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ANALYSIS OF BEDROOM DISTRIBUTION LAYOUTS TO IMPROVE ACOUSTIC COMFORT IN HOSPITAL WARDS

Simone Secchi[1] Veronica Amodeo[1*] Luca Marzi[1] Riccardo Panichi[1]

[1] Department of Architecture, University of Florence, Italy

ABSTRACT

Although noise in indoor environments is considered one of the most important factors affecting health and life quality of users, it is often overlooked during design; several studies highlight how noise pollution in hospitals has increased significantly over the past sixty years, and how exposure to inadequate noise levels causes stress and disturbance for all users. In patients, who represent the most vulnerable group of users within hospitals, excessive noise, especially during the night, is a cause of stress and awakenings that can affect the psycho-physical healing process. Interviews conducted with patients highlight that the most disturbing sources of noise that cause awakening during the night are from activities outside the room. In this paper, starting from the typical configuration (two-bed coupled rooms with toilet), different possible configurations of materials and distributive layouts will be shown, in order to contribute to the reduction of noise transmission from the corridor into the patient room.

Keywords: *Acoustic Comfort, Hospital Room, Acoustics, Layout Design.*

1. INTRODUCTION

Many studies show that noise in the patient room comes mainly from corridor activities (trolley movement, alarms, conversations, etc.) [1-4]. For this reason, regulations in many European countries specify limit values for normalized sound insulation or apparent Sound Reduction Index between bedrooms and corridors; according to [5], requirements of sound insulation between corridors and bedrooms vary especially from 27 dB (France) to 38 dB (Turkey).

These insulation values are justified by the need to protect rooms from noise, but since doors between rooms and corridors are frequently kept open or half-closed, achieving these values is very difficult. In addition, hospital doors often have built-in ventilation grilles and do not have sealing systems on all sides of the door (the bottom rebate usually does not have a rebate profile with seals). For this reason, the architectural design of the hospital ward is very important, especially with regard to the layout of bedrooms and corridors, i.e. the design of the transition space between corridor and bedroom.

The aim of this study is to evaluate the effect of different bedroom configurations and their relationship to the corridor, assuming a specific door sound reduction index. The room type examined is the double room with a private bathroom.

This room type is the most common with reference to medium and long-stay wards in ordinary conditions. The double room can be articulated with different spatial and organizational layouts. The layouts are chosen according to the needs of the Health Care Organization, the movement of the medical staff around the patient, and the level of interaction expected between the patients. Double rooms have some recurring features such as a single access door; the bathroom, without windows, created in the space adjoining the ward corridor; access to the bathroom from inside the room; windows on the side opposite the ward corridor. These conditions, together with other ones imposed by specific national regulations, require that the

[1]**Corresponding author*: *veronica.amodeo@unifi.it.*

dimension of the bedrooms is usually between 20 and 30 square meters.
The double bedroom is the most common room type in European hospitals, although the use of single-bed rooms is increasing in recent years.

2. METHODS

This study was carried out both by means of sound insulation measurements between bedrooms and corridors in a real case of a hospital ward and by means of simulations of Insertion Loss between corridors and rooms in different configurations of the bedrooms and the corridor.

2.1 Measurement procedure

The case study examined was the maternity ward of the Careggi University Hospital in the city of Florence, Italy, which is characterized by a typical layout distribution, as in many Italian and European hospitals (see Fig. 1).

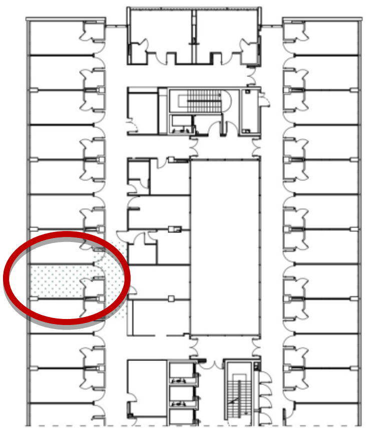

Figure 1. The layout of the Florence hospital. It is highlighted the bedroom where sound insulation measurements were carried out.

For the study, an in-patient room with two beds was selected and the acoustic insulation between the room and the corridor was measured in three different door opening conditions. Specifically, the door was alternatively kept closed, semi-closed, and completely open (see Fig. 2).

Figure 2. The door between the corridor and the bedrooms in the three conditions considered (closed, semi-closed, and open).

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The door was made of a hollow core laminated panel without a rebate on the lower profile and with uncompressed seals on the other profiles. The opening system of the door was a vertical pivot (see Fig. 2). The rating of the sound reduction index, Rw, of the door was not known but it was probably between 20 and 25 dB.
The sound insulation measurements were carried out in accordance with ISO 16283-1 [6], by placing the omnidirectional sound source (a 01 dB dodecahedron, see Fig. 3, right) in the corridor and measuring the difference in sound pressure level (Insertion Loss) between the area of the corridor closest to the room and the room itself.
The measurements were carried out in the frequency range between 50 and 5,000 Hz by means of a two-channel real-time analyzer 01dB Symphonie, with two ½'' diffuse field microphones.
Fig. 3 shows one of the positions of the omnidirectional source (marked with the circle) and of the microphones (marked with the cross). The sound source was not placed in front of the door to avoid direct sound transmission to the bedroom.

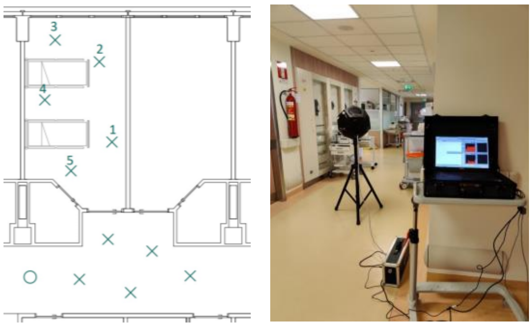
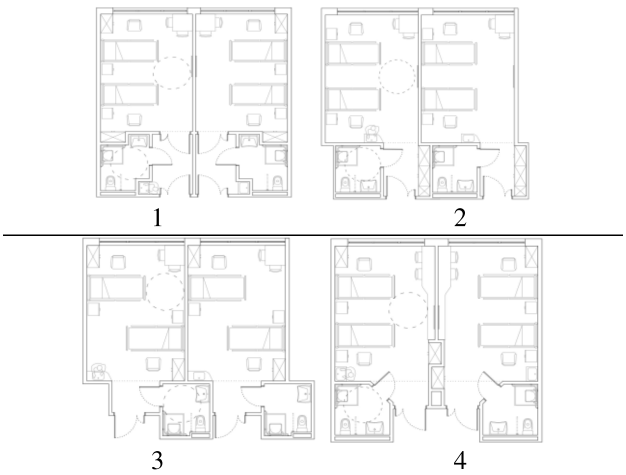


Figure 3. On the left: the positions of the sound source and of the microphones during measurements in the case study. On the right: the sound source and the real time analyser.

2.2 Simulation's procedure

Since the need to keep the door between the corridor and the bedroom open or semi-closed prevents satisfactory room acoustic protection results, we studied some different configurations of the room in order to increase the insertion loss, by keeping fixed the door acoustic performance.

The different layouts were studied with the aim of complying with the regulations on accessibility and functionality of hospital wards and keeping the surface area of the ward and bathroom almost unchanged (about 25 m^2 for the bedroom and about 4 m^2 for the bathroom). Fig. 4 shows the 15 different layouts studied.



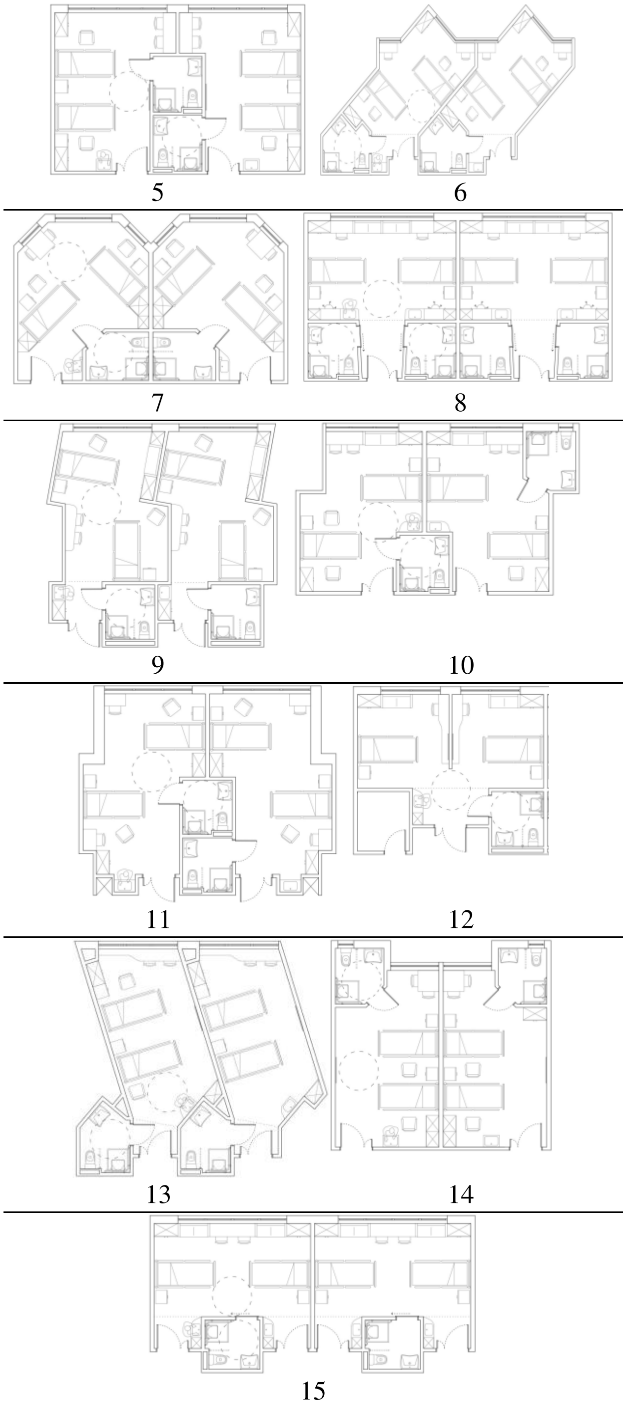


Figure 4. The different configurations of the bedrooms.

The layout n. 14 is the only one that has the bathroom in the wall opposite the corridor, i.e. in the façade. This is a rather uncommon configuration.
Simulations were carried out with the pyramid tracing software Ramsete® [7]. Six omnidirectional sources were placed in the corridor near the door of the bedroom to keep count of different possible positions of the sources in the corridor, while a greater number of receivers was placed in the corridor and in the bedroom (see Fig. 5). The distance between receivers was varied from 0.2 m proximal to the door to 1 m inside the bedroom.

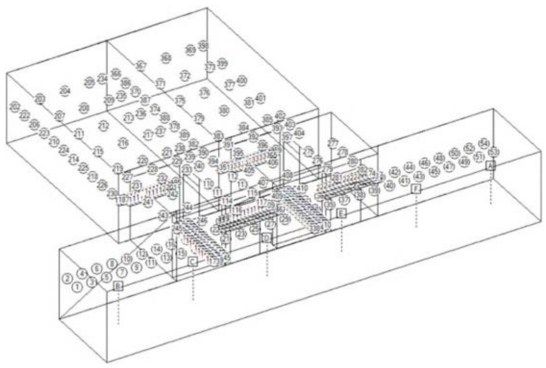


Figure 5. Ramsete® software: The CAD model of the configuration n. 1.

The materials assigned to the interior surfaces of the model (rooms and corridor) were gypsum plaster for the walls and ceiling and linoleum for the floor. The door was assigned a rating of the sound reduction index $R_w = 22$ dB.
The following calculation parameters were set for the simulation:

- Subdivision level = 9 (4096 pyramids traced from each source);
- running time of the rays: 3 s;
- precision level: 0.01 s;
- randomize after 4 reflections from the source;
- temperature and humidity: 20°C, 50%;
- frequency spectrum of sound sources correspondent with the human voice spectrum.

The effect of different configurations on the sound propagation from the corridor to the bedroom was analyzed concerning the differences (Insertion Loss, IL) between the average A-weighted SPL in the corridor and the average A-weighted SPL calculated in the position of the two beds of the room.
On the other side, the complete grid of the receivers was used to create SPL distribution maps in the corridor and the bedroom.
In a subsequent phase of the study, we analyzed how the application of sound-absorbing ceilings in the room and corridor affects insertion loss, in all configurations shown in Fig. 4.
Fig. 6 shows the value of the acoustical absorption coefficient assumed for the ceiling and wall in this part of the study.

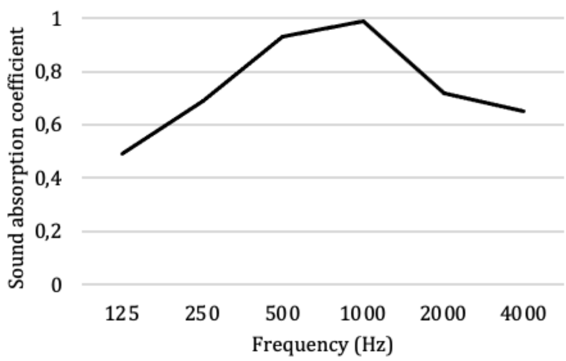


Figure 6. Sound absorption coefficient of the material used for bedrooms and corridor ceiling.

3. RESULTS

Careggi Hospital's inpatient room consists of mostly reflective surfaces, except for the bed. The average measured reverberation time is in the range 0.6 - 0.8 s between 125 and 4000 Hz.
Fig. 7 shows the comparison between the measured values of the rating of normalized sound insulation, DnT,w, between the corridor and the bedroom with the door closed, semi-closed, and completely open (see Figure 2).

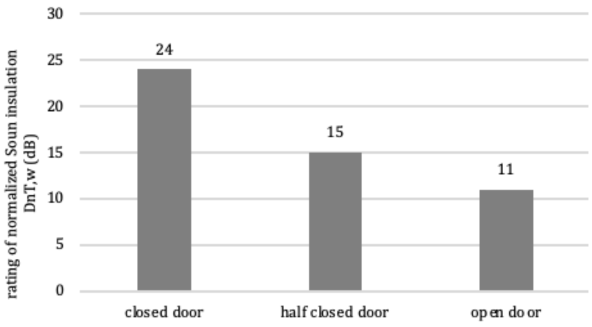


Figure 7. comparison between measured values of normalized sound insulation measured between corridor and bedroom.

Even a small opening of the door causes a large reduction (almost 10 dB) in sound insulation.
Results of measurement were used to calibrate the model used to simulate the effect of different configurations shown in Fig. 4.
Fig. 8 shows the comparison between simulated Insertion Losses in different bedroom configurations (1 to 15, see Fig. 4). In these simulations the ceiling of the bedrooms and of the corridor was considered simply plastered with gypsum (sound reflecting surfaces).

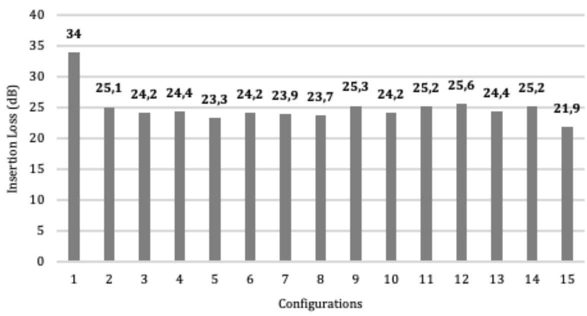


Figure 8. Insertion Loss simulated between the corridor and the bedroom in the configurations described in Fig. 4.

From the results of Fig. 8, configuration 1 is the best one since it is the only configuration with a double door between corridor and bedrooms.
Considering only the single-door layout, configuration n. 12 is the better one, although the differences in many cases are small and probably included in the limit of the uncertainty of the method.
Fig. 9 shows the Insertion Loss concerning configuration 2, which was the one with results more similar to the measured ones. In this case, the characteristics of the ceiling of the room and corridor varied from a sound-reflection surface (gypsum plaster) to a sound-absorbing surface (perforated gypsum panels, see Fig. 6 for the sound absorption coefficient).

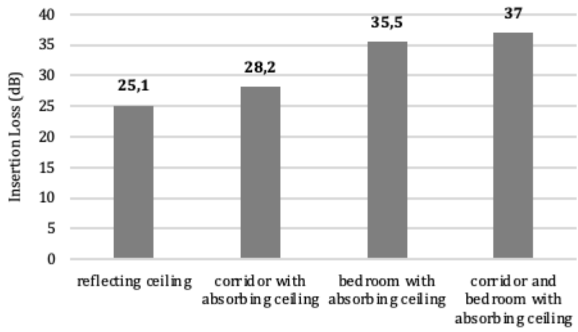


Figure 9. Comparison between Insertion Loss simulated with different sound absorption conditions of the ceiling of bedroom and corridor.

The application of an absorbing ceiling to the corridor and especially to the bedroom increases the Insertion Loss between the corridor and the bedroom. Anyway, it must be noted that the effect of the absorbing ceiling in the corridor depends on the position of the sound source, since, with the sound source placed near the door, direct waves are prevalent and consequently there is a lower effect of the absorbing surfaces.

4. CONCLUSIONS

Protection against noise from corridors to hospital rooms is an essential requirement according to the standards of many European countries. However, the functional requirements of hospitals and the need to keep doors open or semi-closed make it very difficult to achieve good sound insulation values.
The results of acoustic measurements carried out in the main Florence hospital, in Italy, show that the sound insulation between the corridor and bedroom, which is already low with a closed door, becomes inadequate with half-closed or open doors.

The study highlighted how a different configuration of inpatient rooms and the use of sound-absorbing ceilings in the corridor and rooms can significantly improve the insertion loss between these two spaces.
Future developments of this study will better investigate the effect of the shape of the passage from the corridor to the room to obtain acceptable sound attenuation even with not fully closed doors.

5. ACKNOWLEDGMENTS

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