Performance of sound insulation of AAC in massive buildings – experience with EN 12354-1

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Abstract: Design and calculation of building sound performance is standardized in EN 12354. The calculation method of this relatively new standard requires a lot of precise input data. Besides the mass per area of a massive component, values like the vibration reduction index and the loss factor are required. As a consequence of the implementation of EN 12354, plenty of research was initiated about the acoustic properties of different construction materials.

In collaboration with different research institutes and Universities numerous measurements on AAC structures were performed. The results have become the basis for the integration of the EN 12354 into the German standard DIN 4109.

Based on the experience gained in applying the calculation method of EN 12354-1, this paper gives an overview about the acoustic performance of single leaf AAC structures in comparison with other building materials. The sound reduction indices of pure materials as AAC, lightweight concrete or calcium silicate bricks are compared.

In a second step, the calculated sound reduction indices are compared with measurement results of real buildings. It could be confirmed, that the determined sound reduction indices in planning of a building are in sufficient agreement with the measured and quantified sound insulation in the real building.

It is concluded that there is a good correlation between calculated performance on the basis of the material parameters, and the actual measured sound performance for AAC structures. This proves a high level of certainty in achieving the required sound insulation in design and construction of AAC buildings.

Keywords: sound insulation, loss factor, EN 12354-1

1. INTRODUCTION

Today planning of airborne sound insulation of buildings in Germany is performed in accordance with DIN 4109 [6]. Valid since 1989, this method is considered to be relatively accurate to calculate all relevant components for building acoustics.

With the introduction of EN 12354 in 2000, a new approach in building acoustics verification has been implemented. Long known physical effects of sound transmission which were not considered in the past have become relevant boundary conditions now.

In various studies on solid materials, numerous measurements were carried out on existing wall structures. In addition, test results of previous studies were evaluated again with regard to the new requirements. In total, data of more than 150 AAC structures could be collected from which known and new acoustic parameters could be derived forming an excellent basis of the future structural design concept.

This paper presents some of these results. In particular, first experience is provided in applying the new calculation method of airborne sound insulation with AAC structures according to simplified model of EN 12354-1.

2. COMPARISON OF CALCULATION METHODS OF SOUND REDUCTION INDEX – PAST AND FUTURE

2.1. Calculation according to DIN 4109 (1989)

The building acoustic design in Germany is carried out in accordance with Supplement 1 to DIN 4109 (1989) [7] so far. This calculation method assumes global estimated sound transmission mechanisms for separating and flanking elements. In a first step the weighted sound insulation index R'_w [dB] of the separating component should be evaluated depending on the mass per area m' [kg/m²]. It is assumed that the average of the mass per area of all massive flanking components is about $m'_{L,average} = 300$ [kg/m²]. It is allowed to add a bonus of 2 dB to the sound insulation index of AAC components. This bonus takes into account that the special pore structure of AAC decreases the sound transmission along the material.

In case the average of mass per area of all massive flanking components $m'_{L,average}$ differs from 300 [kg/m²] the correction term $K_{L,1}$ [dB] has to be added to R'_w. If $m'_{L,average} \leq 300$ [kg/m²] then $K_{L,1}$ is negative and the final resultant sound reduction index decreases.

The result of this calculation method is sufficiently precise in case all flanking building elements are approximately of the same weight. But slight building elements transmit realistically more sound energy than heavier ones. A design error occurs when a particularly heavy flanking component eliminates apparently in calculation the negative influence of an accompanying light component by evaluation of the arithmetic mean of the mass per area of all flanking building elements.

2.2. Calculation according to future method

The calculation method of airborne sound insulation according to next edition of DIN 4109 is based on procedure of EN 12354-1 (2000). A lot of precise input data are required now. Beside the airborne sound insulation of the separating and all flanking massive building elements of two neighbouring rooms, the type and rigidity of the connections of two adjacent components become very important. This characteristic physical unit is called vibration reduction index K_{ij} [dB].

The calculation of the resulting sound insulation index is an energetic summation of the sound transmittance along all flanking paths. That means that there is no global acquisition of sound transmittance. This allows a realistic reflection of the real sound conductance.

Finally, geometric boundary conditions of the building are included in the calculation method.

Sound insulation index depending on mass law

In general the sound insulation of single leaf homogenous massive walls depends on the mass per area of the material. The mass per area is the product of raw density of the material, and its thickness. This mass law – the relation of mass per area and sound insulation index – is illustrated in an equation or in a diagram e. g. in annex B of EN 12354-1.

According to the simplified model of EN 12354-1, annex B, the following equation (1) is a reliable relation for common monolithic homogenous components. This equation is valid for structures with a mass per area of m' ≥ 150 [kg/m²]:

$$R_w = 37,5 \cdot \log(m') - 42[dB] \tag{1}$$

Some European countries developed special mass law equations that are also given in EN 12354-1, annex B. Each of these equations is also valid for all kind of massive building materials but for different ranges of mass per area. 0Fig. 1 shows the equations mentioned in EN 12354-1, annex B.

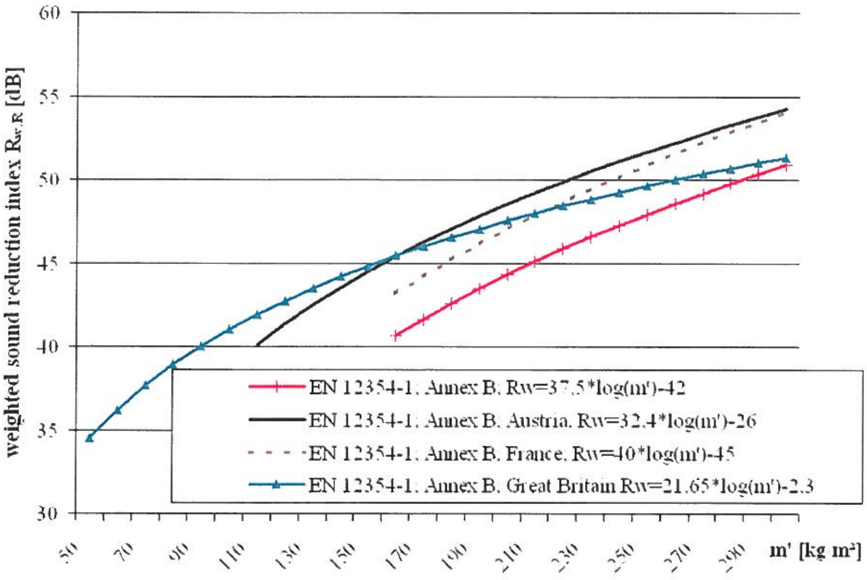

Fig. 1. Mass law equations of EN 12354-1

Influence of total loss factor

The rigidity of the connection in joints of adjacent building elements varies in massive buildings. This effect is accounted for by the loss factor η_{tot}. The higher the loss factor of a building element, the higher is the sound transmittance to adjacent parts of the structure. That means also that the higher the loss factor the higher the sound insulation.

The sound insulation of massive components fluctuates depending on the loss factor. The same structural composition may achieve a range of sound insulation indices depending on the installation conditions in different buildings.

Test results determined in a sound laboratory are not directly transferable to the situation in buildings. It is required to adjust the sound insulation index. In [1] the following equation (2) has been evaluated as the total in-situ loss factor.

$$10 \cdot \log \eta_{tot} = -12,4 - 3,3 \cdot \log\left(\frac{f}{100}\right) \tag{2}$$

This equation is the average of all structures investigated in [2] and [3]. It is valid for all single leaf assemblies and all building materials except those structures with a mass per area less than m' = 100 [kg/m²]. The sound insulation of lightweight structures – like thin AAC walls – would be overestimated. Fig. 20 shows the dependency of in-situ total loss factor with mass per area. The bold red line represents the average of all regarded wall structures. The bottom line shows the in-situ total loss factor of walls with a mass per area between m' = 50 [kg/m²] and 100 [kg/m²].

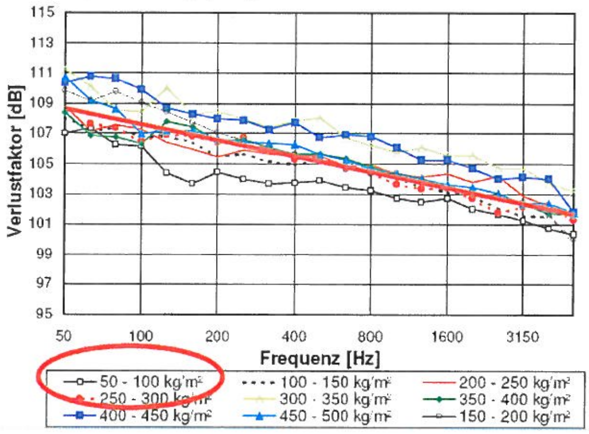

Fig. 2. Total loss factor depending on mass per area (compare [1])

The in-situ loss factor correction term is modified for lightweight structures with a mass per area m' ≤ 150 [kg/m²]:

$$10 \cdot \log \eta_{tot} = -12,4 - 3,3 \cdot \log\left(\frac{f}{100}\right) + 10 \cdot \log \frac{m'}{150} \tag{3}$$

The equation for calculating the sound reduction index of AAC should be divided because of these two different in-situ loss factor correction terms. The result is the continuous equation (4) that is valid for the mass ranges less than 150 [kg/m²] and equal or more than 150 [kg/m²].

$$R_w = \begin{cases} m' < 150\left[\dfrac{kg}{m^2}\right] \Rightarrow 32,6 \cdot \log(m') - 22,5[dB] \\ m' \geq 150\left[\dfrac{kg}{m^2}\right] \Rightarrow 26,1 \cdot \log(m') - 8,4[dB] \end{cases} \tag{4}$$

AAC components achieve a higher sound insulation than other building materials of the same weight. This fact is already considered in calculation procedure of sound reduction index according to DIN 4109 (1989). This was confirmed by Fischer et al. (2002) [1].

Fig. 3 shows a comparison of airborne sound insulation index of structures with the same mass per area made of lightweight concrete, concrete, calcium silicate or clay bricks. AAC achieves the best performance. The equations for sound insulation of lightweight concrete, concrete, calcium silicate and clay bricks are not confirmed by German standard

committee, yet. Therefore the curves are shown to give an impression of the qualitative trend, only.

A comparison of mass law relation of draft DIN 4109-3 (Fig. 3) and equations of EN 12354-1, annex B (0Fig. 1) demonstrates that the performance of airborne sound insulation of AAC is up to 9 dB better than equation (1). In 0Fig. 4 all relations between mass per area and airborne sound insulation were combined.

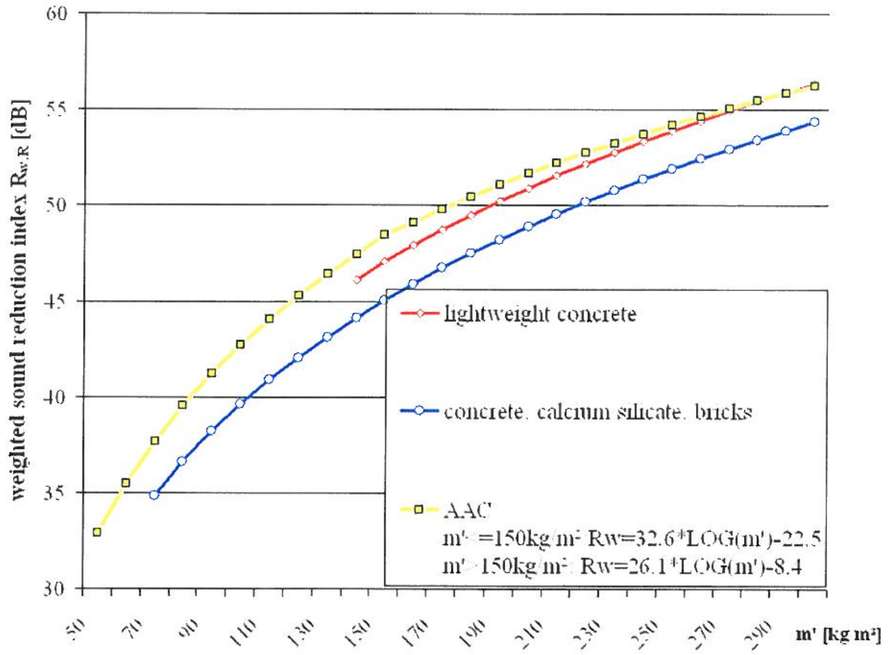

Fig. 3. Mass law equations according to draft DIN 4109

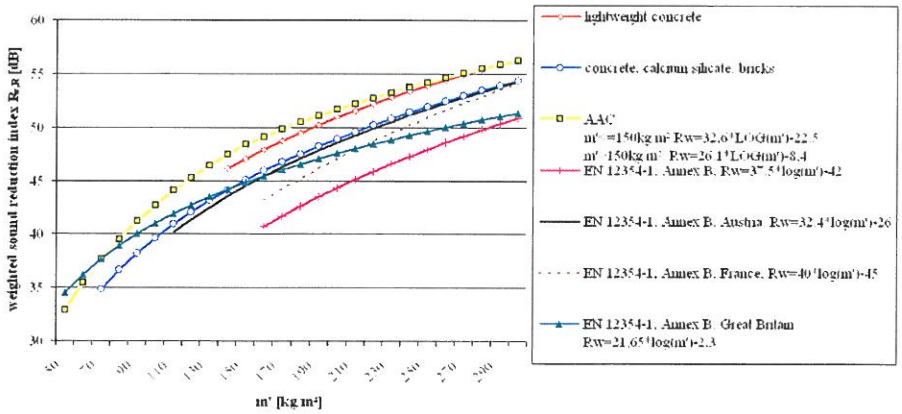

Fig. 4. Comparison of mass law curves draft DIN4109 with EN 12354-1, annex B

3. RESULTS

Comparisons of calculation of weighted sound reduction index in massive building structure according to DIN 4109 (1989) and draft DIN 4109 (similar to EN 12354-1) and test values of sound reduction index according to ISO 140-4 [4] are shown in the following.

Conditions of the calculations:

- In Germany the discussion about the range of uncertainty is not completed. No safety margin is included in our calculation.
- We assume in our calculations that the results according to draft 4109 were determined with an accuracy of one digit.

3.1. Example 1: Separating ceiling

The sound reduction index of the ceiling is calculated between two sleeping rooms one above the other. Fig. 5 shows a sketch of the ground plan.

The thickness of the regarded separating concrete ceiling is 20 cm. The exterior Ytong wall is made of 42,5 cm P1,6/0,30. The inner walls are made of 11,5 cm P4/0,55. The adjacent levels one above the other have the same shape. In Table 1 a summary of all involved components is shown.

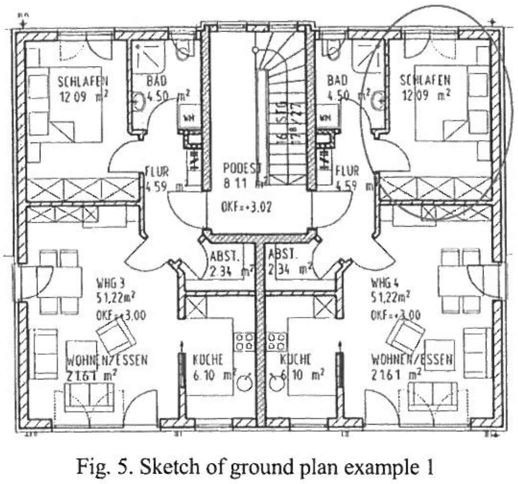

Fig. 5. Sketch of ground plan example 1

Table 1. Example 1: Separating ceiling

Component	Description	Material	Thickness
Separating component	ceiling with floating screed	concrete	20 cm
Flanking component – exterior	exterior wall	AAC Ytong P1,6/0,30	42,5 cm
Flanking component – interior	interior wall	AAC Ytong P4/0,55	11,5 cm

The calculated sound reduction index according to DIN 4109 (1989) is $R'_{w,R} = 54$ dB and according to draft DIN 4109 (EN 12354-1) $R'_{w,R} = 54{,}5$ dB. The result of the measurement on site is $R'_{w,B} = 56$ dB.

3.2. Example 2: Separating wall

The sound reduction index of the separating wall is calculated between two kitchens side by side. Fig. 6 shows a sketch of the ground plan.

The thickness of the regarded separating wall is 24 cm calcium silicate. The exterior Ytong wall is made of 42,5 cm P1,6/0,30. The inner walls are made of 11,5 cm P4/0,55. The ceilings were made of 20 cm concrete with floating screed. The regarded rooms are adjacent. In Table 2 a summary of all involved components is shown.

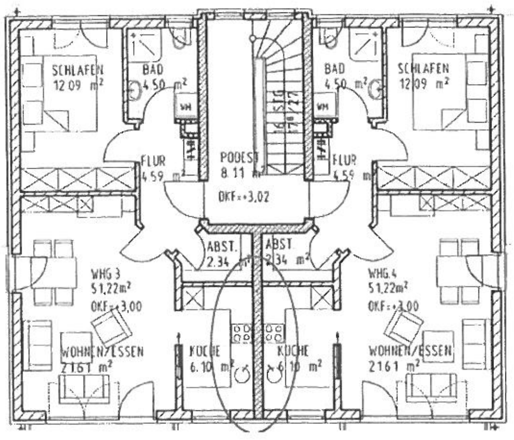

Fig. 6. Sketch of ground plan example 2

Table 2. Example 2: Separating wall

Component	Description	Material	Thickness
Separating component	single leaf wall	calcium silicate; density class 2,0	24 cm
Flanking component – exterior	exterior wall	AAC Ytong P1,6/0,30	42,5 cm
Flanking component – interior	interior wall	AAC Ytong P4/0,55	11,5 cm
Flanking ceilings	with floating screed	concrete	20 cm

The calculated sound reduction index according to DIN 4109 (1989) is $R'_{w,R} = 52$ dB and according to draft DIN 4109 (EN 12354-1) $R'_{w,R} = 54{,}0$ dB. The result of the measurement on site is $R'_{w,B} = 57$ dB.

3.3. Example 3: Internal wall

The sound reduction index of the interior wall is calculated between a living room and a sleeping room side by side. Fig. 7 shows a sketch of the ground plan.

The regarded interior wall is of a thickness of 11,5 cm (AAC Ytong P4/0,55). The outside AAC wall is made of 42,5 cm Ytong P1,6/0,30. The ceilings were made of 20 cm

concrete with floating screed. The regarded rooms are adjacent. In Table 3 a summary of all involved components is shown.

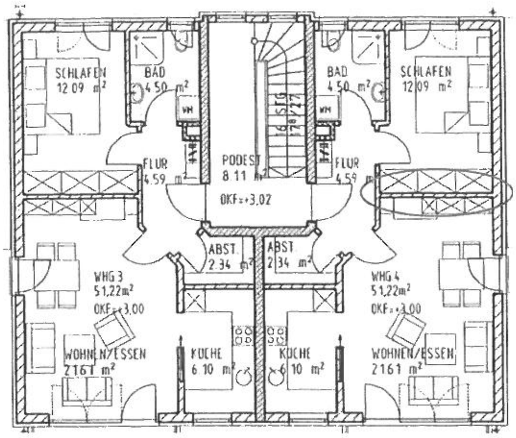

Fig. 7. Sketch of ground plan example 3

Table 3. Example 3: Internal wall

Component	Description	Material	Thickness
Separating component	Single leaf wall	AAC Ytong P4/0,55	11,5 cm
Flanking component – exterior	exterior wall	AAC Ytong P1,6/0,30	42,5 cm
Flanking component – interior	interior wall	AAC Ytong P4/0,55	11,5 cm
Flanking ceilings	with floating screed	concrete	20 cm

The calculated sound reduction index according to DIN 4109 (1989) is $R'_{w,R} = 33$ dB and according to draft DIN 4109 (EN 12354-1) $R'_{w,R} = 37{,}2$ dB. The result of the measurement on site is $R'_{w,B} = 39$ dB.

3.4. Example 4: Separating wall

The sound reduction index of the separating wall is calculated between a living room and a sleeping room side by side. Fig. 8 shows a sketch of the ground plan.

The regarded separating wall is of a thickness of 24 cm calcium silicate. The exterior wall is made of AAC 36,5 cm Ytong P4/0,50. The interior walls are made of AAC 11,5 cm Ytong P4/0,55 and the ceilings of 20 cm concrete with floating screed. The regarded rooms are adjacent.

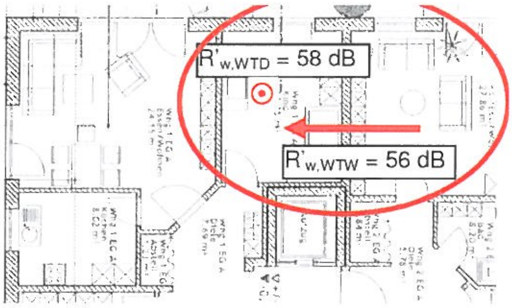

Fig. 8. Sketch of ground plan

Table 4. Example 4: Separating wall

Component	Description	Material	Thickness
Separating component	single leaf wall	calcium silicate; density class 2,0	24 cm
Flanking component - exterior	exterior wall	AAC Ytong P1,6/0,30	42,5 cm
Flanking component - interior	interior wall	AAC Ytong P4/0,55	11,5 cm
Flanking ceilings	with floating screed	concrete	20 cm

The calculated sound reduction index according to DIN 4109 (1989) is $R'_{w,R} = 54$ dB and according to draft DIN 4109 (EN 12354-1) $R'_{w,R} = 56{,}0$ dB. The result of the measurement on site is $R'_{w,B} = 56$ dB.

4. CONCLUSIONS

The certainty of the calculation method according to EN 12354-1 respectively draft DIN 4109-3 and DIN 4109 (1989) is compared with tested values of sound reduction index in this present report. Detailed results of recent research about acoustic properties like mass law and in-situ loss factor of AAC components are considered in the applied calculation method. The sound reduction index of four examples is calculated for structures in massive buildings.

The test value of airborne sound insulation index of massive structures with flanking or separating AAC components is usually better than the calculated value. This is generally a positive fact at first sight. But the accuracy of this calculation method is certainly not satisfactory. Taking into account that there are known very precise input data the expectation of the accuracy is higher now.

The most accurate parameter determined in [1] is given in equation (4). This relation is validated in numerous measurements on AAC structures and has hence gained sufficient certainty.

The highest uncertainty is suspected in the vibration reduction index in joints of adjacent components. There are various types of structures for this detail with a large range of loss factors caused by differing rigidity. The calculation of the separate vibration reduction index of each joint is not precise enough. To verify the result of a calculation with measured data it is required to measure the sound reduction index and also each vibration reduction index K_{ij} of all joints.

There are some other inaccuracies that may affect the difference between measurement and calculation. Different numbers, sizes and positions of openings like doors and windows change the rigidity of joints and the excitability of flanking components. But at present it is not possible to evaluate precisely the influence of these geometrical circumstances.

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