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NOISE CONTROL FOR A BETTER ENVIRONMENT

Noise control in hospitals: considerations on regulations, design and real situations

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ABSTRACT

Hospitals include a variety of different spaces with different requirements and levels of sensitivity but also different activities and equipment that can cause high noise levels. Despite the regulations that usually apply to hospitals, noise control is not an easy task. In Italy, the design and construction of hospital buildings must guarantee the acoustic requirements given by the National Regulation (1995-1997), which refers to all new buildings, and by the new Decree on Minimum Environmental Criteria (2017), which applies to public buildings and refers to the Italian acoustic classification scheme (UNI 11367-2010). However, the need to create spaces suitable for the various types of use entails difficulties in identifying where and how to apply the limits set by the legislation. In addition, there are situations in which, regardless of the legislation, it would be opportune to consider more adequate acoustic comfort. In the paper, we analyse the various situations and evaluate the applicability of the legislation. From experimental measurements performed in real cases, some methodological proposals are reported both to ensure the satisfaction of the requirements imposed by the legislation and to meet the needs for more specific acoustic regulations for hospital.

Keywords: Hospitals, Noise, Acoustic performance
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1. INTRODUCTION

The acoustic conditions in hospital environments are relevant for the patients in order to guarantee their wellbeing. This includes the following issues:

- supporting the acoustical privacy of patients;
- supporting the psycho-physical healing of patients, allowing them to sleep/rest peacefully;
- supporting affective processes, through pleasant sounds capable of inducing feelings of calm and wellbeing.

A good acoustic comfort is also important for the personnel in order to properly perform their duties, avoiding additional causes of fatigue.

During the design process of new healthcare buildings, various aspects should be considered to create a positive environment from an acoustical point of view.

One issue is related to the location, which has to be compatible with the different activities of the surrounding area; in fact, the building is a receiver of the noise from adjacent roads and activities but also a noise source for existing external receivers, considering the noise generated from the technical systems operating in the healthcare buildings and the increase of traffic in the nearby roads. This issue requires an assessment of the environmental noise already present in the area and the noise generated by the new building with respect to the external receiver.

Another important issue is related to the acoustic comfort inside the building. For this purpose, the primary design action is the control of the environmental noise level and of situations of acoustical conflict thorough the correct distribution of noise sources and the selection of sound insulating partitions between spaces. A further action could involve the introduction of pleasant acoustical characteristics in the environment (music, natural sounds).

The control of noise levels and of acoustical privacy in hospitals is usually the subject of national regulations or standards, which can consider the following items:

- choices of a spatial distribution of the various activities, in order to limit or eliminate situations of interference or acoustical conflict;
- use of sound insulating enclosures and internal partitions;
- use of sound absorbing materials to control reverberation;
- careful attention to the sound insulation of technical systems, installations, pipes, air ducts, mechanical equipment.

The design of the spatial distribution of the hospital can be based on the correct location of spaces that require silence (wards, waiting rooms, visiting rooms, etc.) and the use of criteria of acoustical compatibility in the distribution of spaces and activities to avoid the creation of acoustic interference by placing noisy spaces next to areas that require silence.

The acoustic performance of internal partitions and façades is very important to guarantee acoustic comfort, but usually the noise produced inside the indoor environment (health equipment, ventilation systems, sanitary water systems, handling of healthcare equipment and people) is predominant.

Regarding the airborne and impact sound insulation between premises with different uses, it is important to have adequate technical solutions and avoid flanking transmission. Considering the industrialised procedure to build this type of buildings, and the use of curtain wall façades, particular attention needs to be paid to the connection between the façade and the separating walls and floors, to avoid leakage and sound transmission [1].

The façade sound insulation is important not only to reduce the perceived traffic noise but also to reduce the noise emitted by the air treatment unit usually located on the roof of the buildings. The acoustic performance of windows is the main issue to obtain good façade sound insulation. Windows with good acoustic and energy characteristics are quite common [2] although it is difficult to obtain good façade sound insulation when the roller shutters are used. An alternative to the use of roller shutters is the use of louvres as shading systems; in this case the acoustic performance could be improved by using absorbing shading systems [3].

The control of reverberation is also particularly important in monitoring acoustical conditions and improving speech comprehensibility of people who are nearby and reduce the noise of voices of people who are speaking far away. In this regard, also the spatial typology and form of indoor environments is important. For example, there is a great difference between open space layouts and closed room layouts for the patients' rooms and between a sole centralized waiting room and separate waiting areas.

Finally, there are usually many potential noise sources inside the hospital structure such as ventilation, heating, air conditioning, hydraulic systems, hollow conductor systems, elevators, doors and diagnostic equipment [4].

2. THE ITALIAN ACOUSTIC REQUIREMENTS FOR HOSPITALS

Limit values of acoustic performances of hospital buildings are very different from one country to another [5]. In Italy, the limit values are different for public and private hospitals and are described in two decrees: the decree of 5 December 1997 [6], applicable to all kinds of new hospitals built after 1997, and the Decree of 11 January 2017 [7], applicable to new (from 2017) or refurbished public hospitals. For public hospitals, limit values refer to the National standards UNI 11367:2010 [8, 9], for insulation requirements, and UNI 11532:2018 [10], for reverberation requirements. However, the current version of the standard UNI 11532 only gives the description of the relevant parameters (reverberation time, clarity and speech transmission index) but does not give any indications for limit values for hospitals.

In the following, the main performances required for Italian hospitals are synthetized.

The performance required for *façade sound insulation* is the same for public and private hospitals (since the value given by the 1997 decree is greater than that of 2017) and is: $D_{2m,nT,w} \geq 45$.

The performance of *airborne sound insulation of internal partitions* is different for private and for public (new and refurbished) hospitals. In the first case, the limit value refers only to partitions between the hospital and other properties (building units) an is: $R'_w \geq 55$ dB.

For public hospitals, the limit values are given by the Italian Acoustic Classification Scheme (ACS) introduced by the standard UNI 11367 [8, 9], Table 1 (superior performance of annex A and good performance of annex B).

Table 1. Limit values of airborne sound insulation of public hospitals in Italy [8].

Between the hospital and other properties (building units)	$R'_w \geq 56$ dB
Between two hospital rooms or between a hospital rooms and other rooms (vertical partition without doors)	$D_{nT,w} \geq 50$ dB
Between two hospital rooms or between a hospital rooms and other rooms (horizontal partition)	$D_{nT,w} \geq 55$ dB
Between two hospital rooms and other rooms (vertical partition with doors)	$D_{nT,w} \geq 30$ dB

The descriptor used for the airborne sound insulation between rooms inside the hospital is $D_{nT,w}$ and not R'_w, because in this case there are relevant paths of sound transmission (for example, through corridors or air ducts) different from the direct transmission through the partition area.

The requirement of *impact sound insulation* for private hospitals refers only to partitions between the hospital and other properties (building units) and is $L'_{n,w} \leq 58$ dB.

For public hospitals, the limit values are given by the superior performance of UNI 11367:2010 and refers both to partitions between the hospital and other building units and to partitions between two hospital rooms or between a hospital room and other rooms and is $L'_{n,w} \leq 53$ dB.

With reference to the reduction of *noise from building service equipment*, private hospitals must agree to the requirements given by Decree 5 December 1997:

- equivalent sound pressure level from service equipment with continuous operation, $L_{Aeq} \leq 25$ dBA;
- maximum sound pressure level from service equipment with discontinuous operation measured with the "slow" dynamic characteristic, $L_{ASmax} \leq 35$ dBA.

In this case, the measurement does not have to be corrected for the reverberation time. For public hospitals the limit values are given by the superior class of UNI 11367:2010 and are the following:

- corrected equivalent sound pressure level from service equipment with continuous operation, $L_{ic} \leq 28$ dBA;
- corrected maximum sound pressure level from service equipment with discontinuous operation, $L_{id} \leq 34$ dBA;

where:

$L_{ic} = L_{Aeq} + K_1 + K_2$; $\quad L_{id} = L_{ASmax} + K_2$;

K_1 = correction for background noise; $\quad K_2 = -10 \log (T/T_0)$;

T = average reverberation time in the room measured according to EN ISO 3382;

T_0 = reference reverberation time given by: $T_0 = 0{,}5$ s for $V \leq 100$ m^3;

$T_0 = 0{,}05 (V)^{0,5}$ for $100 < V < 2500$ m^3; $\quad T_0 = 2{,}5$ s for $V \geq 2500$ m^3.

In general, the continuous operating equipment is that whose sound pressure level measured with the "fast" dynamic characteristic has oscillations not greater than 5 dB for the whole duration of the operating cycle or of the operating time (i.e. heating, cooling, ventilation systems). The sound level from service equipment is to be measured in a room different from that of the sound source. Measurements must comply with requirements given by annex D of UNI 11367:2010 (adapted from EN ISO 10052 and EN ISO 16032).

With reference to reverberation requirements, there are no limit values for private hospitals (Decree 5 December 1997) while for public hospitals it is necessary to refer to the National standard UNI 11532 (Reverberation Time and Speech Transmission Index), but the current version of this standard gives no limit values for hospitals.

3. CASE STUDIES

3.1. Measurements of noise levels inside hospital rooms

These measurements have been carried out in a maternity ward in a hospital of an important city, with the aim to [11]:

- measure the sound pressure levels due to the equipment and installations (alarms, air ducts etc.) and to the activities in the corridors and in adjoining rooms (voices, movement of trolleys and stretchers etc.);
- measure the sound insulation between two rooms.

The room where measurements were carried out was not occupied during the entire two days of measurements. This condition was verified both through interviews to the hospital staff and through the measure of illumination levels. In fact, for a few moments during the sound level measurements the staff entered inside the room and turned the light on. The measured data during those moments were eliminated from further analysis.

Moreover, some questionnaires were distributed to all patients present in the hospital ward during the time of two weeks, with the aim to better analyse and explain the measurement results.

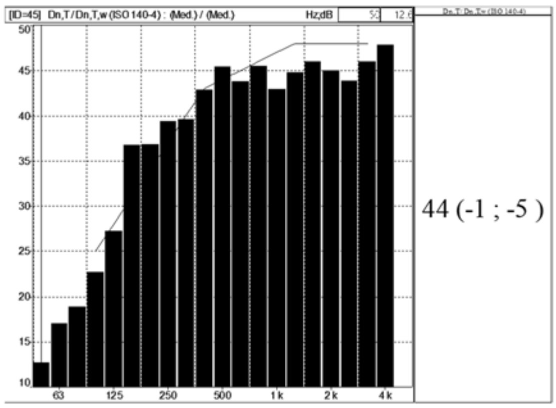

Figure 1. Standardized sound insulation, D_{nT}, between two adjoining rooms of the maternity ward (R'w = 44 dB; $D_{n,w}$ = 41 dB; $D_{nT,w}$ = 44 dB; $T_{avg\ 500\text{-}1000\ Hz}$ = 0.8 s; V = 67.8 m^3; S = 20.4 m^2).

The sound insulation between adjoining rooms was measured according to the procedure described by ISO 16283-1 [12] in rooms normally furnished but not occupied during the measurements. The partition wall was composed by four plasterboard layers

(2+2) separated by a cavity gap partially filled with glass fibre and a single metal stud; the rooms were connected through the corridor and two doors that were closed during the measurements. Figure 1 shows the frequency values of the standardized sound insulation, D_{nT}, between the adjoining rooms.

The Sound Pressure Level measurements were conducted in a furnished room not occupied during the entire two days of the recording. Noises measured inside the room were therefore due only to the air conditioning system and to transmission through the door (toward the corridor) and the partition (toward another bedroom). The dimensions and the finishing of the room were the same as the other bedrooms of the ward. Measurements started at 11.30 a.m. on Friday and finished at 10.30 p.m. on Sunday. Figure 2 shows the time history of the Sound Pressure Level during the measurement period. Nigh periods are evident in the graph since there is a clear drop in the level as a consequence of the turning off of the conditioning system.

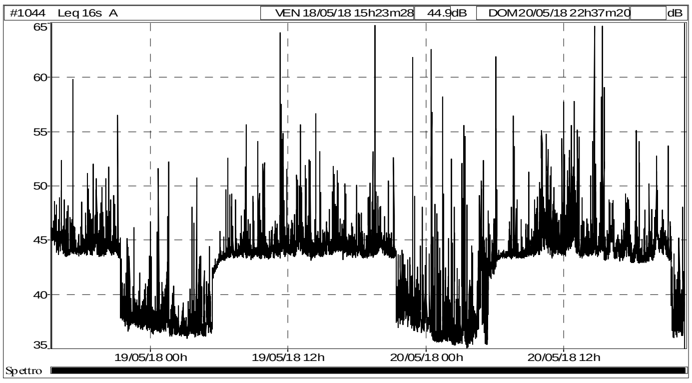

Figure 2. Time history of the Sound Pressure Level in a room not occupied from Friday morning to Sunday night ($L_{Aeq\ night}$ = 38.3 dBA; $L_{Aeq\ day}$ = 45.0 dBA).

The measurement results have been analysed by selecting those noise events that exceeded the equivalent sound pressure level of 45 dBA (on the basis of a sound record with samples every 2 s) during the two night periods. Indeed it has been found in scientific literature that above the SPL of 45 dBA the patient is likely to wake up.

On the basis of this assumption, it has been found that 50 noise events above 45 dBA occurred during the first night, while 191 during the second night. The greater number of noise events recorded during the second night, especially from 4 to 5 a.m., were probably due to a medical emergency in the hospital ward.

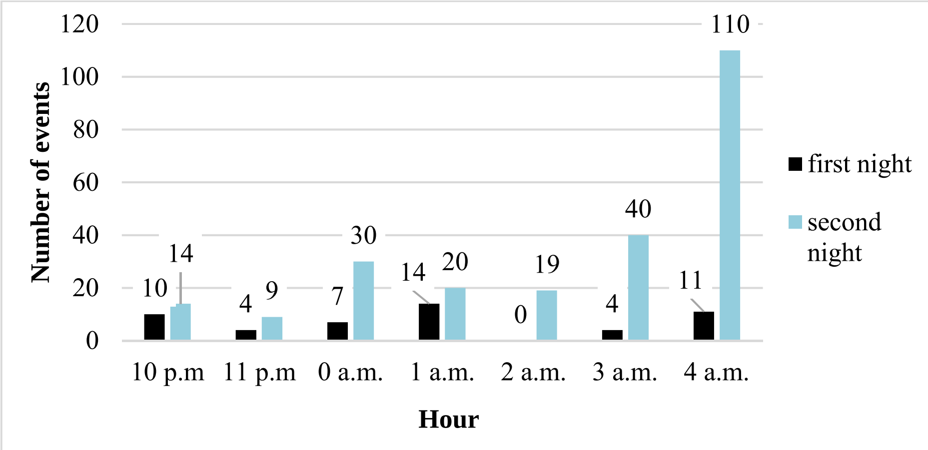

Figure 3. number of noise events with $L_{A,eq}$ > 45 dBA during the two night of measurement.

The survey was composed of 16 questions referred both to the acoustic (8), lighting (3) and colorimetric (2) issues of the hospital. It was filled out by 108 people (about 70% patients and 30% companions). According to the results, 65% of patients declared to be awakened by noise during the night (27% with many awakenings) and about 30% of patients declared that, after the night awakening, they had problems going back to sleep.

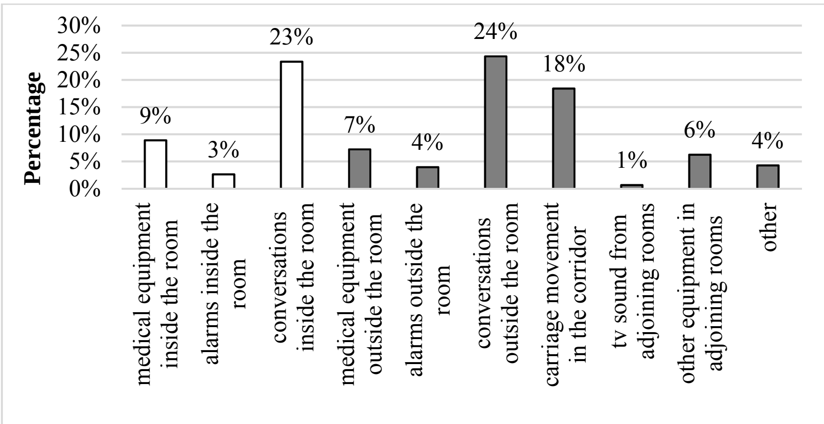

Figure 4. Percentage of answers to the question about the source of disturbing noise (white bars = inside the rooms; gray bards: outside the room).

The main source of noise, according to the perception of patients, was outside the room and mainly came from the corridor (conversations and carriage movements).

The results of the survey also agree with measurement results, since in this latter case, noise inside the room was excluded; despite this, a great number of noise events exceeding 45 dBA occurred during both measurement nights. Moreover, the sound insulation performance of the partition between rooms (R'_w = 44 dB; $D_{n,w}$ = 41 dB; $D_{nT,w}$ = 44 dB) leads to state that the noise coming from the corridor is the main disturbing source during the night.

In spite of this, the new Italian regulation [7] pays greater attention to the sound insulation performance of partitions between adjoining rooms ($D_{nT,w} \geq 50$ dB) than to the sound insulation between a room and a corridor ($D_{nT,w} \geq 30$ dB).

With reference to the continuous operating equipment noise, in this case study, the background noise due to equipment was 36 dBA ($L_{A95} \cong L_{A99}$), during the first night, and 43 dBA during the day. These values, although not corrected for the reverberation time, are largely greater that the limit values set by the current Italian legislation ($L_{ic} \leq$ 28 dB) [7, 8].

3.2 Measurements of the acoustic performance of partitions, façades and noise from service equipment

In order to verify the compliance with the national regulation (Decree 5-12-97 [6]), several measurements were carried out in different wards and offices of a new hospital, before the approval of the new Decree of 2017 [7].

Regarding *façade sound insulation* ($D_{2m,nT,w}$), the legal limit for wards and other hospital areas (surgeries, etc.) is 45 dB, 42 dB for administration and management offices, 48 dB for kindergarten, and 40 dB for lodgings. The preliminary measurements in the wards had highlighted some negative results caused by the noise passing through the box of the roller shutters. An intervention with sound-absorbing material inside the box was then carried out on all the façades facing parking access ramps or roads, which ensured the acoustic insulation results complied with the limit. In the administration and managements offices, the external walls are characterized by continuous glazed façades. The measures have shown that, under standard conditions, the results do not comply with the legal limit, even if only slightly. The cause is attributable to the noise passing between the blind façade panels and the beams / uprights of the façade lattice. In the kindergarten, the results did not comply with the legal limit. The measurements highlighted criticalities for the noise passing through the frame of the doors and windows, especially at the joint with the floor and with the internal walls. This is the typical case in which the legal limit seems too high with respect to the activity inside, where usually the noise generated by the voices of the children is very high. In the guesthouse, the results comply with the legal limit.

Regarding the *airborne sound insulation*, the Italian legislation require compliance exclusively between separate housing units, while the rooms in the hospital and the offices within the same hospital ward, with doors along the same corridor, are considered to belong to the same housing unit. Therefore, between these rooms the established requirement ($R'_w \geq 55$ dB for hospital wards and $R'_w \geq 50$ dB for offices) does not have to be verified. The purpose of the measurements was to assess whether the minimum requirements could be met in order to guarantee privacy between hospital rooms and adjoining offices. The results were between 30 and 46 dB. The lower values are mainly due to the noise passing through the doors and through the air vents. Considering the airborne sound insulations between different wards, usually the results were well above the legal limit. In these cases, in fact, the different wards were on different floors or separated by stairwells or corridors.

Regarding the measurements of the *impact noise level*, all results were found to comply with the legal limits ($L'_{n,w} \leq 58$ dB) when the measurements were made between two different floors. In case of measurements with source and receiving rooms adjacent and on the same floor, the results were much higher due to direct connection between floors and the presence of doors along the same corridor. In this latter case, the legal limit are not considered. The floating floors, in this case, were realized on the whole floor before the lightweight partitions between rooms were built.

Regarding the *noise from discontinuous service equipment* (sanitary equipment, waste water installations, lift, etc.), the legal limit (Decree 5-12-97 [6]) for hospital environments is 35 dBA ($L_{ASmax} \leq 35$). The measurements were made following the procedures of the ISO 16032 standard. It must be considered that the type of source (mostly WC drains), the measurement technique and the normalization procedures, determine a measurement uncertainty of about 2-3 dB. The tests were conducted considering the noisiest configurations referred to the noise of water passing through the drain columns, flushed from the toilets located on the upper floors of the receiving area, and the noise from the toilet drainage of the adjacent bathroom. The preliminary measurements had highlighted some criticalities due to the presence of the drainage columns inside the cavities near the rooms and to the rigid contact of the sanitary ware and the drainage pipes with the prefabricated bath units. Various experiments were therefore conducted in order to identify the most appropriate interventions to reduce the noise inside the hospital rooms. One or more interventions were identified for each of the noisiest configurations, among other the improvement of the acoustic insulation of the wall of the draining cavities by coating with panels of sound-absorbing material with high density and the decoupling of the WC box, suspended toilet and pipes from the bathroom wall by inserting a thin elastic layer. Despite the operations described above, carried out in order to get as close as possible to the values specified in Decree 5-12-97, some situations remain with sound levels slightly above the limit. The values obtained were instead compatible with the reference value for basic performance (L_{id} = 39 dB (A)) reported in the UNI 11367-2010 [8].

Regarding the *noise from continuous service equipment* (heating and ventilation systems, etc.), the legal limit of Decree 5-12-97 for hospital rooms (wards, surgery and rest rooms) is 25 dBA ($L_{Aeq} \leq 25$). For other types of environments (waiting rooms, offices, service and distribution rooms, medical offices, clinics, etc.), the limit value of 35 dBA is considered. The noise is to be measured in a room different from that of the sound source. Therefore, this limit does not apply to the noise level of the fan coils or of any installation parts installed inside the rooms. In consideration of the doubts on this specific point of the Decree 5-12-97 and of the very restrictive limit value (especially if compared to typical background noise), it is standard practice, for compatible situations, to refer to the indications provided by the UNI 8199 standard [13] and now also to the Decree of 2017 [7]. The results of the measurements comply with the reference values of UNI 8199 in most of the situations.

In the following table, a summary of the most relevant results, concerning airborne and facade sound insulation, noise impact levels and service equipment levels measured in the hospital ward, is provided.

Table 1: Summary of the acoustic performance of a new hospital: ● requirement fulfilled; ○ requirement slightly unfulfilled; ▼ requirement unfulfilled; × requirement does not apply.

	$D_{2m,nT,w}$	R'_w	L'_w	L_{ASmax}	L_{Aeq}
Wards	●	×	●	●	●
E.R.	●	-	×	×	○
Administration	○	×	●	●	●
Management	○	×	●	●	●
Kindergarten	▼	×	●	●	●
Lodgings	●	×	×	×	×

4. CONCLUSIONS

The paper reports the analysis of Italian legislation and standards for acoustic performances of hospitals and the results of some experimental measurements carried out in two different hospitals (sections 3.1 and 3.2). In the first case study (a maternity ward in a hospital of an important city), the measurements of sound pressure levels inside the rooms were made. The main noises were due to the equipment and installations (alarms, air ducts etc.) and to the activities in the corridors and partly in adjoining rooms (voices, movement of trolleys and stretchers etc.). The results show values well above the legal limits for service equipment. The results of a survey carried out with the participation of 108 patients and visitors point out that the main disturbing noise comes from the activities in the corridors. These noises are very frequent also during the night and can cause the awakening of patients. The limit values given by Italian legislation keep hardly count of sound insulation between adjacent rooms but not so much of sound insulation between rooms and corridors.

In the second case study, measurements of façade and airborne insulation, impact and service equipment noise, were made in order to verify the compliance with the legal limit given by Italian legislation. It was show how, in some cases, the various types of use entails difficulties in identifying where and how to apply the limits set by the legislation. In other cases, like the noise inside corridors or between corridors and rooms, the legal limits do not apply or are not strict enough to guarantee privacy and acoustic comfort.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Secchi, S., Cellai, G., Fausti, P., Santoni, A., Martello, N.Z., Sound transmission between rooms with curtain wall façades: A case study, 2015, Building Acoustics, 193–208, https://doi.org/10.1260/1351-010X.22.3-4.193
2. Granzotto, N., Bettarello, F., Ferluga, A., Marsich, L., Schmid, C., Fausti, P., Caniato, M., Energy and acoustic performances of windows and their correlation, 2017, Energy and Buildings, 189-198, https://doi.org/10.1016/j.enbuild.2016.12.024

3. Martello, N.Z., Fausti, P., Santoni, A., Secchi S., The use of sound absorbing shading systems for the attenuation of noise on building façades. An experimental investigation, 2015, 5, Buildings, 1346-1360; https://dx.doi.org/10.3390/buildings5041346
4. Del Nord, R., Environmental stress prevention in children's hospital design, Motta Architettura, Milan (2006)
5. Rasmussen, B., Secchi, S., Acoustic regulations for hospitals – Comparison between selected countries in Europe, in proceedings of InterNoise 2019, Madrid, June 16 – 19 2019, Madrid
6. Decreto 5 Dicembre 1997, Determinazione dei requisiti acustici passivi degli edifici (Determination of passive acoustic requirements of buildings) (in Italian), available on line: http://www.gazzettaufficiale.it/eli/id/1997/12/22/97A10190/sg
7. Decreto 11 gennaio 2017, Adozione dei criteri ambientali minimi per gli arredi per interni, per l'edilizia e per i prodotti tessili (Adoption of minimum environmental criteria for interior furnishings, construction and textile products) (in Italian) available on line:http://www.gazzettaufficiale.it/eli/id/2017/01/28/17A00506/sg
8. UNI 11367: 2010, Acustica in edilizia - Classificazione acustica delle unità immobiliari - Procedura di valutazione e verifica in opera (Acoustic classification of buildings - Assessment procedure and on-site verification) (in Italian)
9. Di Bella, A., Fausti, P., Scamoni, F., Secchi, S., Italian experiences on acoustic classification of buildings, in Proceedings of InterNoise 2012, August 19-22 2012, New York, pp. 5598-5609(12)
10. UNI 11532:2018, Caratteristiche acustiche interne di ambienti confinati – Metodi di progettazione e tecniche di valutazione – Parte 1: Requisiti generali (Indoor acoustic characteristics of confined environments - Design methods and evaluation techniques - Part 1: General requirements) (in Italian)
11. Bai, G., Cellai, G., Marzi, L., Secchi, S., Setola, N., Studio del comfort ambientale all'interno dei reparti ospedalieri di maternità (Study of environmental comfort within maternity hospital wards) (in Italian), in proceedings of 46th National congress of Italian Acoustic Association, May 29 – 31, 2019, Pesaro, Italy
12. ISO 16283-1:2014, Acoustics, Field measurement of sound insulation in buildings and of building elements Airborne sound insulation
13. UNI 8199:2016, Acustica in edilizia - Collaudo acustico di impianti a servizio di unità immobiliari - Linee guida contrattuali e modalità di misurazione all'interno degli ambienti serviti (Building acoustics - Acoustic testing of equipment serving building units - Contractual guidelines and measurement methods) (in Italian)