Acoustical characteristics of lightweight solid gypsum walls and their implementation into prediction models

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Introduction

In modern multi storey buildings light solid internal walls without static requirements are often constructed with gypsum blocks. In Germany the thickness of these gypsum walls is 60, 80 or 100 mm, however, the walls with 100 mm are the most used. The density of the gypsum blocks is usually about 900 kg/m³ that means a wall with a thickness of 100 mm has a mass per unit area of about 90 kg/m². Due to this material characteristic one would expect a low direct sound insulation combined with insufficient flanking insulation. However, the light gypsum walls are not connected rigidly to the adjacent building elements but decoupled using flexible elastic interlayers, for instance, made of cork, bitumen or polyethylene foam. These elastic interlayers with a thickness of 3 to 5 mm were fitted on all edges of the gypsum walls. One reason for the decoupling is to avoid the crack formation between the different building elements. As another result of the decoupling different investigations have shown an improvement of the acoustical characteristics of these lightweight gypsum walls compared to other lightweight but rigidly connected walls. Figure 1 shows the construction of a gypsum wall in a building.

Figure 1: construction of gypsum walls in buildings

As a part of a research project [1] at the Stuttgart University of Applied Sciences different acoustic measurements have been performed in order to investigate the direct and the flanking insulation of gypsum walls in the laboratory. The sound reduction index of gypsum walls was measured in a test facility for direct sound transmission with various elastic interlayers. The flanking insulation of gypsum walls was investigated in two different test facilities for flanking transmission, the first one for the horizontal and the second one for the vertical sound transmission. The construction of the gypsum walls in the test facilities was carried out as in real buildings. In addition to the investigations in the laboratory, extended measurements were also done in real buildings. These field measurements were conducted in vertical and horizontal direction like in the laboratory.

Part of the measurements in the laboratory and in real buildings was the determination of the sound insulation between two adjacent rooms with the flanking transmission by the gypsum walls. In addition the vibration reduction index K_{ij} was investigated for the different transmission directions according to the standard DIN EN ISO 10848-1 [2]. One part of the vibration reduction index measurement is to determine the loss factor of the building elements by measuring their structural reverberation time. The other part is the measurement of the velocity level difference between two connected building elements by excitation of one of these building elements with a miniature tapping machine.

An important ambition of the research project is to verify the application of the calculation model according to the standard DIN EN 12354-1 [3] for different transmission situations with flanking gypsum walls. The extensive measurement data from the field and laboratory measurements are used as input data for the calculation model. For the vertical transmission situations in the various buildings with gypsum walls the sound reduction index was calculated according to DIN EN 12354-1 and compared with the measured results. The paper presents some results of the laboratory and building measurements as well as calculated results of the different investigated building transmission situations.

Calculation according DIN EN 12354-1

For the acoustical design of buildings it is necessary to calculate the apparent sound reduction index R'_w of separating building elements like ceilings or partition walls. The problem for the gypsum walls is that the current German standard DIN 4109 [4] does not consider decoupled walls as flanking building elements. The calculation of the apparent sound reduction index in the future German standard DIN 4109 will be based on the calculation model according DIN EN 12354-1.

According DIN EN 12354-1, the calculation of the sound reduction index between two adjacent rooms can be carried out by using the “detailed model” or the “simplified model”. The detailed model calculates with frequency-dependent values. However, the calculation of the simplified model is done with single values (not frequency-dependent). All results shown in this paper are calculated by using the simplified model. The direct sound reduction index of the separating building element (R_{Dd}) and all flanking reduction indexes (R_{Ff} - R_{Fd} - R_{Df}) have to be considered for the calculation of the apparent sound reduction index. That means that in a room with four walls there are altogether thirteen transmission paths, one path for the direct transmission and twelve paths for the flanking transmission. The calculation of the apparent sound reduction index R'_w can be carried out by the following equation:

$$R'_w = -10\lg\left[10^{-R_{Dd,w}/10} + \sum_{F=f=1}^{n} 10^{-R_{Ff,w}/10} + \sum_{f=1}^{n} 10^{-R_{Df,w}/10} + \sum_{F=1}^{n} 10^{-R_{Fd,w}/10}\right]$$

Symbol meaning:

$R_{Dd,w}$ direct sound reduction index
$R_{Ff,w}$ flanking reduction index, transmission path Ff
$R_{Df,w}$ flanking reduction index, transmission path Df
$R_{Fd,w}$ flanking reduction index, transmission path Fd

The several flanking reduction indexes (R_{Ff} - R_{Fd} - R_{Df}) are calculated as follows:

$$R_{ij} = \frac{R_i}{2} + \Delta R_i + \frac{R_j}{2} + \Delta R_j + K_{ij} + 10\lg\frac{S_S}{l_0 \cdot l_{ij}}$$

Symbol meaning:

R_i / R_j sound reduction index of the building element i or rather j in [dB]
ΔR consideration of facing formwork in [dB]
K_{ij} vibration reduction index in [dB]
S_S area of the separating building element in [m²]
l_0 reference-coupling-length in [m]; l_0 = 1m
l_{ij} coupling-length of the building element ij in [m]

For the calculation of transmission situations with flanking gypsum walls the R_i and R_j as well as the K_{ij} are necessary.

Direct sound insulation of gypsum walls - laboratory and building measurements

The sound reduction index of gypsum walls with a thickness of 100 mm and a mass per unit area of about 90 kg/m² and different kinds of elastic interlayers were measured in a wall test facility for direct sound transmission. For decoupled building elements there is usually the expectation of a lower sound insulation because of the reduced energy conduction. But the measurements show that the application of some elastic interlayers can improve the sound reduction index of the gypsum walls. The following table 1 shows the weighted sound reduction index R_w of gypsum walls with 100 mm thickness and a mass per unit area of about 90 kg/m² for the three mostly used elastic interlayers compared to the sound reduction index R_w of a rigidly connected gypsum wall.

elastic interlayers	R_w [dB]
none (rigid junction)	38
cork	38
polyethylene foam	40
bitumen	42

Table 1: weighted sound reduction index R_w of gypsum walls with different kinds of elastic interlayers

The sound reduction index of gypsum walls were also measured in different building situations, for example between a sleeping room and a living room in the same dwelling. Figure 2 shows the average of the sound reduction indexes measured in the buildings compared to the laboratory measurement with the cork interlayers.

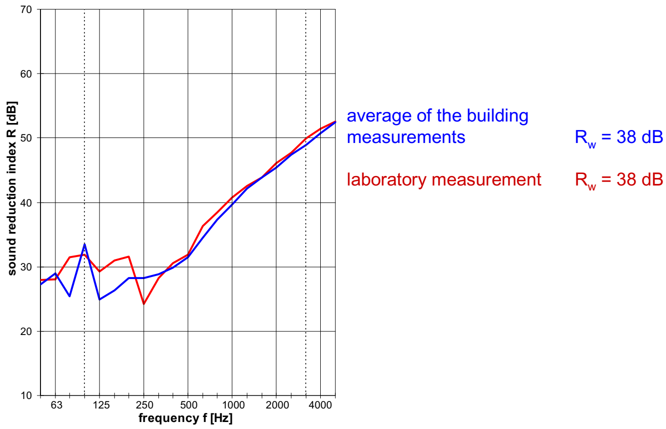

Figure 2: comparison of the sound reduction index, measured in the laboratory and in different buildings

The comparison shows similar results especially at frequencies higher than 315 Hz. The sound reduction index measured in the laboratory can be used as input data for the calculation according DIN EN 12354-1. Due to the fact of the decoupling no in-situ correction has to be made. But the differences between the several elastic interlayers have to be considered for the calculation.

Vibration reduction index of gypsum walls - building measurements

The vibration reduction index K_{ij} was measured on different cross junctions in vertical and horizontal direction in several buildings. The cross junctions were composed by heavy separating building elements like ceilings (vertical) or partition walls (horizontal) and lightweight solid gypsum walls which were decoupled from the separating building elements by elastic interlayers. The K_{ij} measurements contained the transmission path Df respectively Fd from the gypsum wall to the separating building element and also the transmission path Ff from gypsum wall to gypsum wall with the separating building element between. The following figure 3 shows for the transmission path Df respectively Fd the results of all K_{ij} measurements in vertical direction compared to the calculated value according DIN EN 12354-1 for a solid junction with the same mass ratio. The average of all measured vibration reduction indexes is also shown in the graph. The corresponding values for the transmission path Ff are illustrated for the vertical transmission in figure 4. The results from the measurements in horizontal direction are similar.

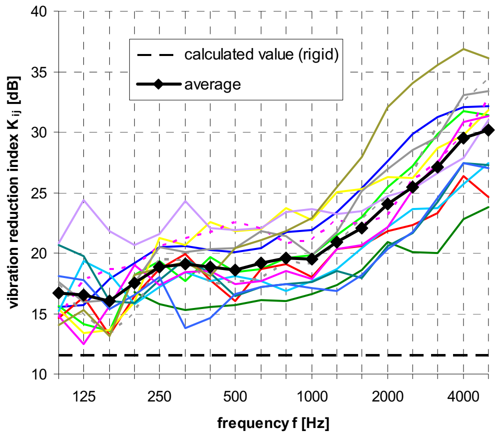

Figure 3: vibration reduction index K_{ij} of gypsum walls, measured in different buildings, path Df / Fd, vertical transmission

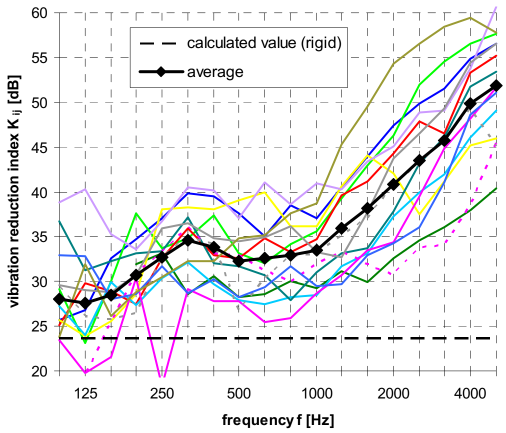

Figure 4: vibration reduction index K_{ij} of gypsum walls, measured in different buildings, path Ff, vertical transmission

The measured K_{ij} is for both transmission paths significantly higher than the calculated value for a rigid junction with the same mass ratio, with an increase to higher frequencies. The variation of the measurement data results due to the different building situations and the workmanship of the decoupling. For the determination of the single value of K_{ij} there was done an arithmetic averaging of the measurement results in the frequency range from 200 Hz to 1250 Hz according the DIN EN ISO 10848-1. The single values for the average of all vertical measurements and the calculated value for a rigid junction are shown in the following table 2.

	vibration reduction index [dB]	
	path Df / Fd	path Ff
average of all vertical K_{ij} measurements	19,1	33,2
calculated K_{ij} (rigid)	11,6	23,7

Table 2: single values of K_{ij} - average of all measurements (decoupled junctions) and calculated value for a rigid junction

The improvement of the vibration reduction index K_{ij} for the average of the decoupled junctions is 7,5 dB for the transmission path Df respectively Fd and 9,5 dB for the path Ff. All measured K_{ij} values were used as input data for the calculation of the apparent sound reduction index according the simplified model of the DIN EN 12354-1.

Comparison of measurement and calculation

In several buildings with internal walls made of gypsum blocks measurements of the apparent sound reduction index R'_w were performed in vertical (ceilings) and horizontal (partition walls) transmission direction. The sound reduction between the rooms beat the legal requirements clear. All measured building situations were calculated with the simplified model according DIN EN 12354-1. As input data for the sound reduction index R_i and R_j of the gypsum walls the laboratory measurement results were used. The calculations were done with two different input data of the vibration reduction index K_{ij}. After the measurements in a building have been performed, the calculations of the investigated building situations have been carried out with the measured $K_{ij,building}$ as input data. On the other hand, after all building measurements were finished, the calculation was done with the average of all vibration reduction indexes $K_{ij,average}$ measured in accordant transmission direction. The determination of the K_{ij} single value was carried out by an arithmetic averaging of the measurement values from 200 Hz to 1250 Hz according annex A of DIN EN ISO 10848-1. Figure 5 shows the comparison between the measured sound reduction index and the two variants of the calculation for some vertical transmission situations with two and three flanking gypsum walls.

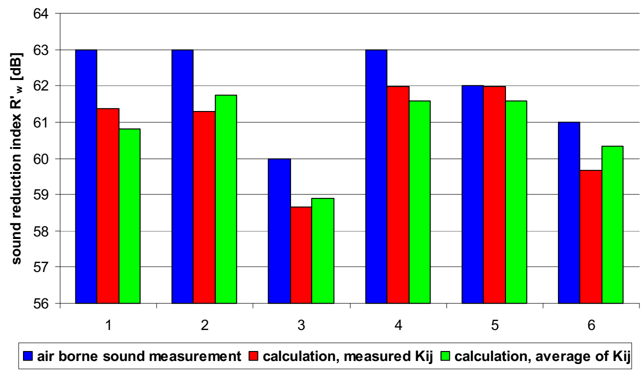

Figure 5: comparison between measured and calculated sound reduction index of **vertical transmission** situations

Both variants of the calculation show similar results, the difference is not more than 0,5 dB. The agreement between the measurement results and the calculated values is quite good. In the most cases the calculated values are slightly lower than the measured sound reduction index.

Figure 6 illustrates a comparison between measurement and calculation for the investigated horizontal transmission situations.

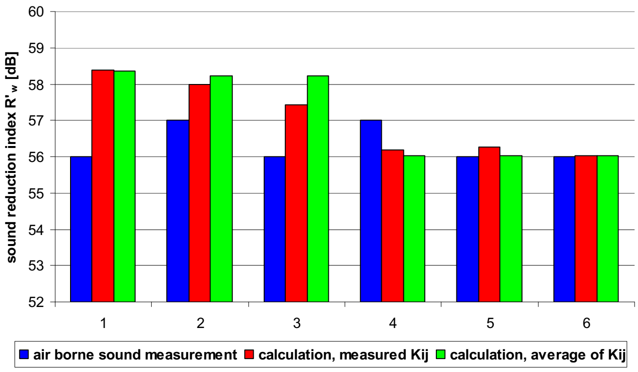

Figure 6: comparison between measured and calculated sound reduction index of **horizontal transmission** situations

Altogether the agreement between measurement and calculation of the horizontal situations is similar to the vertical situations. But for some of the investigated transmission situations the calculation values are higher than the measured results. The reason could be the plastering of the partition walls. If there is no consistent disconnection between the gypsum wall and the plaster of the partition wall the decoupling and hence the flanking insulation of the gypsum wall will decrease.

In summary the calculation with the measured vibration reduction indexes K_{ij} agree with the measured data. Based on the results of the investigations an improvement ΔK_{ij} of the vibration reduction index compared to the calculated value of a rigid junction will be decided for future calculations.

Conclusions

The use of decoupled gypsum walls as non-supporting internal walls in buildings has a couple of advantages. The sound reduction index of gypsum walls can be improved by using elastic interlayers for the decoupling of the wall, especially with bitumen but also with polyethylene foam. The results from the building and laboratory measurements were quite similar so there is no in-situ correction intended. The vibration reduction index K_{ij} and hence the flanking reduction index of gypsum walls decoupled by elastic interlayers, made of cork or polyethylene foam is much higher than the calculated value of a rigid junction. However, the condition for this fact is a good accomplishment of the elastic junction. If this is ensured, a quite good apparent sound reduction index between rooms separated by ceilings or partition walls is attainable. The extensive measurements in different buildings and in the laboratory have approved high sound reduction indexes between adjoining rooms with decoupled gypsum walls as flanking elements.

For the acoustical planning of a building it is necessary to calculate the sound reduction index between adjacent rooms in the building. The problem is that the current German standard DIN 4109 does not consider decoupled walls as flanking building elements. The calculation of the sound reduction index in the future DIN 4109 will be based on the simplified model according the DIN EN 12354-1. Up to now it was also difficult to consider decoupled flanking gypsum walls exactly for these calculations because of the missing input data. The extensive building and laboratory measurements have provided confirmed input data for the decoupled gypsum walls. The calculation with single values according the simplified model of the DIN EN 12354-1 and the measured vibration reduction index of the gypsum walls as input data has shown a comparative good correlation to the actually measured sound reduction index. The calculation with the average of all measured K_{ij} has shown similar results, so these results can be used for the finally decision about the input data for future calculations. The results of the investigations will be a basis for the implementation of lightweight solid gypsum walls in the building elements catalogue of the further German standard DIN 4109.

References

[1] „Umsetzung der europäischen Normen des baulichen Schallschutzes für das Bauen mit Gips-Wandbauplatten" - a current research project at the Stuttgart University of Applied Sciences: „Conversion of the European standards of the structural sound insulation for building with gypsum walls"

[2] DIN EN ISO 10848-1: Akustik - Messung der Flankenübertragung von Luftschall und Trittschall zwischen benachbarten Räumen in Prüfständen; 2006-08 - the German version of EN ISO 10848: Acoustics - Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms

[3] DIN EN 12354-1: Bauakustik - Berechnung der akustischen Eigenschaften von Gebäuden aus den Bauteileigenschaften - Teil 1: Luftschalldämmung zwischen Räumen; 2000-12 - the German version of EN 12354-1: Building acoustics - Estimation of acoustic performance of buildings from the performace of elements - Part 1: Airborne sound insulation between rooms

[4] DIN 4109, Beiblatt 1: Schallschutz im Hochbau - Ausführungsbeispiele und Rechenverfahren; 1989-11 - the German standard regarding sound insulation