Acoustical performance of an innovative dry-wall facade system with high thermal properties

ACOUSTICAL PERFORMANCES OF AN INNOVATIVE DRY-WALL FAÇADE SYSTEM WITH HIGH THERMAL PROPERTIES

Astolfi A., Carpinello S., Pietrafesa C. and Valsesia E.

Department of Energy, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
e-mail: arianna.astolfi@polito.it

Griginis A.

ONLECO S.r.l., Via Pigafetta 3, 10129 Torino, Italy

Prato A. and Schiavi A.

INRIM - National Institute of Metrological Research, Strada delle Cacce 91, 10135 Torino, Italy

De Astis V.

FASSA S.p.a., via Lazzaris 3, 31027 Spresiano, Italy

Zito D.

Fresia Alluminio S.p.a.,Via Venezia 35, 10088 Volpiano, Italy

Cavaleri A.

Nesocell S.r.l.,via Livorno 60, 10144 Torino, Italy

INTESA (INTegrazione ed elevata Efficienza con sistemi a Secco per l'Abitare, Integration and high efficiency with drywall technology for building envelopes) is an innovative solution of a drywall façade embedding electrical, plumbing and HVAC systems, especially designed for residential needs. The INTESA system is usable either for new and retrofit design and is competitive with the traditional wet technology made of clay bricks or blocks. Since the early stage of the project, an integrated approach has been the key element to design the wall system in order to obtain an easy and efficient way of assembling, a perfect integration of the plants, as well as high thermal and acoustical performances. In-field INTESA performances were tested in laboratory and in a real case study through the construction of a prototype building located in Calliano d'Asti, near Turin, where the following acoustical parameters were measured: the apparent sound reduction index (R'), the standardized sound level difference of a façade ($D_{2m,nT}$) and the vibration sound reduction index (K_{ij}), a quantity related to the vibrational power transmission over a junction between structural elements.

1. Introduction

INTESA has been a research project involving different expertise in order to determine a synergy among different technological fields. Two façade and an insulation manufacturers, an HVAC consultant, a consultant in the fields of building physics and a team of researchers participated in the design of the wall system. It raised to address the gradual but deep change the global construction market is experiencing and to meet the growing demand of high-performance solutions. Dry systems are in continuous evolution and they represent a convenient alternative to traditional products, in terms of costs, weight, velocity of assembly and transportation.

2. INTESA wall system

INTESA is a lightweight façade composed by two asymmetric cavities. Its cross section, showed in Fig. 1, is conceived with the aim of improving the thermal and acoustic performances taking into account the best position of the mass and insulating layers, the cavities dimension and the vibrational properties of the studs. It is integrated with the plant system through a false wall that can be installed with a variable gap thickness to host cables and pipes. This layout provides significant benefits if compared to the traditional one: maintenance and inspection are easier and the floor thickness is reduced.

Plasterboard panels with different thicknesses and with air gaps in between activate the mass-spring-mass mechanism, which dissipates acoustic energy. Layers are fixed on innovative transversal hat-profiles, showed in Fig. 2.a, conceived to damp vibrations, further increasing sound insulation. High thermal insulation performance has been obtained through thick layers of cellulose flakes, which were blown-in after the wall installation. The thermal and acoustical behavior of the light wall was further investigated with and without a thin layer of Phase Change Material (PCM), a 5 mm Energain Dupont panel [1].

All the acoustic and thermal bridges were optimized and connection details specifically solved, as can be shown in the plan of the full-scale prototype in Fig. 2.b. In particular, two different types of junction between internal and external walls were designed in order to measure two different values of vibration sound reduction index, K_{ij}, according to the EN ISO 10848-1[2].

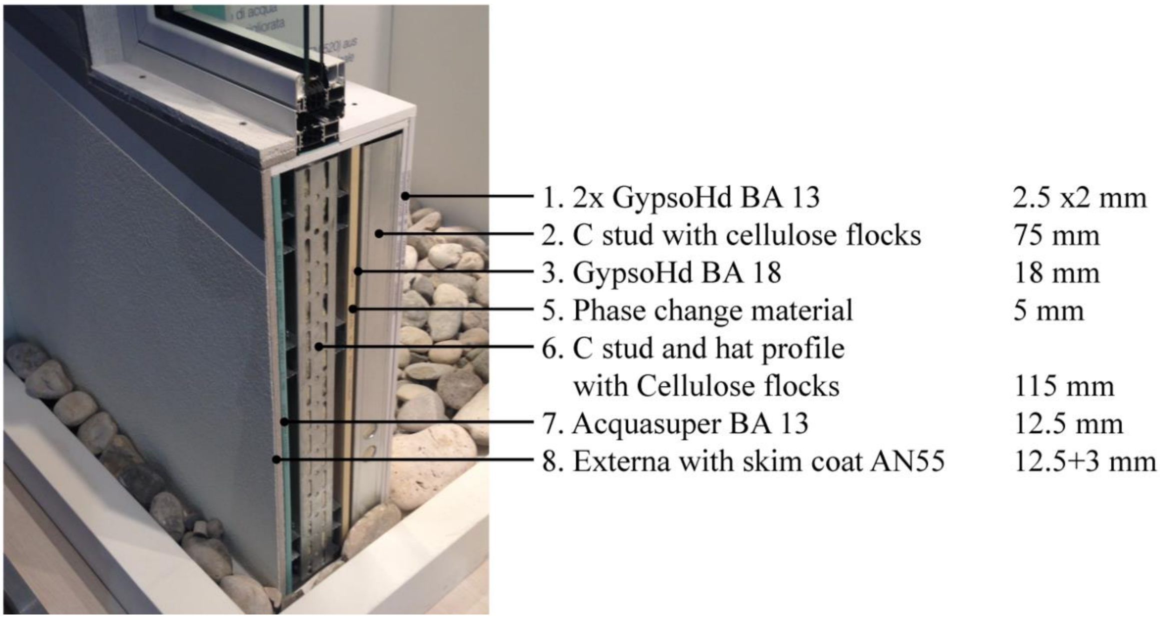

Figure 1. INTESA wall system cross section.

3. Building physics requirements and work methodology for the INTESA system design

The project phase was structured in three main stages: design proposals, laboratory tests on wall components and simulations. In-field measurements were eventually carried out in a full-scale prototype building. At the design stage the first step was to identify the relevant variables determining the envelope performances and to evaluate their relevance and potential influence. The thermal and acoustical performances of the single components were then verified through laboratory tests in order to have data to perform simulations. The target values to be checked in-field were set out on the basis of national and regional legislation, as listed in Table 1.

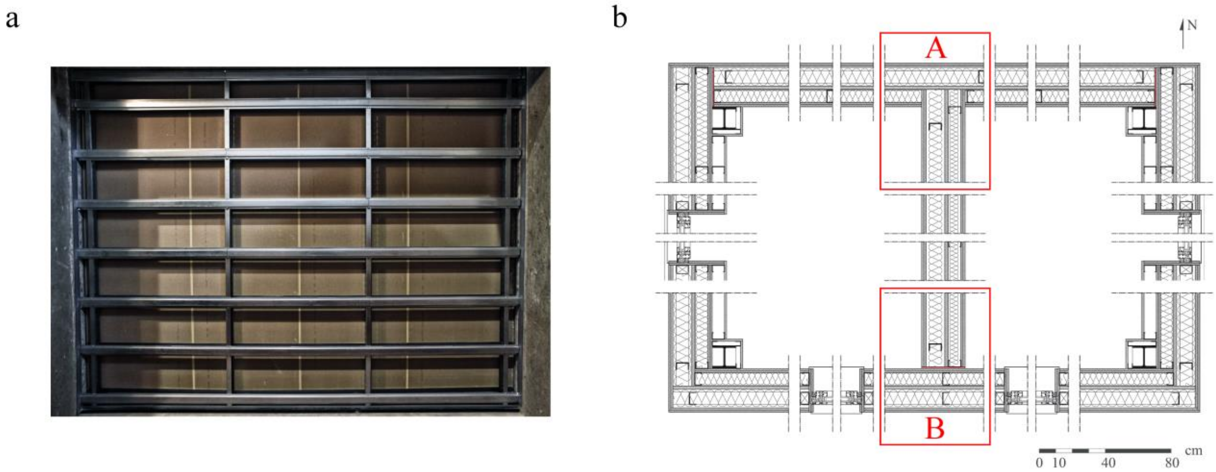

Figure 2. (a) Front view of the INTESA wall aluminium frame; (b) Plan of the prototype, with INTESA used as external and internal wall. Red circles indicate the two different junctions for which K_{ij} measurements were performed. A and B are T-junctions between light walls. In particular, node A is a T-junction with the party wall built in the flanking wall; node B is a T-junction where the party wall is built flush with the flanking wall surface.

Table 1. National and regional legislation limit values verified through in-field measurements.

Parameter	Value	Reference legislation
Thermal trasmittance - opaque vertical envelope, incentive value (U)	≤ 0.25 W/m²K	D.G.R. 4/08/2009, n. 46-11968 [3]
Weighted standardized sound level difference of a façade ($D_{2m,nT,w}$)	≥ 40 dB	D.P.C.M. 5/12/1997 [4]
Weighted apparent sound reduction index (R'_w)	≥ 50 dB	D.P.C.M. 5/12/1997 [4]

3.1 Laboratory measurements

Before the prototype construction, measurements of hygrothermal properties of the wall's layers were performed at the Energy Department of the Politecnico di Torino. INTESA wall was also installed in the laboratory of the National Institute of Metrological Research (INRiM) in Turin, to measure the sound reduction index according to the UNI EN ISO 140-3 Standard [5]. One-third octave band values with and without PCM layer are plotted in Figure 3. The weighted sound reduction index is 68.8 dB and 70.2 dB, respectively, so proving that PCM increased the sound reduction index all throughout the spectrum.

3.2 Simulations

To make a choice about the wall layers position and thickness, iterative acoustical and thermal simulations were done. Solutions were designed and then assessed with all the partners until a balance between energy and acoustic performances versus construction costs, installation and set-up requirements, was reached. Acoustical simulations were performed with INSUL, version 7.0.6, for the sound reduction index in 1/3 octave bands, and SUONUS, version 7.00, to simulate the acoustical properties in-field, i.e. the standardized sound level difference of the façade and the apparent sound reduction index of the partition wall, related to the prototype building.

As example of comparison between measurements in laboratory and simulated values, Fig. 3 shows the one-third octave band sound reduction index of INTESA wall, as obtained from measurements at INRiM and from INSUL v. 7.0.6. A good agreement between the two sets of data is shown, with higher performances at the highest frequency range in the case of measurements.

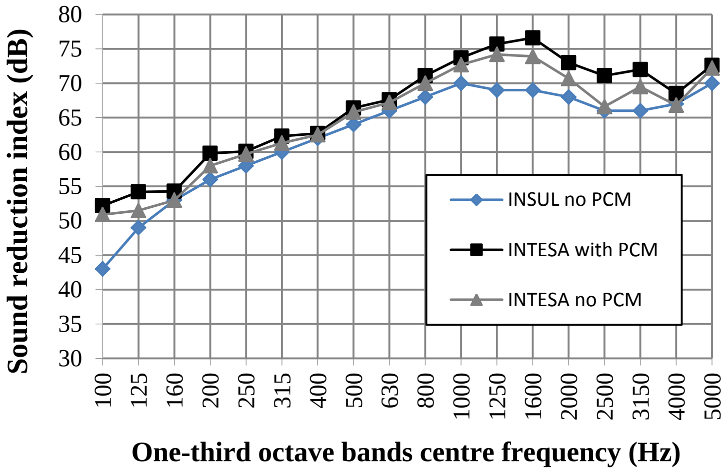

Figure 3. Comparison among one-third octave band sound reduction index of INTESA wall: laboratory measurements with and without PCM and simulation with INSUL v. 7.0.6.

4. In-field measurements

The prototype has been conceived to reproduce all the project details defined at the design stage, as shown in Fig. 2. It was built in Calliano d'Asti (AT) far from noisy streets and other noise sources. It is a double-room building made of a light steel structure with concrete slabs. It lays on supports which create a gap between the base and the ground. Each room has a bare façade facing north, to be used as the testing wall for the thermal measurements, avoiding the presence of direct solar radiation on sensors. The façades facing south have a glazed portion made of an aluminum frame Planet NEO 72 and a double laminated glass sized 44.2/15/33.2 (Fig. 4). The prototype is located far from other buildings to avoid that they can cast shadows on it. Two different external envelopes were set, one provided with a PCM layer (room A in Fig. 4.a), while the other without (room B in Fig. 4.a). The internal partition wall is without PCM layer and the exterior layers (n. 7 and 8 in Fig. 1) were substituted by a double GypsoHD BA 13 (n. 1 in Fig. 1). To avoid vibration interferences from the trucks passing nearby, a resilient layer made of elastic polyurethane 50 mm thick was placed at the base of the metal structure, as shown in Fig. 5.a. Elastic polyurethane layers, 25 mm thick, were also laid to decouple the junctions between external and internal walls needed for vibration reduction index measurement, K_{ij}, as shown in Fig. 5.

Table 3 lists the reference standards used for in-field measurements. As far as the apparent sound reduction index of the separating wall w5 is concerned, two methods have been adopted: the standard method according to the ISO 140-5 [6] (Fig. 6.a) and the sound intensity method, following the

EN ISO 15186-2 [7]. In the last case, measurements were carried out both on the whole wall and the half wall, close to the T-junction (type A), with the aim to exclude the acoustical bridge of the other T-junction (type B).

The K_{ij} values in one-third octave bands for the two types of T-junctions between light walls were measured according to the protocol described in the EN ISO 10848-1 [2] Standard and in Schiavi and Astolfi (2010) [8]. The measurement was performed with the impulse-response technique where the walls were excited with a hammer (direct transient method). The impulsive signal is generated using a plastic-headed and a soft rubber-headed hammer in order to obtain different kinds of excitations in different frequency bands (Fig. 6.b).

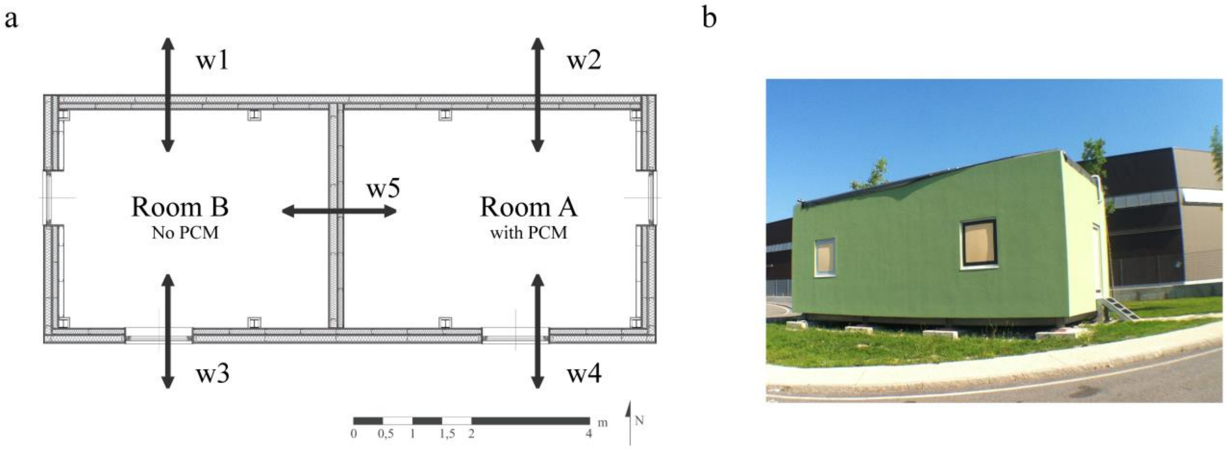

Figure 4. (a) Prototype plan showing reference walls tested for acoustic properties; (b) Picture of the prototype during the summer test.

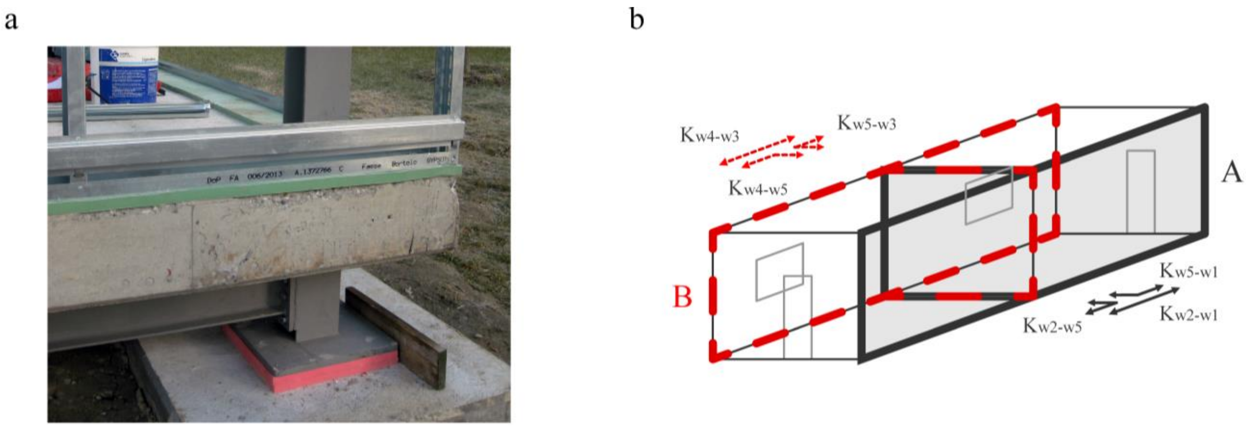

Figure 5. (a) The resilient layer of the base structure; in green the decoupling resilient layer for the wall; (b) Axonometric scheme showing the decoupled walls for K_{ij} measurements (T-junctions A in black and B in red), that were carried out both for the transmission around the corners and along the flanking walls.

5. Acoustic results

Table 3 shows the in-field measurements results. All the measured values satisfy the Italian legislation limit requirements reported in Table 1. Results show that the PCM layer does not give a significant contribution in field, while in laboratory a better performance compared to the case without PCM was obtained in the case of sound reduction index.

Results concerning the weighted apparent sound reduction index obtained with the traditional method and the method based on sound intensity are discordant, as expected. The weighted apparent intensity sound reduction index differs fundamentally from the weighted apparent sound reduction index of EN ISO 140-4 [9] where total sound power from all receiving sources is measured. The definition of the apparent intensity sound reduction index allows directionality of the intensity probe to be used, to selectively measure the sound power from each receiving room surface as desired [7].

Table 2. In-field measurement results. Measured values satisfy the Italian legislation limit requirements.

Measure	Room A (PCM) or B (no PCM)	Figure 4.a reference	Value	Reference standard
Weighted standardized sound level difference of the façade ($D_{2m,nT,w}$)	A	w2	58 dB (-2;-5)	EN ISO 140-5 [6]
Weighted standardized sound level difference of the façade ($D_{2m,nT,w}$)	A	w4	48 dB (-1;-4)	EN ISO 140-5 [6]
Thermal transmittance (U)	A	w2	0.19 W/m^2K	ISO 9869-1 [10]
Weighted apparent sound reduction index (R'_w)	A-B	w5	55 dB (-2;-4)	EN ISO 140-4 [9]
Weighted apparent intensity sound reduction index (R'_w) for entire wall	A-B	w5	60 dB (-2;-4)	EN ISO 15186-2 [7]
Weighted apparent intensity sound reduction index for half wall (R'_w)	A-B	w5	65 dB (-2;-4)	EN ISO 15186-2 [7]
Weighted standardized sound level difference of the façade ($D_{2m,nT,w}$)	B	w1	58 dB (-2;-6)	EN ISO 140-5 [6]
Weighted standardized sound level difference of the façade ($D_{2m,nT,w}$)	B	w3	48 (-1;-4)	EN ISO 140-5 [6]
Thermal transmittance (U)	B	w1	0.21 W/m^2K	ISO 9869-1 [10]

a b

Figure 6. In-situ acoustical measurements. (a) Standardized sound level difference of the façade; (b) Excitation of the test elements for K_{ij} measurements with an impulsive signal generated using a plastic-headed and a soft rubber-headed hammer. The accelerometers are fixed to the test elements using thin biadhesive strips.

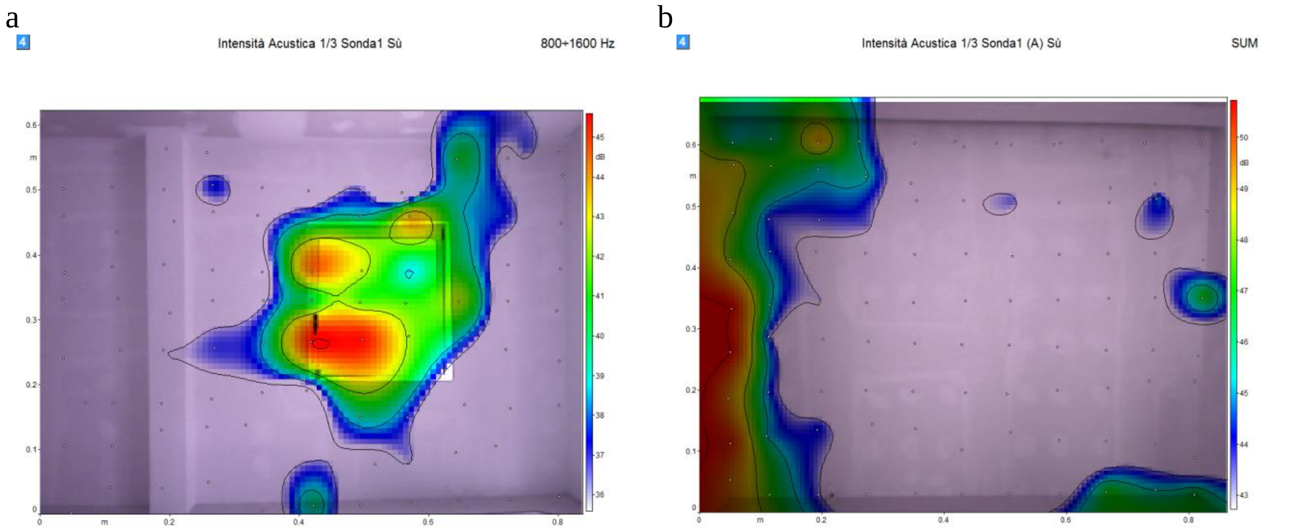

Figure 7. In-situ acoustical measurements. Sound intensity maps for the external wall w3 (a) and for the separating wall w5 (b).

Figure 7 shows the sound intensity maps for the external wall w3, where the acoustic bridge due to the window frame is shown, and for the separating wall w5, where the acoustic bridge due to the T-junction of type B can be easily seen.

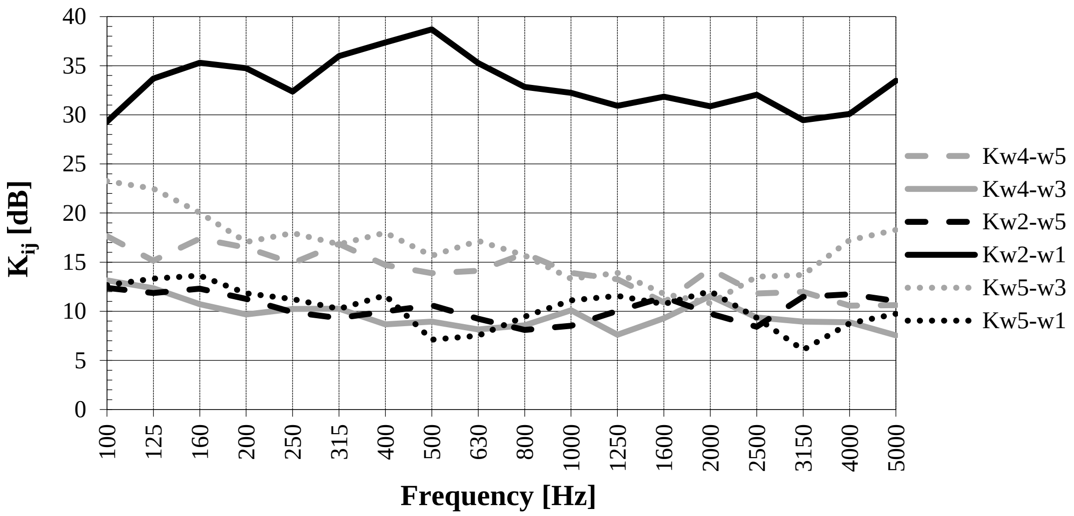

Figure 8. K_{ij} values related to the different transmission paths outlined in Figure 4.

Figure 8 shows the K_{ij} values related to the different transmission paths outlined in Figure 5. The measured values are in good agreement with the empirical values reported in the EN 12354-1 [11] Standard, which take into consideration the mass per unit area of the elements connected to the junction and the junction typology, but not the junction geometry. According to the Standard, for junctions of lightweight coupled double leaf walls, when the masses of the walls are equal, K_{ij} value is 10 dB, both in the case of transmission path around the corner between flanking wall and party wall and in the case of transmission path along the flanking wall. For this last transmission path, higher differences in measured values compared to calculated ones are observed when the party wall is checked into the flanking wall (T-junction of type A in Fig. 2). In this case (path K_{w2-w1}) the measured values of vibration sound reduction index are between 30 and 35 dB, compared to 10 dB obtained for the corresponding path (K_{w4-w3}) when the party wall is built flush onto the surface of the flanking wall (T-junction of type B in Fig. 2). In the case of transmission path around the corner, higher values of about 5 dB are shown when the party wall is built flush onto the surface of the flanking wall (K_{w5-w3} and K_{w4-w5} vs K_{w5-w1} and K_{w2-w5}).

6. Conclusions

INTESA innovative light façade system owns the characteristics to meet legislation requirements, as can be seen in Table 3, and to face the expansion market demand for high standard housing which implies high thermal and noise insulation levels.

Acknowledgements

The research was developed in the framework of the POLIGHT project funded by Regione Piemonte, within the P.O.R.-F.E.S.R. 2007/2013 program, in cooperation with the Department of Energy of Politecnico di Torino, Fassa Bortolo s.p.a., Fresia Alluminio s.p.a., Nesocell s.r.l., Onleco s.r.l. and Tec-imp s.r.l. Particular thanks are extended to SPECTRA s.r.l., Via Belvedere 42, 20862 Arcore (MB) for the sound intensity measurements with their analyzer SOUNDBOOK™ and the sound intensity mapping option.

REFERENCES

1 Wang, J., Long, E., Qin, W., Xu, L. Ultrathin envelope thermal performance improvement of prefab house by integrating with phase change material (2013) *Energy and Buildings*, **67**, pp. 210-216.
2 ISO 10848-1. Acoustics – Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms -- Part 1: Frame document.
3 Deliberazione della Giunta Regionale 4 agosto 2009, n.46-11968, Aggiornamento del Piano regionale per il risanamento e la tutela della qualità dell'aria - Stralcio di piano per il riscaldamento ambientale e il condizionamento e disposizioni attuative in materia di rendimento energetico nell'edilizia ai sensi dell'articolo 21, comma 1, lettere a) b) e q) della legge regionale 28 maggio 2007, n. 13 "Disposizioni in materia di rendimento energetico nell'edilizia".
4 Decreto del Presidente del Consiglio dei ministri 5 dicembre 197. Determinazione dei requisiti acustici passivi degli edifici.
5 EN ISO 140-3:1995. Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 3: Laboratory measurements of airborne sound insulation of building elements.
6 ISO 140-5:1998. Acoustics -- Measurement of sound insulation in buildings and of building elements — Part 5: Field measurements of airborne sound insulation of façade elements and façades.
7 EN ISO 15186-2:2010. Acoustics — Measurement of sound insulation in buildings and of building elements using sound intensity — Part 2: Field measurements.
8 A. Schiavi, A. Astolfi, The Prediction of the Vibration Reduction Index K_{ij} for Brick and Concrete Rigid Junctions, *Applied Acoustics*, **71** (6), 523-530, (2010).
9 EN ISO 140-4:1998. Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 4: Field measurements of airborne sound insulation between rooms.
10 ISO 9869-1:2014. Thermal insulation —Building elements — In-situ measurement of thermal resistance and thermal transmittance — Part 1: Heat flow meter method.
11 EN 12354-1:2000, Building Acoustics — Estimation of acoustic performance of buildings from the performance of elements — Part 1 : Airborne sound insulation between rooms.