the simplified relationships based on the volume classes and separation

component classes are more complex due to the conditions and assumptions described. They have broader relationships regarding the boundaries of the respective classes and the expected difference values. However, from the ratio of volume (V) and partition area (S), a meaningful class formation can be obtained. A classification is, however, only possible if the deviations, i.e., the differences between the two descriptors ($D_{nT,w}$ and R'_w), are defined. If, in addition to a deviation limit (spreading width), a class width is also specified, it is possible to form a class depending on the ratio (V/S). For a fixed class, a certain V/S ratio must always be considered to comply with the agreed error limit. A direct comparison of R'_w and $D_{nT,w}$ is only allowed with a fixed V/S ratio and always leads to a difference (dispersion), except for $V/S = 3.125 \text{ m}^3/\text{m}^2$. Depending on the size of the parting surface and the room volume, the spreading width can be -3 dB to $+6 \text{ dB}$.

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