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COMPARISON AMONG METHODS TO MEASURE THE SOUND INSULATION OF BUILDING FAÇADES

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ABSTRACT

The increasing attention for building insulation regulations asks for reliable protocols of measure. The need to review available procedures is leading to the revision of the standards ISO 140 which will be replaced by the standards ISO 16283. This paper aims to contribute to this revision process by comparing measurement methods for the sound insulation of building façades through an investigation of limits of measurement systems. The paper compares the standards ISO 140-5, the American ASTM E 966 and the Japanese JIS A 1430. Among others aspects, their suggested frequency intervals are compared together with differences evaluating from 100 Hz to 3.15 kHz (as proposed in the ISO 140-5) or in other frequency ranges. Moreover, the limits of the measurements at low frequencies are investigated as the ISO 16283 would like to extend the measurement to one-third octave bands with the centre frequencies at 50, 63 and 80 Hz. The measurement procedures of the SPL at such a low frequency are analyzed both inside and outside the building. Finally, limits of sound insulation measurements for irregular or unconventional rooms are considered.

Keywords: Sound insulation, Low frequency measurements, Building Façades.

1 Introduction

Regulatory requirements for airborne sound insulation are usually specified in terms of single numbers. These are often calculated from spectra in the frequency range between 100 Hz and 3.15 kHz. This range is suitable to assess the sound insulation with sound sources such as speech. Given the stability of instrument responses at middle frequencies, the above range was proposed in the standards ISO 140 and it is currently used worldwide. However, an increased attention for low frequency measurements has been recorded recently. Modern hi-fi, computer audio systems, urban noises and home cinema equipments more and more have a significant sound power output at frequencies below 100 Hz. Consequently, there is a necessity measuring the sound insulation below 100 Hz in order to have some information coherent with the real disturbance for building occupants.

The low frequency request is one of the main modifications which should be inserted in the next ISO 16283-3[1] (2011). This standard will replace the ISO 140-5 (1998), the current standard for the "*Measurement of sound insulation in buildings and of building elements - Field measurement of airborne sound insulation of façade element and façades*". The measurement of insulation at low frequencies show several problems: the sound field in typical rooms is not diffuse and interferences effects are consistent both inside and outside the building.

The paper aims to contribute the revision process by comparing measurement methods for the sound insulation of building façades and by investigating limits of the measurement procedures, with particular attention to low frequency measurements. The scope is to show and try to reduce few sources of uncertainity in the measure of the sound insulation of building façades (Berardi, 2011). The paper is composed by 4 sections: section 2 describes standard methods for the measurement of the sound insulation of building façade and discusses their controversial aspects, section 3 contains an investigation through real field measurements, and section 4 reports a tentative procedure for low frequency measurements together with concluding remarks.

2 Standard methods for the measurement of the sound insulation of building façade

The measurement method for sound insulation of building façades is described in the standard ISO 140-5. Table 1 of the standard contains an overview of the available measurement methods. These can be divided in element and global methods, if respectively a small specimen or a large piece of the façade is considered. For each method, four types of sound sources can be adopted to assess the external sound: a loudspeaker, the road traffic, the railway traffic or the air traffic noise. The last three can only be used when the sound pressure levels (SPL) of the corresponding source is sufficiently high. On the contrary, the use of a loudspeaker represents a method that can always be adopted and that permits an easy and rapid evaluation of the SPL. In this article, only measurements with the loudspeaker are considered. ISO 140-5 indicates where the loudspeaker and the microphone should be placed with respect to the building façade. Paragraphs 5.4, 5.5.2 and 5.7.2 of the ISO 140-5 state that:

- the distance from the sound source to the centre of the test specimen shall be at least 5 m for the element loudspeaker method, and at least 7 m for the global loudspeaker method. The angle of the sound incidence shall be (45 ± 5)°;
- a minimum of five microphone positions shall be used in each room to obtain the average SPL. These positions shall be distributed within the maximum permitted space throughout the room, spaced uniformly according to established distances from the room boundaries or objectives in the room;
- the external microphone should be in front of the façade at a distance of 2.0 ± 0.2 m from the plane of the façade or of 1.0 m from the balustrade or similar protrusions, in the global method, whereas for the element method, the microphone should be attached to the façade, without touching it.

A different procedure of measurement is required in few national standards. For example, according to the American standard ASTM E 966 (2004):

- several incidence angles for the outdoor SPL should be used. The standard suggests 15°, 30°, 45° and 60° and reports weight factors to average the SPL from results with different incidental angles;
- the SPL in the room should be measured sampling the room in fixed positions or using a moving microphone;

[1] The ISO 16283, Acoustics — Field measurement of sound insulation in buildings and of building elements, is currently under preparation. It should be composed by 3 parts: Part 1: Airborne sound insulation; Part 2: Impact sound insulation; Part 3: Façade sound insulation.

- the SPL should be obtained averaging the squared pressure in five or more positions located between 1.2 and 2.4 m from the façade element in the nearby average method, or at less than 17 mm in the flush method (Fig. 1).

Among others aspects, above standards for the measurement of the sound insulation of building façades differ for the frequency interval of measure. The standard ISO 140-5 suggests measurements in the frequency bands from 100 Hz to 3.15 kHz, the ASTM E 966 asks for measurements in one-third octave band frequencies from at least 80 Hz to 5 kHz, and the Japanese standard JAS A 1430 (2009) requires the measurement in a single frequency band corresponding to 500 Hz. The frequency interval is a particularly controversial aspect. In fact, the revision process for the ISO 16283 is trying to extend the measure to low frequencies, and in particular, to one-third octave bands with the centre frequencies at 50, 63 and 80 Hz. However, several problems have recently emerged in literature for low frequency measurements of sound insulation of façades (Pedersen *et al*., 2000, Hopkins and Lam, 2009, Berardi *et al*., 2011).

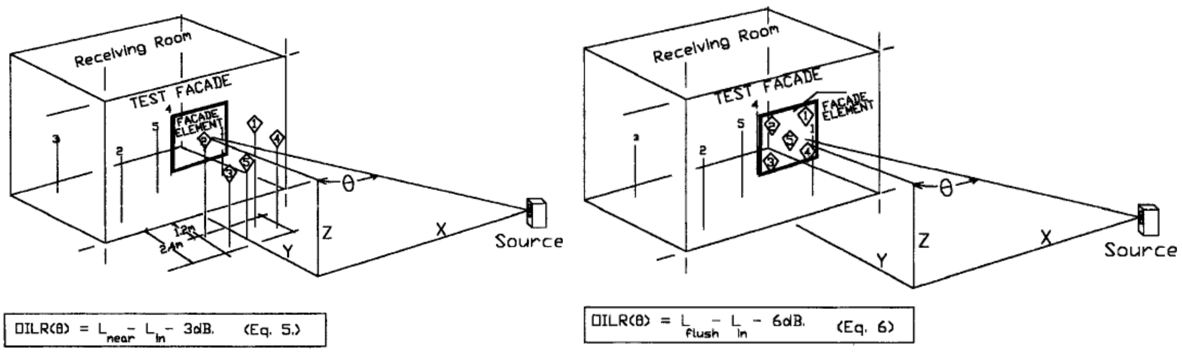

FIG. 2 Geometry—Nearby Average Method

FIG. 3 Geometry—Flush Method

Figure n. 1 – Façade measurements positions according to the ASTM E 966-04 in nearby and flush methods: these correspond to the global and element methods in the standard ISO 140-5 respectively.

3 Investigation of possible configurations of measure for future standards

For the investigation of limits in the measurement of sound insulation of building façades, tests were carried out in a new and empty building (Fig. 2). Two rooms located at the first floor were investigated. These had no balconies or architectural decorative elements, although the presence of two windows on two sides of room 1 made the case interesting. Measurements were carried out using a calibrated measurement chain consisting of a 01 dB Symphonie system and two GRAS 40-AR omnidirectional microphones which were calibrated before every session of measure. A directional sound source was used in front of the façade, whereas an omnidirectional sound source made up of twelve 120 mm loudspeakers was used inside the rooms in order to measure the reverberation time. All the measurements were realized using a non equalized pink noise averaged over 15 s. Air temperature was 25.0 °C in average, whereas humidity was monitored and resulted constant.

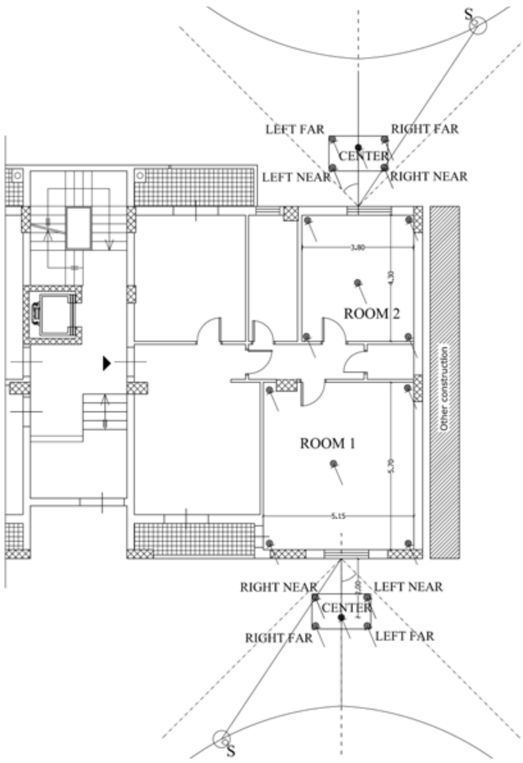

Figure n. 2 – Plan of the building with points of measurement inside and outside the rooms.

3.1 The measure of SPL in front of the façade

The measure of the SPL in front of a façade can be controversial, especially at low frequencies. In this section, only the measure using a loudspeaker as a source is considered. As seen in section 2, the ISO 140-5 allows a certain flexibility positioning the external microphone and the loudspeaker: in the global method, a tolerance of 0.2 m for the microphone exists, whereas it is possible to position the loudspeaker with an angle from 40 to 50°. An extensive study of the effects over sound insulation values of such erroneous positions of the instruments in front of the façade has recently been published (Berardi *et al*., 2011). The study used the same measurement chain which has been used for the present work. Berardi *et al*. (2011) have shown that according to the relative positions of the external source and receiver, destructive interferences among waves may happen in different frequency bands. These interferences are particularly evident at low frequencies, especially considering values in one-third octave bands below 100 Hz, because reflections at low frequencies are in phase. Fig. 3 reports some of the results of the study. All the measurement configurations in the figure agree with prescription for the global method in ISO 140-5, but the sound insulation value resulted up to 2 dB different from one configuration to the other. The theoretical analysis of the interference phenomenon suggests increasing the distance between the loudspeaker and the façade in order to have the interference occurring at lower frequencies.

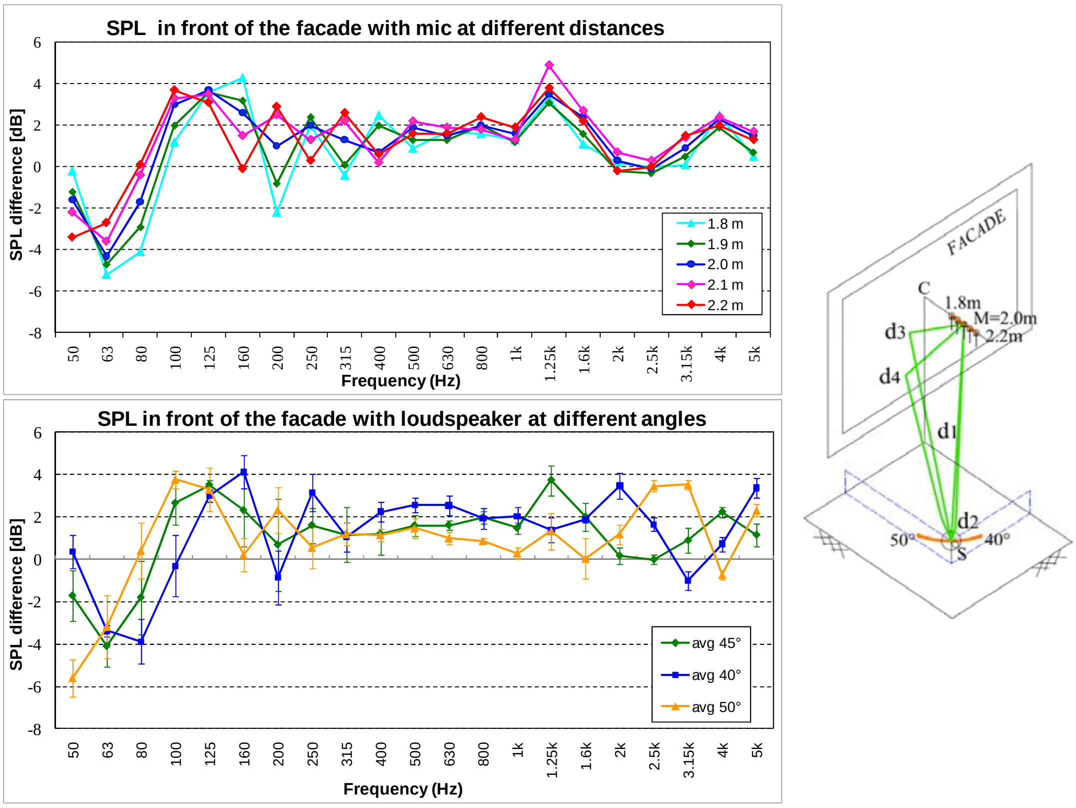

Figure n. 3 – Difference of SPL measurements at 1.8, 1.9, 2.0, 2.1, 2.2 m in front of the façade and at a reference position with the loudspeaker forming an angle of 45° (above) and difference at 2.0 m with the loudspeaker at 40°,45° and 50° (below). Data already reported in Berardi *et al.*, 2011.

The orientation angle of the loudspeaker merits some considerations. This angle is obtained by the perpendicular to the centre of the façade and the line connecting the loudspeaker to the centre of the façade. It should measure 45°. Attention is necessary to position the loudspeaker, without considering the horizontal projection of this angle. In fact, this "horizontal interpretation" results in an angle smaller than 45°. A recent study has discussed the error committed by using the 45° evaluated on a horizontal plane: this erroneous configuration has given single index up to 2 dB far from the value obtained in right positions (Cremonini and Fausti, 2011). Unfortunately, this error is case dependent and as it was studied only for single index of the sound insulation of the façade, no information exists about the error in the different frequency bands.

The above discussion about the interference effects in front of the façade suggests using a procedure which guarantees an highly reliable estimation of the SPL. One possibility is to average measurements in different points. This agrees with prescription in the ASTM E 966 which asks to average five measurements. Fig. 4 reports the SPL for the two rooms in the five points proposed by the ASTM together with their squared pressure average and the measurement at 2 m in front of the centre of the façade. As expected, the average allows to mitigate the peaks of SPL provoked by the interferences of reflections which determined standard deviation among the SPL in the different points greater than 1 dB in any frequency band. Finally, the results shown in fig. 4 indicate the absolute necessity to average measurements in several points, especially at low frequencies.

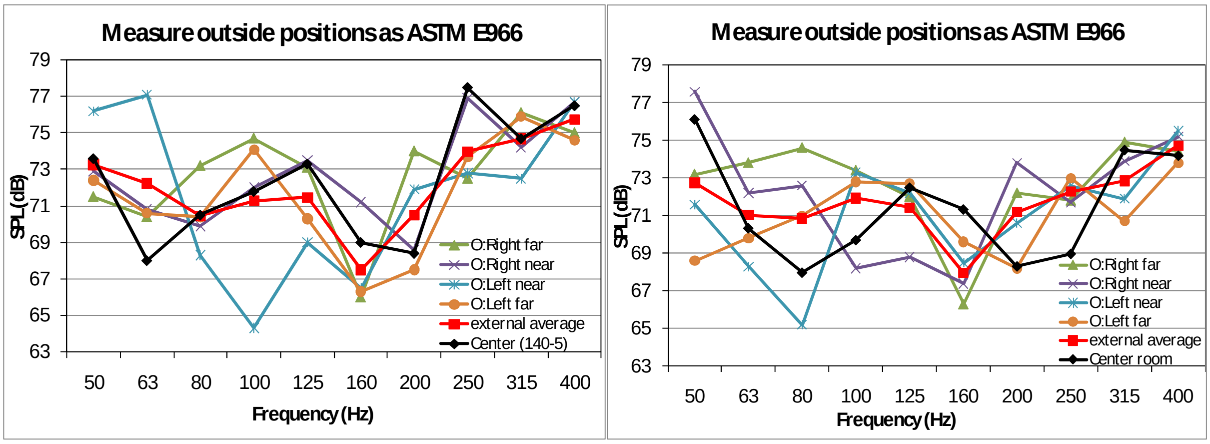

Figure n. 4 – SPL measured in the positions given by the ASTM E 966 for the nearby average method (see fig. 1) in the rooms of fig. 2: room 1 (left) and room 2 (right).

3.2 The measure of SPL inside the building according to the ISO 16283

As already affirmed, the main difference between the ISO 140 and ISO 16283 is the introduction of low frequency measurements. The determination of the SPL inside the building is particularly critical at low frequencies because the sound field in the room is not diffuse. After a recent study by Hopkins (2011), the standard ISO 16283-1 has introduced the possibilities to measure the SPL in the room through a manually-scanned microphone whose paths should form a circle, a helix, a cylindrical-type or 3 semicircles. Fig. 5 reports the SPL measured through the four configurations of the manual scanning method and the average squared pressure in fixed positions in the room. The plots prevent drawing final conclusions from the results because the average values are sometimes lower and sometimes higher than the scanned ones in the two rooms. However, the plots show that a large difference occurs between the scanned and fixed positions methods at low frequencies, especially below 125 Hz. Moreover, the plots show that the results for the cylindrical type and semicircles paths are almost identical, whereas the circle path shows lower values than other manually-scanned paths at low frequencies.

Simmons (1999) and Hopkins and Turner (2005) have studied SPL measurement methods in rooms for low frequency looking at SPL in three-dimensional grids. Among the measurement methods, they assessed the SPL in the corners of a room where the low frequency SPL are higher than in the centre. The measurement of the SPL in the corners of the room is prescribed in the ISO 16032, the norm for the measure of the SPL from service equipments. An investigation of the SPL was performed for this study, measuring the SPL in the four angles of the rooms at different heights (1 m, 1.5 m and 2.5 m). These three heights were chosen as they correspond to that of the head when the body is sitting or lying, that in the ISO 140-5 and that where the highest SPL in the room are expected respectively. Moreover, the SPL was measured in the centre of the room choosing the positions through a MATLAB program which guaranteed a random selection of the positions.

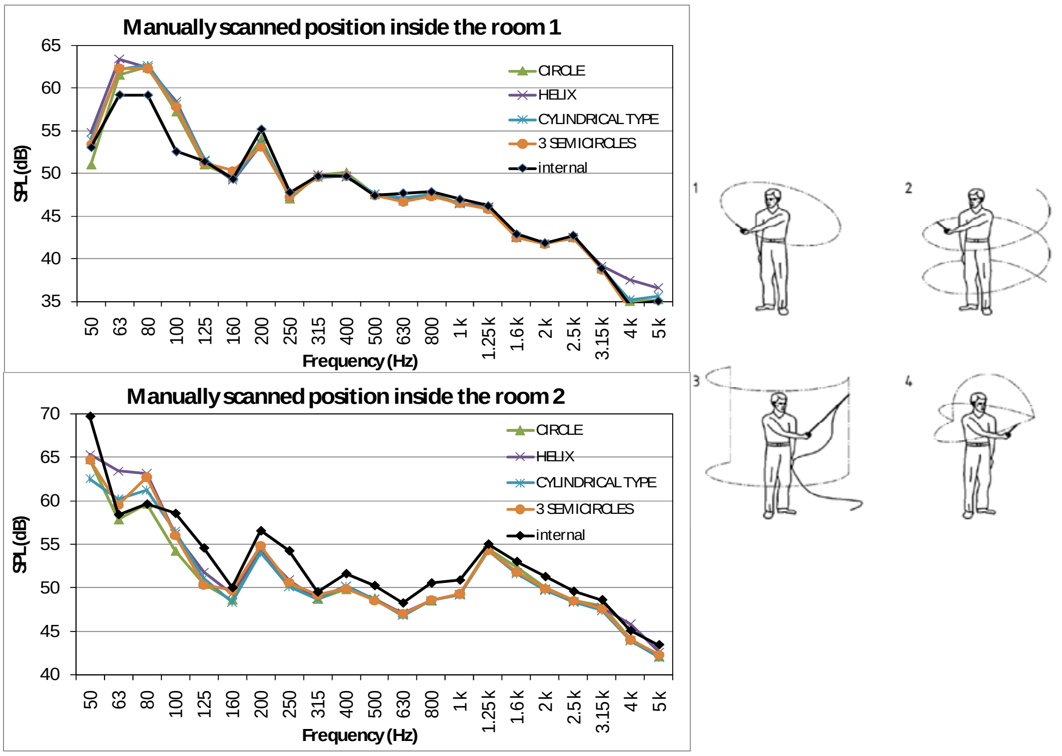

Figure n. 5 – SPL measured through manually-scanned microphone according to the ISO 16283-1, and comparison with the values obtained by average of fixed positions (internal).

Results in fig. 6 confirm the hypothesis. In fact, the measurements below the ceiling showed the highest values and standard deviations. Looking at results in the bands of 50, 65 and 80 Hz, the average SPL in the centre of the room resulted 12.7, 11.9 and 13.9 dB lower than those obtained in the corners at height of 2.5 m in room 1 and 5.3, 5.0 and 7.2 dB in room 2 respectively. Comparing the results at higher frequencies, more similar values were found. In fact, the differences between angle and centre values at the band of 500 Hz and 1 kHz were below 1 dB in both rooms. The standard deviation among measurements in different points were particularly high at low frequency both for measurements in the centre of the rooms and in their corners. This confirms the difficulty obtaining good sampling values if measurements at such low frequencies are required.

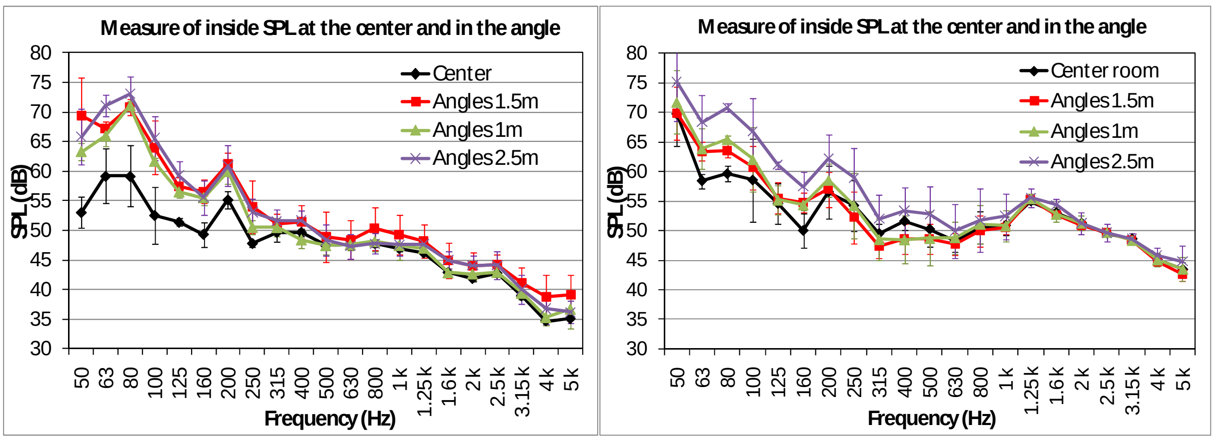

Figure n. 6 – SPL in the corners of the room at different heights (standard deviations refer to the four angles) and average values in the center of the rooms in room 1 (left) and room 2 (right).

The measurement of SPL at low frequency is relevant to people living in the dwelling because sleeping and seating positions in dwellings are often near room corners. Here, the low frequency SPL are higher. ISO 16283 asks to calculate the low frequency energy-average SPL in the 50, 63 and 80 Hz bands by averaging the SPL measured in the classical positions and in the corners. These last are obtained from the energy average of SPL measured in the corners positioning the loudspeaker in different points. Finally, the low frequency energy-average value is obtained by the weighted average of the measurements in the centre and in the corners of the room, weighting these values according to the ratio 2:1.

3.3 The measure of the Reverberation Time

The reverberation time (RT) in the two rooms was determined according to the ISO 3382. Although the reduced volume, given the emptiness of the rooms and hence the low absorption, a long RT resulted, especially at low frequency. It should be emphasized that at frequencies such low as 50 Hz, it should be always checked that the sound source is able to emit a sufficient and stable SPL:

The time history of the room response clearly indentified modes of the sound field at 50 Hz, and it was difficult to select a decay slope to determine the RT. Proof of this is given by the high standard deviation among measurements at low frequencies (0.6 s in room 1 and 0.8 s in room 2 at 50 Hz), whereas at high frequencies, the results obtained in the several measurement points were really similar and the standard deviation significantly reduced being less than 0.1 s at high frequencies.

It is important hence that the future standard for the measurement of the sound insulation of building façade takes into account the uncertainties of the RT measurements. A decay of only 10 or 20 dB can be necessary although the operator should always put attention to the measure.

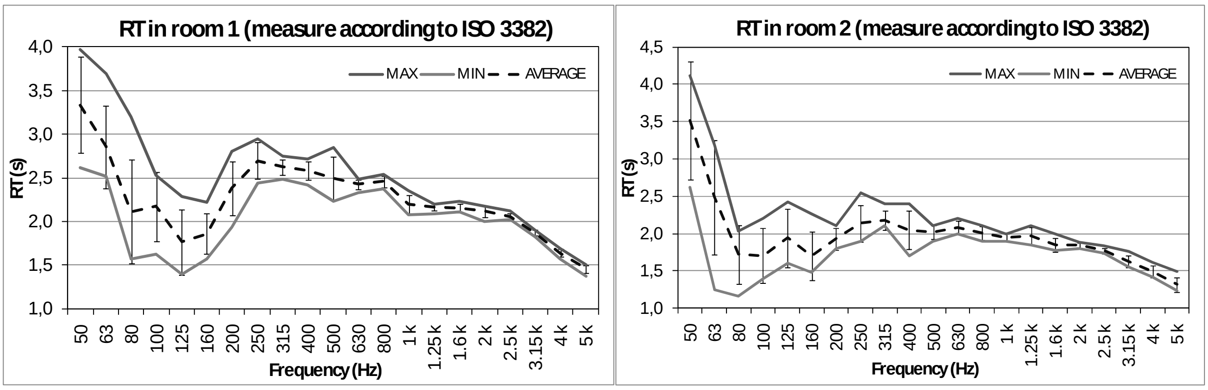

Figure n. 7 – Reverberation time in the two rooms: average of 6 measure points, max and min values.

3.4 The measure in corner rooms and in analogous configurations

An interesting case is the measurement of SPL in corner rooms. These often have one window on a side, but can also have more windows on the two sides. In this case, the standard should clarify how to measure the sound insulation, and where to position the loudspeaker. In fact, the sound source can look at one side only or at both: obviously, the sound entering in the room would be different in the two cases, and hence, the measurement of the sound insulation differs.

The question of corner rooms is similar to all cases in which the sound can enter in the room behind the façade from several directions and boundaries. For example, room 1 in fig. 2 has a window on the main façade and a door-window on the loggia. This geometrical configuration, common in new buildings, allows positioning the sound source on the left or the right of the perpendicular to the façade. Obviously, given the different insulation performances of the windows and walls, the sound energy which would enter in the room is different in the two cases.

Another interesting and confusing case is that of rooms over pilotis. This modern architectural configuration diffused after the Swiss architect Le Corbusier and has represented a common design in new buildings along the XX centaury. In this case, the measure of the sound insulation at the first floor should consider the sound that enters in the rooms from the floor. Similarly, in cases of mansards and rooms with ceiling, the sound enters the room both from the façade and from the roof. Also in this case, the standard does not indicate any configuration of measure and a typology of solution for these cases should be introduced in the standard.

4 A proposal method for low-frequency measurements and conclusions

The paper has discussed several controversial aspects which should be resolved in the future standard ISO 16283-3. The need of reliable and relevant measurements ask for procedures which should consider the sound insulation at low frequencies. These have shown the necessity:

- to average the external SPL in order to reduce the effects of interference. A possible solution for the average is represented by the American standard ASTM E 966 which asks for the average among 5 points of measure;
- to average the internal SPL in order to consider the SPL in the centre of the room and in angular positions. A possibility for this average is represented by the low-frequency procedure in ISO 16283-1. This requires to average the measurement at the centre with the measurement at the corners. The efficacy of this average for the sound insulation of building façade has to be tested, especially for the ratio among the two measurements. This ratio in the new standard for the airborne sound insulation is 2:1 between the values in the centre and in the corners.

Finally, the paper has proposed that in all cases in which the sound could enter in the building from more than one surface, the source should be positioned where the sound insulation gives the lowest value, in order to give a reliant estimation and a value more similar to the occupant perception.

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