Covert Pilot Spoofing Attack via Active Reconfigurable Intelligent Surface

Sound Insulation characterisation of innovative natural ventilated façade in the context of Living Lab installations

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ABSTRACT

Building acoustic standards like EN 14351 and ISO 10140 regulate the measurement of sound insulation of transparent elements, with indications of the test sample dimensions, test conditions, and criteria of adaptations of the results to different on-site conditions. However, given the research on innovative transparent building envelope including internal ventilation as double skin facades, these methodologies present limitations related to the characterization of the high variability of operating conditions in real in-field conditions. To this aim the acoustic performance could be explored with more flexible methods inside the multi-domain context of Living Labs, which present an opportunity for multiple characterizations and testing costs reduction. This work investigates the possibility of using the sound-intensity probe method to evaluate the airborne sound insulation of a transparent building element with internal ventilation. For this purpose, a comparative measurement campaign has been performed on the same building element installed in two Living Labs. The results show good compatibility between the different measurements and scales supporting the application of this methodology for comparative studies in the perspective of innovative building components measurements, and the application in Living Labs.

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1. INTRODUCTION

Building acoustic standards like EN 14351-1 [1] and ISO 10140 [2] regulate the measurement of sound insulation of transparent elements, with indications of the test sample dimensions, test conditions, and criteria of adaptations of the results to different on-site conditions. However, given the research on innovative transparent building envelope including internal ventilation as double skin facades [3], these methodologies present limitations related to the characterization of the high variability of operating conditions in real in-field conditions. To this aim the acoustic performance could be explored with more flexible methods inside the multi-domain context of Living Labs [4], which present an opportunity for multiple characterizations and testing costs reduction. The use of the sound-intensity probe method according to ISO 15186-2 [5] could be a suitable approach. Therefore, this work aims to investigate the variability of the measured data of the same ventilated window module installed in two different Living Labs.

The use of the sound-intensity probe method for building elements transmission loss measurement, and associated error analysis and comparison with other techniques, is well established and documented [6-8]. In all these studies, the flanking transmission, which is inevitable for in-situ measurements, is considered a critical aspect that can significantly affect the accuracy Transmission Loss (TL) measurements. Significant amounts of absorption are suggested to be placed in the receiving room to control the resulting reverberant field. It follows that, as the intensity technique is relatively insensitive to field conditions (compared to standardized methods using sound pressure) [9,10], it is particularly useful in identifying the relative transmission characteristics of the various components in the building façade. However, there is little research on the use of the intensity methods for in-field façades characterizations. This might be due to the complexity of the set-up positioning and conditions required for its implementation (e.g. the distance between the sound intensity probe and the measurement surface and the number of measurement points), which would result in significant limits of application in real conditions. However, automatized systems have been successfully explored in laboratories and could be potentially integrated into the infrastructure of the Living Labs [9].

This work investigates the possibility of using the sound-intensity probe method (ISO15186-2) to evaluate the airborne sound insulation of a transparent building element that can be operated also considering advanced features, such as fan-assisted cavity ventilation. For this purpose, a comparative measurement campaign has been performed on the same building element installed in two Living Labs at Politecnico di Torino (Torino, Italy) and at the Norwegian University of Science and Technology (Trondheim, Norway). Three different operating conditions of the ventilated window have been tested.

2. Methodology

Two different measurements campaigns have been performed by using a sound intensity probe based on ISO 15186-2.

2.1. Test Case Description

The Test Case (TC) on which the different measurement methods are compared is a Triple Glazing Unit (TGU) within a PVC frame, which can be operated including some advanced features aimed at improving energy efficiency and occupant thermal comfort and indoor air quality.

In particular the outer cavity of the TGU can be activated by means of electrical fans, with an airflow path from the outside (with an outer bottom vent integrated into the framing system) to the inside (with an inner top vent integrated into the framing system) in order to provide the indoor environment with primary ventilation air at a temperature level closer to the indoor required temperature, in heating dominated conditions (Supply Air, SA, operation mode). In cooling dominated conditions instead the TGU outer cavity ventilation is used with an airflow path from the outside to the outside (with an outer top vent integrated into the framing system), to reduce the g-value (total solar energy transmittance) of the TGU by removing unwanted solar gains absorbed within the glass layers (Outdoor Air Curtain, OAC, operation mode), while primary ventilation is provided by a fan-assisted vents bypass within the top part of the framing system. Figure 1 shows a schematic of the test case and its operational modes: 1) supply air (SA) mode, 2) outdoor air curtain (OAC) mode, and 3) thermal buffer (TB) mode.

In order to reduce the differences between the air temperature entering the room through the glazing ventilation and the thermal comfort conditions inside the building, the air from the glazing ventilation is conveyed to a PCM to Air heat exchangers, before being delivered to the indoor environment.

Finally, the TGU can also be used as a conventional TGU, in conditions in which solar radiation is not very high and in which ventilation is not needed, by switching off the fans and closing all the vents included in the system. The TGU has a 30 mm outer air cavity, and a 16 mm inner 90% Argon filled cavity, including 4 and 6 mm monolithic glass panes, integrating omniphobic, lowE and selective glass coatings on different surfaces.

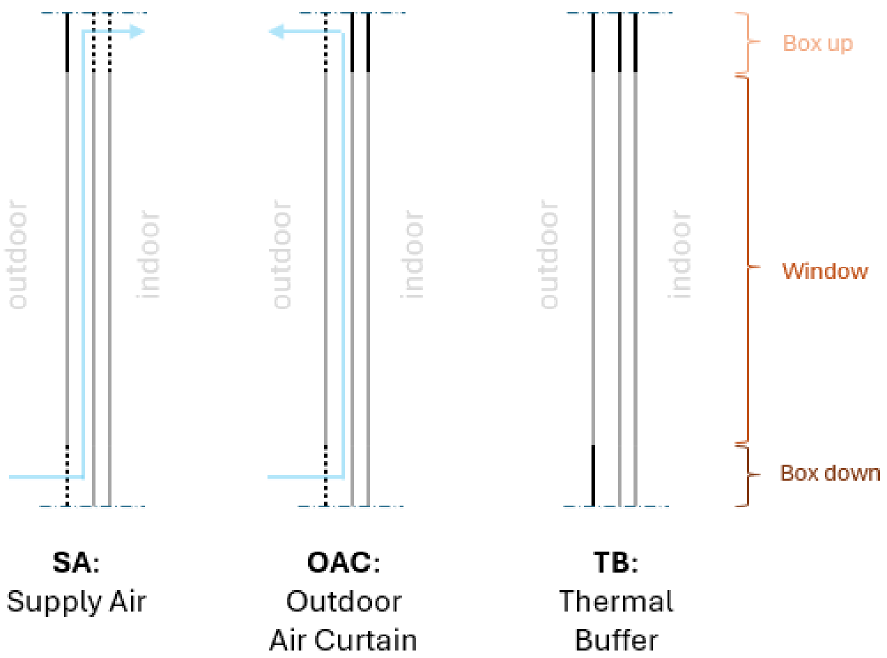

Figure 1: Simplified schemes of the Test Case operation modes: 1) supply air (SA) mode, 2) outdoor air curtain (OAC) mode, and 3) thermal buffer (TB) mode.

2.2. Living Labs

Two different modules of the TC have been installed on the South oriented vertical façade in a Living Lab at Politecnico di Torino (Torino, Italy) and at the Norwegian University of Science and Technology (Trondheim, Norway). Figure 2 shows the TC in both building facades, together with the acoustic measurement grid adopted (size of the mesh detailed below). The Torino LL is a single office room of approximately 10 m^2 floor area within a larger building, with similar rooms on the 4 sides. The Trondheim LL is an independent 1-story timber house of approximately 60 m^2 internal floor area, on a concrete basement.

Both TCs are mounted as infill panels of a curtain wall system (with mullion and transoms connected to the opaque constructions of the living lab). Nevertheless, for the Torino LL this timber CW system is surrounded on the 4 sides by a masonry cavity wall within a concrete frame structure on the first floor of a 4-story and basement building, and the TC Prototype is surrounded by heavy weight concrete infill panels on the two vertical sides. While for the Trondheim LL the aluminum CW system is surrounded on the 4 sides by lightweight timber construction with mineral wool insulation in a 1-story timber frame building, and the TC prototype is surrounded by lightweight glass infill panels on the two vertical sides.

The dimensions of the two modules are detailed in Table 1.

a) b)

Figure 2: Living Lab at a) Politecnico di Torino POLITO (Torino, Italy) and b) Norwegian University of Science and Technology NTNU (Trondheim, Norway).

2.3. Measurements

All the measurements have been performed according to ISO 15186-2, which specifies a sound intensity method to determine the in-situ sound insulation of walls, floors, doors, windows and small building elements. It is intended for measurements that have to be made in the presence of flanking transmission. In general, the building element under test is considered as part of a series of building elements separating two rooms: the source and the receiving rooms. Given that the building element is part of the building façade the source room was considered the indoor environment of the LLs and the outdoor environment was considered as the receiving room. This was also in line with the requirements of a highly absorptive receiving and a more reverberant source room. Moreover, the room volume of the receiving room is not overly important, while a large source room is recommended to improve the accuracy of the intensity sound reduction index in the low frequencies. Two different source room volumes characterize the source rooms in the two LLs as shown in Table 1. Moreover, in both laboratories the room diffusion was improved by the presence of randomly located reflecting objects which are considered beneficial in achieving a uniform sound field in the source room.

The set-up consisted of a sound intensity probe B&K Type 3654, which includes the ½" sound intensity microphone pair Type 4197 for 1/3 octave center frequency measurements between 20-6300 Hz. A sound source (Norsonic Nor276 in NTNU, B&K Omnipower 4296 in POLITO) has been introduced inside the lab and located at one of the corners. A white noise signal has been generated in the 40-8000 Hz frequency range. The set-up allows to perform accurate measurements over the 100-5000 Hz range as required by ISO 15186-2. The sound pressure level (SPL) and the background noise have been measured with an NTI XL2 SPL meter. Temperature and relative humidity data have been monitored throughout the measurement campaigns.

Table 1: Summary of the conditions tested in the two Living Labs.

Description	**LL POLITO**	**LL NTNU**
TC dimensions boxup HxL (m)	0.28x1.00	0.28x1.24
TC dimensions window HxL (m)	1.30x1.00	1.20x1.24
TC dimensions boxdown HxL (m)	0.28x1.00	0.28x1.24
Reverberation Time $T_{20,\ 500\text{-}1000Hz}$ (s)	0.73±0.03	0.71±0.06
Sound source type	B&K Omnipower 4296	Norsonic Nor276
Global Sound pressure level (dB)	104.2	107.5
Background noise (dB)	49.5	61.4
Grid sub-areas (m)	0.20x0.20	0.20x0.20
Number of sub-areas	79	96
Temperature (C°)/ Relative Humidity (%) Atmospheric pressure (Pa)	15.7 66 990.9	4.6 73 972.6

The test procedure consisted of measuring the average sound pressure level in the source room, L_{p1}, and the average sound intensity level on a measurement surface over the façade, L_{In}. On the receiving side, a measurement surface has been defined in order to totally enclose the building element under test. For practicality, the surface subdivided into several smaller sub-areas (0.2x0.2 m). As suggested in the ISO, also a measurement distance of 0.2 m has been used. The procedure for discrete positions with a duration of 10 s each has been applied for all the configurations since it was easier to manage given the extended area of the building element.

Both the sound pressure level and the sound intensity level were at least 10 dB higher (Table 1) than the background sound pressure level as required by ISO 15186-2.

The equation based on ISO15186-2 has been used to evaluate the Apparent Intensity Sound Reduction Index, R'_I:

$$R'_I = \left[L_{p1} - 6 + 10\log\left(\frac{S}{S_0}\right)\right] - \left[\bar{L}_{I_n} + 10\log\left(\frac{S_M}{S_0}\right)\right] \quad (1)$$

where L_{p1} is the average sound pressure level in the source room, L_{In} is the average intensity level in the receiving room (outdoor, in this case), S_m is the total area of the measurement surface, S is the area of the separating building element under test, S_0 is a reference area of 1 m^2.

Figure 3 shows a comparison of the L_{p1} values over different measurement positions in both a) POLITO and B) NTNU LLs in five and six measurement positions, respectively. The data show little variability over the measurement area indicating a good diffusivity of the space. As shown in Table 1, the two source rooms have compatible values of reverberation time. However, below 400 Hz the two LLs show some significant differences that might be due to the source and material/geometrical characteristics of the two source rooms.

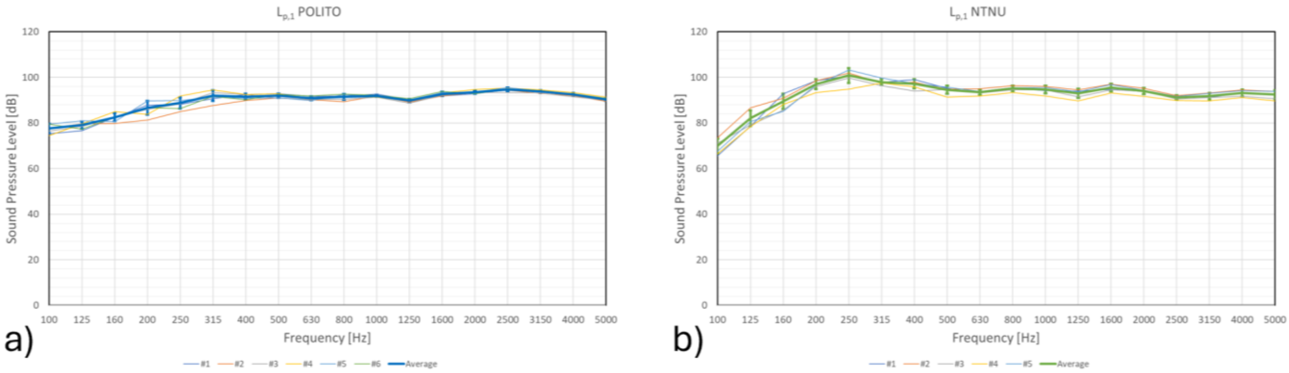

Figure 3: Living Lab L_{p1}measured values for 1/3 octave band at a) Politecnico di Torino POLITO (Italy) and b) Norwegian University of Science and Technology NTNU (Norway).

3. RESULTS AND DISCUSSION

The results of the apparent Intensity Sound Reduction index have been reported in Figure 4 for the upper box, the window and the lower box. It can be noticed that over the frequency range, the data are distributed between 15-45 dB.

There is a larger variability between the two LLs for the upper box showing lower values for the POLITO LL for the three tested configurations. This might be due to the possible differences between the mounting conditions in the two labs. However, the two LLs data show a similar trend with compatible results for SA and TB modes, and lower values for the OAC mode. This is due to the inlet and outlet opening conditions and suggests that the shifted opening SA would allow for a similar performance as the closed condition in TB. It also suggests that only the outer boundary layer (outer vent) of the box contributes to the sound insulation while the inner components have little effect on R'_I.

There is a limited variability between the two LLs for the window showing lower values for the POLITO LL for the OAC configuration above 400 Hz. This might be due to the possible differences between the mounting conditions in the two labs. However, the two LLs data show a similar trend with compatible results for SA and TB modes. This suggests that the window performance area is less sensitive to the shifted openings in SA when compared to the closed conditions (TB). In both cases, the triple glass layers contribute to the sound insulation performance.

There is a significant variability between the two LLs for the lower box showing lower values for the POLITO LL for the SA and OAC configurations in the range 200-630 Hz and above 4000 Hz. The data show a good compatibility in the 800-3150 Hz frequency range. The TB condition outperforms the other two in the POLITO lab, while it results similar to the OAC and SA above 630 Hz. This might be due to the effects of the mounting conditions in the two LLs lower boxes and effects of the cable glands used for other sensors. The application of these sensors is rather different in the two labs and the NTNU LL it affects the performance of the outer boundary layer leading to a performance of the TB similar to the SA and OAC which have an open outer vent.

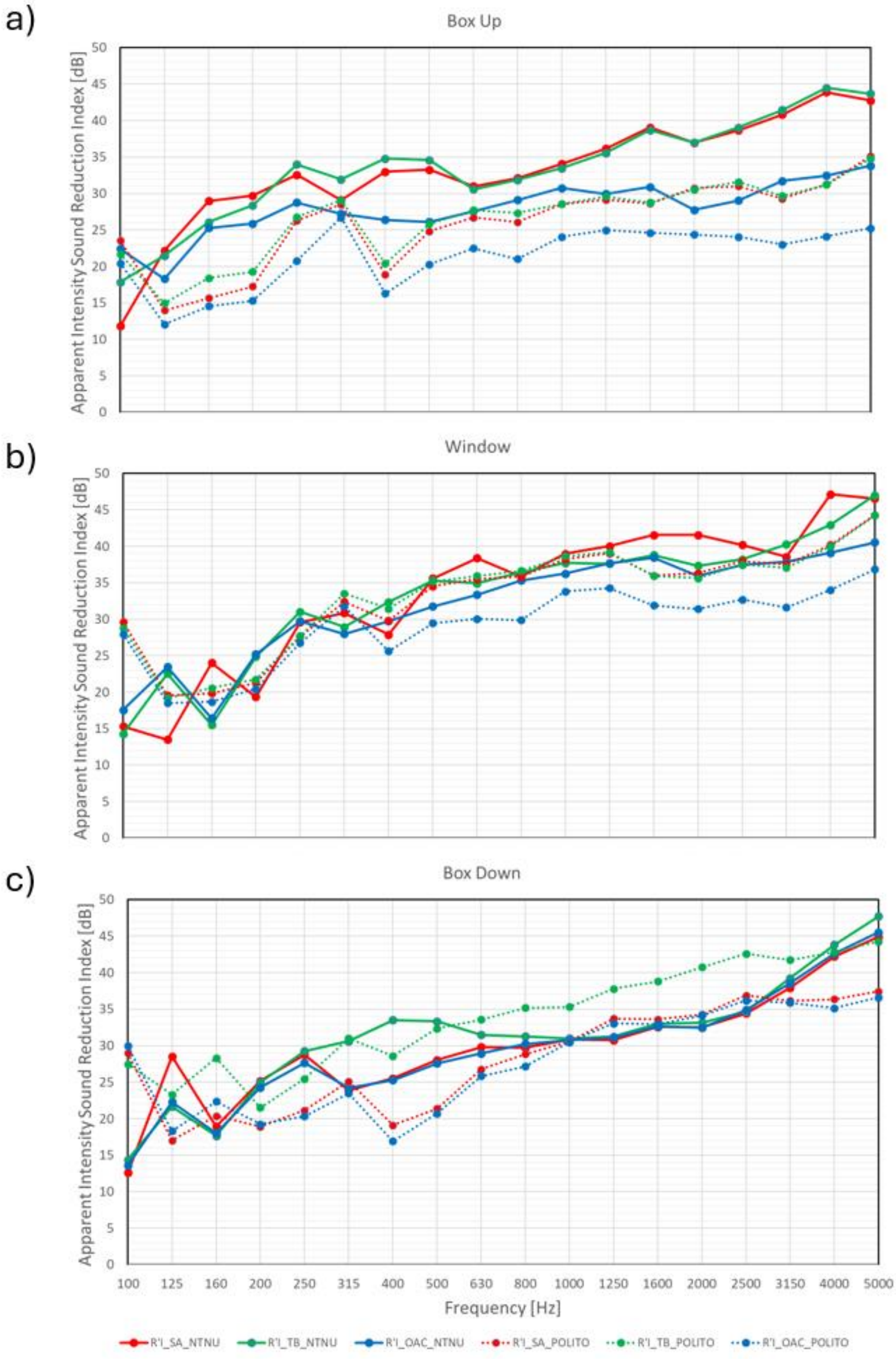

Figure 4: Living Lab Apparent Intensity Sound Reduction Index (R'$_I$) measured values for 1/3 octave band for each part of the building element a) Box up, b) Window and c) Box down

4. FINAL COMMENTS AND CONCLUSIONS

This work has presented an investigation on the possibility of using the sound-intensity probe method (ISO15186-2) to evaluate the airborne sound insulation of a transparent building element with internal ventilation. For this purpose, a comparative measurement campaign has been shown for the same building element installed in two Living Labs at Politecnico di Torino (Torino, Italy) and at the Norwegian University of Science and Technology

(Trondheim, Norway). Three different operating conditions of the ventilated window have been tested.

In general, the results of the comparisons showed less variability for the window part of the building element and higher differences for the upper and lower boxes. This might be due to the differences in the mounting conditions of these smaller parts. The application of other sensors and the need to do perforations of the building component have a significant effect on the acoustic performance. It is crucial then to consider this aspect when integrating the façade test cases in the Living Lab.

It can be concluded that the intensity-based methods potentially could be used for Living Lab characterizations providing useful relative comparisons between configurations. However, more care should be put into the mounting conditions since it affects the reproducibility of sound insulation performance.

Further investigations could be made to manage a comparative measurement campaign on the ventilated window presented here in a standard building acoustic laboratory comparing the pressure-based methods and the sound intensity probe method.

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