Acoustic Measurements on a 1:1 Scale Model of a Shading System for Building Façade in a Semi-Anechoic Chamber

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ABSTRACT

In many buildings shading systems are installed over the façades to enhance both the thermal and the visual comfort of the inhabitants, especially when large windows or curtain walls are used. Although the use of the brise-soleil systems is quite widespread, their acoustic effects on the sound pressure level (SPL) on the building façades and in the urban environment are generally not considered.

This work presents the results of an investigation on a shading system model, in scale 1:1, carried out in a semi-anechoic chamber. The intention of this study was to analyse the changes in SPL given by the presence of the louvres, both on the façade plane (simulated by the floor of the chamber) and at 2 m from it.

Measurements were performed using three different sound source positions and three tilt angles of the louvres. The acoustic behaviour of the system was evaluated with various configurations using louvres without and with sound absorptive material attached to their lower sides.

The measurements highlighted an increase in SPL over the "façade" when the standard louvres are installed, while the sound absorptive louvres give an evident SPL reduction on the façade plane and at 2 m from it.

Keywords: Façade Sound Insulation, Insertion Loss, Shading Devices

I-INCE Classification of Subjects Numbers: 31.1, 51.3, 51.4

1. INTRODUCTION

It is nowadays largely demonstrated how the use of shading devices in buildings can reduce energy consumption to cool them during hot months and to enhance both the thermal and the visual comfort of the inhabitants (1, 2). Furthermore the Italian regulation (3) furthermore makes it compulsory to protect the facades of specific categories of buildings with shading devices. The acoustic properties of this kinds of system are often ignored, while many works has instead investigated the passive noise control provided by the shape of the building façades (4, 5, 6, 7, 8). Recent works have demonstrated with numerical and scale models (9) or with experimental measurements on a case study (10, 11) that the presence of louvres can increase the sound pressure level over the building facades.

This work presents the results of a measurement campaign that has been carried out in a semi-anechoic chamber, on a model (1:1 scale) of a 16 m^2 portion of a shading device, to be attached over the building façades. The intention was to evaluate the Insertion Loss (IL) provided by such a system and an experimentation was made to enhance the acoustic performances of the system: a thin layer of sound absorbing material (melamine, 3 cm thick) was added under each louvre in order to intercept the sound field coming from a sound source (typically a road) and consequently to reduce the sound reflections on the building façade.

The measurements were carried out by placing the model on the ground of the semi-anechoic chamber, which can be easily assimilated as a building façade, while the sound source was moved in three different positions, to analyse as many angles of incidence of the generated sound field.

120 microphone positions under the model were used as receivers, placed directly in contact with the floor of the chamber, to evaluate the Insertion Loss (IL) in dB provided by the different configurations studied. A second microphone grid with 49 positions at 2 m from the floor, was used to

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evaluate the differences in term of sound pressure level ($\Delta_{SPL,2m}$), due to the presence of the shading system. The sound pressure levels measured with the blank façade were taken as reference values, in analogy with the IL measurements.

The first measurement set-up was intended to give indications on the effect of shading systems on the façade sound insulation thanks to the influence of the façade shape, as suggested by the EN 12354-3 – Annex C (12). The second set-up of the measurements refers to the analysis of the effect of the shading system on the exterior sound environment.

2. MEASUREMENTS SET-UP

The measurements were carried out in a semi-anechoic chamber of 10.1 m x 9.5 m x (h) 8.3 m. The chamber respects the requirements of the ISO 3745 – Annex A (13) with a low cut-frequency under 50 Hz and a high cut-frequency above 10 kHz. The measured background noise, with the air plant on, is less than 18 dB, as global value.

2.1 Model of shading system

Designers can choose between a variety of types of shading devices: they differ in shape, dimensions, materials, spacing of the louvres etc. The choice of a system rather than another depends on various factors, which can be more technical, related to their efficiency in reducing solar irradiation and in distributing the daylight, or simply aesthetical.

The aim of this study is to give some useful data related to the acoustic behaviour of a very common type of shading device: the model has 40 louvres (0.2 m x 2 m, 1.8 cm thick) organised in 2 columns of 20 elements each and spaced at a distance of 0.2 m from each other.

The model was made with pine plywood boards, assembled in 4 modules 2 m x 2 m each. This material was chosen due to its low cost and because it is simple enough to work, but also because it is quite a sound reflective material, like the real shading devices are.

The louvres were designed with the possibility of varying their tilt angle, since many systems offer this option in order to optimise the control of solar irradiation on the façades (14), in relation also to different periods of the day and of the year.

The model was placed on the floor of the semi-anechoic chamber (Figure 1) with its top touching the sound absorbing wedges of the chamber and the other three sides protected by a boundary of polyester fibre, 25 cm thick and 1 m large. The polyester fibre was used in order to reduce as much as possible the sound diffraction through the lateral mullions of the structure.

The floor of the semi-anechoic chamber acoustically resembles a building façade, such as a curtain wall (glass). For simplicity, the floor of the chamber will be hereafter called directly "*façade*".

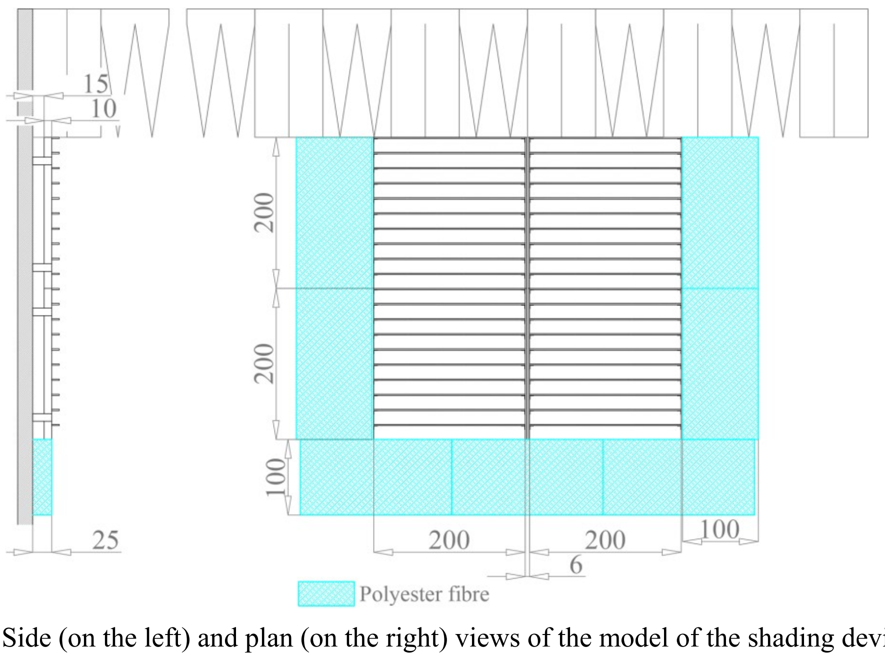

Figure 1 – Side (on the left) and plan (on the right) views of the model of the shading devices in the semi-anechoic chamber. Dimensions are expressed in cm.

2.2 Sound source positions and microphone arrays

The sound source used for the measurements was a directional loudspeaker, used in general in the façade sound insulation measurements (15, 16). Three different sound source positions were chosen in order to evaluate various angles of incidence of the generated sound field to the plane of the façade. The sound source was always aligned with the centre axis of the model and its acoustic axes was variously oriented respectively by 30°, 45° and 60° with respect to the plane of the façade. The different source positions were chosen in order to simulate a fixed position of the noise source, for example a road close to the building façade (Figure 2): the different angles correspond respectively to different floors of the building, as illustrated in Table 1. The three source positions in the semi-anechoic chamber are showed in Figure 3.a.

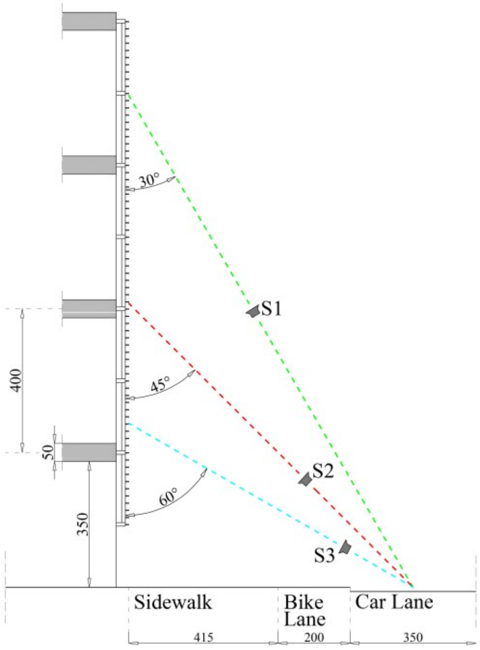

Figure 2 – Section of a hypothetical building façade and a road. The source positions in the semi-anechoic chamber are showed as a fixed road lane. Dimensions are in cm.

Table 1 – Source positions in the semi-anechoic chamber and corresponding floors with reference to a hypothetical building with a road at road lane (noise source) at 6 m from the façade.

Sound source position	Angle between the direction of sound and the façade plane	Corresponding floor
S1	30°	1st floor
S2	45°	2nd floor
S3	60°	3rd floor

For the measurements were used ½” pre-polarised pre-amplified free field condenser microphones and a real time spectrum analyser, with 1/3 octave frequency band filters.

Figures 3.b and 3.c shows the microphone grids respectively used for the IL and for the $\Delta_{SPL,2m}$ measurements. The 120 microphone positions under the shading devices were organised in 10 columns spaced 40 cm from each other and 12 lines spaced 30 cm from each other. The microphone grid at 2 m from the façade was instead smaller, with 7 x 7 positions, with the columns spaced by 30 cm and the lines spaced by 40 cm. The smaller dimension of the array over the shading devices was chosen in order to avoid as much as possible measuring the sound reflections given by the part of the floor not occupied by the model in the semi-anechoic chamber.

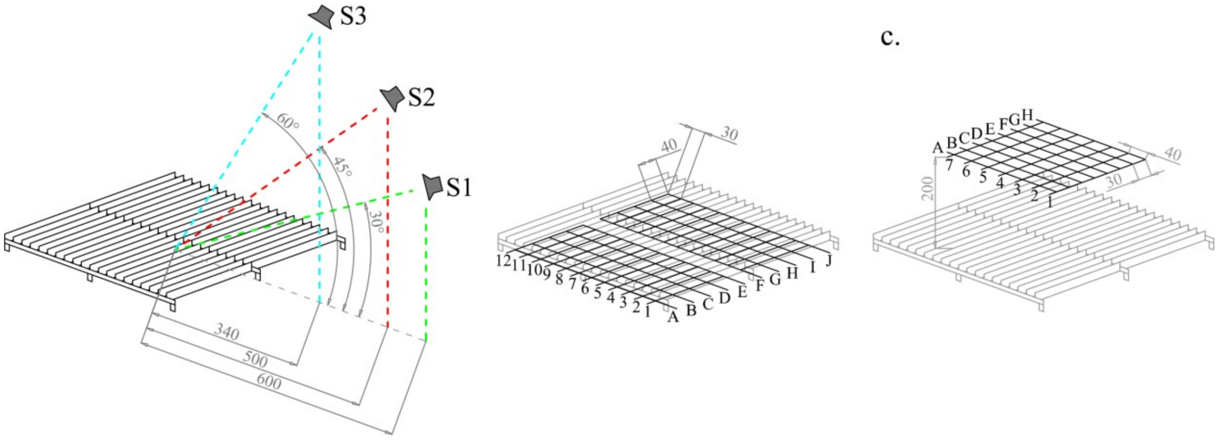

Figure 3 – a. Scheme of the positions of the noise source. b. Scheme of the 120 microphones positions on the floor, under the model. c. Scheme of the 49 microphones positions at 2 m from the floor. Dimensions are in cm.

2.3 The louvres of the shading device

All the measurements were repeated with different configurations of the façade (the floor of the semi-anechoic chamber), using all the three different sound source positions for each series: the first set of measurements was carried out with the blank floor of the semi-anechoic chamber (Figure 4.a); the second series of measurements was made with standard shading devices (Figure 4.b); in the last measurement set up the slabs were covered with a layer of melamine foam, 3 cm thick (Figure 4.c), on the lower side (toward the sound source). The sound absorption coefficient of the melamine (Figure 5) was measured accordingly to the standard UNI EN ISO 10534-2:2001 (17).

Figure 4 – a. The blank floor of the semi-anechoic chamber with the polyester fibre around the perimeter of the area studied. b. The standard shading devices. c. The sound absorbing shading devices.

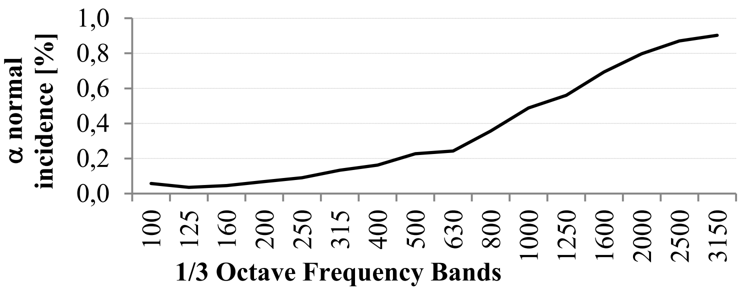

Figure 5 – Normal incidence sound absorption coefficient of a 30 mm thick melamine panel.

The measurements were carried out using different tilt angles of the louvres of the shading device, in order to evaluate the acoustic performances in different configurations, as it is very common to use adjustable louvres that give a versatile shading control. The tilted positions of the louvres (30° or 45°) are interesting because of their greater sun shading effect while the horizontal position is often used for visibility purposes since it does not affect the vision from the inside to the outside. The different angles and the detail of the dimensions as well are shown in Figure 6; the dashed lines in the figure represent the mullions of the system, placed at 15 cm from the floor of the semi-anechoic chamber.

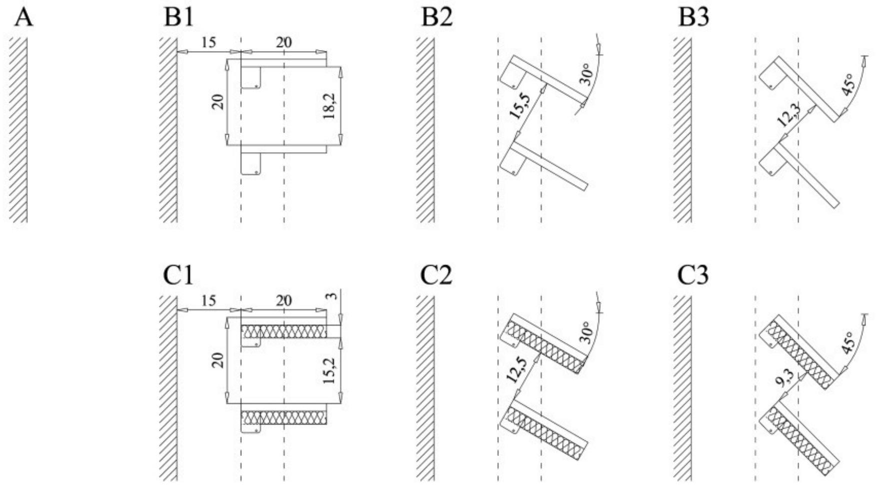

Figure 6 – Scheme of the different studied configurations of the *lamellae* of the shading system. A is the blank façade, without the system. From B1 to B3: standard *lamellae* variously tilted. From C1 to C3: sound absorbing *lamellae* variously tilted. Dimensions are in cm.

3. MEASUREMENT RESULTS: THE INSERTION LOSS

The Insertion Loss (IL) of the shading device was calculated as the difference in sound pressure levels (SPL) in dB measured with the blank façade (reference SPL) and the SPL measured with different configurations of the shading devices.

$$IL = SPL_{(blank\ facade)} - SPL_{(shaded\ facade)} \text{ [dB]} \tag{1}$$

$SPL_{(blank\ facade)} = Average\ SPL\ measured\ on\ the\ blank\ façade$ [dB]

$SPL_{(shaded\ facade)} = Average\ SPL\ measured\ on\ the\ shaded\ façade$ [dB]

The IL was calculated as the difference of the averaged SPL between the 120 microphone positions, but in order not to lose important data regarding the spatial distribution of the IL, also colour maps were made. All measurements were performed in the frequency range from 100 Hz to 5 kHz, in 1/3 octave frequency bands.

3.1 The average Insertion Loss in 1/3 octave frequency bands

In the following Figure 7 are shown the results of the IL measurements, in dB, in 1/3 octave frequency bands. The graphs below show the averaged values obtained by all 120 microphone positions. Each graph reports three curves that refer to as many Source positions. The left column reports the measured IL provided by the standard shading devices, respectively with not tilted, 30° tilted and 45° tilted louvres. The right column refers to the IL given by the sound absorptive shading devices, even in this case variously tilted.

It is interesting to observe that the IL provided by the standard shading devices is almost negligible, if not negative: it is possible to see that the curves vary from 0 only in a range within ±2 dB. The progression in tilting the louvres of the system causes a corresponding decrease in the IL, and the smaller angles of the sound source with respect to the façade cause a higher IL.

The sound absorbing shading devices offer instead a good protection from external noise: the SPL abatement over the façade surface rises up to values around 10 dB, for the higher frequency. The IL provided by the sound absorbing shading system is however limited by the sound absorption properties of the melamine panels used in the experimentation (Figure 5). In this case is presented a raw prototype: a better tuning of the louvres should be carried out in order to optimise the noise abatement at specific frequency bands, for example related to the traffic noise (18). The effects due to the source position and the louvres tilt angle are similar to what is observed for the standard shading system. In general, the IL increases when the angle between the direction of the source waves and the façade plane is lower; at the same time IL is reduced when the tilt angle of the louvres is increased.

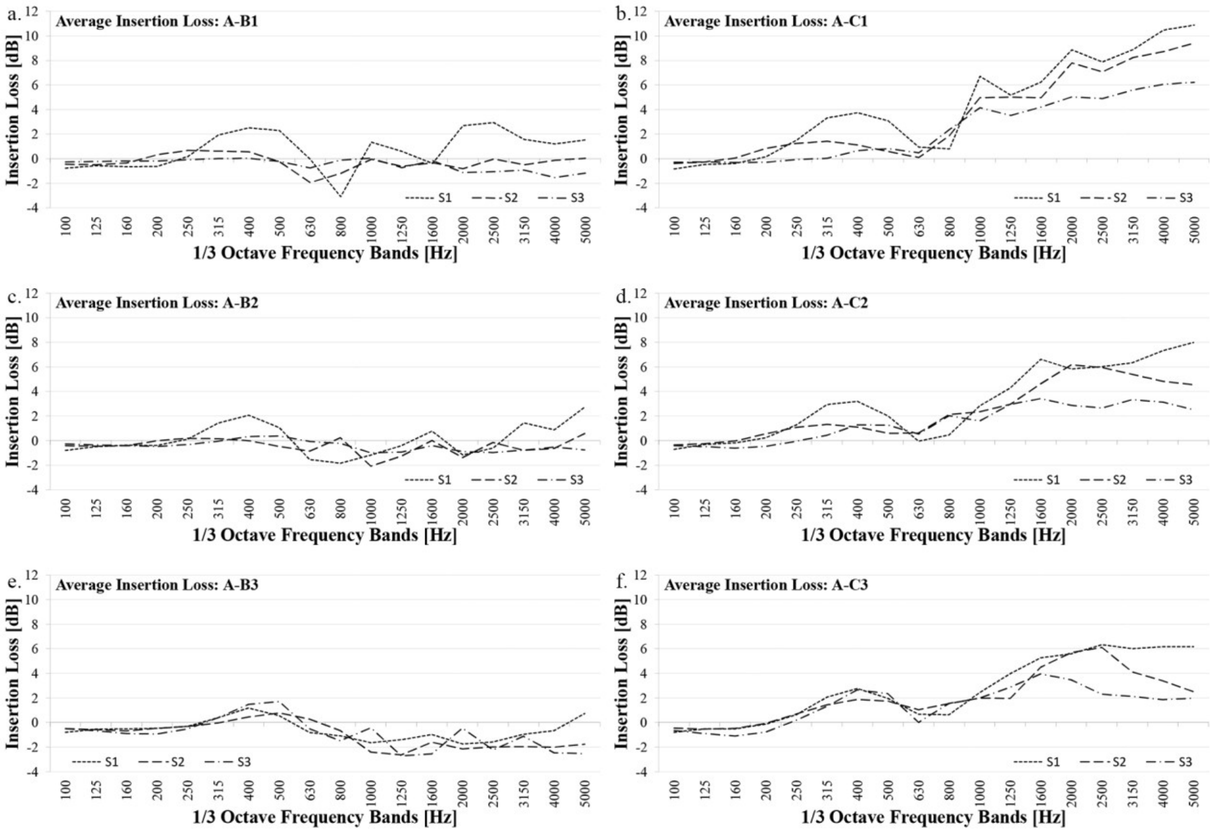

Figure 7 – Average Insertion Loss in dB, variable in frequency. Each graph reports the IL obtained for the three different source positions (S1, S2, S3, see Fig. 2). On the left (a. c. e.): IL of the standard shading devices. On the right (b. d. f.) IL of the sound absorbing shading devices. From top to bottom, different tilt angles of the louvres (see Fig. 3).

3.2 Insertion Loss spatial distribution in broad-band frequency

The colour maps were made in order to better evaluate the spatial distribution of the IL provided by the shading devices in the various configurations studied. Graphs were plotted for each 1/3 frequency band as well as for each source position and tilt angle of the louvres, but for brevity only the colour maps related to the broad band values in dB (linear), referring to the loudspeaker in position S1 (Fig. 2), are reported in the following figures 8 to 10.

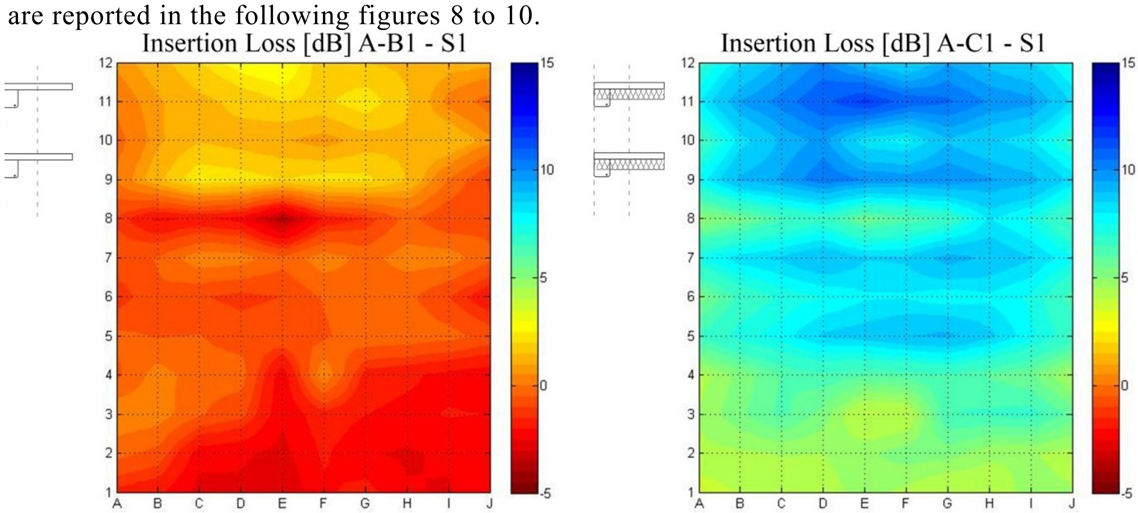

Figure 8 – IL in dB provided by the standard shading device (on the left) and by the sound absorbing shading devices (on the right) over a 4 m x 4 m surface. Louvres are not tilted.

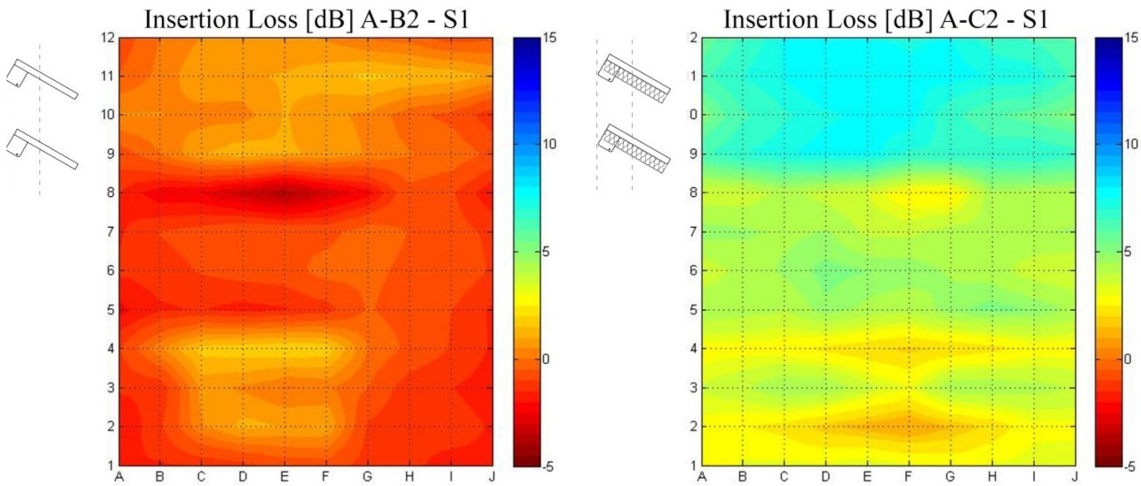

Figure 9 – IL in dB provided by the standard shading device (on the left) and by the sound absorbing shading devices (on the right) over a 4 m x 4 m surface. Louvres are tilted by 30°.

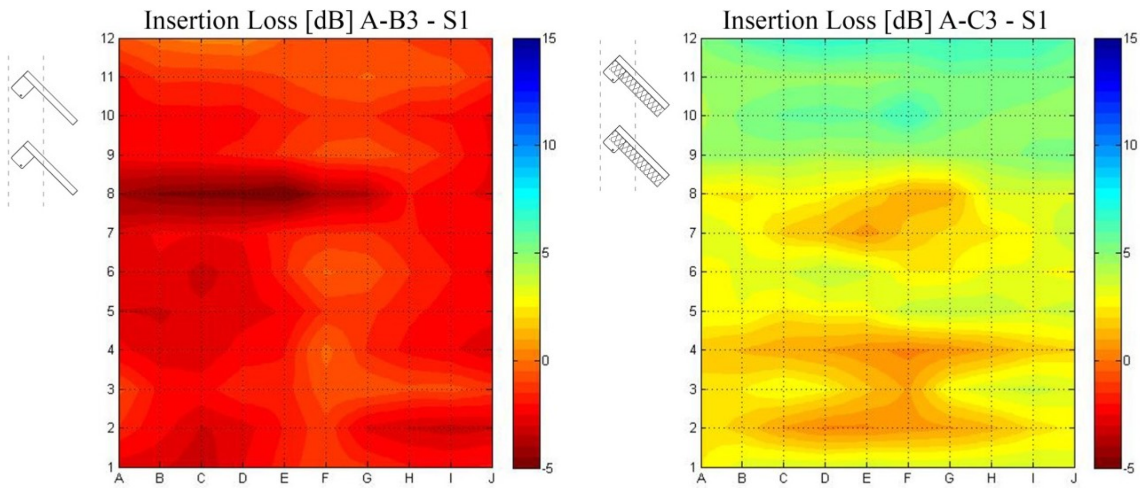

Figure 10 – IL in dB provided by the standard shading device (on the left) and by the sound absorbing shading devices (on the right) over a 4 m x 4 m surface. Louvres are tilted by 45°.

The plots were obtained as the linear interpolation between the IL values measured at each microphone position. The resulting figures show again that the standard louvres are totally ineffective in providing sound protection, but on the contrary they enhance the SPL over the façade in specific areas: this aspect is particularly noticeable when the louvres are tilted by 45° (Figure 10, on the right), with an increment in SPL of almost 5 dB at line 8.

The sound absorbing shading devices in general offer a fair noise protection. It is interesting to observe how the IL tends to increase in the higher parts of the studied area and when the louvres are not tilted. It is possible to explain this phenomenon because the sound field is more intercepted by the louvres when the sound source is closer to the façade: the apparent free space between two consecutive not tilted louvres was reduced, while by tilting them the open space increases. This aspect is seen both for the standard shading system and the sound absorbing one.

3.3 Insertion Loss as average in broad-band frequency

Figure 11 represents the IL in dB averaged from all 120 microphones positions, in broad-band frequency (linear). The graph is a synthesis of the IL provided varying both the sound source position and the tilt angles of the louvres. The figure below clarifies more the variations in IL due to the angle of incidence of the generated sound field to the façade: there are losses of more than 2 dB in the IL provided by the shading system when the sound field hits the façade with an angle of 30° with respect to an angle of 60°. This means that in general the shading devices tend to play a less relevant role as noise barriers with the increase in the distance between the noise source and the device itself, or when the angle of incidence to the façade tends to 90°.

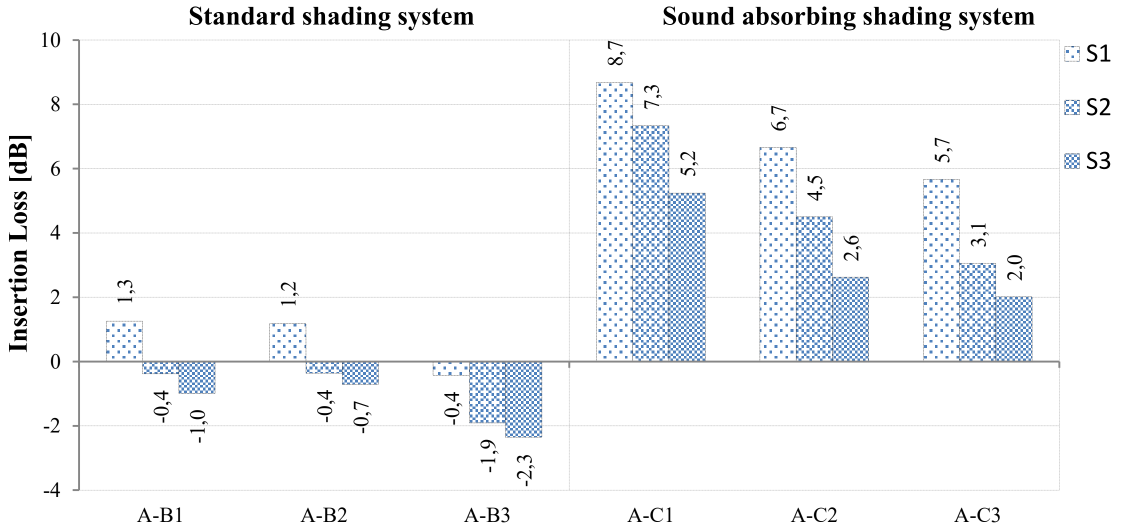

Figure 11 – IL in dB provided by the standard shading device (on the left) and by the sound absorbing shading devices (on the right). The colour of the columns in the graph is related to the source position (S1, S2, S3, see Fig. 2).

4. MEASUREMENT RESULTS: $\Delta_{SPL,2m}$ AT 2m FROM THE FACADE

Measurements at 2 m from the façade were carried out in order to evaluate the noise reduction in the nearby urban environment provided by a shielding device attached to a building façade. As previously mentioned a microphone grid with 7x7 positions was used.

To evaluate the efficiency of the shading devices in their various configurations it the $\Delta_{SPL,2m}$ was calculated in analogy to the IL.

$$\Delta_{SPL,2m} = SPL_{(2m,blank\ façade)} - SPL_{(2m,shaded\ façade)} \text{ [dB]} \quad (2)$$

$$SPL_{(2m,blank\ facade)} = Average\ SPL\ measured\ at\ 2m\ from\ the\ blank\ façade \quad \text{[dB]}$$

$$SPL_{(2m,shaded\ facade)} = Average\ SPL\ measured\ at\ 2m\ from\ the\ shaded\ façade \quad \text{[dB]}$$

4.1 Average $\Delta_{SPL,2m}$ in 1/3 octave frequency bands

The graphs in the following Figure 12 reports the $\Delta_{SPL,2m}$ as the average of the 49 microphone positions. Similarly to the results showed for the IL (Figure 7), in the left column are shown the SPL differences measured with the standard shading devices, while in the right column the data measured with the sound absorbing devices are represented. Each graph reports three curves, respectively referring to the three source positions used in the measurements.

The effect of the standard shading devices on the SPL at 2 m from the façade is almost irrelevant. The curves are all around 0 dB, with the exception of the ones referring to the loudspeaker in position S1: the SPL at 2m slightly increases by 2 dB at high frequencies, without significant differences due to the louvres tilt angles. This increase in SPL is slightly more marked when the louvres are tilted by 45°: the sound reflective surface of the louvres is more exposed to the direct sound field generated from the loudspeaker. In general, the standard shading devices do not play an important role in SPL differences at 2 m from the façade.

The sound absorbing louvres can slightly reduce the SPL up to 3 dB only at higher frequencies. It is interesting to note also in this case how the tilt angle of the louvres is almost non influential in the performance of the system, while the sound source position plays a more relevant role. The effect of the sound absorbing shading system is anyway limited by the sound absorption properties of the melamine (Figure 5), similarly to the effect observed in the IL measurements.

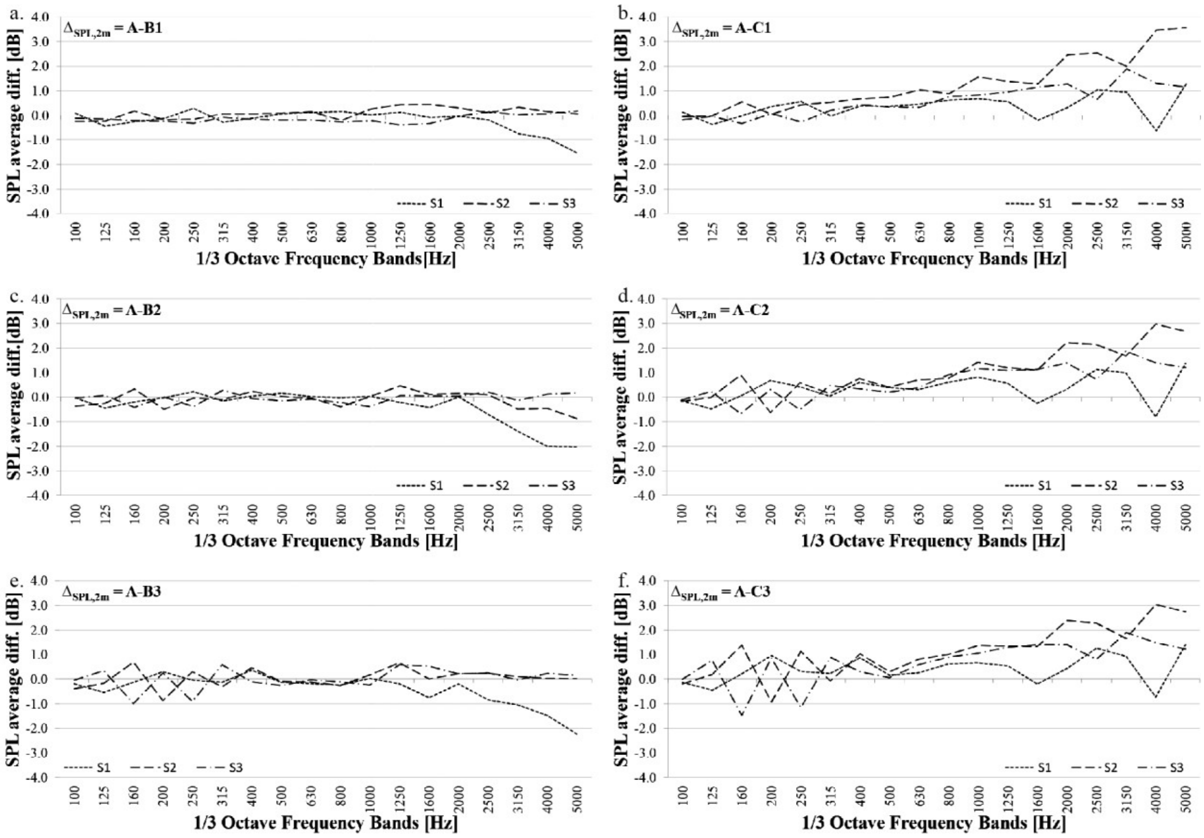

Figure 12 – Average differences in SPL at 2 m ($\Delta_{SPL,2m}$) from the façade in dB, variable in frequency. Each graph reports the $\Delta_{SPL,2m}$ obtained from three different source positions (S1, S2, S3, see Fig. 2). On the left (a. c. e.): $\Delta_{SPL,2m}$ of the standard shading devices. On the right (b. d. f.) $\Delta_{SPL,2m}$ of the sound absorbing shading devices. From top to bottom different tilt angles of the louvres (see Fig. 3). louvre

4.2 $\Delta_{SPL,2m}$ spatial distribution

The spatial distribution of $\Delta_{SPL,2m}$ was evaluated in analogy with the IL measurements. The plots in the following Figures from 13 to 15 show the $\Delta_{SPL,2m}$ values as colour maps given by the linear interpolation of the 7 x 7 measured values. Here are reported for brevity only the figures obtained for the broad-band frequency values referring to the loudspeaker in position S1.

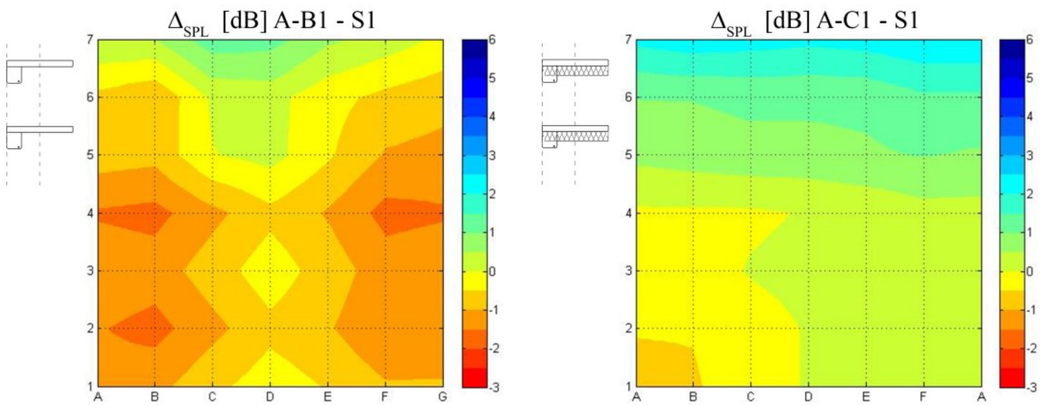

Figure 13 – $\Delta_{SPL,2m}$ in dB measured in presence of the standard shading device (on the left) and of the sound absorbing shading devices (on the right). Louvres are not tilted.

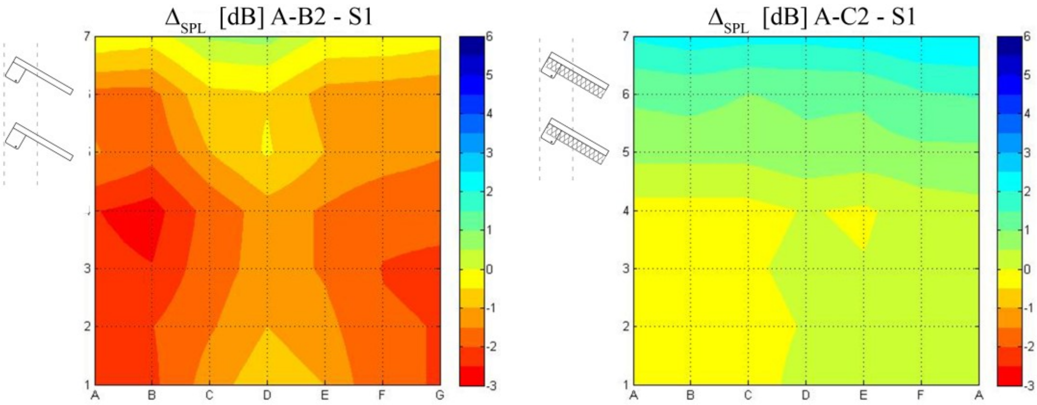

Figure 14 – $\Delta_{SPL,2m}$ in dB measured in presence of the standard shading device (on the left) and of the sound absorbing shading devices (on the right). Louvres are tilted by 30°.

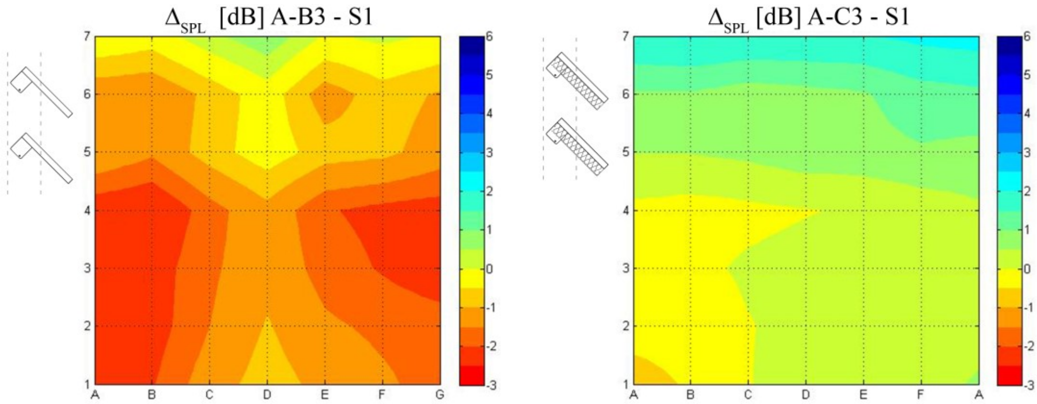

Figure 15 – $\Delta_{SPL,2m}$ in dB measured in presence of the standard shading device (on the left) and of the sound absorbing shading devices (on the right). Louvres are tilted by 45°.

In general few differences are visible due to the tilt angles of the louvres, both in the presence of the standard and the sound absorbing shading devices.

The plots referring to the standard louvres present a strange median area with a less negative effect in term of $\Delta_{SPL,2m}$: this fact is caused by the presence of the mullion, which has a smaller sound reflecting surface exposed to the generated sound field, than the surface of the louvres.

The sound absorbing louvres seems not to have an important role in SPL reduction at 2m from the façade, with values in dB not so far from 0, while they reach a positive Δ up to 2 dB only in the higher part of the graphs. Anyway the sound absorbing shading devices do not cause an increase in SPL, as the standard louvres seem to do.

4.3 $\Delta_{SPL,2m}$ as average in broad-band frequency

Even for the measurement of $\Delta_{SPL,2m}$ is presented a quick evaluation with values averaged between all 49 microphone positions, in broad-band frequency.

The standard shading devices have quite a negative behaviour, if compared with the sound absorbing louvres. On the other hand, the $\Delta_{SPL,2m}$ results not to have many analogies with the IL measurements. First of all, results are not always correlated to the source positions. The SPL at 2 m from the façade seems to increase as much as the generated sound field tends to be parallel to the façade itself. In any case the sound absorbing shading devices do not cause the same effect: when the sound source is at 45° with respect to the façade the $\Delta_{SPL,2m}$ is greater than in the other two positions.

In general it is confirmed that the tilt angle of the louvres does not have an important role in the SPL variation at 2 m from the façade.

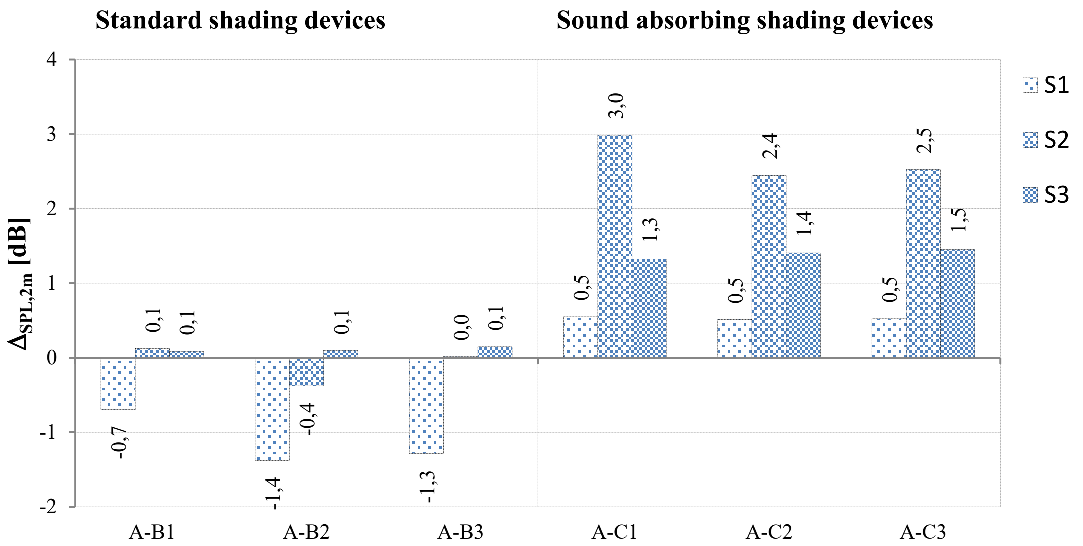

Figure 16 – $\Delta_{SPL,2m}$ in dB provided by the standard shading device (on the left) and by the sound absorbing shading devices (on the right). The colour of the columns in the graph is related to the source position (S1, S2, S3, see Fig. 2).

5. CONCLUSIONS

The IL measurement results highlight the relatively important role that the shading devices play on the SPL over the building façade where they are installed.

In general it is possible to say that standard shading devices can increase the SPL over a building façade, in particular at higher frequencies, when the sound field can be reflected by the louvres on the façade. The effect of the standard louvres on the façade is almost negligible at low frequencies, with IL values around 0 dB.

The sound absorbing shading devices can reduce the SPL over the façade up to 10 dB at higher frequencies. This effect is obviously related to the performance of the sound absorbing material used in the experimentation.

Both of the shading device systems studied (respectively with standard and sound absorbing louvres) present a correlation between the IL, the louvres tilt angles and the sound source position. The IL decreases with the increase in the tilting of the elements towards the sound source.

The IL rises for smaller angles between the direction of the sound waves and the façade plane: this fact means that the shading devices are more efficient as noise reduction system at higher floors, as well as the sound source is closer to the façade.

The measurements at 2 from the façade were aimed to evaluate the possibility to reduce the sound reflection from the façade in the urban environment. The measurement results show again that the standard louvres can increase the SPL in front of the façade, while the sound absorbing devices can reduce it by up to 3 dB at high frequencies.

The experimental measurements have demonstrated how conveniently modified louvres can have multiple functions, in addition to their main role as shading devices. The sound absorbing lower sides of each louvre can highly reduce the SPL on the building facades and at the same time they can partially reduce the sound reflection from the façade into the urban environment.

Further studies will be focused on the optimisation of the single louvre to tune its sound absorption to reduce as much as possible the noise deriving from vehicular traffic.

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