The façade sound insulation and its classification

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Summary
The sound insulation of façades plays a key role in the improvement of internal living comfort and protection of the inhabitants from the disturbing noise coming from the outside of the buildings. Only in few countries, on-site measurements and evaluations are made, in order to verify the real performance of building façades. Italy is one of them and ITC CNR, the main Italian Building Research Institute, has collected a dataset of such measurement results that can be considered unique of its kind, taking into account that on-site façade sound insulation measurements are less frequent and more complicated than internal sound insulation measurements. Starting from this dataset, all the factors that influence the final performance of the façade are analyzed and in particular the main acoustic and non-acoustic parameters, such as wall structures and glazing layers, window percentage and volume/surface ratio. The internal sound level is evaluated taking into account the contribution of outdoor or neighbor noise.

PACS no. 43.55.+p,43,50+y

1. Introduction
The purpose of the research study carried out at ITC CNR of Milan was to review, analyze and interpret substantial field data referring to the façade sound insulation performance. This study has been possible due to the cooperation with the following prominent Bodies which granted permission to use their own data (see Table I) in the context of the COST TU0901[1] activities [2, 3]:
- University of Padova (UNI PD),
- Bicocca University of Milan (UNI MI),
- University of Florence (UNI FI),
- Edinburgh Napier University (BCP).
These data are referred to measurements performed in Italy by ITC-CNR, UNI PD, UNI MI and UNI FI, and to measurements performed in France by BCP (about 2/3 of data were collected in Italy).

2. Setting of the dataset
The detailed dataset which has been developed was structured as follows:

a) Acoustic data:
- measured: external sound level, internal sound level, background noise, reverberation time;
- estimated: weighted sound reduction index Rw of windows (or glass) on the façade.
b) Parameters related to the tested façades:
- building unit typology and storey;
- façade typology and surface;
- typology and volume of the room;
- typology, surface, and glass of windows on the façade;
- typology and layers of the façade wall;
- surface % of window and of wall on the façade;
- presence of ventilation and/or shutter boxes on the façade.
- Data were divided into key category groups to investigate the influence of the features of the façade on the measured quantities. According to the façade typology, the data are divided into three key category groups:
- balcony: the façades with a balcony;
- corner: the façades including corners with or without balcony;
- plane: the plane façades without balconies.
plane: the plane façades without balconies.

To investigate the effect of the wall typology, five sub-groups are defined, according to the number of layers (single layer wall or cavity wall) and the mass of the wall.

Table I. Number and source of on-site measurement data.

<table>
<thead>
<tr>
<th>DATA SOURCES</th>
<th>Total Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITC CNR</td>
<td>90</td>
</tr>
<tr>
<td>UNI FI</td>
<td>30</td>
</tr>
<tr>
<td>UNI MI</td>
<td>33</td>
</tr>
<tr>
<td>UNI PD</td>
<td>83</td>
</tr>
<tr>
<td>BPC</td>
<td>98</td>
</tr>
<tr>
<td>TOTAL DATA</td>
<td>334</td>
</tr>
</tbody>
</table>

3. Influence of the acoustic and non-acoustic parameters

3.1. Comparison of the different descriptors

The described dataset of façade sound insulation measurements was used as a starting point for the calculation of various single-number quantities (SNQs): the $D_{2m}$, $D_{2m,n}$ and $D_{2m,nT}$ third-octave band values were calculated, according to ISO 140-5 [4], applying the following equations:

$$D_{2m} = L_{1,2m} - L_2 \, \text{dB},$$
$$D_{2m,n} = D_{2m} - 10 \log(A/A_0) \, \text{dB},$$
$$D_{2m,nT} = D_{2m} + 10 \log(T/T_0) \, \text{dB},$$

All the SNQs analyzed below originate from $D_{2m,nT}$ third-octave values; basic statistics (minimum = min; maximum = max; average = avg and standard deviation = std) on the whole sample is presented in Figure 1, showing that sound insulation of the façades generally increases with frequency, although a local peak around 100 Hz is observable. At the lowest frequencies, sound insulation performances drop. Standard deviation of the results is between 4.5 dB at middle frequencies and 7.5 dB in the highest frequency bands.

The following SNQs were determined:
- $D_{2m,nT,w}$, calculated as defined in ISO 717-1 [5];
- $D_{2m,nT,Atr}$, as the $D_{2m,nT,w} + C_{tr}$ calculated from 100 to 3150 Hz;
- $D_{2m,nT,tr50}$ calculated applying the following equation:

$$D_{2m,nT,tr50} = 10 \log \left( \frac{1}{T} \sum_{i} 10^{D_{2m,nT,i}/10} \right),$$

where:
- $i$ is the index of the third-octave band, from 50 to 5000 Hz;
- $L_{traffic,i}$ is the level of the traffic reference spectrum at third-octave band $i$;
- $D_{2m,nT,i}$ is the measured standardized sound level difference value at third-octave band $i$.

The equation (4) applies the evaluation method of the SNQ proposed in ISO CD 16717-1 [6].

The descriptors $D_{2m,nT,w}$ and $D_{2m,nT,Atr}$ are currently adopted by the regulations of some European Countries for defining façade insulation legal requirements or classes, (see Table II, which presents the façade sound insulation descriptors currently in use in European Countries and the number of countries which use them) and the last one $D_{2m,nT,tr50}$ is a new parameter firstly proposed by COST Action TU0901 [7].

Table II. Different façade sound insulation descriptors used across EU countries.

<table>
<thead>
<tr>
<th>DESCRIPTORS</th>
<th>N° OF COUNTRIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{2m,nT,w}$</td>
<td>3</td>
</tr>
<tr>
<td>$D_{2m,nT,Atr}$</td>
<td>6</td>
</tr>
<tr>
<td>$R'_{w}$</td>
<td>2</td>
</tr>
<tr>
<td>$L_{inside}$</td>
<td>6</td>
</tr>
</tbody>
</table>

In order to assess the effects of an extended frequency range, general statistics of the SNQs of the façade insulation are calculated as given in Table III. $D_{2m,nT,Atr}$ and $D_{2m,nT,tr50}$ have very similar statistical properties due to their similar nature. Their average values are, however, about 3 dB and
The two SNQs which refer to the traffic noise spectrum show slightly lower standard deviation than $D_{2m,nT,w}$. Figure 2 shows the distribution of the values of the three different descriptors $D_{2m,nT,w}$, $D_{2m,nT,Atr}$ and $D_{2m,nT,tr50}$ for the façade sound insulation for the whole dataset; the maximum data distribution, corresponds to three different values of the façade sound insulation of the three considered descriptors; for $D_{2m,nT,tr50}$ the maximum corresponds to 36 dB, for $D_{2m,nT,Atr}$ to 37 dB and for $D_{2m,nT,w}$ to 41 dB. As shown in Figure 2, $D_{2m,nT,w}$ generally takes higher values than the other two descriptors and the distribution of $D_{2m,nT,w}$ is wider (from 24 dB to 50 dB) than that of $D_{2m,nT,Atr}$ and $D_{2m,nT,tr50}$ (23 dB to 46 dB); this trend depends on the fact that $D_{2m,nT,w}$ does not include the traffic noise spectrum adaptation term and that the influence of traffic noise is greater for the highest-performance façades.

As a complementary analysis, useful to estimate the classification classes and their steps and range, the minimum, the maximum and the average values of the three principal descriptors of the façade are compared in Figure 3.

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For the comparison, Italian regulations set $D_{2m,nT,w} = 40$ dB as minimum allowed value in residential buildings.

Another aspect that must be considered is the translation from the current descriptors into a harmonized one. For example, to translate the $R'$ descriptor into the $D_{2m,nT}$ descriptor, predictive relations, such as the one that follows, defined in EN 12354-3 [8] can be applied:

$$D_{2m,nT} = R' + \Delta L_{fs} + 10\log \frac{0.16V}{T_0 S},$$

where:
- $R'$ is the apparent sound reduction index of the façade;
- $\Delta L_{fs}$ is the sound pressure level difference due to the façade shape;
- $V$ is the volume of the receiving room, in cubic meters;
- $T_0$ is the reference reverberation time; for dwellings given as 0.5 s;
- $S$ is the façade area viewed from inside, in square meters.
Table IV. Multi-variable linear regression analysis between different façade typology and $D_{2m,nT,w}$.

<table>
<thead>
<tr>
<th>Façade typology</th>
<th>balcony</th>
<th>corner - balcony</th>
<th>plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Standard deviation</td>
<td>P-value</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>Room volume V</td>
<td>0.218</td>
<td>0.0300</td>
<td>0.096</td>
</tr>
<tr>
<td>Façade surface S</td>
<td>1.617</td>
<td>0.0001</td>
<td>0.396</td>
</tr>
<tr>
<td>V/S</td>
<td>4.138</td>
<td>0.0001</td>
<td>1.824</td>
</tr>
<tr>
<td>V / window %</td>
<td>0.095</td>
<td>0.0016</td>
<td>0.017</td>
</tr>
<tr>
<td>Window %</td>
<td>26.931</td>
<td>0.0011</td>
<td>9.186</td>
</tr>
</tbody>
</table>

Thus it is necessary to assign a value to the correction term $10\log(0.16V/(T_0S))$ in the equation (5). Therefore, the non-acoustic parameter V/S ratio and its distribution have been analyzed in this study.

Considering the total amount of the data (334 data), the average volume is 90.2 m$^3$ and the average V/S ratio is 4.6 m. However, the volume of a significant number of rooms exceeds 100 m$^3$. If both offices and schools are excluded, considering only flats (235 data), houses (43 data), hotel (1 data) and hospital (1 data), with a sample of 280 rooms in total, the V and V/S average values are then significantly lower: 41.9 m$^3$ (std = 19.61) and 3.9 m (std = 1.34), respectively. In that case the correction term in the equation (5) is 0.96 dB. Taking into account that from the graph of Figure 4 the maximum of the distribution of V/S ratio is at the value of 3.7 m, corresponding to a value of 0.73 dB of the correction term, this value along with 0.96 dB are the more relevant ones for the case of residential rooms.

### 3.2. Correlation between SNQs and non-acoustic parameters

The correlation between the SNQs and the non-acoustic parameters for different façade typologies is investigated by an analysis-of-variance approach.

![Figure 4. Distribution of the V/S ratio.](image)

The total variation in the dependent variables are treated in a systematic way. Then, the p-values of the relation between the various parameters for the SNQs investigated are calculated to determine the value of the test statistics significance; if a p-value was found to be less than 0.05, then the result would be considered statistically significant.

As shown in Table IV, in the case of a façade with a balcony, the selected parameters are all influential on the $D_{2m,nT,w}$. This makes measurements more sensitive to many non-acoustic parameters as room volume, façade surface, window percentage (= S window / S façade).

In the case of a plane façade, the room volume has the highest influence on the window-percentage ratio. It should be noted that the façade surface and the V/S ratio seem to have no significance in this case.

On the other hand, in the case of a corner façade, when multiple source positions are used for the measurements, the influence of the non-acoustic parameters can be neglected.

The façade construction material could affect its sound insulation performance. However, considering that the construction typologies included in the dataset are characterized by masonry walls, the sound insulation of the façade is highly dependent on the window performances. The correlation coefficients were used to assess the influence of window performance on the façade sound insulation; they describe the linear dependency between two well correlated quantities, in terms of coefficient value. When their values approach extreme values ±1.0 the correlation between the observed quantities is considered to be high. In Table V the main parameters related to the windows in the tested façade are correlated to the different SNQs. It is shown that window percentage and insulation properties of the glass ($R_{W,\text{glass}}$) predominantly determine the insulation properties of the whole façade.

Focusing on the performance of the glass and analyzing the spectrum adaptation term $C_t$, it is interesting to underline that the value of $C_t$ increases as the $R_W$ of the glass increases and
consequently the difference between SNQ-without-LF \((D_{2m,nT,w})\) and SNQ-with-LF \((D_{2m,nT,tr50})\) increases as the performance of glass increases; an example is shown in Table VI for two glass typologies.

Table V. Correlation coefficients between the window’s parameters and the SNQs.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>(D_{2m,nT,w})</th>
<th>(D_{2m,nT,Anr})</th>
<th>(D_{2m,nT,tr50})</th>
</tr>
</thead>
<tbody>
<tr>
<td>window %</td>
<td>0.281</td>
<td>0.254</td>
<td>0.244</td>
</tr>
<tr>
<td>(R_w),glass</td>
<td>0.45</td>
<td>0.45</td>
<td>0.438</td>
</tr>
<tr>
<td>(S)window</td>
<td>0.102</td>
<td>0.11</td>
<td>0.137</td>
</tr>
<tr>
<td>(R_w),glass / window%</td>
<td>0.33</td>
<td>0.297</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table VI. Influence of the glass typology on the façade insulation (SNQs and spectrum term \(C_w\)).

<table>
<thead>
<tr>
<th>Glazing layers</th>
<th>(D_{2m,nT,w})</th>
<th>(D_{2m,nT,tr50})</th>
<th>(C_w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.1/15/4</td>
<td>41</td>
<td>35</td>
<td>-5</td>
</tr>
<tr>
<td>4/12/4</td>
<td>31</td>
<td>29</td>
<td>-2</td>
</tr>
</tbody>
</table>

4. Other descriptors

As shown in Table II there are different façade sound insulation descriptors and they may be divided into two big categories: the former, including \(D_w\), \(D_A\) and \(R_w\) expressing the performance directly, the latter, including the \(L_{inside}\), expressing it indirectly. In order to study the relationship between the two approaches, a new measurement campaign has started and data are being collected. Figure 5 shows an example of result, where the blue curve is the \(L_{Aeq}\) measured inside a room of a dwelling located near an airport and the red one is the outdoor \(L_{Aeq}\) measured in front of the façade, both measured over a 24-hour time period.

The sound insulation of the façade of the tested room is known from previous measurements thus allowing a comparison between the different quantities. By the time this paper must be submitted, the results of these analysis will not yet be fully available; they will be presented at the conference.

Figure 5. Trend of the indoor and outdoor \(L_{Aeq}\) for a room near an airport.

5. Conclusions

All the analyzed descriptors of the façade sound insulation are mutually well correlated, but the values of correlation coefficients are somewhat lower in the case of an extended frequency range, thus additional precaution is needed if the low frequencies descriptor is adopted. In fact, below 100 Hz, the façade sound insulation performances drop, and a significant spread at low frequencies is highlighted by the frequency analysis results. The measurement difficulties and the uncertainty at the lowest frequencies, which occur in practice, produce such result.

The values of the descriptor that include the \(C_w\) term are on average 4 dB lower than values with no adaptation term. But considering only the average, this could be a limit; because the average can highly underestimate or overestimate the spread between the high and low performances of a window and therefore of the façade. In fact, the analysis on the influence of the window performance showed that the value of \(C_w\) increases as the \(R_w\),glass of the glass increases.

The distribution of \(D_{2m,nT,w}\) is wider (26 dB wide from 24 dB to 50 dB) than the distribution of \(D_{2m,nT,Anr}\) and \(D_{2m,nT,tr50}\) (23 dB from 23 dB to 46 dB) since the influence of the \(C_w\) is greater for the highest-performance facades.

Considering \(D_{2m,nT,tr50}\), the maximum value of the data distribution shifts from 41 \((D_{2m,nT,w})\) to 36 \((D_{2m,nT,tr50})\) dB. Therefore if the LF descriptors are adopted without properly changing the limits of the regulation in force, a very large amount of the existing housings will fall below the law limit (at least in Italy). Moreover, for new dwellings a great effort will be required to builders and manufacturers to satisfy the requirements with the new descriptors.

Regarding the descriptors of the \(L_{inside}\) and their relation with both the external sound level and the
façade sound insulation, a particular care is needed
to take into account the contribution due to noise
sources inside the building.

Acknowledgement

The authors gratefully acknowledge the COST Action TU0901 for funding the STSM on the
façade sound insulation and, University of Padova, Bicocca-University of Milan, University of
Florence and Edinburgh Napier University, for providing data for the dataset.

References


