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EFFECT OF FACADE SHAPE FOR THE ACOUSTIC PROTECTION OF BUILDINGS

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ABSTRACT

Façade sound insulation can be improved by using high performance components or by modifying the shape of the façade. In many cases, when high acoustic insulation levels are required, the use of high performance components cannot be sufficient, for technical or economic reasons.

The European standard EN ISO 12354-3 [1] gives a simplified method to estimate the influence of the façade shape in the reduction of sound power level at the outside of the building envelope. In particular, the influence of the façade is evaluated for a number of building typologies as a function of the general direction of the incoming sound and of the acoustic absorption coefficient of the surface of the underside of the balcony.

In the paper, the results of a study on the influence of the façade shape on the incoming sound is evaluated with reference to a great number of different typologies of buildings facades.

The study has been carried out by means of a prediction software based on the modified theory of the ray tracing (pyramid tracing).

With reference to a typical urban configuration, results are expressed as level difference between the simple plane façade and the façade with different kind of shielding.

INTRODUCTION

The Standardized Façade Level Difference $D_{2m,nT}$ can be evaluated by means of Eq. 1, defined by EN ISO 12354-3 [1].

$$D_{2m,nT} = R' + \Delta L_{fs} + 10 \log (V / 6 T_0 S) \text{ (dB)} \quad \text{(Eq. 1)}$$

Where:
R' is the façade sound reduction index (dB);
V is the volume of the receiving room (m^3);
T_0 is the reference value of the reverberation time (0,5 s);
S is the total area of the façade as seen from the inside (i.e. the sum of the area of all façade elements) (m^2);
ΔL_{fs} is the level difference due to façade shape (dB), given by eq. 2.

$$\Delta L_{fs} = L_{1,2m} - L_{1,s} + 3 \text{ (dB)} \quad \text{(Eq. 2)}$$

Where:
$L_{1,2m}$ is the average sound pressure level at 2 m in front of the (shaped) façade (dB);
$L_{1,s}$ is the average sound pressure level on the outside surface of the façade plane, including the reflecting effect of that plane (dB).

The estimation of the level difference ΔL_{fs} can be carried out by means of the empirical method defined in annex C of EN ISO 12354-3.

According to this method, it can be deduced that the effect of the façade shape may be positive (less sound transmission) or negative (greater sound transmission), depending on the height of the line of sight and on the weighted absorption coefficient of the inside surface of the balcony (figure C1 of EN ISO 12354-3 [1]). The positive effect is due to the shielding effect given by façade components like balconies or galleries, while the negative effect is due to the reflection of sound by external surfaces of the façade.

In the case of staggered terraces, the positive effect in sound insulation may be up to 7 dB. Figure C.2 of EN ISO 12354-3 [1] gives the level difference ΔL_{fs} for different façade shapes and sound source orientations.
In literature [2 to 5] there some studies about the effect of other types of façade shapes. Anyway, these studies are referred to the analysis of a limited number of balconies shapes.
In this paper, the effect of many kinds of external façade shielding and balconies are analysed by means of the computational method described in the following.

THE CASE STUDIED

The case studied is referred to a typical urban context with buildings five floors height, aligned along a road 10 meters wide and with sidewalk 2.5 meters wide on both sides of the road (figure 1).
The road is run through by vehicles placed in its central line and has a length of 70 meters to take count of the effect of the sound coming from the lateral sides of the façade.

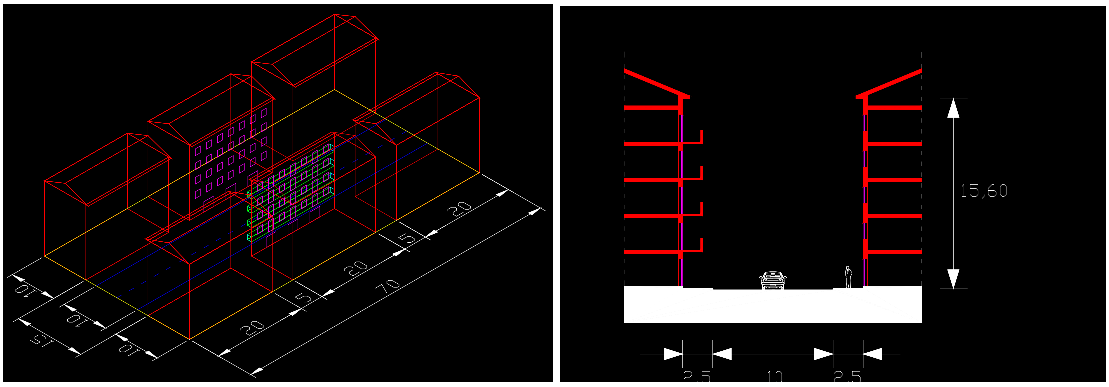


Figure 1 – Axonometric view and vertical section of the case studied.

The building façade analysed is that on the right side of the vertical section of figure 1.
The plane façade drawn in figure 1 (right) is assumed as reference to evaluate the effect of different façade shape.
The façade of the building on the opposite side of the road has balconies 1.5 meters wide and the effect of different shapes of the main building on this façade has also been evaluated.

THE CALCULATION METHOD

Calculations have been carried out by means of a simulation program base on the technique of the modified ray tracing (pyramid tracing).
The characteristics of the building façades, assumed in the calculations, are the followings:
- masonry façade and balcony finished with reflecting plaster;
- window sill in reflecting masonry without openings;
- road surface in concrete (reflecting).

The following software parameters have been assumed as input for the calculations:
- receivers placed on a vertical section plane passing through the centre of the façade with a grid space of 0.2 meters;
- traffic line source (vehicles) reproduced as an array of point sources at a distance of 3 meters each other;
- level of accuracy of the simulation: 10, corresponding to 8 x 2^{10} pyramid traced form each sound sources;
- time of following of the run of each pyramid: 2 seconds, corresponding to a maximum distance run by each ray of 2 x 340 = 680 meters;
- humidity of the air: 75%;
- temperature of the air: 15°C;
- diffraction level: 2, corresponding to the maximum number of diffraction considered for each ray.

THE RESULTS

Figure 2 shows the results of the simulation referred to a façade with a balcony 1.5 meter wide, with the lines of equal sound pressure level calculated with the grid space of the receivers of 0.03 meters.

The values used for the comparison of the effect of different façade shapes are those referred to the points placed at a distance of 0.2 meters from the façade plane and at the eight of 0.3, 1.6 and 2.4 meters form the floor.

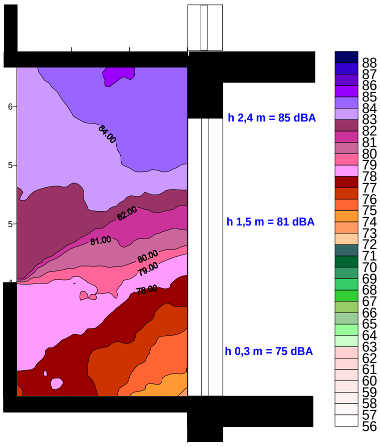


Figure 2 – Lines of equal sound pressure level in the case of a balcony 1.5 meters wide; 4 meters large, at the first floor of the builing.

Because of the very long computation times, all the simulations have been carried out with a grid space of receivers of 0.2 meters.

The results have been compared with those obtained with a grid space of 0.03 meters (figure 2) and have shown no relevant difference.

Figure 3 shows the results in the case of balconies 1.5 (left) and 3 (right) meters wide and 4 meters large; the façade analysed (and compared with the plane façade) is the one on the right side of each graph.

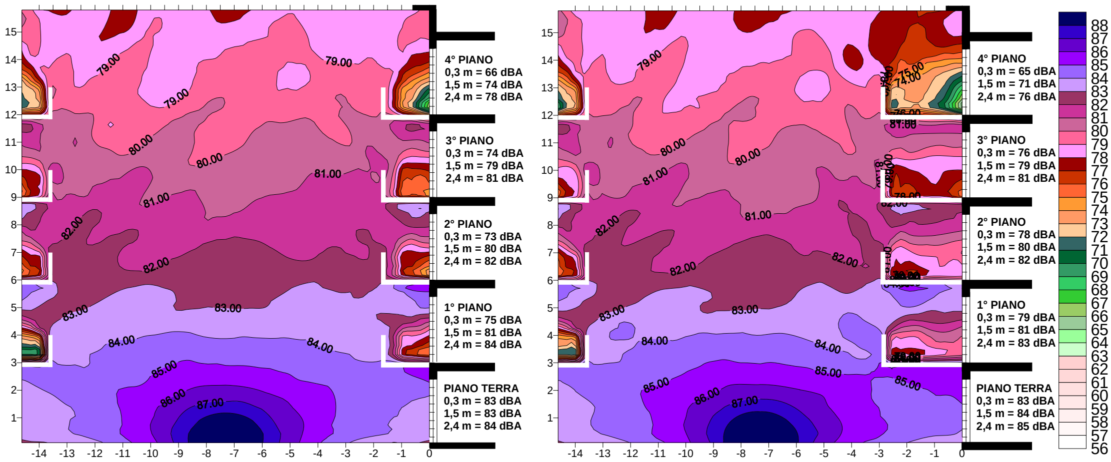


Figure 3 – Lines of equal sound pressure level in the case of balconies 1.5 (left) and 3 (right) meters wide and 4 meters large (receivers with a grid space of 0.2 meters)

The effect of horizontal light shelves placed at the top or the bottom of the window has also been evaluated, but are presented only in the final table of synthesis (table 1, lines 7 and 8).

Figure 4 shows the results in the case of terraces 1.5 and 3 meters wide, with the façade staggered.

In this case, the reduction in sound pressure levels is due also to the increasing distance between the façade and the traffic line.

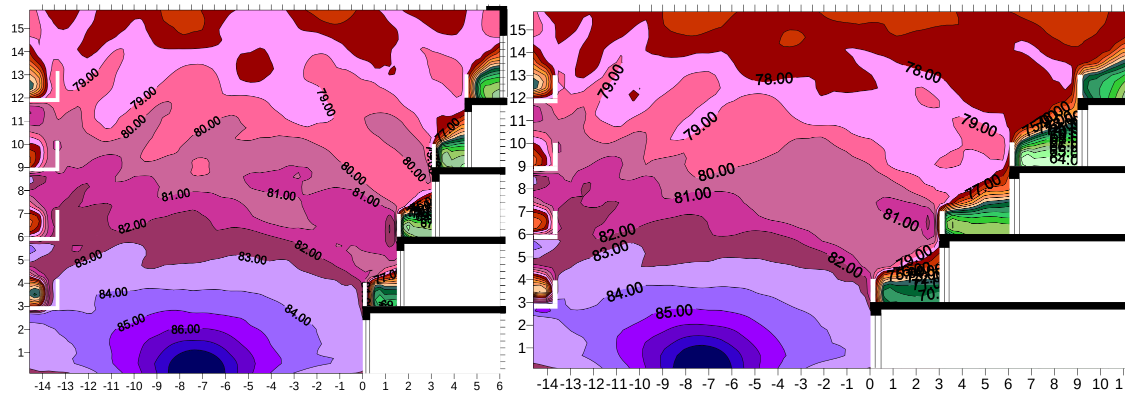


Figure 4 - Lines of equal sound pressure level in the case of balconies 1.5 (left) and 3 (right) meters wide and 4 meters large (receivers with a grid space of 0.2 meters)

In table 1, the results of the level difference between plane façade and shaped façade are synthesized, with reference to the central receiver of the façade (at a distance of 2.4 meters from the floor and at 0.2 meters from the façade plane).

In the case of facades with balconies or galleries, the reduction of sound pressure level may be achieved also with the use of absorbing materials positioned in the inside surfaces of the balcony or gallery or in the façade surface. These materials may reduce the sound reflected by the surfaces of the façade and increase the level difference due the façade shape.
The absorber system used for the simulations is a resonant system whose details and sound absorption coefficient are shown in figure 5.
The system is TOPAKUSTIK® produced by Fantoni group.

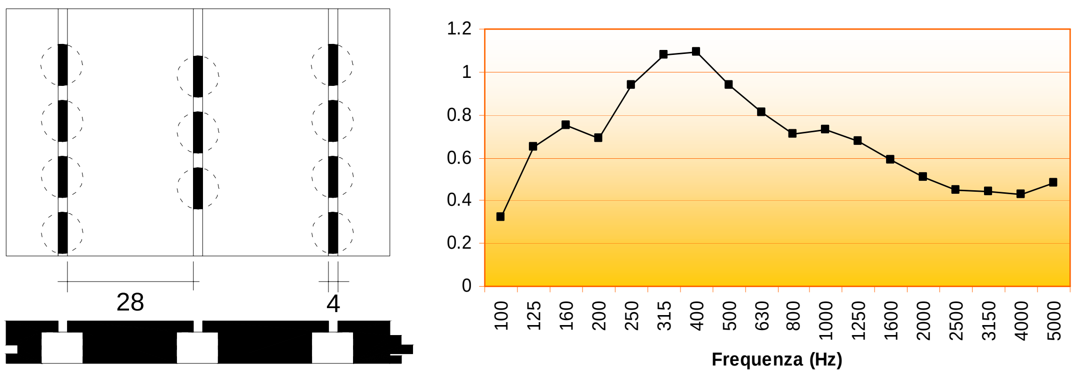


Figure 5 – Detail and sound absorption coefficient of the absorbing system used for the façade surfaces

Table 2 shows in synthetic form all the results of the difference between plane façade and shaped façade with absorbing material in different positions.
The red line indicates the position of the absorbing material of the facade.

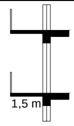
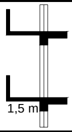
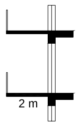
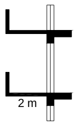
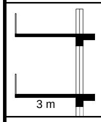
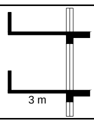
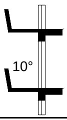
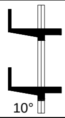
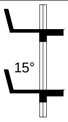
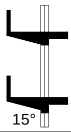
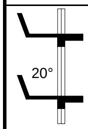
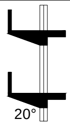
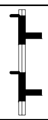
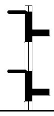
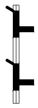
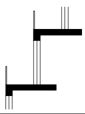
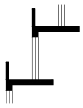
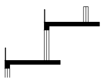
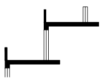
Façade shape	Ground Floor	1° Floor	2° Floor	3° Floor	4° Floor	Ground Floor	1° Floor	2° Floor	3° Floor	4° Floor	Ground Floor
	0	-1	-1	1	3		0	1	1	2	6
	0	-2	0	1	3		-1	1	1	2	7
	-1	-1	-1	1	4		-1	1	1	2	9
	0	2	1	3	7		-1	0	0	2	5
	0	2	1	5	6		-2	-1	0	3	6
	0	2	1	3	7		-2	-1	1	3	5
	0	0	0	1	1		0	0	1	2	2
	0	1	1	3	3		-1	2	3	5	4
	0	0	1	3	3		0	5	6	11	8
	0	2	4	5	5		0	7	10	12	11

Table 1 – Level differences between plane façade and shaped façade referred to the central receiver of the façade (2.4 meters above the ground); columns 2 to 6: …; columns 8 to 12 …

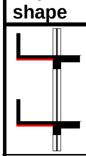
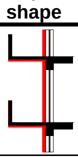
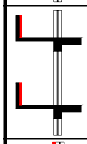
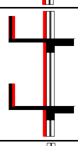
Façade shape	Ground Floor	1° Floor	2° Floor	3° Floor	4° Floor	Façade shape	Ground Floor	1° Floor	2° Floor	3° Floor	4° Floor
	0	3	3	3	8		0	3	4	6	9
	-1	2	1	2	8		2	5	3	5	11

Table 2 – Level differences between plane reflecting façade and shaped façade covered with the absorbing system of figure 5 (the red line indicates the position of the absorber)

CONCLUSIONS

From table 1, the following main consideration may be deduced:

- balcony depth (lines 1 – 3 of table 1) : the effect of the balcony depth is relevant (positive) only for the higher floors. At the ground floor the balcony depth is not relevant
- balcony length (gallery): in general the study points out that the effect of balcony length greater than 4 meters is not relevant;
- structure of the window sill: full section of the window sill creates a greater reduction of 1 – 3 dB if compared with an open banisters; this positive effect increased at higher floors;
- inclination of the window sill (lines 4 – 6, left): an inclination of 10° forward produces a positive effect of 1 dB at every floor, as a consequence of the reduction of sound transmission for diffraction over the upper side of the window sill;
- inclination of the downward surface of the balcony (lines 4 – 6, right): the inclination of this surface of the balcony produces no relevant effect on sound propagation;
- inclination upward of the light shelf (lines 7 – 8, right): for inclinations greater than 30° upward the level difference may increase of 2 – 3 dB at higher floors, in compared to horizontal light shelves;
- staggered façades (lines 9 – 10) with full window sills produce a great positive effect on level difference; with staggers of at least 3 meters, the level difference may be greater than 10 dB, but this effect is partially due to the increased distance between the façade plane and the traffic line.

From table 2, referred to façades partially or totally covered with the absorbing material described in figure 5, the following further consideration may be deduced:

- at the ground floor the effect of absorbing linings is relevant only with complete covering of façade surfaces;
- the effect of absorbing linings of the façade increases at higher floors;
- in general, the better solution, with minimum use of absorbing material (and also better protection of this material from atmospheric agents) is that with the absorbing material positioned in the downward side of the balcony and in the inside surface of the window sill.

References

[1] EN ISO 12354-3: “Building acoustics — Estimation of acoustic performance of buildings from the performance of elements - Part 3: Airborne sound insulation against outdoor sound”.

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[3] Hossam El-Dien H., P. Woloszyn, “Prediction of the sound field into high-rise building facades due to its balcony ceiling form”, Applied Acoustics, 65 (2004), 431-440.

[4] Hossam El-Dien H., P. Woloszyn, “The acoustical influence of balcony depth and parapet form: experiments and simulations”, Applied Acoustics, **66** (2005), 533–551.

[5] Hothersall DC, HoroshenkovKV, Mercy SE., “Numerical modelling of the sound field near a tall *building with balconies near a road*”, Journal of Sound and Vibration (1996), **198(4)**,507–15.