BNAM 2018
Baltic-Nordic Acoustics Meeting
15-18 April 2018
Harpa, Reykjavík, Iceland

Sound absorbers used in pre-fabricated operating room modules

Maria Quinn
Saint-Gobain Ecophon (Hyllinge, SE), maria.quinn@ecophon.se

The noise level in operating rooms can be particularly difficult and may affect the ability of the staff to hear the proper oral instructions; it also affects their perceived stress and well-being. Sound peaks can reach 110decibel (dB) when tools are in use.

The requirement for reverberation time (RT) in operating rooms is according to Swedish Standard 25268 < 0.6 seconds. Pre-fabricated modular solutions for operating rooms made of glass and metal adversely affect the sound environment as the absorption of sound is non-existent. Pre-fabricated modules without any acoustic supplement are calculated to around 2.0seconds in RT.

In our research the modular ceiling was replaced with a sound absorbing ceiling with Absorption Class A. Both standard sized rooms (65m²) and the larger Hybrid room (105 m²) was treated with absorbers. To gain better understanding on the sound environment we also chose to measure Speech Clarity (C50) and Strength (G).

Acoustic measurements in the standard size rooms showed a RT of 0.7seconds and in the Hybrid 0.9seconds. The standard operating room had good outcome but the Hybrid would not be approved according to SS 25268. Standard room C50 measures A-weighted 5.6dB, which is close to what is commonly sought (between about 6 and 10dB) in a space where voice communication is important. It has a relatively high clarity for high frequencies where the important consonant sounds are information carriers in our voice. Strength (G) still measures high for low frequencies which can be exhausting when the noise level becomes high.
Replacing the ceiling modules with absorbing tiles enabled the operating room to almost reach the criteria according to the standard. Without acoustical treatment both room types would have failed.

Introduction

Noise levels have steadily increased in hospital over the last >40 years, both daytime and night time [1]. The noise level in operating rooms (OR) can be particularly difficult and research shows that this may affect the ability of the staff to perceive proper oral instruction; it also affects their perceived stress and well-being. Sound peaks can reach 110decibel (dB) when saw and drill are in use [2, 3]. Kracht, Busch-Vishniac and West showed, in a study from 2007 in Johns Hopkins Hospital, that orthopaedic surgery was found to have the highest L_{eq} at approximately 66dB(A) [4].

Neurosurgery, urology, cardiology and gastrointestinal surgery followed closely ranging from 62-65dB(A). For neurosurgery and orthopaedic surgery peak levels exceeded 100dB over 40% of the time [4].

Medical errors due to noise are a safety concern that needs to be prevented in all possible ways [5]. There are ways to reduce noise by changing working ways and raise awareness of noise inducing behaviour [6].

Sound absorbing material can improve the sound environment quite dramatically in an operating room as shown by MacLeod M et al in the Quieting Weinberg 5C case study [7] and in other sound dense room such as the Coronary Intensive Care unit shown in a study by Blomkvist V et al from 2005 [8].

Hypothesis

In this building project, the client had chosen a complete package solution for the operating rooms with a modular solution that enables great flexibility for future changes in the business. All the technologies and displays available on the wall surface are integrated in the module unit. This gives maximum use of surface and is functional and hygienic. The visual impression of the room is beautiful and perceived as pure and aesthetic and building time is heavily reduced with the extra bonus that normal daily work is not as affected as with the traditional way of building.

However, there is a disadvantage of modular solutions; floors, walls and ceilings adversely affect the sound environment as the absorption of sound is more or less non-existent. This is due to the module material properties of glass and metal, which instead of decreasing the reverberation time instead contribute to increase it. The requirement for reverberation time in operating rooms is according to Swedish Standard 25268 max 0.6seconds [9]. In the project planning stage we performed calculations of expected reverberation time (T20) in the module and the results were alarmingly far from the minimum requirements with a T20 of 2,0-2,2seconds! In order to create a good sound environment and meet the standard, it was decided to replace the modular metal ceiling with a sound absorbing ceiling with Absorption Class A [10, 11].

Absorption Class A is the highest class and has a very good ability to absorb sound energy. The product chosen was a glass wool mineral absorbent - *Ecophon Hygiene Performance* ™ *40mm.* This is used as a comprehensive ceiling solution with the exception of the Laminar Air Flow (LAF) ventilation, pendants and lighting, giving coverage of approximately 80% of the total ceiling area. No absorbents were mounted on the wall. The absorbers were assembled in existing grids from the modular manufacturer (Hospitaltechnik, DE). Both Operating Room 9 (65m²) and the Hybrid Room 10 (105m²) were treated with absorbents. The absorbent fulfill all cleaning requirements for high specialist area (methods, cleaning agents and disinfection according to national practice).

All 14 new operating rooms (standard) were 65m² and we chose to measure one of them, room 9. We also measured the larger operating room of 105m², this operating room was built with the purpose to work as a Hybrid, room 10. A hybrid operating room is a surgical theatre that is equipped with advanced medical imaging devices such as fixed C-arms, CT scanners or MRI scanners. These imaging devices enable minimally-invasive surgery. Installing a hybrid OR is a challenge to standard hospital room sizes, as not only the imaging system requires some additional space, but there are also more people in the room as in a normal OR. A team of 8 to 20 people including anaesthesiologists, surgeons, nurses, technicians, perfusionists, support staff from device companies etcetera can work in such an OR [12].

We wanted to compare the two room types as we believed reverberation time most likely would be met for room 9 and probably not for the Hybrid after replacing the metal ceiling with absorbents. As Hybrids are becoming more common it is important to gain knowledge on room acoustic parameters for these rooms as well. To gain better understanding on the sound environment we also chose to measure Speech Clarity (C50) even though it´s not included in the standard [9].

Construction and acoustical measurements were conducted in 2017 at Sundsvall sjukhus, Lasarettsvägen 21, 856 43 Sundsvall, Sverige.

Method

Measurement was performed with the Room-Capture program. Evaluation was done in Room Capture and with manual calculation from exported data from the program. Room acoustic parameters were evaluated according to ISO 3382-2. Microphone: B & K 4006, Snr: 1498468. The acoustician also reported Early Decay Time (EDT) in the same graph as reverberation time, considering that EDT correlates better with what we hear from the acoustics of the room compared to the T20.

Rooms were built with wall modules assembled together, 3-glass windows on one wall and one sliding door on the adjacent wall. Floor material was vinyl carpet on concrete. Ceiling material consisted of mineral wool absorbents (Ecophon, SE) placed in metal grids with 200mm space above. The hybrid had two more doors adjacent to the window and one door beside the window (facing the corridor). Lead was incorporated in the walls of the Hybrid due to radiation from the CT.

Result

The mean of the reverberation time in room 9 is 0.7seconds (as to Figure1). The T20 is expected to decrease slightly when all installations are in place. The limit of 0.6 is not met but during an inspection it is most likely that it would be approved and it correlates well with what we calculated prior to the measurement. Further acoustic treatment can lower the value.

The mean of the reverberation time in the Hybrid is 0.9seconds (as to Figure1) and the measurements show a very uneven curve, which is strongly affected by the hard parallel surfaces that create flutter-echoes. Overall, the measurement for the Hybrid would *not* be considered approved according to SS 25268 for Swedish conditions. The deviation from the limit is substantial and in absolute need of further acoustical treatment.

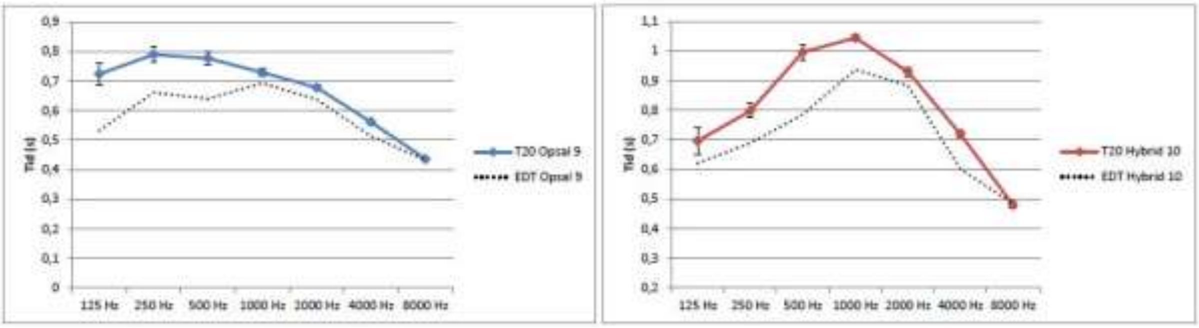

Figure 1: Reverberation Time OP 9 (blue), Hybrid (red)

C50 measures well for OR 9, the arithmetic mean between 125-8000Hz is 6dB (as to Figure 2), and the aim for good speech intelligibility is generally considered 6dB or higher.

The arithmetic mean between 125-8000Hz in the Hybrid is 4.8dB (as to Figure 2).The measurement is very unevenly distributed over the frequency spectrum with a clear drop at the important frequency range 1000Hz. Flutter-echoes also affects the measurement value negatively primarily in this frequency range. This adversely affects speech comprehension. The C50 is expected to increase quite a bit when people are in the Hybrid as a "wall" of people works well to break the echoes. However further treatment is advised for good speech intelligibility.

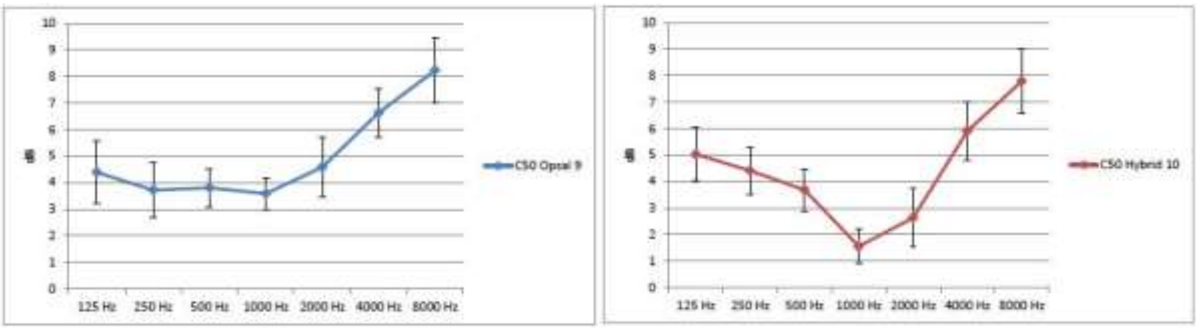

Figure 2: Speech Clarity OP 9 (blue), Hybrid (red)

Discussion

Reverberation time (T20) and EDT

Reverberation time (T20) is the measurement value used when inspecting rooms to fulfil Swedish Standard SS 25268. Reverberation time is the time it takes for the sound to drop 60dB after the audio source turns off. The T20 is evaluated between -5dB and -25dB and the reverberation time is extrapolated from it. Reverberation time should be evaluated after completion of construction and measured in rooms furnished for the intended purpose. The reverberation time usually decreases when decoration is introduced into a room, however, measurement is usually done in refurbished rooms. The rooms in this specific case were sparsely furnished during measurement as it was performed when not in use, a substantial amount of equipment will be brought in according to what kind of procedure will be done.

The reverberation time is mainly influenced by the surface treatment of the room. A long reverberation time can be experienced with the room sounding sonorous or echoing, while a short reverberation time can be felt like the room sounds subdued.

The measurement value does not always correlate with the experience of the sound. Early decay time (EDT) often shows higher correlation with the human experience. EDT evaluates the soundtrack from 0dB to -10dB, which then better agrees with the sound we actually hear. For this reason, EDT is also reported side by side with the T20 in this report. EDT is not included in the standard.

Clarity (C50)

Clarity is a measure of how the noise energy in space diminishes with time. The C50 evaluates the energy within the first 50ms and compares it with the sound remaining after 50ms. If the room contributes with early reflexes and then dies out quickly, you get a high C50 value.

A high C50 is strongly related to speech intelligibility, this being our brain integrating the early reflexes and joining it with the direct sound, which makes us perceive the sound stronger. A high C50 is especially important in the frequency range 1000-4000Hz where a large amount of information-bearing consonants in our voices are present

Clarity is primarily influenced by the design and layout of the room. It is also strongly affected by the proportion of reflective surfaces that are in direct proximity to the source of sound.

A highs sound pressure level in a busy environment can be very negative, as all the sources of sound in the room will be enhanced by the room. People also set their voice level higher than other sounds in a room to be heard. So when the sound level increases in the room, voice levels also tend to increase. This in turn increases the volume further, creating a snowball effect, also known as the Lombard effect.

As mentioned in the introduction the average sound pressure levels are generally high in operating rooms. The combination of high sound pressure levels and long reverberation time creates a challenging sound environment for people working in a room with complex tasks and medical responsibility for patients. It is of outmost importance that staff is able to conduct their work in the most beneficial setting possible. Speech intelligibility is crucial for patient safety and it is dependent on the above acoustical parameters.

Sound pressure level, reverberation time and speech clarity can largely be influenced by the amount of absorption present in a space. More absorption lowers the sound pressure level, shorten the reverberation time and increase speech clarity. We believe the finding in this study is important information as a planner/purchaser might think that if they purchase a package solution surely all building demands would be fulfilled? As the demands differ from country to country that is not the case. Note that none of the rooms would be approved unless the exchange from existing ceiling to absorbent tiles was made.

Limitations of study

Measurements were only done in two rooms hence no general conclusion can be drawn from its results. The features of the mineral wool used may not be approved by all standards in other countries.

Conclusion

It is important to be aware of the affect room material has on several sound parameters as the operating room often is exposed to disturbing noises. Introducing sound absorbing materials affects reverberation time, speech clarity and sound pressure level in a positive way, which has impact on both staff and patient. It is mandatory for the operating rooms to fulfil the reverberation time minimum limits to be accepted for use. Additional use of wall-panels would also further have a positive impact on both reverberation time and speech clarity. Additional use of base sound absorbers above the ceiling panels would probably lower reverberation time considerably and improve speech clarity in the hybrid room.

Disclosure

Ecophon, Maria Quinn, Concept Developer Healthcare. Erling Nilsson, Acoustician

LN Akustik, Kristian Orellana, Acoustician

References

[1]. Busch-Vishniac IJ, West JE, Barnhill C, Hunter T, Orellana D, Chivukula R. Noise levels in Johns Hopkins Hospital. *J Acoust Soc Am*. 2005;118:3629–3645.

[2]. Sentinel Event Alert Issue 50: “Medical device alarm safety in hospitals” A complimentary publication of Issue 50, April 8, 2013 The Joint Commission

[3]. Ryherd, Okcu, Ackerman "Noise pollution in hospitals: Impacts on staff", J. Clin. Out. Mgmt. 2012, vol 19, no 11, p491-500

[4]. Kracht JM, Busch-Vishniac IJ, West JE. Noise in the operating rooms of Johns Hopkins Hospital. *J Acoust Soc Am*. 2007;121:2673–2680.

[5]. Beyea SC. Noise: a distraction, interruption, and safety hazard.
AORN J. 2007;86:281–285.

[6]. Engelmann CR, Neis JP, Kirschbaum C, Grote G, Ure BM. A noise reduction program in a pediatric operation theatre is associated with surgeon’s benefits and a reduced rate of complications: a prospective controlled clinical trial. *Ann Surg*. 2014;259:1025–1033.

[7]. MacLeod M, Dunn J, Busch-Vishniac IJ, West JE, Reedy A. Quieting Weinberg 5C: a case study in hospital noise control. *J Acoust Soc Am*. 2007;121:3501–3508.

[8]. Blomkvist V, Eriksen CA, Theorell T, Ulrich R, Rasmanis G. Acoustics and psychosocial environment in intensive coronary care. *Occup Environ Med*. 2005;62:e1.

[9]. Swedish Standard Institute.,”SS 25268:2007 Acoustics – Sound classification of spaces in buildings –Institutional premises, rooms for education, preschools and leisure-time centres, rooms for officework and hotels

[10]. Swedish Standard Institute.,”SS EN ISO 354:2003 Acoustics – Measurement of sound absorption in a reverberation room.

[11]. Swedish Standard Institute.,”SS EN ISO 11654:1997 Acoustics – Sound absorbers for use in buildings – Rating of sound absorption.

[12]. https://en.wikipedia.org/wiki/Hybrid_operating_room