EFFECTS OF CONSTRUCTION JOINTS OF DOUBLE BRICK WALLS ON SOUND INSULATION AND ON K_{ij} VALUES. CASE STUDY IN RETROFITTED HOUSING

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Abstract

Most part of the building stock in Spain (more than 18 million dwellings) was built between the 40's a 80's, before the first regulation on sound insulation in Spain was approved. The supporting structure of common multifamily blocks in this period was usually composed of concrete frame structures formed by pillars and slabs, where partitions were erected on the slabs. At his time, partitions were very light to reduce the dead load. Most common partitions were single leaf ones composed of hollow brick walls and perforated brick walls, with a surface mass ranging from 80 to 170 kg/m^2. The typical airborne sound insulation performance of this walls, $D_{nT,A}$, varies from 32 dBA to 40 dBA, which is far from the current standards.

This work studies the increase in airborne sound insulation when a 50 mm light ceramic brick wall with elastic interlayers lines a existing single leaf partition. Airborne sound insulation as well as K_{ij} measurements were performed in a laboratory which simulated the structure of an existing building. This research work shows the effects of junction construction details on airborne sound insulation in buildings. K_{ij} measurements were also performed across double ceramic brick walls. This paper shows the relationship between good design, the increase in sound insulation and the increase in K_{ij} values.

Keywords: K_{ij}, junctions, sound insulation, retrofitting, 12354 predictions.

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1 Introduction

In Spain there are more than 18 million homes, not including holiday homes. Most part of them, approximately 8,3 million, were built between the 40's and the 80's as shown in figure 1, just before the first regulation on protection against noise in buildings, NBE CA 81[1] came into force.

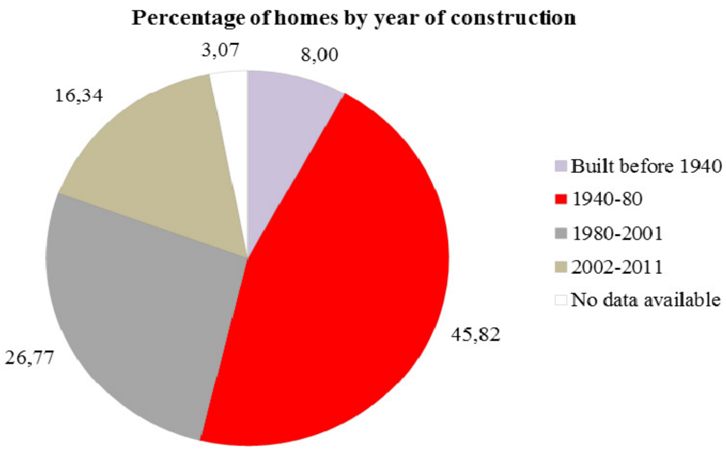


Figure 1. Percentage of homes by year of construction. As it is shown, more than half of the building stock in Spain was built before the 1980's, according to the latest census available. Source: Spanish 2011 census [2].

In this period, buildings experienced a great evolution. The ones dating from the first quarter of the 20th century in Spain were commonly supported by solid walls ($m \geq 300$ kg/m^2) and floors were composed of wood beams or brick vaults with a thick layer of deafening consisting on sand, rubble or aggregate material.

In the 1940's, concrete structures became popular. First concrete slabs were supported by brick walls, but in the 1960's house blocks were formed by a grid structure composed of slabs and pillars. In this scenario, reducing the dead load was crucial to reduce the budget of concrete structures, thus separating walls became increasingly thinner and lighter. Common separating walls were formed by hollow ceramic blocks, whose surface mass ranged from 80 to 170 kg/m^2. As a result, homes experienced a reduction in sound insulation. Typical in situ sound insulation values range from $D_{nT,w} + C$ = 32 dBA to 40 dBA, which is far from the current standards.

This paper explores the possibilities of improving the sound insulation of existing light brick walls by installing a 50 mm light ceramic brick wall with elastic interlayers. This work shows the big effect that junctions have on sound insulation, particularly the junctions between the façade and the partitions.

In addition, the structure-borne sound transmission across the brick walls was studied and reduction vibration index measurements, K_{ij}, were performed. There are many works that show the structure-borne transmission across the floor of cavity walls [3]–[7], but there are not so many data of the flanking transmission across the façade and partitions.

EN 12354[1] predictions were made as well. They show the importance of having accurate input data of constructive elements and junctions.

2 Description of the work

Airborne sound insulation tests and K_{ij} tests were performed in Acusttel, a laboratory which had a facility which is similar to the structure of a typical building in Spain dating back the 1960's. The setup was formed by three floors supported on concrete pillars where it was possible to build any partition, façade, floating floor or ceiling as it is erected in a building. Figure 2 shows an outline of the chambers and the setup built in the lower chamber to divide the space into two rooms: the source room and the receiver room.

[1] Predictions have been made according to the draft of ISO/DIS 12354-1[8].

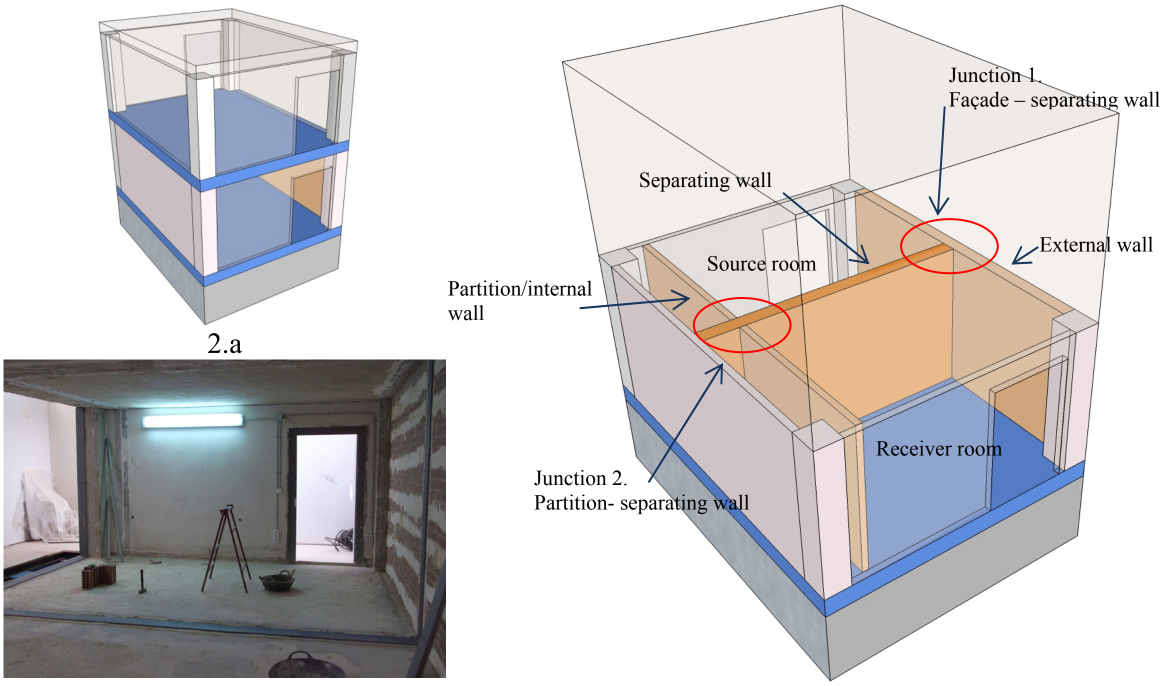


Figura 2 Chambers outline. 2.a. Structure of Accusttel showing the pillars and slabs. 2.b. Photo of the facilites, when one of the walls was under construction. 2.b. The bottom chamber was used in the tests. A partition which divided the space was built. One flanking element was built as a facade. Another partition was built as if it were an internal wall

This structure was used as a demonstrator to simulate a field situation, where there were two rooms divided by a wall. One of the flanking elements was built as a double wall façade and the other partition was a single leaf hollow brick wall, which was like an inner partition in a dwelling. This was called configuration C1. Based on this configuration, several modifications related with the walls and junctions were undertaken, and in each modification in situ airborne sound insulation tests were performed and K_{ij} measurements of the junctions with the façade and walls were also performed.

The work flow was as follows.

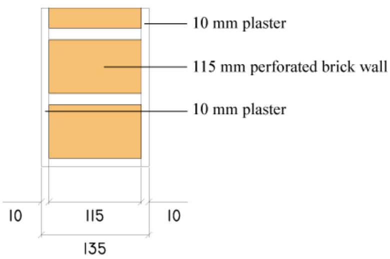
1. Configuration C1. A single leaf wall was built consisting on a 115 mm perforated brick wall, plastered on both sides. (m= 142 kg/m^2, ρ = 1054 kg/m^3, R_A= 44 dBA). This is a common partition in existing buildings in Spain, whose junctions with the façade and partitions are rigid. Airborne sound insulation and K_{ij} were tested. Figures 3 and 4 show the details of each construction element and its junctions respectively.

2. Configuration C2. The separating wall was lined with a 50 mm hollow ceramic block on elastic interlayers. The 40 mm cavity between both walls was filled with mineral wool, as it can be seen in figure 3. The elastic interlayers were formed by 10 mm elastified polyestyrene (EEPS, s' = 6-8 MN/mm^3). The flexible interlayers were installed in the junctions with the floors to avoid the structure-borne transmission via the floors.
   Airborne sound insulation and K_{ij} measurements were performed. In this particular arrangement, the hollow ceramic block was installed letting the flanking walls be continuous across the separating wall, that is to say, works to avoid flanking transmission were not performed in the junctions.

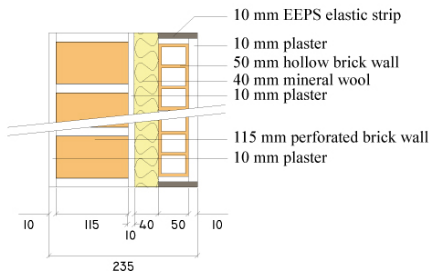
(Total surface mass m = 196 kg/m^2, R_A = 61,9 dBA)

3. Configuration C3. Junctions with the façade and the partition were modified to prevent flanking construction as illustrated in figure 4. Airborne sound insulation and K_{ij} measurements were again performed.

The aim of this work was to reproduce a retrofitting situation where good and bad practice design were comparable. One of the objectives was to assess the in situ airborne sound insulation and the effect that junctions had on it. In addition another goal was to obtain experimental values of K_{ij} of double hollow brick wall junctions.



3.a

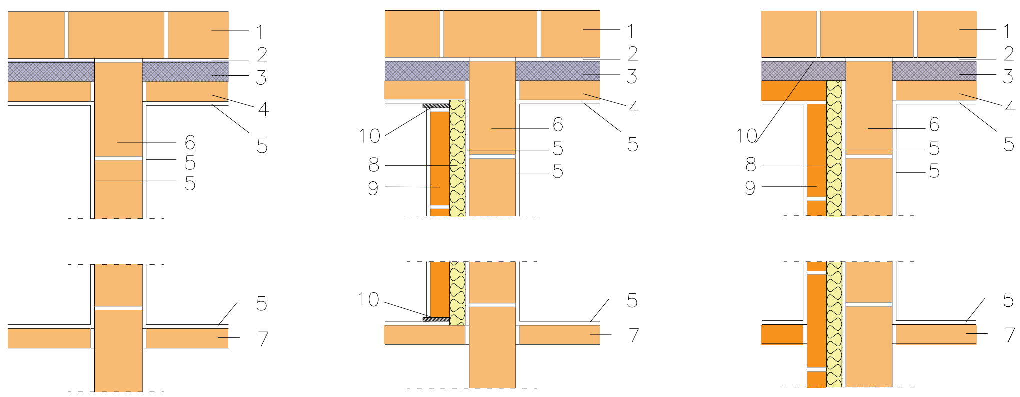


3.b

Figure 3.a. Separating wall in configuration C1. Figure 3.b. Separating wall in configurations C2 and C3.

Table 1 shows the dimensions of the rooms where the tests were performed. As it is shown, the volumes are smaller than 25 m^3. This is a problem in the measurement of sound insulation in the low frequency range, because of non-diffuse acoustic field. This also has an influence in the modal overlap factor and the mode count. Nevertheless, surfaces and volumes in the demonstrator are quite representative of a small room in a common housing block.

Figure 4 shows a plan section of the junction details with the facade and the internal wall of the three configurations described. No works were performed in the floor or in the ceiling.



Configuration C1 Configuration C2 Configuration C3

1. 115 mm face ceramic brick wall, m= 162 kg/m^2
2. 10 mm cement render
3. 40 mm cavity filled with extruded polyestyrene (non absorbent material)
4. 50 mm hollow brick wall.
5. 10 mm plaster
6. Separating Wall: 115 mm perforated ceramic brick wall,, m= 122 kg/m^2
7. Internal partition: 50 mm hollow brick wall. m=44kg/m^2
8. 40 mm mineral wool
9. 50 mm hollow brick wall. m=44kg/m^2
10. 10 mm EEPS elastic strips

Figure 4. Plan view of junction details of C1, C2 and C3 configurations.

Table 1. Dimensions of the rooms

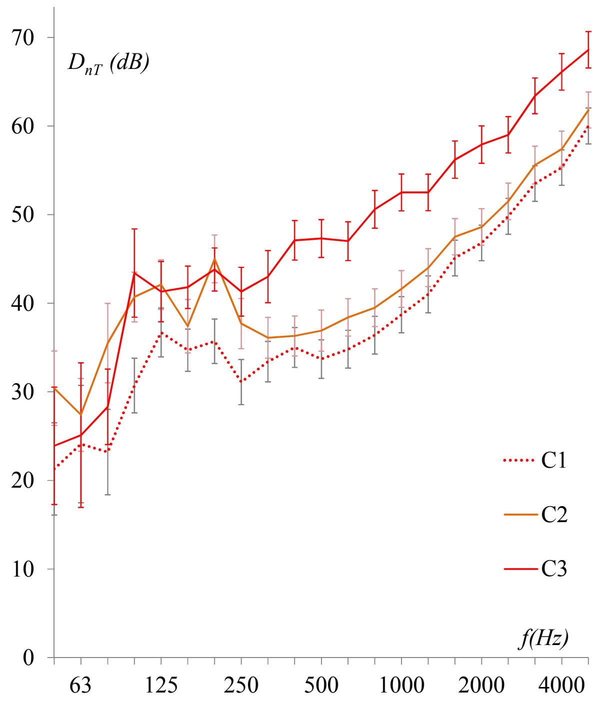
Source room volume	21,6 m^3
Reception room volume	21,6 m^3
Separating wall surface	7,3 m^2
Clearance	2,4 m
Source room surface	9,0m^2
Reception room surface	9,0m^2

The airborne insulation tests were performed according to ISO 140-4[9], as when the tests were performed ISO 16283-1[10] had not been not approved yet. K_{ij} measurements were performed according to ISO 10848-1[11] and ISO 10848-4[12].

According to ISO 10848-1[11], it is important for the precision of K_{ij} that transmissions over surrounding junctions do not have an influence on the K_{ij} measurements. Thus elastic interlayers were also installed in the junctions of the walls with the pillars and the rest of the chamber walls.

3 Effects of brick linings in the airborne sound insulation, D_{nT}

Figure 5 shows the results of the standardized level difference, $D_{nT,}$ found in the three different arrangements. The uncertainty is also shown[2]. As it can be seen, the increase in airborne sound insulation between C1 and C3 is + 12 dB. But in C2, when the hollow brick wall is installed, but there is not a remedial work performed in the flanking elements, the increase is only +3 dB. This is due to dominant flanking transmissions across the façade and the internal partition. These results show the importance of designing junctions correctly.



C1
$D_{nT,w}$ ($C_{100\text{-}5000}$, $C_{tr,100\text{-}5000}$) = 40 (0, -3)
$D_{nT,A}$ = 39,3 ± 0,7 dBA

C2
$D_{nT,w}$ ($C_{100\text{-}5000}$, $C_{tr,100\text{-}5000}$) = 43 (0,-3)
$D_{nT,A}$ = 43,0 ± 0,8 dBA

C3
$D_{nT,w}$ ($C_{100\text{-}5000}$, $C_{tr,100\text{-}5000}$) = 52 (0, -4)
$D_{nT,A}$ = 51,7 ± 0,8 dBA

Figure 5. D_{nT} results for configurations C1, C2 and C3.

[2] Uncertainties were calculated by means of Monte Carlo simulations according to ISO/IEC Guide 98-3/suppl.1:2008[13].

Biggest differences occur in the mid and high frequency bands, whereas from 50 – 200 Hz, results of D_{nT} are quite similar in C2 and C3.

4 Results of K_{ij}

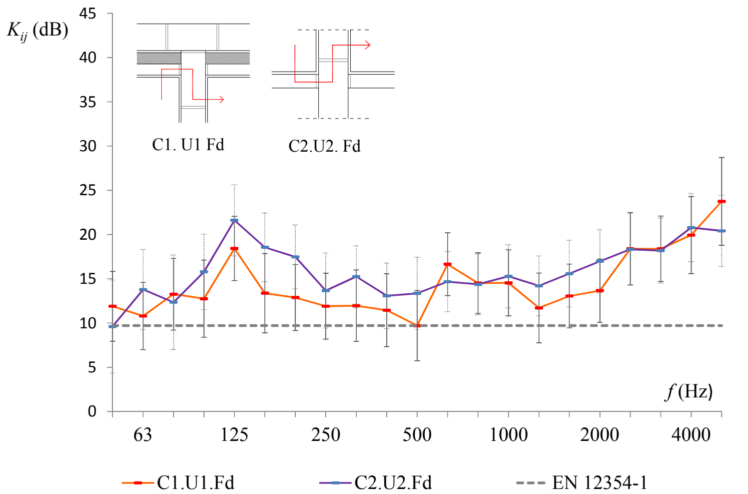
In this work, the vertical flanking transmission across the brick walls is studied. Reduction vibration index results are given in the next sections for the three configurations. Uncertainties[3] are also given.

4.1 Arrangement C1: Rigid junctions

Configuration C1 junctions are basically rigid. Theoretical K_{ij} values for rigid junctions are frequency independent and have a constant value according to Annex E of EN 12354-1[14]. Figure 6 represents only transmission *Fd* across the façade and the inner partition. Theoretical values are presented in grey. All the results are presented with the expanded uncertainty. Similar values were found for transmission *Ff*.

As seen in fig. 6, values in the low and high frequency range are irregular and high. According to several authors, [5], [15], this is due to a low modal overlap factor below 500 Hz and the conversion of bending waves to in-plane waves at the junctions.

K_{ij} mean values are calculated as the average of results from 200Hz to 1250 Hz. These are compared to the theoretical values according to EN 12354-1[14].



Mean K_{ij}

C1.U1.Fd

K_{test}=12,8 ± 1,3 dB

K_{12354} = 9,7 dB

C2.U2.Fd

K_{test}=14,6 ± 1,2 dB

K_{12354} = 9,7 dB

Figure 6. K_{ij} results of path *Fd* in Configuration C1 (rigid junctions)

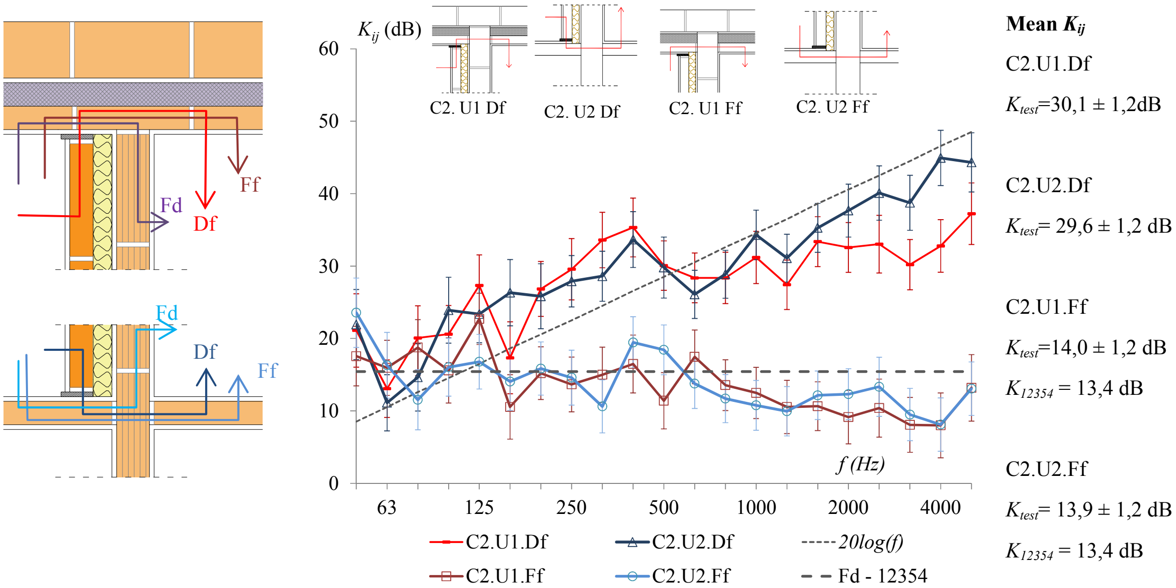
4.2 Arrangement C2:

Closer inspection of C2 joints, figure 7.a, shows that transmission *Df* goes across the brick lining and the elastic strip, whereas transmissions *Ff* and *Fd* are similar to rigid junctions. K_{ij} results confirm this idea. Figure 7.b shows clearly the differences in performance between transmissions *Df* and *Ff*.

$K_{ij\text{-}Df}$ results are frequency dependent. The theoretical slope for a wall junction with flexible interlayers is approximately *20 log(f),* according to Pedersen [15] and the Annex E of the draft of ISO/DIS 12354-1[8]. In figure 7.b it is represented the slope *20·log(f)* which is very to the slope of junction C2.U2 (separating element- partition). $K_{ij\text{-}Ff}$ have a similar performance to rigid junctions.

[3] Uncertainties were calculated by means of Monte Carlo simulations according to ISO/IEC Guide 98-3/suppl.1:2008 [13].

As studied by several authors, [5], [16], when an elastic interlayer is introduced between two elements, it attenuates the path which crosses the elastic interlayer, but it does not remove much of the acoustical energy. Energy rather redirects to other paths with no flexible interlayers. This effect can be seen in *Ff* transmissions in figure 9 as well.



7.a 7.b

Figure 7.a. Plan view of junction details of C2. Figure 7.b. K_{ij} results of paths *Df* and *Ff*

4.3 Arrangement C3

In configuration C3, flanking elements such as the internal partition and the inner leaf of the façade are discontinuous, thus flanking transmissions are avoided. This results in an increase in sound insulation and also in the increase in K_{ij} results in all paths: *Ff*, *Df* and *Fd*. Figure 8 shows all paths for the junction U1, the junction between the separating wall and the façade. As seen, K_{ij} values increase with the frequency.

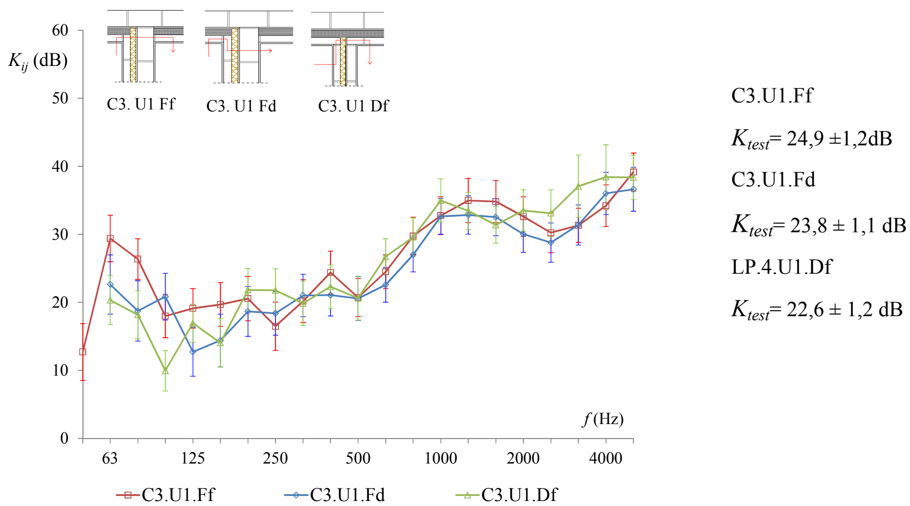
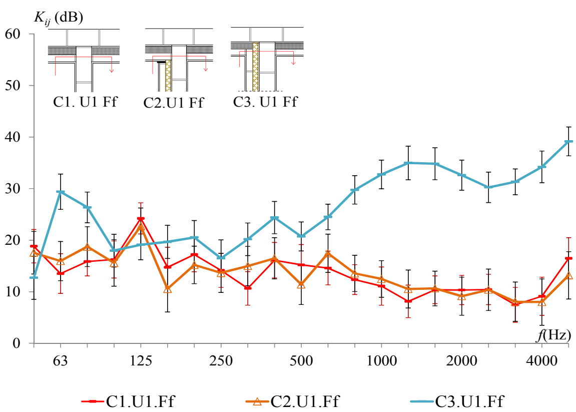


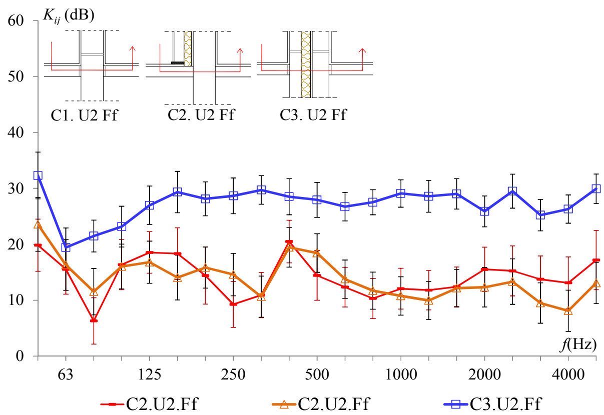
Figure 8. K_{ij} results of the junctions with the façade (Configuration C3)

4.4 Increase in K_{ij} due to good flanking design

When flanking elements are disconnected, as in configuration C3, K_{ij} values increase, that is to say the attenuation of joints increases. Figures 9.a and 9.b show the variations in K_{ij} for paths *Ff* across the two junctions studied: junction U1 (façade- separating wall) and junction U2 (inner wall – separating wall).



9.a



9.b

Figure 9.a. K_{ij} results of *Ff* path for the junction with the façade (U1). Figure 9.b. K_{ij} results of *Ff* path for the junction with the inner partition (U2).

5 Results of predictions

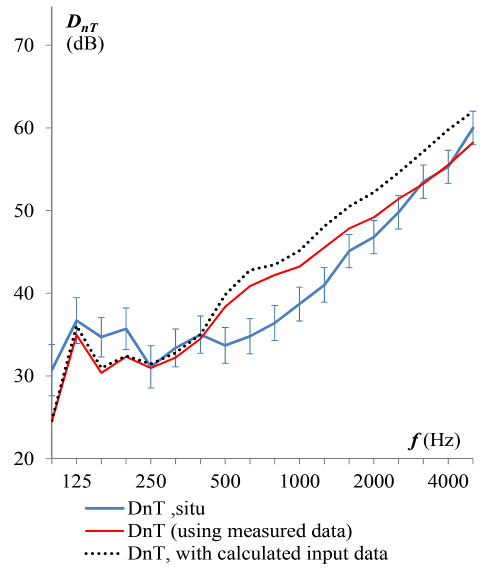
Predictions according to ISO/DIS 12354-1[8] were carried out and compared with the airborne sound insulation results obtained in the measurements. Two types of predictions have been performed depending on the following input data:

1. Predictions P1, where $\overline{D_{v,ij,situ}}$ (normalized direction-averaged vibration level difference) and T_s (structural reverberation time) have been obtained in the measurements.
2. Predictions P2, where K_{ij} and T_s values have been calculated according to ISO/DIS 12354-1 [8].

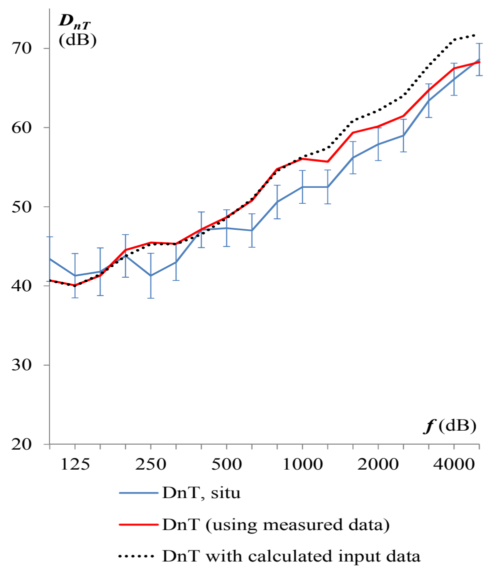
In the predictions, most of the *R*, sound reduction index, data of the construction elements such as the separating walls, façade, floors, etc. were obtained from available laboratory test from manufacturers. In the calculus, these data were corrected for resonant transmission. Whenever there was not available measured data of a specific element, such as the floors, data from a very similar element was used instead. Thus it was assumed some errors could take place in the predictions. Calculated sound reduction indexes were not used in any prediction.

Figure 10 shows the results of calculated D_{nT} according to predictions P1 and P2 for configurations C1 and C3 respectively.

When compared with D_{nT} values obtained in the measurements, predictions using measured $\overline{D_{v,ij,situ}}$ and T_s values are more accurate than those using calculated data. The mean difference $D_{nTtested} - D_{nT\,P1}$ is 2,7 dB, whereas the mean difference $D_{nT\,tested} - D_{nT\,P2}$ is 4,3 dB.



10.a



10.b

Figure 10.a. D_{nT} calculated values using measured values of $\overline{D_{v,ij,situ}}$ and T_s. P1. Figure 10.b. D_{nT} calculated values using calculated data. P2.

6 Conclusions and discussion

D_{nT} results show that good design of junction details is vital to ensure sound insulation and comply with requirements. This case study simulated the retrofitting of two rooms with a hollow brick lining with flexible strips on top and bottom. A difference of 9 dB has been found between good and bad practice design.

The elastic strips installed in the brick lining minimize the flanking transmission across the floors. After that, the vertical structure-borne transmission across the brick walls becomes important and was studied in this work.

The vibration reduction index, K_{ij}, expresses the vibration attenuation over junctions and experimental results show a big increase when the façade and interior partitions do not connect both leaves of the separating wall.

One of the problems of predictions is the need of accurate data concerning the construction elements, *R, η, m*, and the junctions, K_{ij}, T_s. Predictions carried out with measured joint data are more precise than those preformed with calculated data. This proves that more available data is necessary and that research on the structure borne transmission across joints must keep on.

Acknowledgements

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