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Verification of sound insulation performance of housing by field measurements and/or calculations – A case study

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ABSTRACT

During the design process for housing, the sound insulation performance is determined considering material properties and flanking sounds according to international standards, guidelines and material specifications. Typically, simulation software is also included in this process. Building elements and junctions are carefully designed and analysed. While the design stage is vital, the construction process and application of acoustic details are equally important. Some unforeseen circumstances at construction stage can include changes in materials, incorrect application that causes flanking sound transmission, disruption of materials and sound leaks through unfilled mortar etc. Therefore, verification studies are necessary through acoustic measurements. Countries differ in requirements for the verification. Some countries may require measurements after construction, while others require only inspection at site, or in some cases calculation reports are sufficient. Therefore, cross studies are important to ensure that acoustic calculations will actually comply with the measurement results. The intention of the study aims to contribute to comparison of acoustic calculation results with site measurements. Six existing buildings were measured and acoustic performance was calculated using dedicated software packages. Some issues are highlighted that cause variance between the results.

1. INTRODUCTION

The acoustical requirements in dwellings vary between countries [1] as well as descriptors to evaluate sound insulation [2]. To develop a common scheme, the COST Action TU0901 *Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions* project, see [3] and [4], has been carried out, and the draft acoustic classification scheme in [3] was transferred into a WI (Work Item) for an ISO standard, current document "ISO/NP 19488 (ISO/TC 43/SC 2) - Acoustics - Acoustic classification of dwellings" [5]. Some information about the development process and challenges are explained in [6]. The data from COST TU0901, see [3], shows that verification with acoustical measurements is mandatory nationally in 7 European

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countries, and mandatory in some local areas in 5 European countries. The assessment of complaints is dealt with measurements sometimes in all 29 countries, see [3], Ch. 9. This shows the importance of high correlation between initial calculations at the design stage and the measurement results that include the effects of site conditions. However, the site performance is affected by flanking transmissions and sound leaks or other defects, which may occur due to detailing and/or construction errors [4].

This case study aims to compare the acoustic performances determined with calculations and with measurements based on some case studies. The differences will be analysed and measures to increase accuracy will be discussed.

2. FIELD MEASUREMENTS − CASE STUDY

Six case buildings were selected for a case study and measurements made in 2017-2018. All buildings were built after 2011 and they had reinforced concrete structural system. The wall types were masonry, except for façade elements in one building, which had prefabricated façade panels applied on a steel framework. In three of the buildings floor elements were built with infill blocks and a thinner layer of reinforced concrete. A full description of building elements is given in Table 1. The sound insulation of façade elements, floors, walls between neighbours and walls between the rooms of a dwelling were measured according to ISO 16283, parts 1-3 [7]. All buildings were occupied at the time of measurement. One dwelling from each building was selected for evaluation of the sound insulation performance. However, according to ISO/NP TS 19488, 10% of the building elements should be measured in order to determine the acoustical performance, if verified by field measurements only. This was not possible due to restrictions about access permission to dwellings. Further information about the measurements is available in [8].

The results were given in $D_{nT,A,tr}$, $D_{nT,A}$, $L'_{nT,w}$. A definition of these indices can be found in ISO 717-1 [9]. Partitions between neighbours and partitions inside the dwelling were measured and evaluated separately. ISO/NP TS 19488 [5] didn’t include sound insulation criteria for partitions inside the dwelling, but such criteria appeared in Turkish Regulation [10], [11]. Therefore, partitions inside the dwelling were also measured.

3. CALCULATIONS WITH SIMULATION SOFTWARES

Most often, acoustic building design is handled based on calculations with the data provided in architectural drawings. In order to follow similar patterns, calculations were applied using three steps: First, the material properties were derived from architectural drawings, relevant literature and company websites. Secondly, the building elements details were derived, and their performance was calculated using Insul software. Thirdly, the building was modelled, and building performance was calculated using SonArchitect software. The study was conducted with existing buildings, which imply that there may be some unknown changes in materials or details at the construction stage.

3.1. Element performance

The building element definitions and codes are given in Table 1. The sound insulation of building elements was calculated using Insul software. This software uses theoretical calculation methods and applies also corrections derived from empirical studies. Airborne sound insulation of walls and floors was calculated in weighted sound reduction index, R_w and impact sound insulation of floors was calculated in $L_{n,w}$. Software’s stated deviation margin was 3 dB.

Table 1: Building element definitions

	Walls		**Façades**		**Floors**
	W-1 -2 -3		**F-1 -2**		**FL-1**
1	2 cm plaster	1	2 cm plaster		8 mm laminated parquet
2	**8,5 / 13,5 / 19 cm hollow brick**	2	**13,5 / 19 cm hollow brick**	1	7 cm screed
3	2 cm plaster	3	5 cm polystyrene-EPS	2	**20 cm concrete**
	W-4	4	0,5 cm plaster	3	2 cm plaster
1	2 cm plaster		**F-3**		**FL-2**
2	**8,5cm hollow brick**	1	2 cm cement board		8 mm laminated parquet
3	5 cm mineral wool	2	5 cm mineral wool	1	3 cm screed
	in cavity + ties(spacing: 90cm)		in 10 cm cavity	2	4 cm polystyrene-XPS
4	**12,5 cm hollow brick**		point connection (spacing 90cm)	3	3 cm screed
5	2 cm plaster	3	**15 cm aerated concrete**	4	**15 cm concrete**
	W-5 -6 -7	4	2 cm plaster	5	2 cm plaster
1	2 cm plaster		**F-4**		**FL-3 -4 -5**
2	**20 / 25 / 30 cm concrete**	1	composite façade panel:		8 mm laminated parquet
3	2 cm plaster		**1 cm concrete**	1	~6 cm screed
	W-8		**18 cm foam concrete**	2	**~10 cm concrete**
1	2 cm plaster	2	20 cm cavity, double stud	3	**~20 cm brick/ pumice / EPS**
2	**comp. brick + mineral w. fill**		(stud depth: 9cm, spacing: 60cm)		**infill blocks**
3	2 cm plaster	3	1,25 cm gypsum board	4	2 cm plaster

3.2. Building performance

The building performance was calculated using the SonArchitect software. This software calculates the flanking transmission according to calculation methods in ISO 12354, parts 1-3 [12]. The building geometry was simplified and transferred in the SonArchitect software. Wall and floor assemblies were assigned with their pre-calculated R_w and $L_{n,w}$ values. The junction characteristics, room functions, and requirements were defined in the software.

4. COMPARISON OF RESULTS

The calculated building performance was compared to the measurement results of buildings. If the results varied strongly due to an assumption or modelling error, adjustments were made to increase the representative power. From one perspective, too many interventions can weaken the strength of the comparisons. Most of the times, material characteristics are roughly defined at the design stage of a project, and subject to change during construction. This means that the acoustical projects are prepared blindfolded. Additional constructional elements can be introduced such as bonding ties or nails whose affect was not foreseen during the calculations. Therefore, the initial results have the representative power of the deviations that can occur in real life. On the other hand, step-wise correction can actually help to explain these aspects.

The comparison was then repeated and differences were discussed.

4.1. Adjustments applied to simulation models

The results showed mostly good correlation, however some of the differences were due to construction conditions that were unforeseen in the project drawings. These caused deviations between measured and calculated results in this study. The primary adjustment was done after analysing the site conditions. The site conditions that caused the difference were (a) wall ties between two leafs of bricks ($D_{nT,A}$ decreased from 65 dB to 49 dB), (b) ventilation apertures ($D_{nT,A}$ decreased from 31 dB to 26 dB) and (c) gaps at the perimeter and threshold of the doors (Figure 1).

The calculated impact sound insulation values showed high deviation from the actual state. In all cases, the first calculations of element performances were done without cover (screed as finishing material). Resulting $L_{n,w}$ varied between 77 – 88 dB. The effect of finishing material was introduced as reduction of impact sound insulation, ΔL, based on the data of timber floor covering. Standard application of laminate parquet includes a thin foam underneath which is believed to have caused the difference between primary results and actual state. Adjustment was done to the finishing material. The measured values of laminated parquet with 3 mm foam underneath were selected from Insul software material database. Results were more realistic, when the measured ΔL was applied instead of the predicted ΔL.

(a) (b) (c)

Figure 1: Unforeseen construction conditions (a) Wall ties [13],
(b) Ventilation apertures, (c) door gaps

In one of the buildings, deviation occurred due to the simplified model of the building. In the actual state reinforced concrete wall was 20 cm wider and prevented the flanking transmission to the brick wall at the junction (Figure 2). When this was neglected, $D_{nT,A}$ of the partition was found to be 52 dB. Improvement was possible by introducing a resilient connection (55 dB), or increasing the accuracy by modelling 20 cm wall (56 dB). Both improvement solutions were in line with the measurement result (57 dB). In two other partition walls, adding the structural columns of the building into the model increased the accuracy by 1 dB.

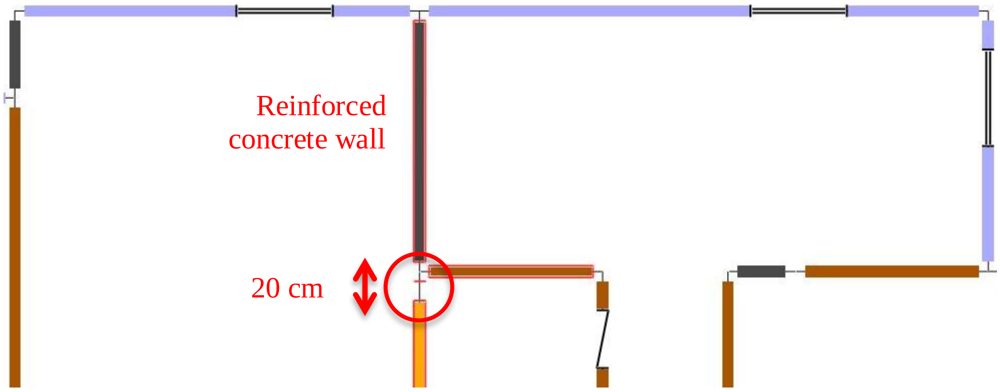


Figure 2: Detailed modelling of the junction on plan drawing

4.2. Evaluation of deviations

After corrections, the average value for deviations and maximum adverse deviations were reported based on the building element type. Adverse deviation occurs when the measured results are below the simulated results (i.e. actual state is worse than the designed state). According to

ISO/NP TS 19488 the overall acoustic performance is defined according to the most adverse measurement result [5]. Therefore, adverse deviation can explain how the final acoustic performance will be affected from the calculation/simulation errors.

The final comparison of measurement and calculation results is given for façade sound insulation (Figure 3), for floor elements airborne (Figure 4) and impact (Figure 5) sound insulation and for partition walls' airborne sound insulation (Figure 6 and Figure 7). ISO/NP TS 19488 presents an acoustic classification scheme with 4 dB intervals [5]. Therefore, deviations of 4 dB or more are considered as important and marked with red in the charts.

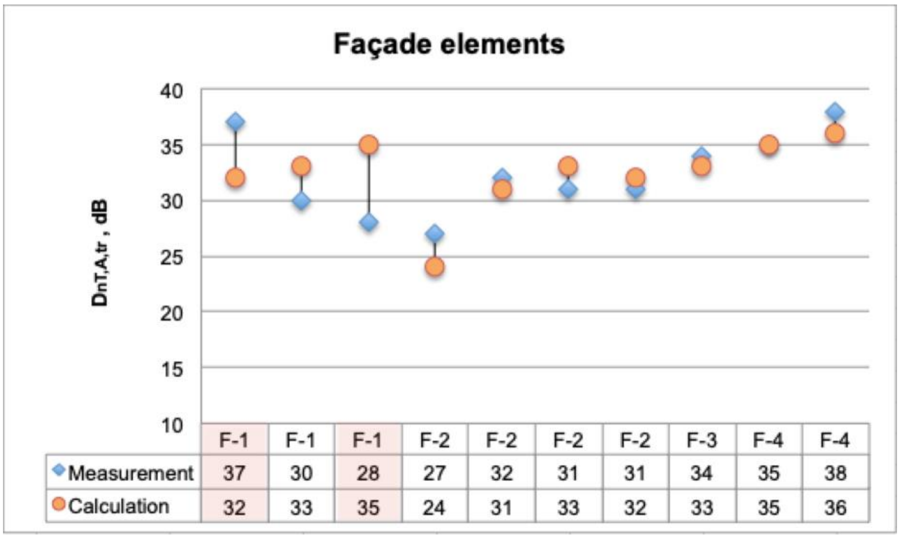


Figure 3: Comparison for façade elements

The façade sound insulation (Figure 3) depends not only on the façade wall, but also on the windows and connections. The window type was defined in some projects, but not named in others. Since the most typical window type was 4+12+4 mm insulation glass in Turkey, this assembly was used for all buildings. The average deviation for façades was 2.5 dB. Maximum adverse deviation (measured result < simulated result) was 7 dB.

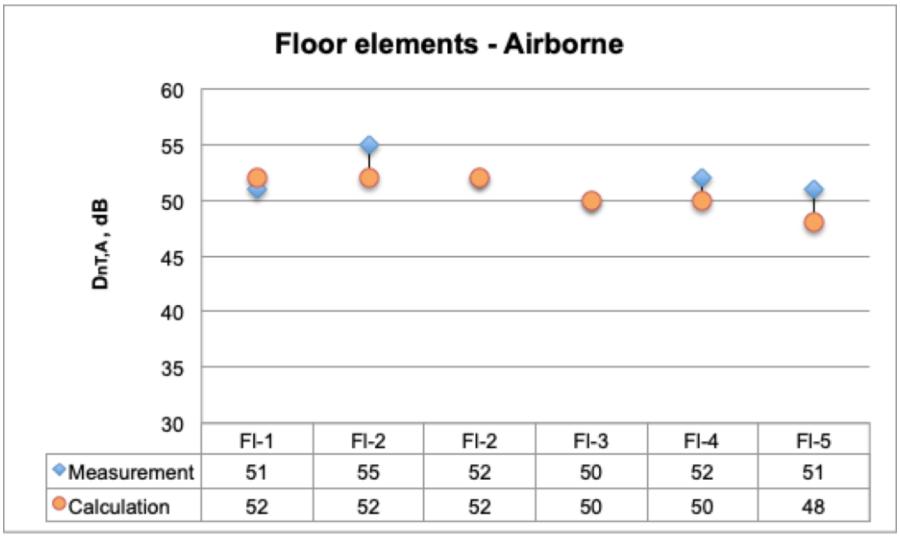
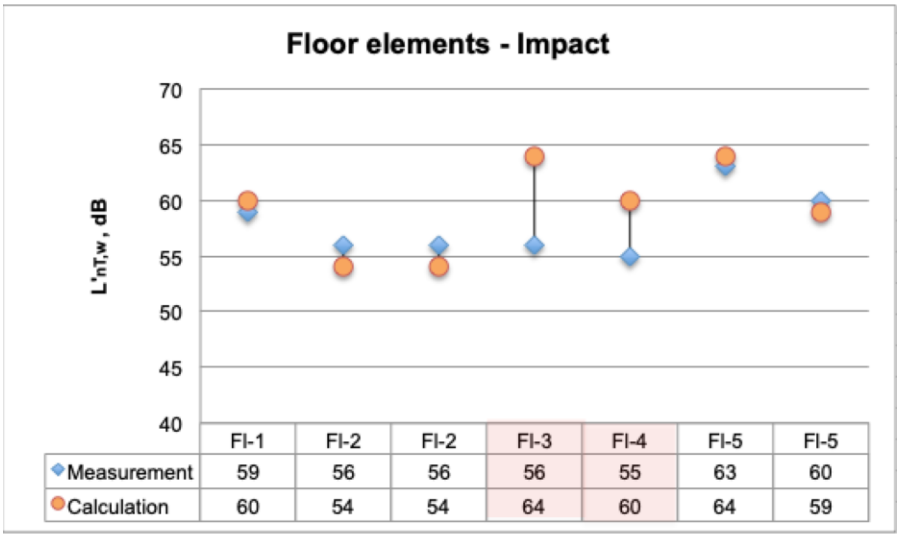


Figure 4: Comparison for airborne sound insulation of floor elements

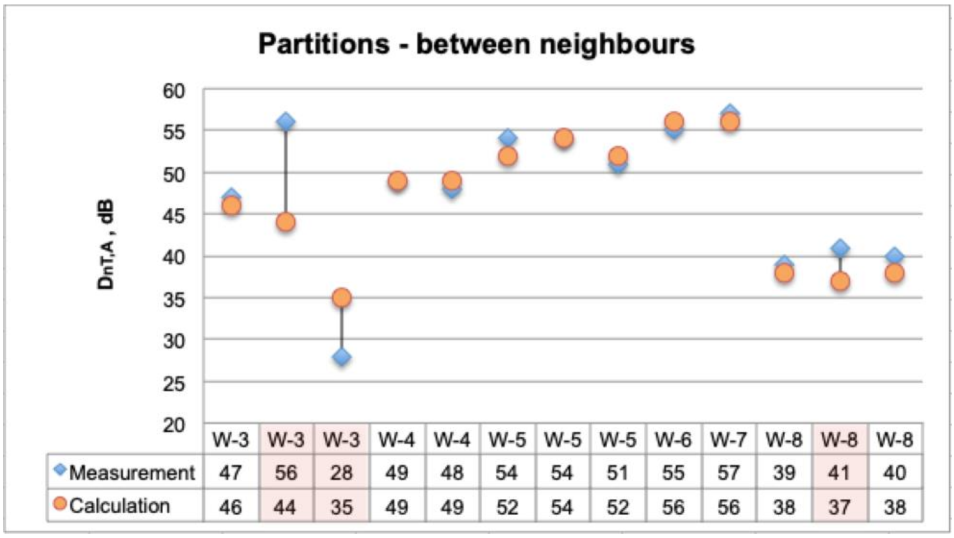
The calculated airborne sound insulation of floors (Figure 4) showed good correlation with the measurement results. The average deviation for airborne sound insulation of floors was 1.5 dB. Maximum adverse deviation was -1 dB.



	Fl-1	Fl-2	Fl-2	Fl-3	Fl-4	Fl-5	Fl-5
◆ Measurement	59	56	56	56	55	63	60
● Calculation	60	54	54	64	60	64	59

Figure 5: Comparison for impact sound insulation of floor elements

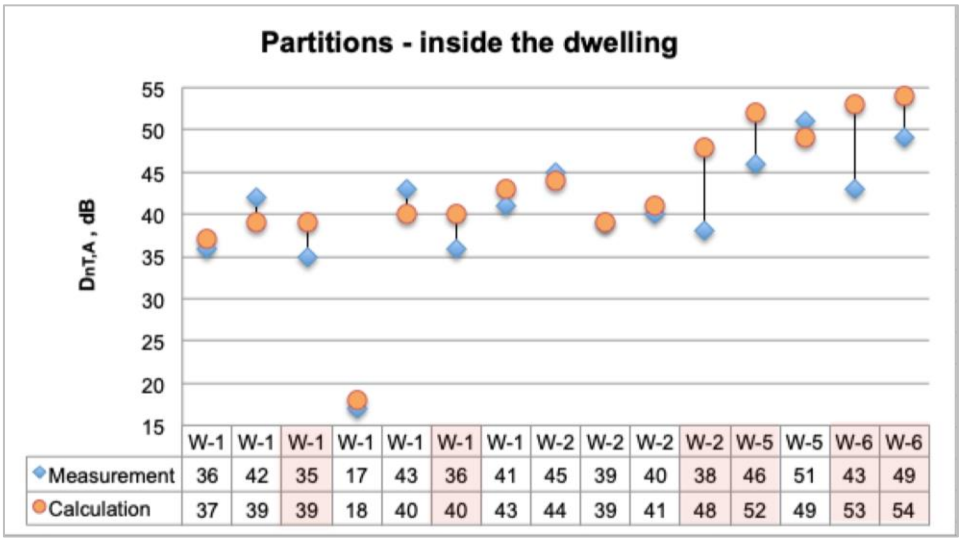
After floor covering adjustment, the calculated impact sound insulation (Figure 5) was also comparable with the measurements except in two cases: Floor type 3 (Fl-3) and Floor type 4 (Fl-4), both floors with infill blocks. Fl-3 was constructed with brick infill blocks and Fl-4 was built with pumice (a type of volcanic rock aggregate used in light-weight building blocks) in-fill blocks. While being constructed with expanded polystyrene (EPS) blocks, Fl-5 showed good correlation. The others were results from reinforced concrete floors. The average deviation for impact sound insulation of floors was 2.9 dB. Maximum adverse deviation was 2 dB.



	W-3	W-3	W-3	W-4	W-4	W-5	W-5	W-5	W-6	W-7	W-8	W-8	W-8
◆ Measurement	47	56	28	49	48	54	54	51	55	57	39	41	40
● Calculation	46	44	35	49	49	52	54	52	56	56	38	37	38

Figure 6: Comparison for partition walls between neighbours.

Finally, the evidence for partition walls was analysed in two groups. The partitions between neighbours (Figure 6) showed good correlation. Wall type 3 (W-3) was measured in a building at two spots: between neighbouring kitchens and between the dwelling and the apartment corridor. The calculated result was lower than measurements between neighbours and higher between the dwelling and the corridor. The second may have occurred due to weak door connection. Although the door leakage was taken into consideration, the actual state still showed lower performance. On the other hand, the reason for difference at the elements separating the kitchens is unknown, and can be due to a change at construction stage. The average deviation for partitions between neighbours was 2.5 dB. Maximum adverse deviation was 7 dB (due to wall between dwelling and the corridor).



	W-1	W-1	W-1	W-1	W-1	W-1	W-1	W-2	W-2	W-2	W-2	W-5	W-5	W-6	W-6
◆Measurement	36	42	35	17	43	36	41	45	39	40	38	46	51	43	49
●Calculation	37	39	39	18	40	40	43	44	39	41	48	52	49	53	54

Figure 7: Comparison for partition walls inside the dwelling

Calculation results for partitions inside the dwelling (Figure 7) showed more deviation from the actual state compared to other elements. Most of the times, this was due to the indirect airborne sound transmission through corridors. In all of the cases the doors inside the dwelling had weak sound insulation, 18 mm medium density fibreboard (MDF) with approximately 12 mm gap at the threshold and no gaskets. In one case, the sliding door, which separated the living room and the bedroom, had approximately 15 mm gap at the perimeter and the measurement showed that the sound insulation was reduced to only 17 dB for this partition. The calculation results were close to the actual state when the leakage was taken into account. The average deviation for partitions between rooms in the dwelling was 3.5 dB. Maximum adverse deviation was -10 dB.

5. DISCUSSION AND CONCLUSIONS

Sound insulation calculations and/or field measurements are necessary for verification of acoustic performance in dwellings. In the design stage, sound insulation calculations are applied to estimate the acoustic performance and most of the times software are included in the process. During and/or after the construction stage, the necessary verifications are typically made based on the field measurements. Some countries also have the obligation defined in their legislations. This indicates the importance of correlation between these two verification methods and acoustic consultants should know what can go wrong and how much deviation should be expected.

In this case study, measurement results in six residential buildings were compared with calculation results. Some major differences were related to site conditions that did not appear on the project drawings: wall ties between two leafs of bricks, ventilation apertures and large gaps at the perimeter and threshold of the doors. Correctly modelling these details was important. The measured ΔL of floor coverings in software database resulted better than the predicted ones. Detailed modelling was found to be important for correctly representing the flanking paths. The average deviation was less than 3 dB for façades and partitions between neighbours. Average deviation was 3.5 dB and maximum adverse deviation was 10 dB for partitions inside the dwelling. Weak doors inside dwellings caused indirect airborne sound transmission between rooms through corridors. The results of this study implies that calculation/simulation assumptions and modelling play an important role on the achieved result. According to ISO/TS NP 19488 the most adverse result determines the overall performance. Although the average deviations are low, the maximum adverse deviations may result in drop of overall performance equivalent to 2 classes (e.g. Class E instead of Class C). This shows the importance of aiming for higher sound insulation at the design stage, correct detailing and inspection at the construction stage. Since the study was conducted with existing buildings, the results depend on the data derived from project drawings and material properties derived from literature and market research. Further studies are recommended where the construction process is also observed.

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