DANISH SOUND

INNOVATION PROJECT

IMPROVING NOISE AND ACOUSTICS IN DANISH HOSPITALS

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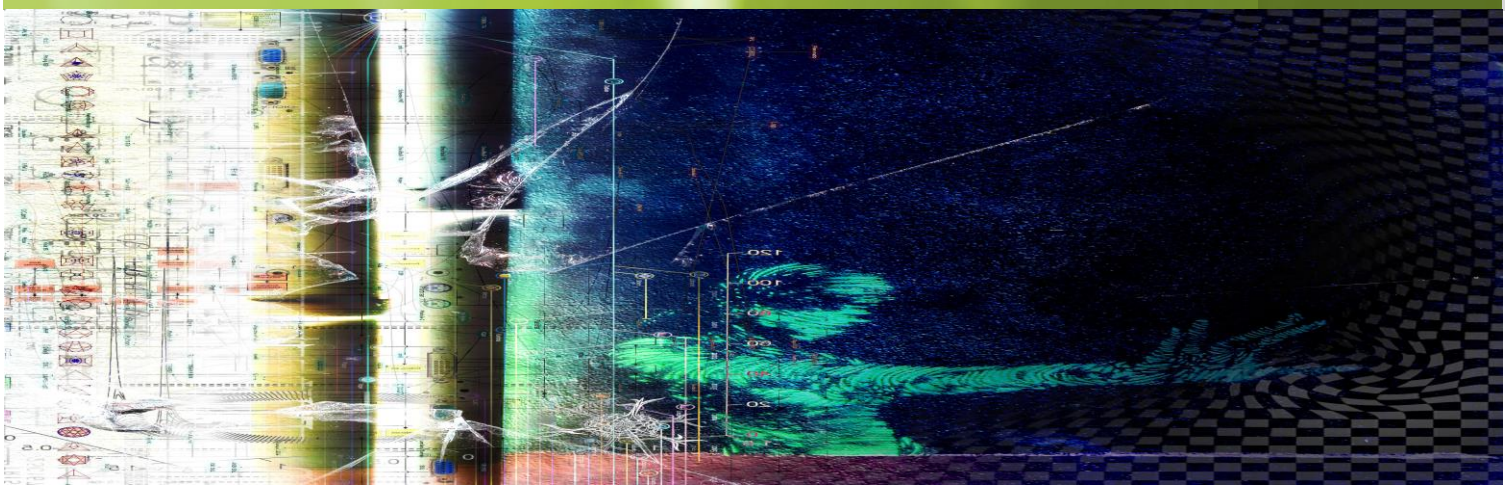
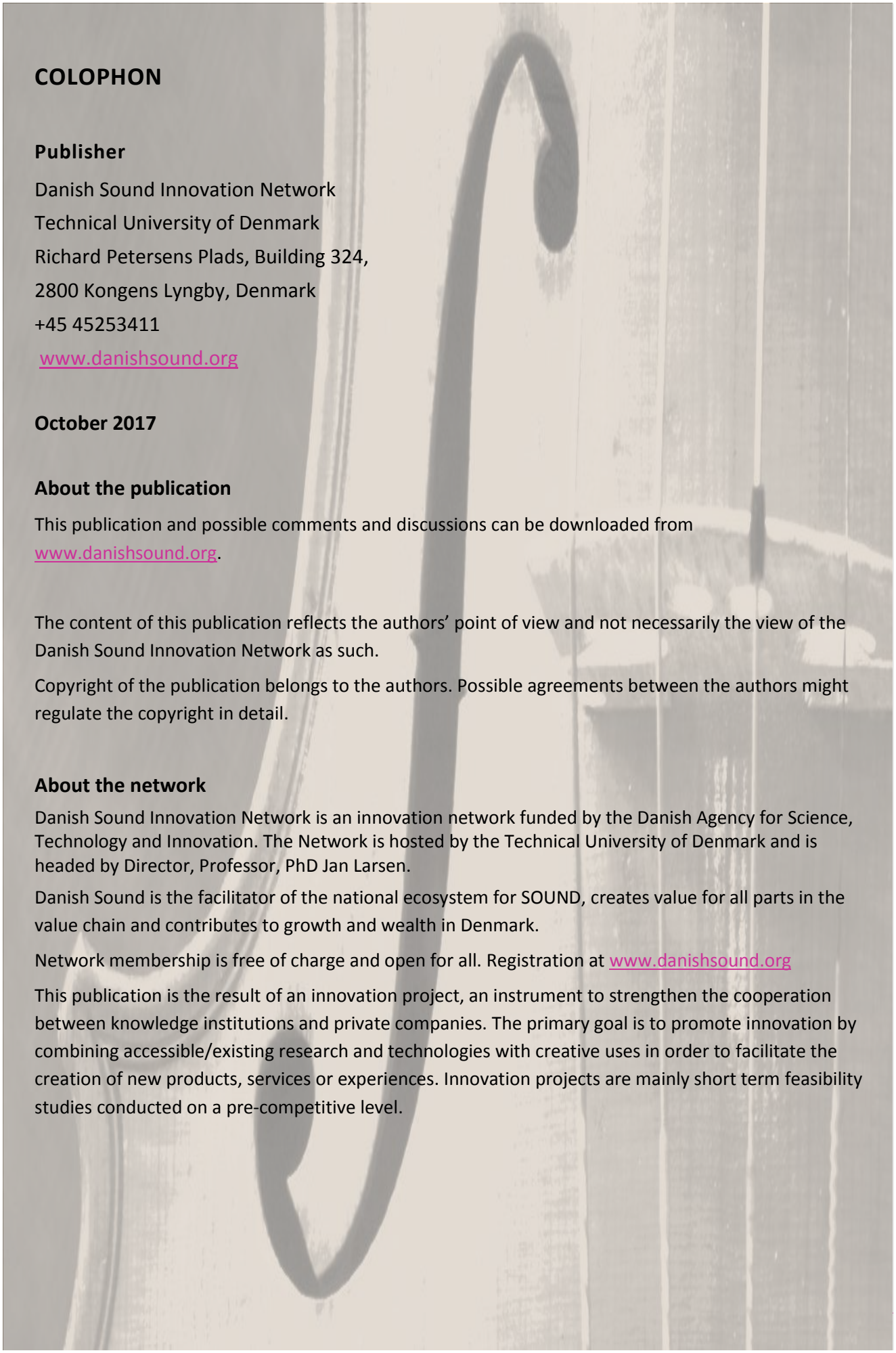


It has been found that the four room acoustic parameters, such as early decay time (EDT), reverberation time (T_{20}), clarity (C_{50}) and speech transmission index (STI) could not predict the annoyance level in staff, well. Furthermore, questionnaires were found insufficient alone to collect the desired information from staff. In this study the a MR-department at Hvidovre hospital was investigated by measuring the room acoustics parameters EDT, T_{20}, C_{50} and STI along with noise levels measured over 24 hours and staff from the department were interviewed about noise disturbance. It was found that room acoustic parameters were acceptable according to the recommendations to hospitals in the Danish Building Regulation 2015. However, noise levels reached very high levels, and the staff was very disturbed by noise. These results reveal that room acoustic recommendations for hospitals in BR15 are insufficient as it has no noise limits. Therefore, considerations to noise exposure should be included in the design process of hospital departments with exceptionally noisy equipment. In similar future studies, both interviews and questionnaires are recommended to be used to collect subjective data.

DTU Elektro Institut for Elektroteknologi | Ecophon SAINT-GOBAIN A SOUND EFFECT ON PEOPLE | NIRAS | HENNING LARSEN ARCHITECTS | REGION H Hvidovre Hospital



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Danish Sound Innovation Network is an innovation network funded by the Danish Agency for Science, Technology and Innovation. The Network is hosted by the Technical University of Denmark and is headed by Director, Professor, PhD Jan Larsen.

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This publication is the result of an innovation project, an instrument to strengthen the cooperation between knowledge institutions and private companies. The primary goal is to promote innovation by combining accessible/existing research and technologies with creative uses in order to facilitate the creation of new products, services or experiences. Innovation projects are mainly short term feasibility studies conducted on a pre-competitive level.

PREFACE

This publication is the result of an innovation project entitled *Improving noise and acoustics in Danish hospitals.* The project is financed by the Danish Sound Innovation Network through a grant from the Danish Agency for Science, Technology and Innovation and co-financed by participating partners Mai-Britt Beldam from Ecophon, Christoffer Andreas Weitze from Niras, Finnur Kári Pind Jörgensson from Henning Larsen and Jens Hjortkjær from Hvidovre Hospital, and Cheol-Ho Jeong from DTU,. The project is completed in the period August to October 2017 and managed by Technical University of Denmark, project manager Cheol-Ho Jeong.

INTRODUCTION

BACKGROUND

The negative influence of noise in healthcare sectors has been long time known, first officially mentioned by Florence Nightingale in "Notes on Nursing" in 1859 [1]. Noise in hospitals has been found to have influence on patients in terms of patients' sleep [2-3], length of hospital stay [4] and medicine intake [5]. Hospital noise has also been found to have influence on hospital staff in terms of stress [6], burnout in nurses [7], tendency to unwillingly perform medical errors [8] and challenges in communication leading to medical errors [9-10]. Since the 1960s, it has been investigated how to bring down noise levels in hospitals [11]. Newer intervention projects have, besides trying to replace noisy equipment with less noisy equipment and reduce the sound level and number of various alarms, also focused on educating staff in less noisy behavior. These intervention projects have shown a varying effect [12-14], often with the conclusion that noise levels should be brought down by room acoustic improvements.

In previous work trying to investigate and improve hospital acoustics [15], it was found that the reverberation time alone could not predict the noise disturbance of the staff in Bispebjerg hospital. This conclusion was mainly a result of a particular unsatisfied department, the x-ray department, which along with having excellent room acoustics, was also observed to be exposed to a high background noise level from equipment. In the study questionnaires were found to be a limited tool to investigate staff's perception of noise in individual rooms, as the staff is moving around from room to room. As a continuation of the work by Larsen in 2017, this study will investigate if the level of disturbance of noise and acoustics is also observed in similar departments to the X-ray department but in another hospital. Furthermore other methods to collect subjective data are taken in use and tested.

OBJECTIVE

The objective of this study is to answer the two following research questions.

1. Does it apply for other hospitals that hospital staff are unsatisfied with the acoustic environment though the room acoustics theoretically are good, based on recommendations from the Danish Building code?

2. What is the best method to collect subjective data from staff?

METHODS AND RESULTS

THEORY

In the conduction of the project, interviews were performed. The theories studied for the interviews performed are listed. The methods and theory used for the interviews performed, were picked in the best of the researcher's believes. The sources used are Refs. [16-17].

The 7 phases of an interview investigation

1. **Thematise the interview** – Ask *why* and *what* before *how*
2. **Design** - Go through all seven phases before performing the interview. Choose an approach:
    a. Detect something, *they* don't know – let the objects protest, design interview to perform a real discovery
    b. Construct something *they* want to happen – challenge the objects, the desire of creating something new. Nothing exists inside ourselves, only things which have been constructed by us.
    c. Understand something *they* don't understand - Knowledge can be both perspective and objective at the same time. Respect/praise diversity and understand it.
3. **Interview** - Produce an interview guide: From research questions to specific interview questions. Research interest, interview style and analysis should be in accordance.
4. **Transcription** - Transcription from speech to text
5. **Analysis** - Validation during the procedure
    a. Grounded theory – Open coding, analysis, investigation, comparison, conceptualize, categorization of data.
    b. Deductive analysis – You cannot understand something without a point of reference.
6. **Verification** - Reliability, validation
7. **Reporting** - Communication, keep the report in mind during the entire process

METHOD

The room acoustic parameters, EDT, T_{20}, C_{50}, and speech transmission index (STI) were measured in three rooms in Hvidovre hospital. The three rooms were a control room to a MR-scanner (floor area: 14.6 m^2, volume: 38.0 m^3), an examination room (floor area: 13.5 m^2, volume: 38.0 m^3) and a nurse/control room to five MR- scanners (floor area: 102.9 m^2, volume: 288.2 m^3). The parameters were measured in accordance with ISO 3382-2 [18] with the software DIRAC, with an omnidirectional speaker and a microphone playing e-sweeps. To ensure fair STI measurements, it was ensured that the signal to noise ratio was above 15 dB for the frequencies 63 to 8000 Hz.

Noise was measured in the control room and the nurse/control station with a B&K 2250 sound level meter, which was set to log every 10 seconds, measuring A-weighted sound pressure level, L_{AFmin} and L_{AFmax}. One sound level meter was placed in one end of the control room. Two sound level meters were measuring in the nurse/control station, one was hanging from the ceiling at the area, which the staff said was the most noisy area. The other was placed in the middle of the room.

Interviews were performed at the time when the sound level meters were removed. The interview was performed informal, as a group interview, unstructured, and as a receptive interview. An interview guide

was produced in correspondence with [16], which can be seen in Table 1. The group interviewed was interviewed about the nurse/control station.

The questionnaires used in [15] were revised with an 11-point numerical scale for four questions per room evaluated. Two additional questions were added, one based on the theory that introverts are more sensitive to noise [19], asking:

Do you see yourself as:

With the possibility to answers: *Introvert, Extrovert, I don't know*

And one asking:

Do you have a quiet place at work, where you can have a break?

With the possibility of answering *yes* or *no.*

Unfortunately, time did not allow sending out questionnaires to the staff in the department.

Table 1: Research questions and corresponding interview questions.

Research question	Interview questions
What influence does noise have on hospital staff?	What causes noise in the room? In your own words how does noise influence you and your work at the hospital?
How can the working environment regarding noise be improved with design of room?	How do you think the noisy environment can be improved?

RESULTS

ROOM ACOUSTIC PARAMETERS

In Figure 1 the room acoustic parameters measured are shown for the three rooms, control room (CR), Examination room (Exa) and the nurse/control station (NS). The reverberation time T_{20} shows values below the recommended values in BR15 [20]. The early decay time shown in Appendix show more unstable values, which are especially unstable for the low frequencies for Exa and NS compared to the high frequencies. The values for Clarity in Figure 1, B, are considered high for the high frequencies for all three rooms, although lower for the low frequencies (125-250 Hz) for Exa and NS. Generally the room acoustics are considered acceptable and in correspondence with BR2015 for the three measured rooms.

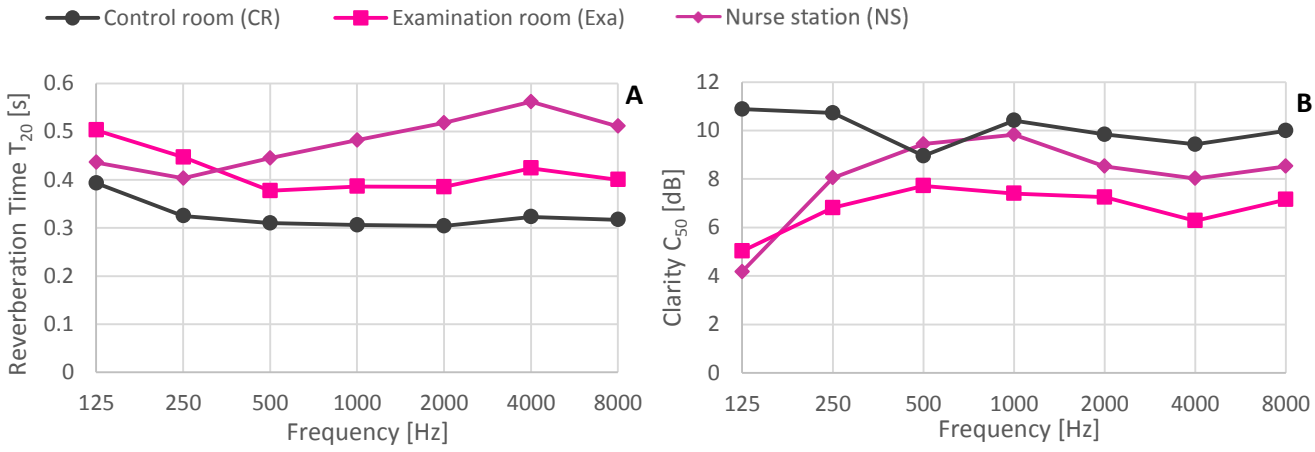

Figure 1: Room acoustic parameters over the frequency bands 125 to 8000 Hz. A) shows Reverberation Time T_{20} in seconds and B) shows Clarity index C_{50} in decibels.

NOISE

In Figure 2 the noise levels obtained in the two rooms NS and CR are shown. The data shows average levels of noise, which correspond well to the levels obtained in [21] and are considered high. The peak levels (L_{AFmax}) reach up to 91 dB, which is considered very high when taking into account that the rooms are acoustically treated with a suspended ceiling with perforated ceiling panels and comparing with the room acoustic parameters measured.

The noise levels as a function of frequency shown in Appendix show highest levels at 500 and 1000 Hz, as the noise is A-weighted, it shows approximately equal sound pressure levels for all frequencies in the 1/1 octave band.

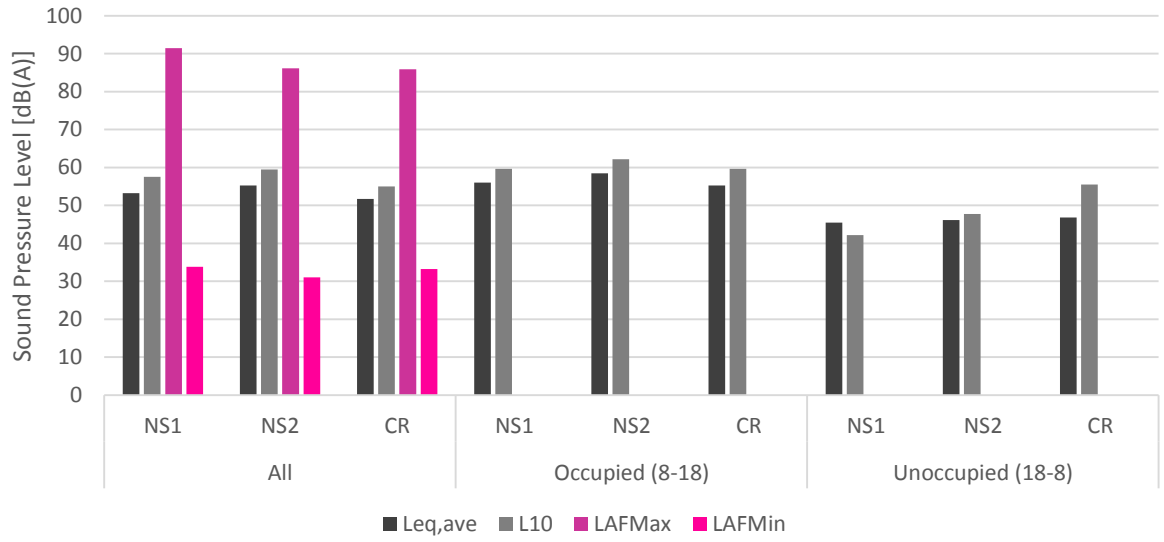

Figure 2: Noise levels in the two rooms NS and CR. Leq,ave is the average noise level, L10 is the 90 % quantile and the max value LAFmax and minimum value LAFmin.

INTERVIEWS

The interviewed staff reported that noise was a large problem and especially came from MR-scanners, a technical room to which the door was closed most of the time, and human voices. They expressed that it was especially noisy when all five MR-scanners were running at the same time. It was mentioned that it was sometimes hard to focus on writing reports due to noise, but that they had a room with glass walls in which they could withdraw for writing reports and similar tasks. However, the room was adjacent to the waiting room, which caused that patients would tap the glass wall to ask questions. Furthermore, the staff explained, that they always were on call, also when they were eating lunch or taking a break. The influence of noise caused tiredness and sometimes headaches. It was also mentioned that some of them felt that they got used to the noise. One mentioned that she found it unprofessional that patients lying in the scanner and colleagues on the phone could hear them joke with one another, which she thought was due to the large room with many people.

According to the staff, the room could be improved regarding noise by installing acoustic room dividers. Flexible solutions to separate the large room, when they were many people in the room was suggested. For example an acoustic screen which could separate the tables which were used for each individual scanner, when many people were present. The staff liked that they could call on each other from one end of the room to the other.

INNOVATION

On short term this project leads to focus on the issues about noise in healthcare facilities. Up until now we don't have much research about how sound and noise affects staff and patients and there simply doesn't exist a mapping of the situation just now.

The Danish building regulation sets room acoustic demands on reverberation time only (and only T20) despite the fact that we hear so much more. From a research point of view we have a lot of studies from both the education and office segment showing that if we evaluate a room on several acoustic descriptors instead of just one – then we are more likely to build rooms that support the activity. In Sweden, Norway and Finland we see clarity of speech (C50 and/or STI) as a part of the evaluation of classrooms – and in the appendix to the Danish building regulation for schools (SBI218 [22]) we also see STI mentioned as a descriptor for open spaces. In 2012 a new ISO standard was published in regards to acoustics (ISO 3382-3) and in this standard T20 is not even included.

It seems as if it is time to look further into acoustic demands for healthcare facilities – and with this project we have made the first 'baby steps' towards new guidelines showing that fulfilling today's demands according to BR15 is not enough to secure a healthy sound environment.

So – what can be done – in the longer run? We need more research to be sure of what activities take place in what rooms and then together with anthropogenic field work learn about what an optimum sound environment would look like. We need intervention studies to find out what solutions could live up to the end users' needs and then we could continue the work with new standards and guidelines for healthcare facilities.

The hygiene demands on the hospitals are sometimes difficult to fulfill with the acoustics products that are on the market today and further investigations could lead to product development (e.g. not many manufacturers have acoustic wall solutions appropriate for hospital use). From an Ecophon point of view there exist one wall solution that live up to the acoustic and hygienic demands – but on the other hand the design is very limited and the installation (the trims and frames) are not suitable in all rooms/facilities.

This study however shows the need for development of existing products and maybe new products made specifically for healthcare facilities with high demands. In this matter the project also revealed that hygiene demands are often 'forgotten' when installing a new ceiling or wall absorber – the right people are simply not being asked and therefor the cleaning methods are 'adjusted' to secure that the products are not being damaged (which unfortunately leads to not sufficient cleaning). This project could therefor – as a 'side effect' also lead to better understanding of the total process of changing a facility into better conditions for both acoustics and hygiene.

This project is interesting not only for Denmark and Scandinavia because it broadly questions how sound and acoustics affect people in hospitals in a lot of different scenarios – and we must consider this to be a world-wide question. Commercially the project gives the partners (Ecophon, Niras and Henning Larsen) great possibility to start discussions and develop projects in their markets based on these initial findings. There is no doubt that being part of this innovative project – in regards to learning about how the actual acoustics are perceived by the end users – will give the partners an advantage in their markets, since they will be the only ones that know exactly what it looks like in the 'real world' and what it feels like.

To reach the politicians to fundraise money for better sound environments in healthcare, this project should be followed up by new projects. It is a great way to start off with a mapping of the actual situation (measurements and numbers) in comparison with feed-back from the end users – and a future project where we look at the patients' feed-back would be highly interesting.

In a public system like the Danish system, the length of hospital stay in regards to acoustics, medication intake in regards to acoustics and general recovery in regards to acoustics could be really relevant to investigate.

NOVELTY, DEMAND & REALIZABILITY

- The first attempt to investigate the noise and acoustics in Danish hospitals
- Qualitative correlation between objective acoustics/noise measurement and subjective noise disturbance
- Use of mixed methods including questionnaires and group interviews
- Evaluation of the current acoustic regulation BR15 and weaknesses identified
- Further suggestions to the current regulation BR15

IMPACT

The main impact of this project is increasing awareness of noise and acoustics in hospitals, leading to more investigation on hospital soundscape. This project leads to a conference session called hospital acoustics in Baltic-Nordic acoustic conference in April 2018, Iceland.

CONCLUSION

It was found that the MR-department in Hvidovre Hospital, which is similar to the X-ray department in Bispebjerg hospital, was also very noisy according to the staff and to the performed noise measurements. It was found that the room acoustics in the three tested rooms were satisfactory according to BR15. The average noise levels were furthermore found to be high and the peak levels reached levels that were extremely high. These results show that a satisfactory sound environment in hospitals cannot alone be obtained by following the current recommendations in BR15. The recommendation is not sufficient and should be improved furthermore in such ways that the solutions reduce the disturbance level in staff.

It was tested to use unstructured group interviews for this type of project. The method was found successful but it is recommended to combine the method with a quantitative method as handing out questionnaires (mixed methods) to obtain even more precise results. Furthermore, anthropogenic field work could possibly also benefit this kind of projecat, but should be tried out in future projects.

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APPENDIX

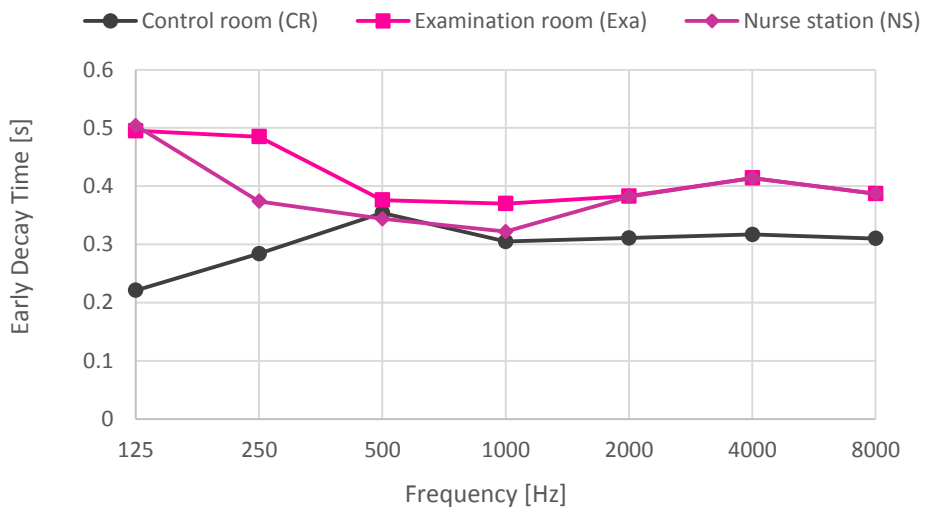

Figure 3: The Early Decay Time in seconds as a function of frequency.

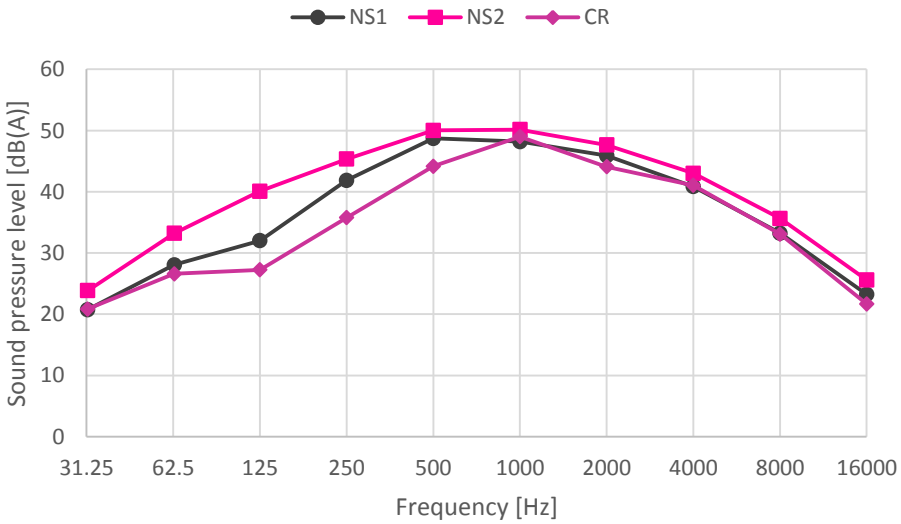

Figure 4: Average noise levels over the frequencies from 31.5 Hz to 16000 Hz.