Acoustic Design Recommendations for Intensive Care Units

Per Hiselius[1], Conn Aiken[2], Cheol-Ho Jeong[2]

[1]*Saint-Gobain Ecophon, Hyllinge, Sweden*

[2]*Department of Electrical and Photonics Engineering, Technical University of Denmark, Denmark*

Abstract

The acoustic design of an intensive care unit (ICU) should ensure low noise levels and short reverberation times to support effective communication and, as far as possible, reduce noise-related stress for both patients and staff. In multi-bed patient rooms, it should also provide adequate acoustic privacy between patients. As these requirements can be partly contradictory from an acoustical perspective, a study was conducted in which twelve different room configurations were evaluated using a full-scale mockup of an intensive care unit. Three different types of screens between bedside areas were assessed, together with the effect of adding sound-absorbing wall panels, as well as the combined effect of screens and wall panels. The results of the study provide tangible outcomes that can be used as input for acoustic design recommendations for intensive care environments.

Keywords: intensive care unit, acoustic privacy, screens, acoustic treatment.

1. Introduction

The acoustic environment of an intensive care unit, ICU, is important for several reasons. For the patients there can be a direct impact on the recovery time [1]. But the ability to communicate with low effort and high clarity among hospital personnel, as well as with members of family or close friends, is also important. In addition, the acoustic environment of the room, not least the noise level, also affects the work environment of the staff, with several potentially negative consequences [2]. It has also been shown that for ICU nurses, poor room acoustics can have a significant degrading effect on both the perception of workload and the self-reported ability to perform their duties [3]. For these reasons, it is important to have a good acoustic environment in ICU wards and similar settings. However, for multi-bed patient rooms, it is also important to consider the privacy between patients. While lowering the reverberation time by adding absorption will be beneficial for speech communication between patients and staff, and for lowering the noise level in the room, there is a risk that it has a negative effect on the privacy between patients. As partitions such as screens or curtains are often used between patients, it would be valuable to have a better understanding of how these affect the acoustics of an ICU ward in general, and more specifically on how they may contribute to acoustic privacy between patients.

2. Measurements

2.1 Room configuration

Getting access to an ICU ward is challenging, and even more so, to be able and allowed to reconfigure it with different acoustic treatments. Instead, a full-scale mockup of an intensive care unit was built at the headquarters of Saint-Gobain Ecophon, Hyllinge, Sweden. A room measuring 12.9 m by 7.3 m, with an original ceiling height of 3.5 m, was configured to replicate the main features of an ICU ward. As such it was equipped with four beds, a nurse's desk, as well as with other attributes such as TV monitors and furniture to create an acoustic environment that would resemble a real ICU ward well enough to be able to evaluate the impact of different acoustic treatments.

The room was configured in 12 different ways according to Table 1. Four different types of partitions were evaluated, where one of these four was without any screens or curtains. One partition type was polymer curtains, 1.8 m wide and 2.3 m tall, commonly used at hospitals in Sweden. These were hung approximately 2.6 m above the floor as shown in Figure 2. Another type of partition was foldable hospital screens, 2.25 m wide and 1.45 m tall. As reference, 1.2 m x 1.5 m office screens were used. However, these were used in sets of two, making the pair 2.4 m wide and 1.5 m tall, i.e.

Corresponding author: *Per.Hiselius@ecophon.se.*

similar in size to that of the hospital screens shown in Figure 2. The major difference between the office screens and the hospital screens is that the hospital screens are not designed to provide any sound absorption, whereas each office screen provides an absorption area ranging approximately between 0.75 m² at 125 Hz to 3.5 m² at 4 kHz. The positioning of the partitions can be seen in Figure 1. The beds were standard beds 0.9 m wide, and 2 m long put on pallets to make the height more similar to hospital beds. The three beds positioned side-by-side were separated by approximately 4 m center-to-center. The floor was linoleum on concrete, the ceiling was painted concrete, and the walls were made of double gypsum boards, with ten 1.6 m by 0.7 m windows on the wall opposite the nurse's desk.

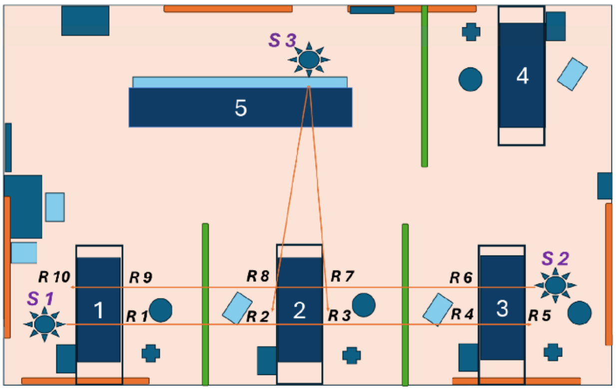

Figure 1. A schematic view of the room, including the beds (1-4), the Nurse's desk (5), position of screens in green and the wall panels in orange. The 3 source (S) and 10 receiver positions (R) are also included.

The suspended acoustic ceiling, when used, was a 20 mm porous absorber (1.5 kg/m²) designed primarily for healthcare applications, positioned with an airgap of approximately 0.8 m. The six 2.7 m x 1.2 m, 40 mm thick wall panels, also designed primarily for healthcare applications, were positioned such that the lowest part of the panels was approximately between 1.3 and 1.4 m above the floor. This was to replicate a real scenario where wall panels must be fitted high enough to allow for medical equipment and installations to be fitted on or against the walls. Further, as can be seen in Figure 1, the wall panels were not placed in an optimal position. Due to the positioning of doors, some of the panels were placed such that they were partly or fully opposing each other. However, such circumstances may occur also in a real scenario.

2.2 Measurement configuration

To evaluate the acoustic properties for each of the twelve room configurations described in Table 1, twelve source-receiver combinations (cf. Figure 1) were used. Source positions 1 and 2, and five receiver positions for each of these, were chosen so that the spatial decay rate of speech ($D_{2,S}$) according to ISO 3382-3:2022 [4] could be evaluated. Although an ICU ward is not an open plan office in a strict sense, the standard explicitly mentions hospital wards among examples of other open working areas for which ISO 3382-3:2022 may be relevant. A third source position, with two receiver positions, was also added so that the privacy between the nurse's desk and bed 2 could be evaluated. Finally, all twelve source-receiver combinations (cf. Figure 1) were used to estimate the average reverberation time of each room configuration. For all measurements the source center and receiver heights were positioned 1.2 m above the floor.

Figure 2. Photos of the room with reflective hospital screens and curtains in-between beds.

Table 1. The twelve room configurations evaluated, with three basic setups and four partition types for each setup.

Setup	Acoustic ceiling	Wall panels	Partition type between beds
1	No	No	a: No partitions b: Office screens c: Hospital curtains d: Hospital screens
2	Yes	No	a: No partitions b: Office screens c: Hospital curtains d: Hospital screens
3	Yes	Yes	a: No partitions b: Office screens c: Hospital curtains d: Hospital screens

All measurement results are based on room impulse responses, assessed from a 10.9 s e-sweep signal using the Dirac software *(B&K type 7841, version 6.0)*, a Norsonic omnidirectional loudspeaker *(Nor 276)*, power amplifier *(Nor 280)* and a B&K free field microphone *(Type 4188)*. T20 and C50 [5] values are of particular interest in this study. T20 is used to evaluate whether the room complies with the building code, while C50 is used to evaluate the clarity of the speech in the room. Note that the parameters are averaged across the octave bands centered from 500 Hz to 2 kHz, indicated as *mid*-frequencies.

3. Results

Mid-frequency reverberation time is shown in Figure 3. Figure 3a shows that without acoustic treatment the room does not comply with a building code such as Danish Building Standard (BR18) [6], having reverberation times significantly exceeding 1 s. A highly absorbing suspended ceiling (cf. Figure 3b) in combination with absorbing screens decreased the mid-frequency T20 below 0.6 s, which was not the case for the reflective hospital screens or when no partitions were used. At 125 Hz and 250 Hz, T20 exceeds 0.6 s for all these cases. However, when the wall absorbers are added, the ICU ward becomes in compliance with the building code. Further, as can be seen in Figure 3c, the difference in T20 between different types of partitions also becomes small in the fully treated room.

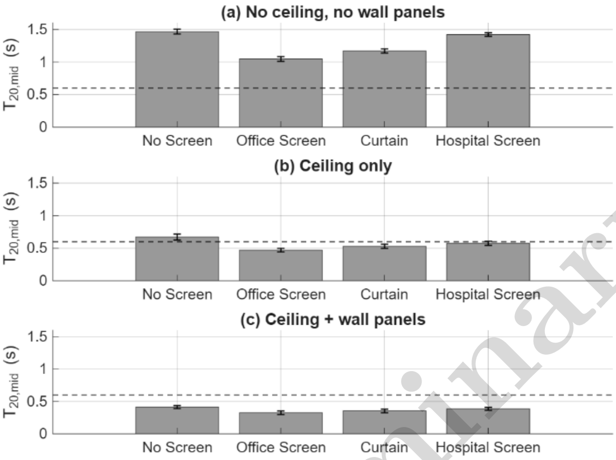

Figure 3. Mid-frequency T20. (a) Setup 1, (b) Setup 2, (c) Setup 3.

The speech clarity (C50) is defined as the energy ratio between early and late arriving energy, with 50 ms as the cut-off time between the two. The speech clarity, as shown in Figure 4, is about 3-5 dB for a nurse seated close to the bedside, talking to a patient. With the highly absorbing ceiling, the improvement of clarity is substantial, about 8-9 dB, and an additional 4 dB improvement is shown when the wall panels are added.

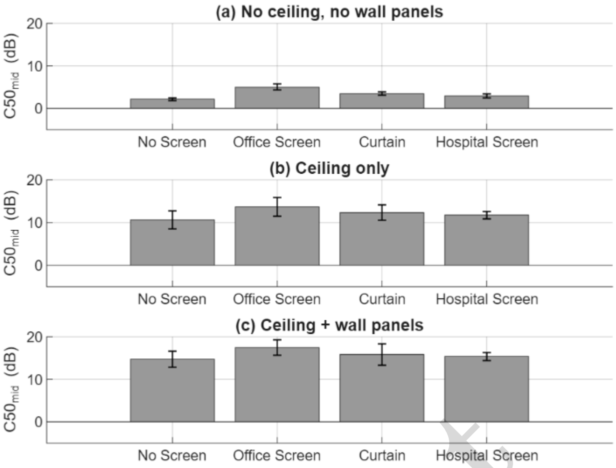

Figure 4. Mid-frequency Clarity C50 at beds. (a) Setup 1, (b) Setup 2, (c) Setup 3.

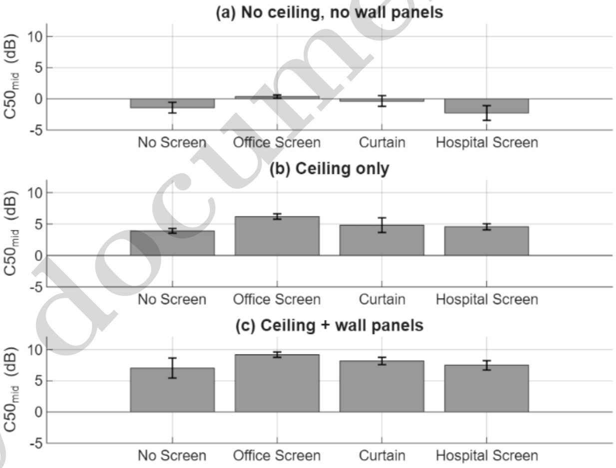

Figure 5. Mid-frequency Clarity C50 from nurse's desk. (a) Setup 1, (b) Setup 2, (c) Setup 3.

For a nurse speaking from the nurse's desk with receivers R2 and R3, the speech clarity with no acoustic treatment in the room was negative, meaning the late-arriving energy exceeds the early-arriving energy. With the ceiling treatment in place, C50 is increased by about 6 dB, on average, and an additional 3 dB improvement is achieved when wall absorbers are added. The best speech clarity is obtained with the absorptive office screen followed by curtains.

However, the variation in C50 between the different types of partition is rather small for the fully treated condition, giving a freedom to choose the type of partition depending on other criteria, e.g., privacy between beds.

It is also of interest to study how easily speech is overheard between beds. Our measurements show that the speech clarity is quite poor with no treatment, which is rather positive in terms of speech privacy, but negative in terms of noise levels and reverberation times. Further, it can be noted that hospital screens outperform the other types of partitions in terms of speech privacy, i.e., it has the lowest C50 for Setup 3 in Figure 6, when the ceiling and walls are acoustically treated.

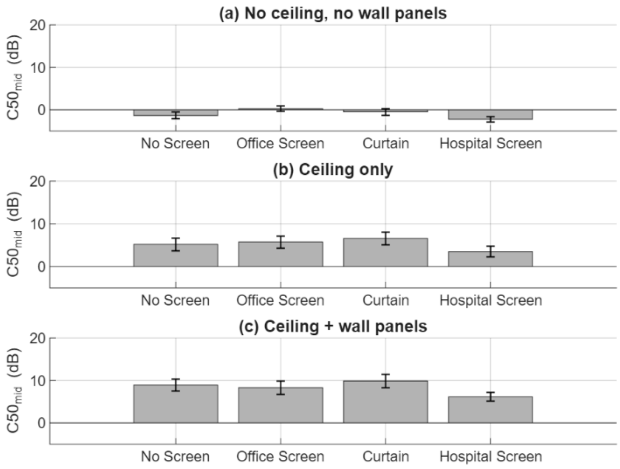

Figure 6. Mid-frequency Clarity C50 between beds. (a) Setup 1, (b) Setup 2, (c) Setup 3.

4. Discussion and design recommendations

The acoustic environment of a multi-bed ICU ward, and similar premises, presents a fundamental design conflict between the clinical need for clear communication and the ethical requirement for patient privacy. Our measurements confirm that achieving compliance with regulatory standards, such as a reverberation time limit of 0.6 s according to BR18 [6], requires comprehensive acoustic treatment. In the fully treated Setup 3 (absorbent ceiling and wall panels), T20 converged to approximately 0.4 s, creating a stable environment for clinical tasks that need concentration and clear communication.

While acoustic treatment is essential for regulatory compliance, it also substantially improves speech clarity, with direct bedside measurements showing an increase of up to 13 dB compared to untreated rooms. However, while absorbing materials are generally preferred for noise and reverberation reduction, the hard-surfaced reflective hospital screens appear to be superior for maintaining patient confidentiality. These screens effectively lower the speech transmission index (STI) for neighboring beds to a Fair level (0.48–0.51), while maintaining Excellent intelligibility directly at the bedside, as shown in a follow-up study [7].

The results suggest that it can be recommended to install both high-performance suspended acoustic ceilings and absorbent wall panels (Setup 3) to meet building standards and to ensure sufficient speech clarity for critical staff communication. Second, this configuration also allows for choosing partitions between beds that promote privacy. While not explicitly illustrated here, screen height has a minimal effect on performance provided the speaker remains positioned below the top of the screen as shown in other studies, e.g.,[7][8].

5. Conclusion

A full-scale mockup of an intensive care unit environment was experimentally evaluated. To satisfy national building regulations, it was imperative to treat both ceilings and walls with highly absorbent materials that also meet strict hygiene standards. Once the room was acoustically treated, excellent speech clarity was achieved for both bedside conversations and communication between the nurse's station and the bedsides. Regarding the privacy issue between adjacent beds, hospital screens outperform other alternatives by effectively preventing the direct transmission of speech. Therefore, it can be recommended to (1) acoustically treat both the ceiling and the walls with highly effective absorbers, (2) implement screens between all beds, (3) utilize reflective screens to maximize speech privacy, and (4) encourage seated communications among nurses, patients and families.

References

[1] Johansson, L., Knutsson, S., Bergbom, I., and Lindahl, B., “Noise in the ICU patient room - Staff knowledge and clinical improvements,” Intensive and Critical Care Nursing, vol. 35, pp. 1–9, Aug. 2016.

[2] Ryherd, E., Persson Waye, K., and Ljungkvist, L., “Characterizing noise and perceived work environment in a neurological intensive care unit,” *The Journal of the Acoustical Society of America*, vol. 123, no. 2, pp. 747–756, 2008.

[3] Blomkvist, V., Eriksen, C., Theorell, T., Ulrich, R., and Rasmanis, G., “Acoustics and psychosocial environment in intensive coronary care,” *Occupational and Environmental Medicine*, vol. 62, no. 3, 2005.

[4] ISO 3382-3: *Acoustics – Measurement of room acoustic parameters – Part 3: Open plan offices.* Geneva: International Organization for Standardization, 2022.

[5] ISO 3382-1: *Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces.* Geneva: International Organization for Standardization, 2009.

[6] Danish Transport, Building and Housing Authority: *Building Regulations 2018 (BR18).* Copenhagen: Danish Transport, Building and Housing Authority, 2018.

[7] C. Aiken: *Assessing Speech Intelligibility and Privacy Conditions in Intensive Care Units* (MSc Thesis). Technical University of Denmark, 2025.

[8] J. H. Rindel and C. L. Christensen, “Acoustical simulation of open-plan offices according to ISO 3382-3,” in *Proc. of Euronoise 2012*, (Prague, Czech Republic), pp. 630-635, 2012.