DOI: 10.61782/fa.2023.0507

IMPACT SOUND FROM BALCONIES IN BUILDINGS

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ABSTRACT

With the increasing urban densification, balconies are gaining in popularity as they improve the living quality in homes. Thermal insulation between balconies and the building's façade is currently state of the art in Germany. The most popular balcony construction is a reinforced concrete balcony, separated from the building by a thermal insulation element (TIE), to reduce the thermal energy losses. The impact sound transmission from balconies, however, is a topic that has not been properly addressed to date. Within this research project, laboratory and in-situ measurements were performed to investigate the impact sound transmission from balconies. First, this paper compares the current German standard DIN 4109 with the proposed changes and discusses its advantages, disadvantages and limitations. Frequency-dependent and single-number predictions will then be made for a building situation in accordance with current and planned national and international standards such as ISO 12354-2. The second part will focus on the measurement of input values for the prediction. The last part is dedicated to results in buildings, comparing the levels of direct and flanking impact sound transmission with the prediction methods.

Keywords: *building acoustics, impact sound, balcony, prediction*

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1. INTRODUCTION

The increase in airborne sound insulation against outdoor noise, achieved by the development of higher quality walls and windows regarding both heat and sound, leads to an increased sensitivity of the inhabitants towards noise that is generated by neighbours. Furthermore, outside areas of flats, such as balconies, are becoming more popular, which leads to higher impact sound immission that can cause disturbances. These two points were considered in 2018, when the German standard of requirements on sound insulation in buildings DIN 4109 [1] was revised. This standard now contains requirements for balconies on the normalized impact sound pressure level in the field as $L'_{\mathrm{n,w}} \leq 58$ dB. However, for loggias, which are often difficult to differentiate from balconies in modern buildings, the requirement is $L'_{\mathrm{n,w}} \leq 50$ dB.

In order to avoid thermal bridges and thus prevent mould, balconies are thermally separated from the building's outer hull. The design with thermal connection elements (TIE) can be regarded as a generally recognised rule of technology in Germany. The design of the TIE that separates the balcony from the building is primarily based on static requirements. The elements consist of reinforced bars and thrust bearings, sheeted by thermally insulating material such as extruded polystyrene. The main goal of this research project is to provide characteristic acoustical values for a TIE that can be used to compare products and to predict the impact sound transmission in buildings. To achieve this, measurements and numerical investigations were performed to understand the structure-borne sound transmission through these TIEs [2].

DIN 4109 contains a method using single number values and vibration reduction indices (K_{ij}) to predict the impact sound transmission in buildings. Material parameters of the building elements are thereby used as "input parameters". This method can be applied to balconies in the same way as currently done for floors, namely according to Part 2 of the German standard.

In [2] and [3], the current situation was described and methods for generating input data for balconies, in particular connecting elements for the thermal separation of balcony and façade, as well as approaches for prediction were presented. This paper develops the standardized methods and validates them with measurements. In addition, methods for including floor coverings (FC) in the prediction of impact sound insulation are presented.

The prediction of the normalized impact sound pressure level is done in DIN 4109:2018-01 with K_T values for tabulated transmission situations which only consider the orientation of the sending and receiving room. In principle, these can also be used for balconies and access balconies, but are only valid for an area-related mass of the exterior walls of $m' \geq 150$ kg/m^2. These K_T values cannot be used for fully glazed facades, as they are predominantly found in balconies. The prediction of airborne sound transmission in DIN 4109-2 is based on a simplified model in ISO 12354-1 [4], where the direct and flanking transmissions are calculated and summed energetically to give the resulting airborne sound insulation. The current proposal of the working group responsible for the prediction methods of DIN 4109-2 also includes an explicit calculation of the direct and flanking transmission for impact sound according to ISO 12354-2:2017-11 [4], as described in this article.

As part of the research project, numerous measurements have been carried out on test setups in the laboratory as well as on construction sites since 2017. A detailed description and validation of the laboratory test setup is published in [2].

2. PREDICTION METHODS FOR BALCONIES AND ACCESS BALCONIES

For impact sound transmission in buildings, the transmission into an adjacent room of a second unit diagonally below the balcony must be considered. In the case of access balconies, the horizontally adjacent living space is also often in need of protection, since the access balcony corresponds to the communal hallway.

TIEs and FCs on the balcony such as stilt bearings each cause a reduction in impact sound, which must be taken into account in the prediction, see Figure 1. Since the TIE must be present anyway due to thermal insulation, the total resulting impact sound reduction can be calculated as a combination of both as a function of frequency or measured on a laboratory test structure with TIE and FC and used for the prediction.

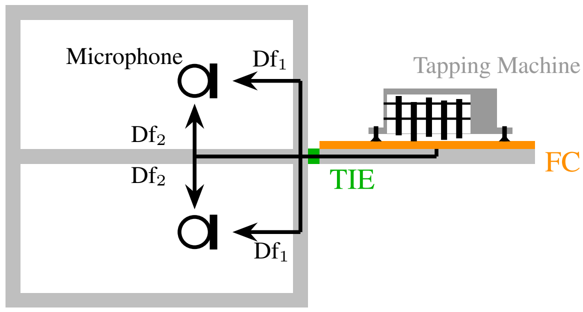

Figure 1: Sound transmission paths DF_1&2 for impact sound from balconies for symmetrically built units with heavy outer walls.

2.1 DIN 4109-2:2018-01

The German standard DIN 4109 regulates the requirements and prediction of sound insulation in buildings in Germany. The history of this series of standards is described in [5]. The thermally separated balcony can be considered as a floor. In this case, the prediction can be made with Equation 1 following DIN 4109-2. The K_T values can be taken from Table 2 of DIN 4109-2 for different transmission situations of excited ceiling and receiving room. For rooms located next to or diagonally below the excited ceiling, K_T is set as +5 dB.

$$L'_\mathrm{n,w} = L_\mathrm{n,eq,0,w} - \Delta L_\mathrm{w} - K_\mathrm{T} + u_\mathrm{prog} \quad (1)$$

$$L'_\mathrm{n,eq,0,w} = 164 - 35 \log_{10} m' \quad (2)$$

This method can be used for access balconies. For this purpose, the equivalent weighted normalized impact sound pressure level of the raw ceiling, $L_\mathrm{n,eq,0,w}$ is determined using the area-related mass m' of the balcony according to Equation 2. The impact sound reduction compared to a rigid connection without support is ΔL_w. The u_prog is a safety coefficient of 3 dB.

An additional FC as shown in Figure 1 (orange) can be taken into account in the resulting ΔL_w if values from laboratory measurements are available subsection 3.2 [6].

For balconies, footnote b of Table 2 in DIN 4109-2 considerably restricts the scope: *Prerequisite: to ensure sufficient joint insulation, the walls between the excited ceiling and the receiving room must be rigidly connected and have an area-related mass $m' \geq 150$ kg/m^2.*

This requirement is not met for many balconies, as there is usually a door, often with floor-to-ceiling window elements, adjacent to the balcony. Thus, the procedure is not applicable for many balconies.

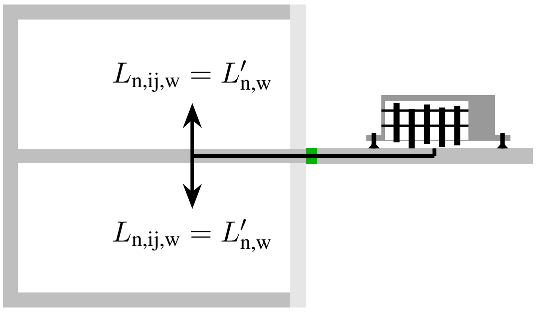

Figure 2: Normalized flanking impact sound pressure level for balconies with full-height glazing.

2.2 DIN 4109:202X

The working committee responsible for the next DIN 4109 has adopted the simplified model of ISO 12354-2 in its current draft. Here, all weighted normalized flanking impact sound pressure levels $L_{\mathrm{n,ij,w}}$ are determined individually according to Equation 3 and then summed up according to Equation 5 to the weighted normalized impact sound pressure level in the field $L'_{\mathrm{n,w}}$. For ceilings applies:

$$L_{\mathrm{n,ij,w}} = L_{\mathrm{n,eq,0,w}} - \Delta L_{\mathrm{w}} + \frac{R_{\mathrm{i,w}} - R_{\mathrm{j,w}}}{2} - K_{\mathrm{ij}} - 10\log_{10}\frac{S_{\mathrm{i}}}{l_0 l_{\mathrm{ij}}} \quad (3)$$

$$L_{\mathrm{n,d,w}} = L_{\mathrm{n,eq,0,w}} - \Delta L_{\mathrm{w}} - \Delta L_{\mathrm{d,w}} \quad (4)$$

$$L'_{\mathrm{n,w}} = 10\log_{10}\left(10^{0.1\cdot L_{\mathrm{n,d,w}}} + \sum_{j=1}^{n} 10^{0.1\cdot L_{\mathrm{n,ij,w}}}\right) \quad (5)$$

In the case of impact sound transmission from balconies with adjacent walls (Figure 1), the direct transmission is not existing, and the resulting normalized impact sound pressure level is given by Equation 6, where each flanking path is calculated by Equation 3. The equivalent weighted normalized impact sound pressure level $L_{\mathrm{n,eq,0,w}}$ is determined from the area-related mass m' of the balcony according to Equation 2. The resulting impact sound reduction ΔL_{w} for FC and TIE results from laboratory tests, see subsection 3.2. The airborne sound insulation values $R_{\mathrm{i,w}}$ of balcony i and $R_{\mathrm{j,w}}$ of flanking path j are calculated or taken from test certificates. Data for additional layers on flanking path j $\Delta R_{\mathrm{j,w}}$ such as a floating floors, a suspended ceiling or a stud wall can also be calculated or taken from test certificates and added frequency dependent to the ΔL_{w}. The calculation for single number values is different from ISO 12354 as only half of the lower value is taken into account. The vibration reduction index K_{ij} is, depending on the transmission path, the K_{13} (Df_2) or the K_{12} (Df_1) of the cross joint from calculation or measurement. The area of the balcony S_{i} and the connection length l_{ij} give the last term of the equation.

$$L'_{\mathrm{n,w}} = 10\log_{10}\left(\sum_{j=1}^{n} 10^{0.1\cdot L_{\mathrm{n,ij,w}}}\right) \quad (6)$$

$$L'_{\mathrm{n,w}} = L_{\mathrm{n,ij,w}} \quad (7)$$

For a balcony with a full window façade, the $L'_{\mathrm{n,w}}$ corresponds to the $L_{\mathrm{n,ij,w}}$ for the transmission to the ceiling, there are no further first-order flanking paths [7]. The weighted normalized impact sound pressure level in the field is given by Equation 7 as shown in Figure 2. For lightweight components, such as full window façades, the $K_{\mathrm{ij,min}}$ according to Equation 8 shall be applied.

$$K_{\mathrm{ij,min}} = 10\log_{10}\left[l_{\mathrm{f}} l_0 \left(\frac{1}{S_{\mathrm{i}}} + \frac{1}{S_{\mathrm{j}}}\right)\right] \quad (8)$$

In many situations, the façade has both wall and window surfaces. For these situations, each transmission path must be calculated separately, taking into account the respective connection length. It should be noted here that the transmission to the ceiling and external wall each have two parts: The transmission in the area of the full-height glazing with $K_{\mathrm{ij,min}}$ and the connection length l_{ij} of the glazing, and the transmission in the area of the wall with K_{13} of the cross joint and the connection length l_{ij} of the balcony to the wall. The total transmission on the path ij is then the energetic sum of both parts. For the construction described in section 4, this is shown in Table 2. To meet the requirements, the prediction uncertainty coefficient u_{prog} with 2 dB (current DIN: 3 dB) is to be added to the predicted $L'_{\mathrm{n,w}}$.

An overview of the possible scenarios and how they can be predicted according to the current DIN 4109 and the proposed DIN 4109 is presented in Table 1

	Current DIN	Proposed DIN
only wall	Junction	Cross-Junction +
only window	Correction	$K_{\mathrm{ij,min}}$ −
mixed	$K_{\mathrm{T}} = +5$ dB	+ and −

Table 1: Scenarios for Balconies

3. INPUT DATA

3.1 Impact Sound Reduction of Thermal Insulating Elements ΔL_{TIE}

The impact sound reduction for TIEs as well as for FCs is determined in the laboratory either separately or in combination. Analogous to the test method for FCs according to ISO 10140 [8], the normalized impact sound pressure level of the ceiling is determined, but from structure-borne sound measurements according to Equation 9. The test procedure requires two measurements. The average velocity level on the ceiling is measured when the ceiling L_{v0} and when the balcony L_{v} are excited and from this the normalized impact sound pressure level of the ceiling is determined in each case according to Equation 9. Since the radiation factor has no effect on the calculation of the difference, it was set to 1. The measurements are shown in Figure 3a and Figure 3b and standardized in [9]. Subsequently, the impact sound reduction of the connecting element is determined from the difference of the normalized impact sound pressure level of the ceiling according to Equation 10. The single number value is calculated in accordance to the reference ceiling method in EN ISO 717-2 [10].

$$L_{\mathrm{n}} = L_{\mathrm{v}} + 10\log_{10}\sigma + 6 + 10\log_{10}\frac{S}{A_0} \quad (9)$$

$$\Delta L = L_{\mathrm{n0}} - L_{\mathrm{n}} \quad (10)$$

3.2 Impact Sound Reduction of Floor Coverings on the Balcony ΔL_{FC}

The impact sound reduction of FCs is usually determined in an FC test room according to ISO 10140 [8] as shown in Figure 4. For this purpose, 1.) the normalized impact sound pressure level of the bare floor L_{n0} and 2.) the normalized impact sound pressure level of the ceiling with FC L_{n} are measured. The frequency-dependent impact sound reduction of the FC is calculated according to Equation 10.

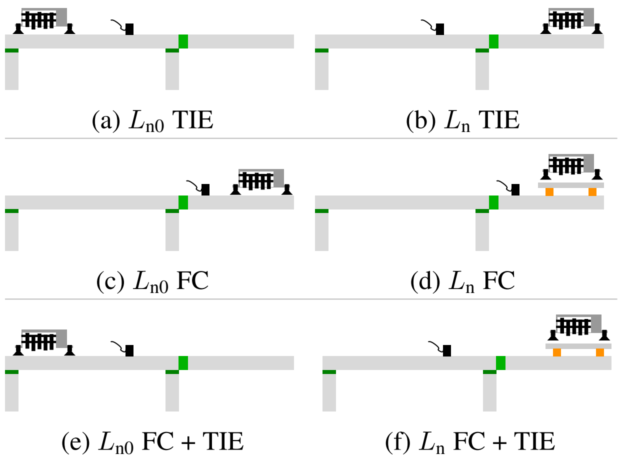

Figure 3: Determination of the impact sound reduction of floor coverings (FC) and thermal insulation elements (TIE) on the test rig with the location of the tapping machine and the accelerometers.

A FC can also be applied to the balcony slab of the test rig in order to directly determine the resulting impact sound reduction of TIE and FC. Therefore, the measurement procedure as shown in subsection 3.1 is used. To determine the impact sound reduction of the FC, the accelerometers are placed on the balcony when the tapping machine is located on the balcony (L_{n0}) and on the FC on the balcony (L_{n}), see Figure 3c and Figure 3d.

For the combined reduction of TIE and FC, L_{n0} is determined when accelerometers and tapping machine are located on the ceiling and L_{n} is measured by accelerometers on the ceiling when the FC on the balcony is excited as shown in Figure 3e and Figure 3f.

Figure 4: Stilt bearing with a 5 cm thick concrete slab in the floor covering test room at HFT Stuttgart.

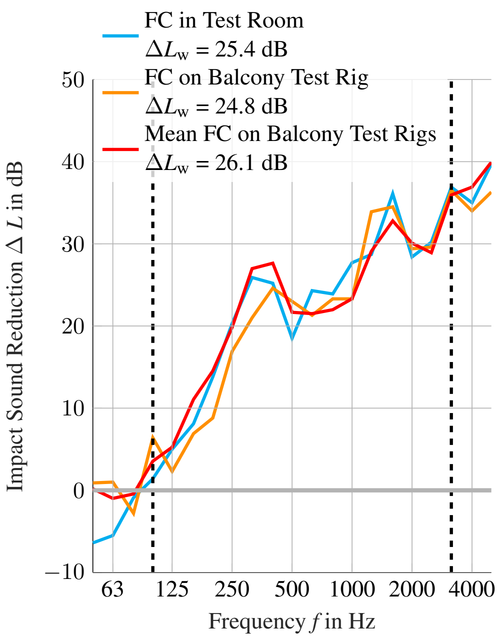

Figure 5: Impact sound reduction of the FC, measured in the FC test room and on the test rig for TIEs.

Figure 5 shows the reduction of the FC shown in Figure 4 measured in the FC test room (cyan) and on the balcony test rig. The FC was measured on multiple balcony test rigs. The mean value (red) is the arithmetic mean of all measurements, the single measurement (orange) is the one on the balcony further evaluated in Figure 6. The reduction is sufficiently similar regarding both the single number value and the frequency-dependent curve.

The impact sound reduction of the TIE, the FC, and the combination of TIE and FC both measured and calculated are shown in Figure 6. The measurement of the combination and the calculated combination show good agreement for all frequencies.

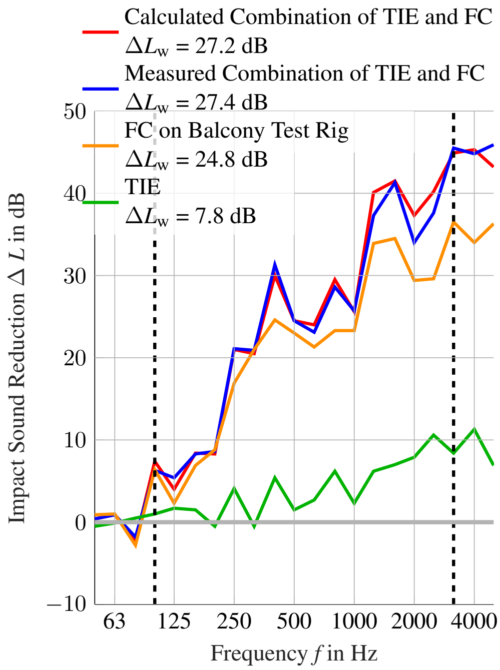

Figure 6: Impact sound reduction of the TIE, the FC, combined measurement and calculated addition of TIE and FC.

As with other sets of sound insulation layers, an addition of the single number values $\Delta L'_{n,w}$ leads to significantly higher values then the determination of the single number value from the added frequency-dependent values $\Delta L'_n$. A reliable method to determine the combined single number value from both single number values could not be found.

4. CONSTRUCTION SITE MEASUREMENTS

On a construction site near Stuttgart (Germany), a freely cantilevered reinforced concrete balcony without FCs (waterproofing, walkway covering) could be measured, see Figure 7. Ceiling and floor are made of reinforced concrete, the exterior and lateral interior walls of the receiving room are made of calcium silicate bricks and the rear interior walls are gypsum wallboards.

To estimate the normalized impact sound pressure levels, accelerometers were attached on each surface since no windows were installed and to determine the single flanking path transmission. A frequency-independent radiation level of 1 was used. The shifted reference curves in Figure 8 to Figure 10 are those of the resulting normalized impact sound levels for all transmission paths considered.

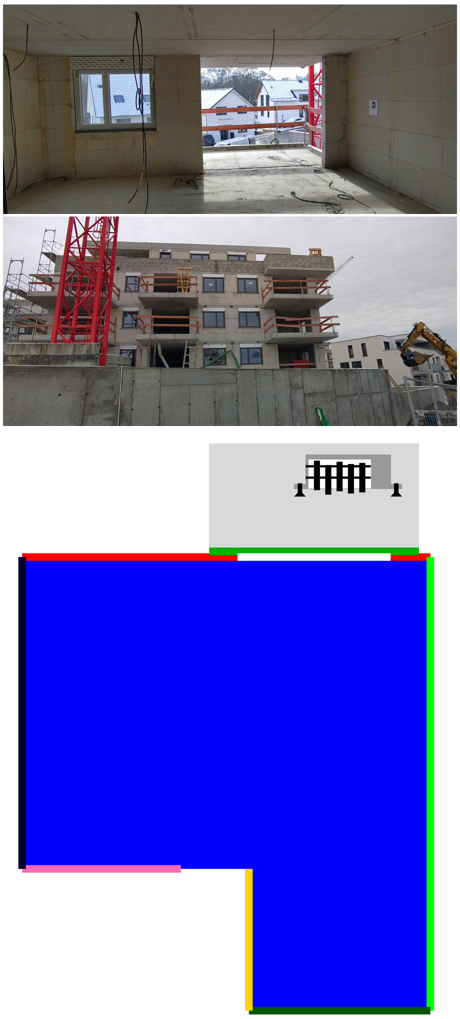

Figure 7: Inside and outside views and floor plan of the construction site.

The colours of the floor plan in Figure 7 correspond to the colours of the curves in Figure 8 to Figure 10. When measuring the velocity levels on the ceiling above the reception room, the transmission via the window opening and via the wall to the ceiling cannot be separated as in the forecast calculation since the ceiling vibrates as one structure. The calculation of L'_n was analogous to Equation 5 with frequency-dependent values. The single-number values $L_{n,w}$ and $L'_{n,w}$ were determined according to DIN EN ISO 717-2 [10].

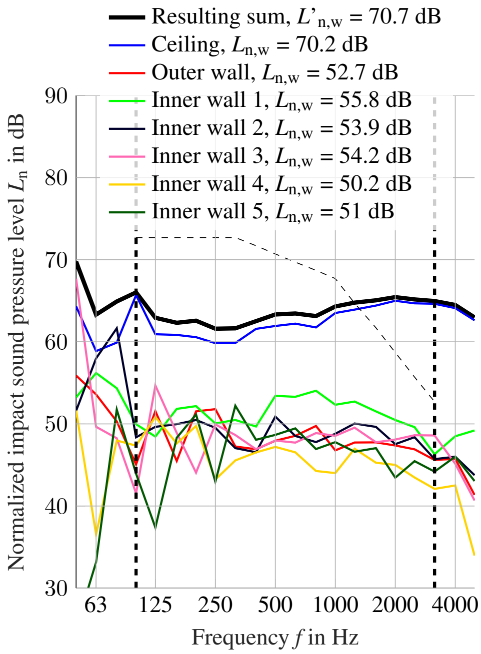

Figure 8: Measured normalized impact sound pressure levels when the ceiling is excited (vertical transmission).

Figure 8 shows the measurement results for the excitation of the ceiling. The direct transmission (path Dd according to Equation 4) determines the normalized impact sound pressure level in the field L'_n. The normalized flanking impact sound pressure levels of the walls above 100 Hz are about 10 dB below the level of the ceiling. This is consistent with other measurements and the expectation of a concrete ceiling with heavy walls.

Figure 9 shows the normalized flanking impact sound pressure levels of all components when the balcony is excited. The sum is calculated from the single flanking paths. A measurement with microphones was not possible, since no windows were installed. Here, too, the radiation of the ceiling determines the total level. The transmission via the outer wall (red) cannot be neglected above 500 Hz. The contributions of the other flanking paths to the total transmission are lower.

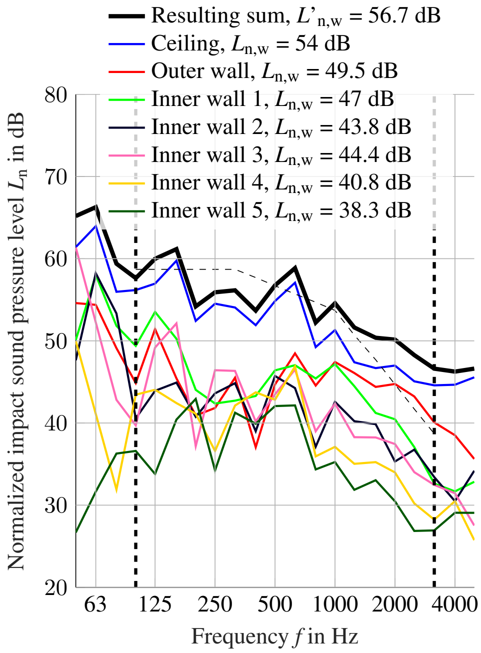

Figure 9: Measured normalized impact sound pressure levels when the balcony is excited.

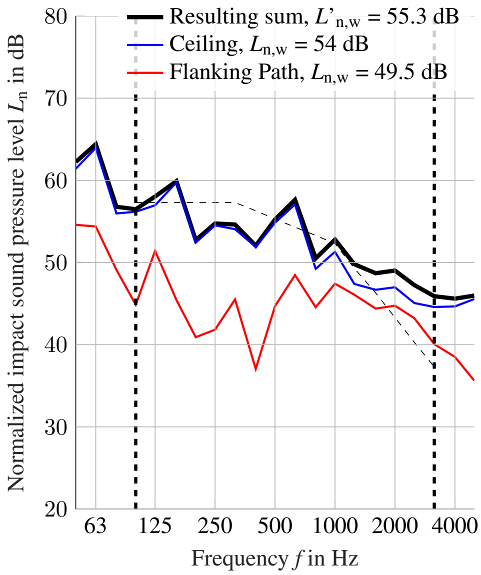

Figure 10: Measured normalized impact sound pressure levels on the first order paths when the balcony is excited.

Figure 10 shows the levels of the ceiling and the outer wall with the total level determined from only these two transmission paths. However, the difference to the measurement with all flanking paths is approx. 1.5 dB in the single-number value.

Since higher-order transmission paths are not taken into account in the proposed prediction method, a across-the-board addition of 2 dB could be applied. This value for the consideration of higher order transmission paths also resulted from further measurements in buildings.

5. COMPARISON BETWEEN MEASUREMENT AND PREDICTION

Table 2 summarises the prediction according to Equation 6 for the building situation shown in Figure 7. The weighted impact sound reduction of the TIE ΔL_w was determined in the test stand and corresponds approximately to the measured value in-situ [3]. The paths $Df_{1\&2,\text{ Wall}}$ correspond to Figure 1, path $Df_{2,\text{ Window}}$ corresponds to Figure 2.

dB	$Df_{1,\text{ Wall}}$	$Df_{2,\text{ Wall}}$	$Df_{2,\text{ Window}}$
$L_{n,eq,0,w}$	68.7	68.7	68.7
ΔL_w	12.2	12.2	12.2
$\frac{R_{i,w}-R_{i,w}}{2}$	2.8	0	0
K_{ij}	6.2	5.8	-3.7 ($K_{ij,min}$)
$10\log_{10}\frac{S_i}{l_0 l_{ij}}$	9.4	9.4	4.5
$L_{n,ij,w}$	43.7	41.3	55.7
$L'_{\mathbf{n,w}}$		**56.1**	

Table 2: Calculation of the flanking normalized impact sound level for the example from Figure 7.

Within the scope of the research project, measurements have been carried out in four building situations so far. The measured normalized impact sound pressure levels with all flanking paths (AF) and only the outer wall and ceiling (PF) were derived from velocity measurements. The results are presented in Figure 11 together with the results of the prediction according to DIN 4109:2018 and the method presented here. Measurement 1 is presented in detail in this paper.

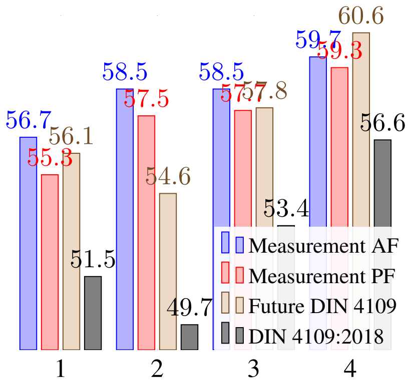

Figure 11: Overview of all measurements with the associated prediction without prediction uncertainty coefficient.

The agreement between measurements and prediction calculations with the proposed procedure is significantly better than with the previous procedure with K_T values. In these 4 examples, the current DIN 4109 is on average 5.5 dB lower then the AF. The proposed DIN differs by only 1.5 dB. It should be noted that a safety factor of 2 dB is applied in the future verification procedure. Except for building situation 2, the verification is thus on the safe side. It is remarkable that the requirement of $L'_\mathrm{n,w} \leq 58$ dB is only safely met in one case.

6. CONCLUSION

The impact sound transmission from balconies and access balconies into adjacent rooms requiring protection can be predicted much more reliably with the presented method than with the method of the currently valid DIN 4109-2:2018. Additionally, the weakest path can be determined and improved. It should therefore be adopted in the new DIN 4109-2 as suggested by the responsible working committee. Further research will be carried out to investigate the perception of impact sound from balconies.

7. ACKNOWLEDGEMENTS

This project is funded as part of iCity by the Federal Ministry of Education and Research (BMBF).

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