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Measurements and prediction of sound insulation of innovative ventilated façade solutions

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ABSTRACT

This work is part of *Progetto Involucro*, a research project funded by the Emilia-Romagna Region in the frame of POR-FESR 2014-2020. It aims at testing innovative ventilated façade solutions for improving buildings' energy and acoustic performance. Two identical test buildings (prototypes) are built in real scale on the same site and different ventilated façade solutions are installed on the South facing walls. In order to evaluate the performance of different alternatives, a benchmark solution is installed on the first prototype, while all the other innovative solutions are installed on the second one and they all are tested under the same environmental conditions. Sound insulation measurements are performed on site with the aim to investigate the contribution of different rainscreens in relation to their fastening system and individual component elements such as natural ventilation grills, open joints and potential openings on the external side. Furthermore, a measurement campaign focused on flanking transmission is conducted to evaluate sound transmission across the façade junctions for each innovative solution installed. This paper shows the preliminary results of the measurement campaign. Data obtained from on-site measurements are commented and discussed in relation to the values calculated using the model proposed in the ISO 12354-3 standard.

Keywords: Innovative Ventilated Façade, ISO 12354-3, Calculation Model

1. INTRODUCTION

This contribution shows the preliminary phases of development of *Progetto Involucro*, which aims at testing innovative Opaque Ventilated Façades (OVF) solutions for the improvement of building energy and acoustic performances. Different OVF solutions are installed on the South facing walls of two identical building prototypes and are tested under the same environmental conditions.

In parallel with the monitoring of energy performance, a global study was conducted on the acoustic behavior of the ventilated façade. This document illustrates the iterative method and the different types of measurements carried out *in situ*, in order to refine the forecast calculation model for the evaluation of façade insulation in the case of ventilated façades. The acoustic measurement campaign conducted on the test buildings are shown and commented in relation to the modelling according to the ISO 12354-1,3:2017 standards (1, 2).

Previous literature investigated factors that affect the final sound insulation for ventilated façades and ventilated double-skin façades. Experimental tests (3) were conducted to evaluate different insulation layers to be placed in the cavity and the influence of open joints that characterize ventilated façades. The presence of open joints affects the performance determining a decrease in the single-number rating of the façade sound insulation up to 3 dB. A detailed measurement campaign is presented in Ref. (4), where the influence of the opening of the cavity is tested by measuring, step by step, the sound insulation of the façade as the space of the cavity was varied from hollow to filled, both with open and sealed joints. In the open joints condition, the filling ratio of the cavity has stronger effects on the acoustic behavior of the façade. Other works investigated ventilated double skin façades (5, 6), proposing simple calculation models based upon the determination of the coincidence frequency, the structural resonance frequency, cavity resonances and evaluating the presence of openings.

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2. HIGH-PERFORMANCE ENVELOPE DESIGN

2.1 The test buildings

The twin test buildings are located in San Mauro Pascoli (FC, Italy) and they were completed in February 2019. The building prototypes are tested under the same environmental and weather conditions in order to allow precise comparison between different alternatives: one of the solutions is kept as a benchmark on the first prototype, while all the other solutions alternate on the second prototype. A global view of the two buildings is provided in Figure 1.

The test buildings have a rectangular base (external dimensions 3.4 m x 3.2 m) and are two-story high, for a total external height of about 7 m. The structure of both the prototypes is in Cross Laminated Timber (CLT), with 3-plies 100 mm panels for the vertical elements and 3-plies 120 mm panels for the horizontal partition. A 260 mm EPS thermal coat is applied on the North, East and West walls. The South facing wall, on which the OVF solutions are mounted, is a masonry wall (250 x 300 x 199 mm) with a 100 mm rockwool layer installed on the side of the ventilated façade. The choice of a mixed structure was deemed of interest for the possibility of investigating sound transmission through different structures, given the importance that CLT is gathering as a construction material (7, 8, 9). A roof with an inclination of approximately 5 degrees, provides shading and protection from weather exposure.

In order to investigate the thermal and energy behavior of the OVFs, the South facing façade of the two buildings is equipped with a resident monitoring system that provide a systematic acquisition of the hygro-thermal information. For each envelope, the system includes over 80 resistance temperature detector, 4 anemometers, a pyranometer and an electric energy meter combined with smart device.

Figure 1 – Global view of the twin test buildings (left) and scheme of the realization of buildings (right).

2.2 Ventilated façade solutions

Figure 2 shows a construction detail of the ventilated façade-floor junction. In particular, the buildings are built using a balloon frame system, with continuous vertical walls; the floor is only fixed on two of the four edges and it is not rigidly connected to the brick wall. An aluminum alloy structure (T vertical mullions and L brackets) is directly connected to the brick wall to achieve a 15 cm fixed cavity of ventilated façade.

During the experimentation, the innovative OVF solutions mainly concerned different types of rainscreen in relation to their fastening system (dashed box in Figure 2) and the proportion of open joints. In Table 1 and 2 the different configurations tested are shown with their respective features. Regarding the selection of the significant solutions, the one made of gres tiles with integrated PCM was not considered, due to two main reasons: first, it would be troublesome to simulate the sound reduction index for direct transmission; second the acoustic performance of the entire system is not affected by PCM contribution, as also confirmed by recent literature (10). Finally, it should be noted that the automated shutters (Figure 2) are hermetically closed in all configurations.

2.3 Research method

The two buildings have been object of an extensive measurement campaign: the façade sound insulation measurements were complemented by evaluating the vibration reduction index for all junctions that involve the façade, and by measuring the vibration velocity level of all walls when the sound source was active outside. This paves the way to correlating, in a future work, the contribution in terms of radiated sound power provided by each wall to the overall internal sound field. Part of these measurements are described in the paper and have been used for the implementation of the ISO 12354 model.

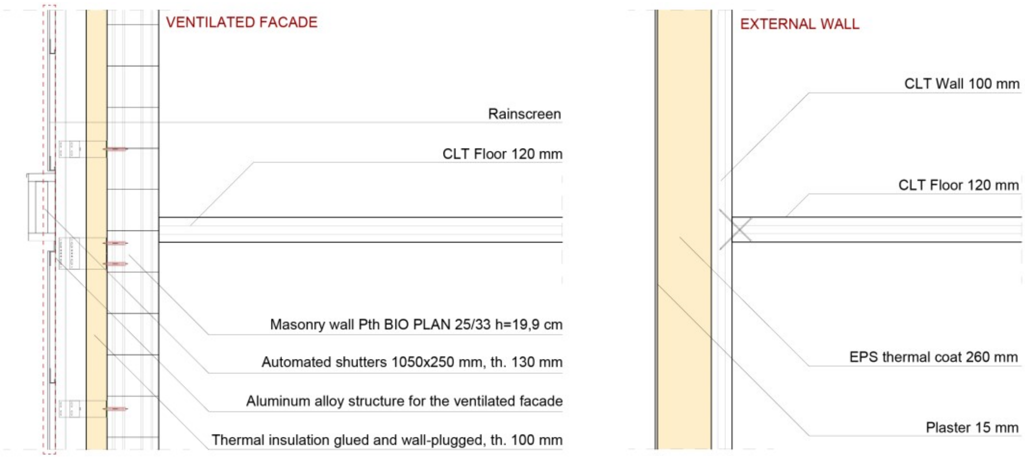

Figure 2 – Construction details: the ventilated façade-floor (left) and external wall-floor junction (right).

Table 1 – Technical and acoustic features of five configurations tested

Conf.	Layers	Total thickness (m)	m'_{wall} (kg/m^2)	$m'_{ext\text{-}tile}$ (kg/m^2)
A	Plastered Masonry	0.26	248	-
B	Plastered masonry + rockwool	0.36	255	-
C	Plastered masonry + rockwool + metal structure + Gres tiles 1200x2400 mm	0.52	255	15
D	Plastered masonry + rockwool + metal structure + HoneyComb/Gres tiles 1200x2400 mm	0.56	255	22
E	Plastered masonry + rockwool + metal structure + Gres standard tiles 600x600 mm	0.57	255	24

Table 2 – Mechanical characteristics of different rainscreen tested

Conf.	Description	Fastening system	Number slabs	Thickness (mm)	Dimensions (mm)	$S_{open\text{-}joints}/S_{façade}$ %
C	Gres tiles	Innovative	4	6.5	1200 x 2400	1.2
D	HoneyComb/Gres tiles	Traditional	4	15 + 6.5	1200 x 2400	2.0
E	Gres standard tiles	Traditional	32	10	600 x 600	3.8

3. THE ISO 12354 MODEL

According to the standard ISO 12354-3 (2), the sound insulation of a façade can be estimated through the apparent sound reduction index R', the influence of the outside shape of the façade ΔL_{fs} (i.e. presence of balconies and similar) and the room dimensions:

$$D_{2m,nT} = R' + \Delta L_{fs} + 10log\left(\frac{V}{6T_0 S_{tot}}\right) \quad \text{(dB)} \tag{1}$$

where V is the volume of the receiving room, S_{tot} is the total area of the façade as seen from inside and ΔL_{fs} is the level difference due to façade shapes, that in our specific case can be assumed equal to 0 dB.

The apparent façade sound insulation R' is given by:

$$R' = -10\log\left(\sum_{i=1}^{n}\tau_{e,i} + \sum_{f=1}^{m}\tau_f\right) \quad \text{(dB)} \tag{2}$$

where $\tau_{e,i}$ is the direct transmission coefficient through all the façade elements, τ_f is the transmission coefficient relative to flanking transmission paths, n is the number of façade elements for direct transmission and m is the number of flanking façade elements. Equation 2 can be reformulated as follows:

$$R' = -10\log\left(\sum_{i=1}^{n}\frac{S_i}{S}10^{-R_i/10} + \sum_{f=1}^{m}10^{-R_{ij}/10}\right) \quad \text{(dB)} \tag{3}$$

where R_i is the sound reduction index for element i of the façade and R_{ij} is the sound reduction index for the flanking transmission as explained in the ISO 12354-1 standard (1).

4. MEASUREMENT CAMPAIGN

4.1 Method

The procedure for measuring of the façade sound insulation on site is described in ISO 16823-3 (11). The standardized level difference is defined as:

$$D_{ls,2m,nT} = D_{ls,2m} + 10log\frac{T}{T_0} \quad \text{(dB)} \tag{5}$$

where $D_{ls,2m}$ is the difference between the sound pressure level $L_{1,2m}$ measured at 2 m from the façade at a height of 1.5 m and the average of the sound pressure level in the receiving environment L_2 (six random positions for measurement), T_0 is the reference reverberation time (0.5 s for dwellings). The reverberation time has been measured according to ISO 3382-2 (12). Using the global loudspeaker method, the source is placed in four different positions on the ground outside the building at a distance D > 3.5 m from the façades with a sound incidence angle equal to 45° ± 5° (Figure 3).

The sound pressure level near the façade depends on several factors, investigated by Hopkins (13). As a rule-of-thumb, for a point source near the ground and façade–receiver distances between 1 and 2 m, the diffraction effects are only likely to be significant in the low-frequency range. As in this case, it occurs for façades with dimensions < 5 m.

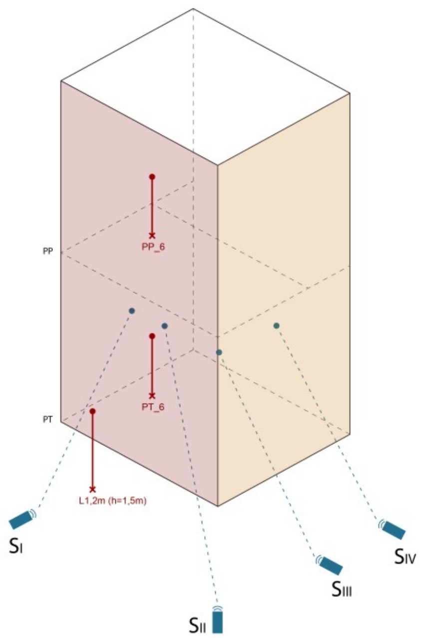

Figure 3 – Scheme of the measurement setup used with indication of the position S_I, S_{II}, S_{III}, S_{IV} sources.

4.2 Results

The source positions analyzed in this paper are S_I and S_{II}, both pointing towards the ventilated façade (Figure 3); the measured façade sound insulation values are shown in Figure 4 in one-third octave bands. Comparing solutions C, D and E with the reference façade A there is general improvement in the overall acoustic performance. Considering equal material and typology of construction solution (Conf. C and D), a larger area of open joints (Conf. E) affects the results up to 5 dB. Moreover, with the same dimensions and similar surface mass of the slabs (Conf. C and D), the fastening system influences the behavior of the façade at most up to 2 dB.

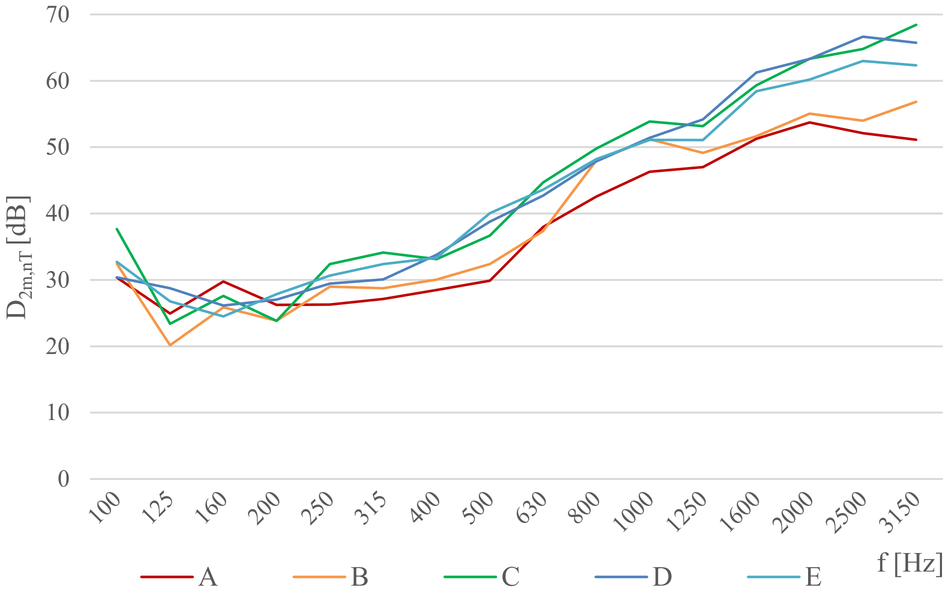

Figure 4 – Standardized sound level difference of façade measured on site in one-third octave bands.

5. MODELLING THE ELEMENTS ACCORDING TO ISO 12354

5.1 Input data

The ISO 12354 model is heavily influenced by the input data; therefore, the building acoustics modelling phase is extremely important for the correct application of the calculation model.

It is recalled that the element i consists of the different configurations of façade shown in Table 1, while the external wall for flanking transmission paths consist of a wall in CLT 100 mm panels with a 260 mm EPS thermal coat. In this case it was not possible to retrieve the input data from laboratory certificates. Therefore, the input data for the apparent sound reduction index R_i of the façade under investigation and the elements of test building involved in the flanking transmission R_j were calculated using a commercial software (14) (Figure 5).

5.2 Flanking transmission

The flanking transmission is generally considered negligible for the façade sound insulation: for the cases in which rigid elements are connected to rigid elements in the receiving room, a reduction of 2 dB is generally deemed acceptable to account for flanking transmission (2). It can anyway be evaluated according to the ISO 12354-1 standard in frequency, calculating the τ_{Ff} and the τ_{Df} transmission paths. In our specific case, only direct-to-flanking transmission paths Df were present; moreover, given the peculiar characteristics of the structure under analysis, only the contribution of the vertical elements enclosing the façade were considered.

The Annex of ISO 12354-1 does not provide indications to estimate flanking transmission in this type of junctions (Figure 2). For this reason, the vibration reduction index K_{ij} of the junctions involving the façade were measured according to the ISO 10848-1 standard (15).

In particular, K_{ij} measurements were conducted in façade configurations with and without the external rainscreen, namely configurations C and B. In Figure 6, it can be noticed that the flanking transmission through the façade-CLT wall joint is not influenced by the presence of rainscreens (orange and green lines). Therefore, they were subsequently adapted according to the structural reverberation time measurements of the involved elements in each configuration. Since the L junction is a junction composed of different and non-homogeneous elements, there is a noticeable difference between the transmission path $D_{v,ij}$ (continuous line), where the i element (masonry wall) is excited, and the transmission path $D_{v,ji}$ (dashed line), where the j element (CLT wall) is excited. For these reasons the calculation model was implemented first neglecting the lateral transmission (called "ISO 12354"), and then using as input data the measured K_{ij} ("ISO 12354_Var. 1"), the measured values of $D_{v,ij}$ only for the path MASONRY-CLT ("ISO 12354_Var. 2"). Finally, the calculation was implemented considering only the R_i of the masonry wall ("ISO 12354_Var. 3") for the i element (façade) in the flanking transmission paths R_{ij}, given the particularity of the façade connection.

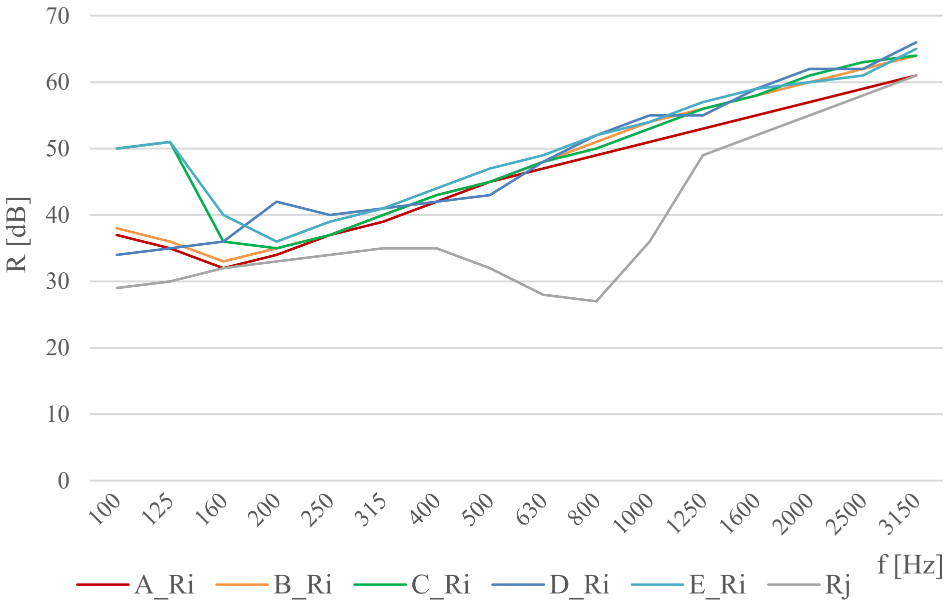

Figure 5 – Input values of the sound reduction index R_i of the different configurations of façade and the sound reduction index R_j of the lateral elements.

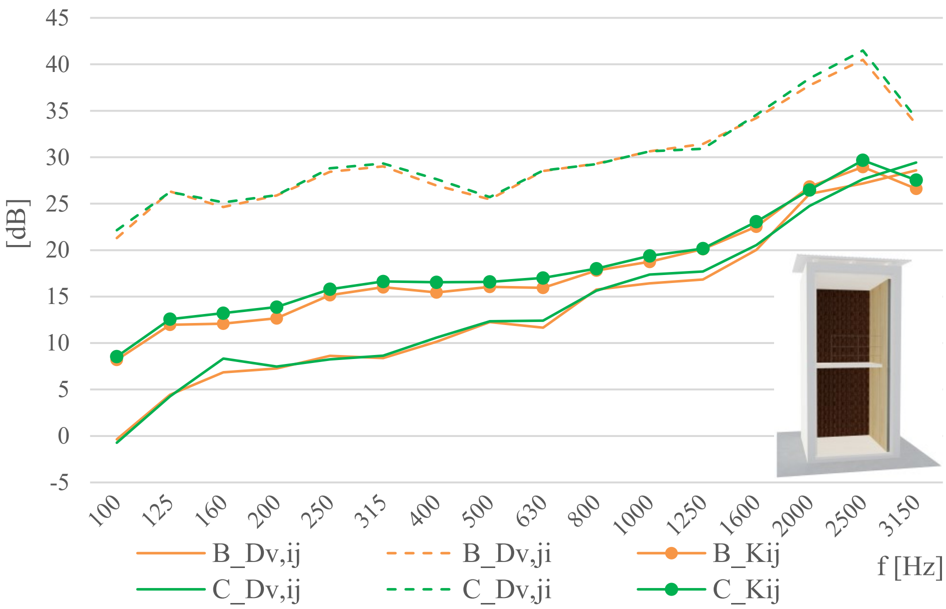

Figure 6 – $D_{v,ij(ji)}$ and K_{ij} for the "L vertical junction" transmission path measured in B and C solutions.

5.3 Results

Figure 7 shows the results obtained implementing the model considering the different above-mentioned variables applied to the same solution (Conf. E). There is a progressive improvement in the medium-low frequency range, reducing the calculation error, as illustrated in ISO 12354. The results can be conveniently discussed in term of comparisons between the standardized level difference of the different façade configurations measured on site and the calculated values implemented considering the model “ISO 12354_Var. 3”, see Figure 8. In general, the ISO model is strongly influenced by the contribution of the direct transmission. For this reason, it can be noticed that having no suitable input data can lead to high errors, especially considering masonry with clay blocks and solution D. The best match between measured and calculated results is observed in Conf. E, i.e. the simplest façade assembly.

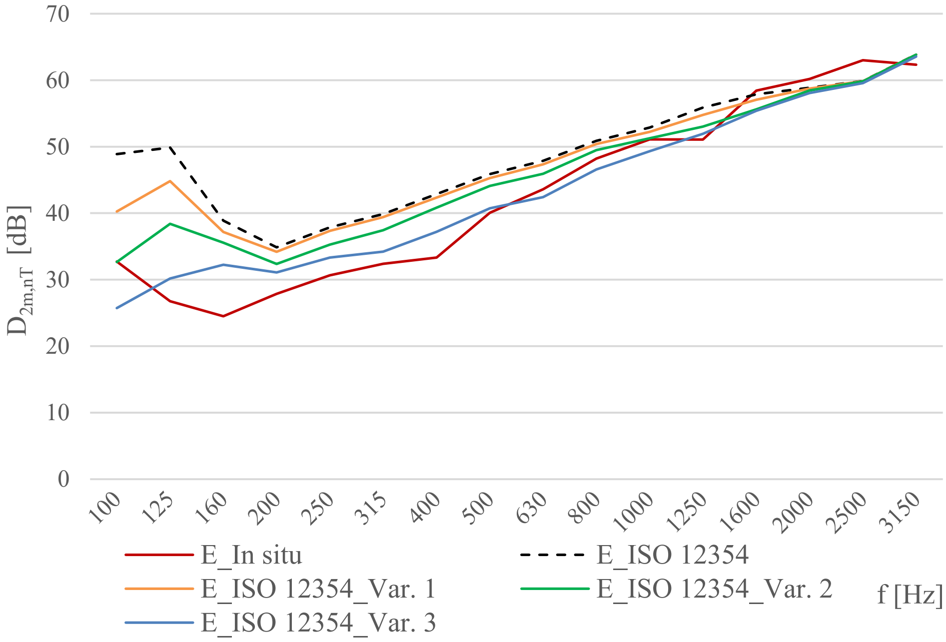

Figure 7 – Difference between measured and calculated values of the standardized sound level difference of E configuration in relation to different variables.

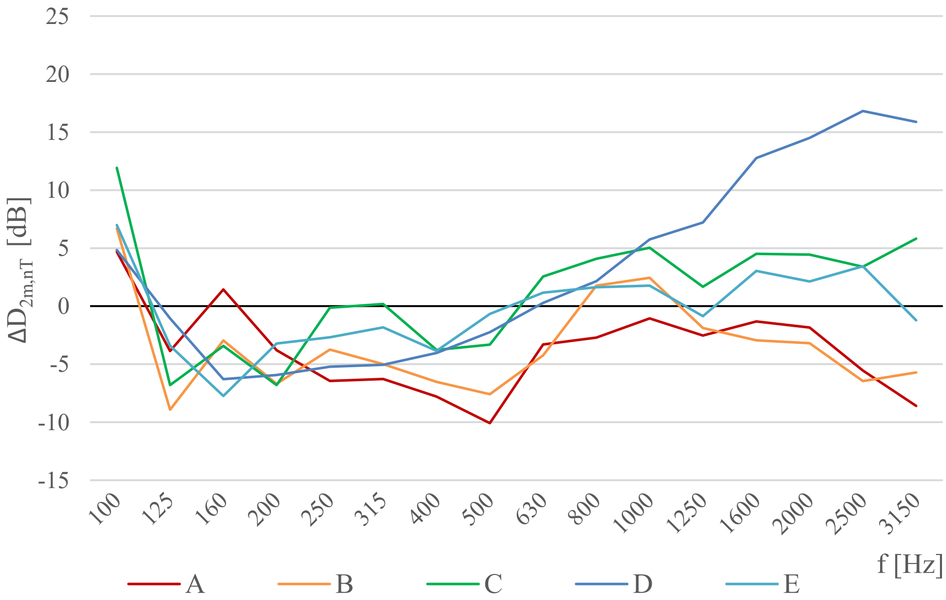

Figure 8 – Difference between measured and calculated values of the standardized sound level difference of the façade considering the model “ISO 12354_Var. 3”.

6. FINAL REMARKS

The paper shows some preliminary results of the study of the acoustic behavior of ventilated façades done during the experimentation of *Progetto Involucro*. This work is focused on the comparison between the measured values of the standardized level difference of façade and the values obtained from the calculation model in according to ISO 12354 standards. The ISO calculation model was implemented using simulated values starting with the physical and mechanical properties of different elements. The flanking transmission was included in the model using the values obtain by the measurement campaign of vibration transmission through the building elements. From the acoustic point of view, the ventilated façade system is particularly complex to be modelled, because the ISO calculation model does not keep into consideration the presence of external layer with open joints. In terms of performance, the ventilated façade has a good performance but is affected by the presence of open joints, possibly openings or by the fact that the metal structure of the façade is rigidly connected to the masonry wall.

In the future work, the analysis will be focused on the lateral elements involved in the flanking transmission paths. In this respect, the results obtained by measurements of the vibration velocity level of walls when the sound source was active outside will be correlated to the overall internal sound field.

ACKNOWLEDGEMENTS

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