DTU Library

Influence of architectural layouts on noise levels in Danish emergency departments

Jeong, Cheol-Ho; Jakobsen, Hannah C.W.

Published in:
Journal of Building Engineering

Link to article, DOI:
10.1016/j.jobe.2021.102449

Publication date:
2021

Document Version
Peer reviewed version

Journal Pre-proof

Influence of architectural layouts on noise levels in Danish emergency departments

Cheol-Ho Jeong, Hannah C.W. Jakobsen

PII: S2352-7102(21)00306-5

DOI: https://doi.org/10.1016/j.jobe.2021.102449

Reference: JOBE 102449

To appear in: *Journal of Building Engineering*

Received Date: 2 December 2020

Revised Date: 4 March 2021

Accepted Date: 21 March 2021

Cheol-Ho Jeong: Conceptualization, Methodology, Software, Formal analysis, Project administration, Supervision, Writing - original draft. Hannah C.W. Jakobsen: Methodology, Investigation, Writing - review & editing

A revised version submitted to ***J. of Building Engineering***

Special issue on Hospital and Healthcare Design, Construction and Operation

Influence of architectural layouts on noise levels in Danish emergency departments

Cheol-Ho Jeong[a)] and Hannah C.W. Jakobsen

Acoustic Technology, Department of Electrical Engineering,

Technical University of Denmark, 2800 Kongens Lyngby, Denmark

[a)] Corresponding author: *chj@elektro.dtu.dk*

Abstract

This study aims to evaluate the effects of architectural layouts of emergency departments on activity patterns/work routines and consequent noise levels. Three Danish hospitals' emergency departments that had different layouts were investigated via on-site noise measurements over three days and observations of noisy activities. The time-averaged noise levels in the three emergency departments turned out to be significantly different, ranging from 50 to 59 dBA. During the observation of noisy activities, the noise levels and occurrences of individual activities were noted and correlated with the long-term measurements. Major noise sources that have high correlations with the three-day noise levels are identified as loud staff communication and noise from alarms/electronic devices. Potential remedies are suggested in connection to the emergency departments' architectural layouts. Especially unnecessarily loud communication between medical staff and loud and frequent equipment/patient transportation noise need to be improved for more comfortable acoustic environments.

Keywords: Architectural layout, hospital emergency department, noise level, work patterns, communication noise

1. Introduction

Florence Nightingale pointed out that all unnecessary noise in hospitals was harmful in the following quote "Unnecessary noise is the most cruel absence of care which can be inflicted on either sick or well," in her book "Notes on Nursing" published in 1859 [1]. The noise levels measured in hospitals are, unanimously agreed by all, not satisfactory, for example, Refs. [2-7]. They largely violate the current noise limit recommended by the World Health Organization (WHO), namely 35 dBA [8]. From the previous noise measurements, it is clearly concluded that hospitals are unacceptably loud and chaotic, with an increasing trend in the noise level from 1960 to 2005 [2]. Poor room acoustics and loud noise negatively affect medical staff in terms of speech communication, job demands, fatigue, stress, burn-out, and hearing loss [9,10]. Unpredictable loud noises can distract staff, interrupt their performance, and increase medical dispensing errors particularly for complicated tasks [11,12]. The negative effects of noise are also well documented in association with a parent's comfort, recovery and sleep quality. [13,14,15] However, no previous work has discussed how much noise was inevitable and how much was unnecessary, which is indeed a very challenging question to answer and could also be highly case-dependent.

Dominating noise sources in hospitals are not only related to building operations but also to building occupants, such as conversations, medical activities, transportation of medical equipment and patients [16]. In an attempt to understand which noise sources could potentially be avoided and which range of noise levels is realistically achievable with current state-of-the-art technologies, we aim to conduct analyses of individual activities and work patterns in connection to the architectural design of hospitals, thus gaining insight into which noise sources could be controlled without compromising the quality of patient care. To the best of the authors' knowledge, only a few studies have correlated objective acoustics parameters and architectural layouts in hospitals [16-18]. Particularly Ocku et al. tried to link the floor layout designs to the reverberation times [18], but did not look into a correlation with noise metrics.

In this study, we measured the noise levels in three hospital emergency departments (EDs) that had quite different architectural layouts. Via an observation study of the activities in the EDs, we aimed to find out the noisy activities that contribute significantly to the total noise level and correlations between the noise levels of individual activities and long-term noise measurements. The final objective was to suggest useful guidelines to reduce unnecessary noise in the ED and to provide insights on good architectural designs. Unfortunately, we could not get a permission for room acoustics measurements and collecting subjective perception from hospital staff and patients, so instead we used the objective measures that have been proved to have a good correlation with staff and patient's perception of soundscape in hospitals. The contributions of this study are three-folds: (1) to categorize the loud noise activities in the ED and present their noise levels, (2) to correlate individual sources' noise level with the long-term noise measurements, and (3) to suggest useful design guidelines that help decrease the noise levels in relation to the architectural layout of the emergency department.

2. Three emergency departments

An ED in Denmark normally consists of emergency treatment rooms (ER), a triage (TRI), and a bed unit (BU). ER is a room for minor or less critical cases, where patients are typically examined, treated, and usually sent home afterwards. According to a medical doctor Marie-Laure B. Jacobsson (Sjællands universitetshospital, Køge), approximately four patients pass through here per hour on average. TRI is a room for more serious problems and thorough examinations. Afterwards, patients are either sent to another department of the hospital or receive proper treatments and are then sent home. The average duration of the stay in TRI is six hours according to Dr. Jacobsson. BU is a room for patients in need of intensive care and under observation. The patient stays in BU for a longer time. In this study, only one sound level meter was permitted for noise measurements, which was located at a safe location in the TRI areas in all three hospitals. Therefore, all measured noise levels only represent the sound environment in the TRI.

2.1. Hospital A

Layout: In Hospital A, the three branches of the emergency department, namely ER, TRI, and BU, were physically separated. ER was separately located in an adjacent part of the building and BU was also fairly secluded and not shown in Fig. 1(a). Between these two sections, the reception was located together with the staffs' main organizational workstation marked as "Office area" in Fig. 1(a). TRI was located along the hallway with exits to the other parts of the hospital.

Noise consequences: It was noticed that TRI was the main section of loud activities, which spread noise widely. The entrance hall reserved for ambulance arrivals was noisy. At this central intersection, an alarm phone as well as a printer room were placed next to the office. A sound level meter was placed at this intersection, shown as a solid circle in Fig. 1(a). Patients were located in the ward along the TRI hallway and some areas in the hallway were used for bedridden patients as well. The lengths of the triage hallways were about 15 meters, enabling medical staff to communicate with raised voice from one end to the other.

2.2. Hospital B

Layout: Hospital B had the three main functions of the department separated as well. ER and BU were located outside the main TRI room. At the time of this observational study and noise measurement (April 2019), Hospital B just introduced this new triage, which was basically one big room containing 12 beds and a centrally located office area, as shown in Fig. 1(b). The beds were separated by protruding walls. If stricter privacy was needed, moveable room separators were additionally used. A computer was located just next to each bed to minimize the need for back and forth communication with the central office area.

Noise consequences: It was noticed that most activities could be heard by all individuals in the room as a consequence of one big open space. If one part of the room was noisy, such as coughing, noise coming from medical devices like respirators, the whole TRI became noisy. Moreover, the transportation setup contributed to increases in the noise level. Ambulance staff entered from the left door with patients and exited to the same door again. If patients were being transferred to another department, they left out of the right exit. Through this exit door, clean beds were transported to replace used ones. This created a lot of loud transportation noise, which affected everyone in TRI.

Figure 1. Three emergency departments. (a) Hospital A, (b) Hospital B, (c) Hospital C. The sound level meter location is indicated as a red solid circle and transportation paths are indicated with arrows. (color online)

2.3. Hospital C

Layout: Hospital C had three branches of the emergency department widely spread as shown in Fig. 1(c). Through the official entrance, the waiting room was located, which was directly connected to the reception. The rest of the ward was a relatively open space, moderately separated by glass walls. ER was located at the left end with an exit to the rest of the hospital. The other end of the hallway, where the patients arrived by ambulances, was the TRI section, where more acute patients were treated. In between ER and TRI hallway, there were separate rooms, such as an office for medical staff and a printer room.

Noise consequences: The three main functions were well separated, ending up with less interactions and reduced noise. This excessively long distance of the hallway (42 meters) prohibited from a loud communication style, such as yelling. However, this long distance might affect other aspects of the staffs' daily work routine negatively.

3. Observation study

This observation study was intended to identify loud noisy activities and how frequently they occur, and how loud such individual noise events could be. We installed a class-1 sound level meter (Fusion, 01 dB) at a secure place and monitored the sound pressure level real-time on the mobile phone via a 3G data modem. The sound level meter was located close to a reflecting surface in all three hospitals for consistency, and therefore the effects of sound reflection on the noise measurement were supposed to be similar. The most important consideration in determining the measurement spot was security and safety of the sound level meter, meaning that nobody accidentally touched or stopped it by any means. Prioritizing the security of the sound level meter, the height of the sound level meter location varied from 1.5 m to 2.5 m. For this observation study, the second author stayed close to the sound level meter (about 1.5 m apart from the sound level meter) in TRI and observed loud and peculiar noise sources. Once a noise event was noticed, its noise type, the starting and ending time were noted, and later the corresponding equivalent noise level for each incident was calculated using logged sound pressure levels. Note that the identified noise incidents lased for different time durations, and therefore the time information was used to quantify the sound exposure together with the equivalent noise level.

Previous research has used various noise metrics. It has been widely accepted to use the overall noise levels [16], i.e., noise levels containing all audible frequency contents from the 1/3 octave bands centered from 20 Hz to 20 kHz. The A-weighting network is the most suitable to approximate the frequency selectivity of the human auditory system, particularly for rather quiet sound around 40 dB [8]. Different indicators, such as equivalent, minimum, maximum, peak noise levels, have commonly been used in hospital noise measurements [8,19]. In this study, most noise levels are presented using the equivalent A-weighted noise levels. The observation in each TRI sections lasted about 3.5 hours.

3.1. Communication noise

Clear communication between staff is absolutely crucial, but the way it is conducted significantly affects the sound environment. Particularly in the three EDs measured, we found significantly different communication patterns. In general, many staff conversations were unnecessarily loud. In Hospital A, conversations with raised voice across the rooms and hallway were found to increase the noise level. In addition, personal conversations between staff increased the noise level. The noise level distributions are shown in Fig. 2. In Hospital A, raised communication noise between staff along the hallway was found to be the major problem, while in Hospital B the open structure of the TRI made all communication loud everywhere. The A-weighted equivalent noise levels ($L_{Aeq,T}$) over a time duration T is expressed as follows:

summarizes the equivalent noise level, the occurrence of noise events, and total duration of identified noise events during the observation study in the hospitals.

According to the WHO community noise guideline [8], the signal-to-noise ratio (SNR) should be at least 15 dB when listening to complicated messages. In Sec.4, the background noise level in Hospital A, B, and C, from the long-term measurements were found to be 49.0, 53.5, and 44.5 dBA, respectively, and therefore the SNRs for the staff communication in Hospital A, B, and C ranged 13, 15, and 14 dB respectively. This concurred with the suggested 15 dB SNR in the WHO guideline surprisingly well [8].

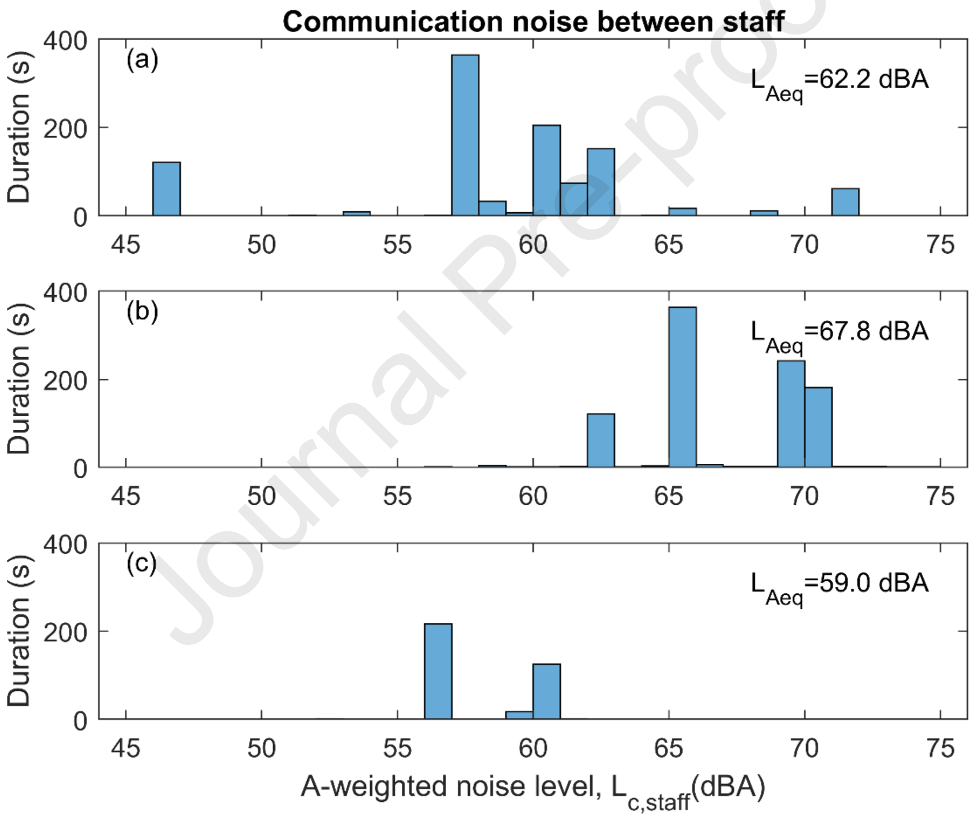

Figure 2. Histogram of staff communication noise. (a) Hospital A, (b) Hospital B, (c) Hospital C.

(single column, color online)

Another important type of communication is communication between the staff and patients, of which the noise level, $L_{c,staff\text{-}patient}$, is largely affected by the communication style and acoustical factors, such as room acoustics and background noise. A similar noise trend to the staff communication was found in this type of communication in Fig. 3 and the resulting equivalent noise levels were 61.3, 69.1, and 59.9 dBA in Hospital A, B, and C, respectively. The noise level at Hospital C was the lowest, being 5 dBA and 9 dBA lower than Hospital A and B, respectively. In terms of the SEL, Hospital C was about 6 dBA and 7 dBA quieter than Hospital A and B, respectively.

Figure 3. Histogram of Staff-patient communication noise. (a) Hospital A, (b) Hospital B, (c) Hospital C. (single column, color online)

3.2. Transportation noise

Medical activities are inevitable and must be prioritized, but transportation activities and non-medical activities could be minimized or optimized. The main transportation noise was associated with bed transportation with and without patients, but also related to food and test transportation.

In Fig. 4, the noise levels caused by transportation of patients, $L_{t,patient}$, are shown. Hospital A had many transportation incidents (*N*=24) with relatively long duration per incident (L_{Aeq} of 59.9 dBA). Hospital B did not have many incidents (*N*=13) yet with high noise levels due to its open space nature (L_{Aeq} of 67.6 dBA). Hospital C had a small number of transportation with low noise levels (L_{Aeq} of 59.1 dBA). In terms of sound exposure, the noise levels in Hospital A and B were 9 and 10 dBA higher than that in Hospital C.

Figure 4. Histogram of patient transportation noise. (a) Hospital A, (b) Hospital B, (c) Hospital C.

(single column, color online)

The patients arriving by ambulance are brought in by paramedics, who did not spend as much time as the hospital staff. During the observations, it was evident that a lot of the transportation related to ambulance arrival or departure were quite noisy mainly because of the paramedics. Therefore, the paramedics should make efforts to bring down the noise caused by them. This was particularly pronounced in Hospital A and B, whereas the problem was less significant in Hospital C, partly because the ambulance staff entered via a secluded entrance. The location of the central entrance for bedridden patients arriving by ambulance led to more frequent noise in Hospital A than Hospital B, where the patients arrived and left at different exits according to their symptoms and mostly remained in their respective sections. This makes the noise exposure in Hospital C about 10 dBA lower than those in Hospital A and B.

On the other hand, the transportation noise, which did not involve patients, $L_{\text{t,non-patient}}$ is shown in Fig. 5. Hospital C had the most incidents of transportation without patients, which might be attributed to the longest hallway as shown in Fig. 1(c). Especially the noise of trolleys was noticeable in this category, although most of them were quieter than the incidents observed in Hospital B in this category. In terms of sound exposure, the noise levels in Hospital A was the lowest, being about 8 and 7 dBA lower than those in Hospital B and C, respectively.

Figure 5. Histogram of non-patient transportation noise. (a) Hospital A, (b) Hospital B, (c) Hospital C. (single column, color online)

3.3. Noise from electronic devices and alarms

Another noise category is sound events caused by alarms and electronic devices, e.g., phone rings and printers. There have been a series of studies that claimed that hospital alarms and electronic devices were unnecessarily loud, for example, Ref. [22]. In Fig. 6, the noise distribution of electronic devices and alarms is shown. Hospital B had a lot of phone ringing and Hospital C had quite some noise incidents of printer working noise near the reception, which could have been moved to another place to reduce the noise impact. Hospital C had the centrally located reception, where many conversations and phone calls were audible, but with relatively low noise levels. Hospital A and C had equivalent noise levels of 60.9 and 59.5 dBA, while the equivalent noise level in Hospital B was 66.8 dBA. In terms of sound exposure, the noise level in Hospital B was 13 dBA higher than that in Hospital A and 14 dBA higher than in Hospital C.

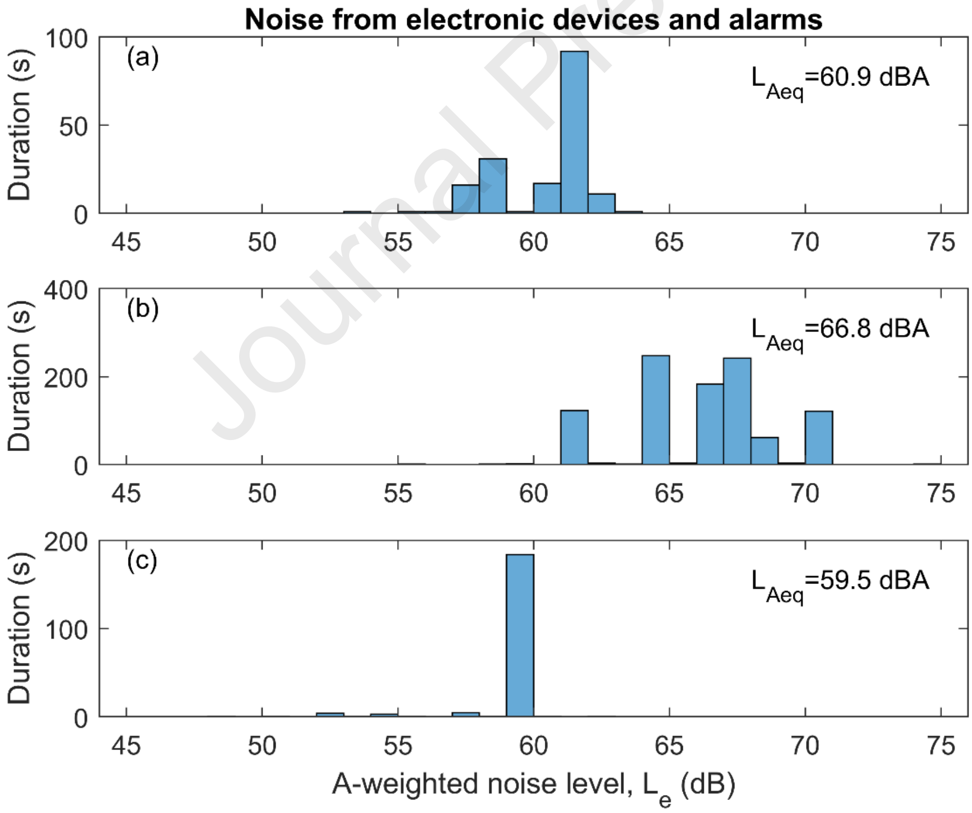

Figure 6. Histogram of electronics and alarm noise. (a) Hospital A, (b) Hospital B, (c) Hospital C.

(single column, color online)

3.4. Noise from non-medical activities

The non-medical activity noise includes noise from door slamming, item dropping, and footsteps, some of which are related to highly stressful situations during critical medical activities. This type of noise is regarded to occur randomly and irregularly, but in Hospital B, about 30% of the incidents was related to rustling of room separators. Hospital A was quietest (58.9 dBA), while Hospital B and C had noise levels 6 and 1 dBA higher than that in Hospital A, respectively, in terms of sound exposure.

Figure 7. Histogram of non-medical activity noise. (a) Hospital A, (b) Hospital B, (c) Hospital C.

(single column, color online)

Table 1. Summary of the equivalent noise level ($L_{Aeq,T}$) in dBA, number of noise incidents (N), and total duration of noise incidents in second (T) for the noise sources identified in the hospitals.

Journal Pre-proof

level by 9 dB is equivalent to an increases of the number of events by a factor of 7.9. Therefore, the noise level increase of 9 dB cannot be explained solely by the number of the visitors during the noise measurement, which supports our hypothesis that work routines and the architectural layout in the ED affect the sound environment. It is also evident in Fig. 8 that the background noise level during the measurement was quite different in the hospitals measured.

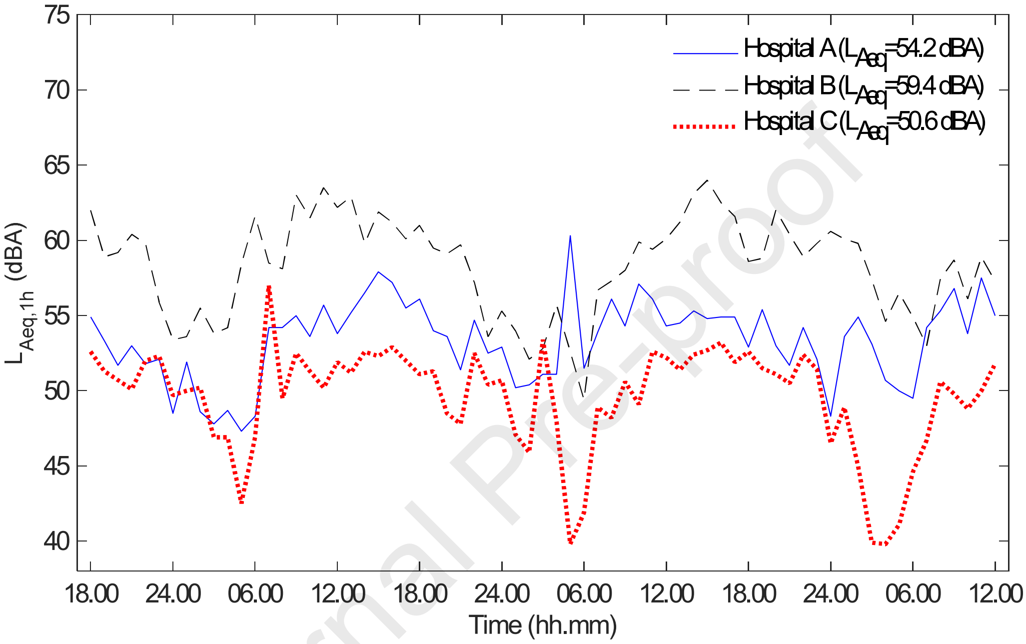

Figure 8. Measured noise levels over 66 hours in three hospitals. (single column, color online)

In Fig. 9, the occurrence rate, OR(*N*), which is defined as the fraction of time that a level exceeds *N* decibels [16], is shown using the A-weighted equivalent noise level and C-weighted peak level. From Fig. 9(a) using the A-weighted equivalent level, we could estimate the background noise level based on the concept of L_{90}, the percentile noise level exceeded for 90% of the time of the measurement duration [24]. In the hospital context, this background noise level is likely to represent the noise level with no or quiet medical treatment and staff's communication. In Fig. 9(a), L_{90} was found in each hospital by drawing a horizontal line from the OR value of 90%, ending up with quite different background levels of 49.0, 53.5, and 44.5 dBA in Hospital A, B, and C, respectively. It is already clear that even the background noise alone cannot fulfil the stringent WHO guideline of 35 dBA [8].

OR(N) using the peak levels, OR$(N)_{peak}$, has been used in several recent studies, concluding that OR$(90)_{peak}$ was strongly related to subjective perception of staff [19] and OR$(75)_{peak}$ to the patient satisfaction [20]. Shibi et. al. also concluded that the OR$(100)_{peak}$ was strongly correlated with the staff perception of noise-related health effects, such as distraction, stress, fatigue, and tension headaches [21]. In this study, we could not collect subjective evaluations from staff and patients, and instead used OR$(N)_{peak}$ in Fig. 9(b) to evaluate the staff and patients' perception of the hospital noise. From Fig. 9(b), OR$(75)_{peak}$ values were 14%, 42%, and 7% in Hospital A, B, and C, respectively. Therefore, it is likely that the patient satisfaction varied significantly based on the conclusion in Ref. [20]. However, OR$(90)_{peak}$ values are similarly small as 0.49 %, 0.64 %, 0.62%, respectively, and therefore the staff could not experience huge differences. Again, OR$(100)_{peak}$ values are all below 0.001%, so it is unlikely to impact the staff's subjective perception. All in all, Hospital B seemed to have the most demanding noise condition, particularly for patients.

Using the noise levels from the individual noise sources from Sec. 3, a correlation analysis [25] was made in Table 2. There are strong correlations between the total noise level, L_{total}, and the two noise sources, namely, staff communication and electronic and alarm noise ($L_{c,staff}$ and L_e). The transportation without patients has the weakest correlation with the 3-day-long noise levels in the three hospitals, indicating that it is unlikely to be seen as a major noise source, either having low noise levels or relatively low frequency of occurrence.

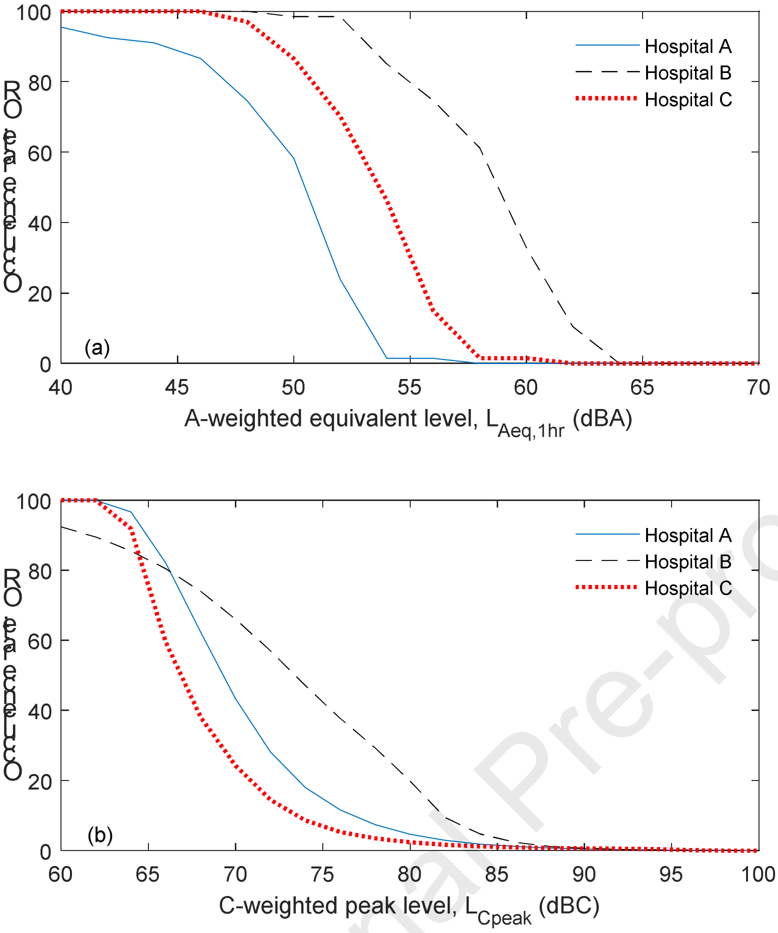

Figure 9. Occurrence rate (OR) curves in the three hospitals. (a) L_{Aeq} and (b) L_{Cpeak}. (single column, color online)

Table 2. Pearson correlation coefficients among L_{total}, $L_{c,staff}$, $L_{c,staff\text{-}patient}$, $L_{t,patient}$, $L_{t,non\text{-}patient}$, L_{e}, L_{act}, indicating the strength of the linear dependence between the pairs of variables. Correlation coefficients larger than 0.9 are indicated in bold.

5. Discussions and suggestions to reduce noise level

Hospital A: Patients' consultations in the triage hallway and the communication style between the staff led to a high noise level. Consultations were preferably moved to closed rooms for reducing noise as well as privacy purposes. Noise of alarm beeping and noise from the administrative office area were identified as problematic and partly unnecessary. Another subjectively found prominent noise source was the footwear of the staff members. Many wore flip-flops or clogs without heel straps causing slapping noise for every step. The doors of the wardrooms slammed occasionally, so soft close dampers would be recommendable.

Hospital B: There was a continuous noise from respirators over the majority of the observation time and noise measurement, which significantly elevated the background noise in the ward. Phone conversations were often overly loud. Additionally, the chairs for visitors placed at the bottom of each bed could be moved to the head end of the bed, as people raised their voice due to the long distance from the chair to the patient. The footstep noise was also loud here. It should be noted that the new triage was introduced one day before the noise measurements and observation were conducted. As a result, the staff was not accustomed to the new environment, which might have influenced the noise level negatively, as they were still in an adaptation process.

Hospital C: The centrally-located reception could have been moved to a closed room to minimize the noise spread and to protect the patients' privacy. The waiting room could also be secluded from the rest of the ward. Electronic devices such as printers could have been moved to another closed or secluded location.

In general, we could suggest that ER needs be detached from TRI, or remotely situated and isolated as much as possible to minimize noise spread between ER and TRI. Small and separate patient rooms are preferred to avoid loud communication across rooms or hallways in terms of noise, but there are other reasons. A previous noise study in a Korean hospital highlighted that when the TRI was well separated from small ERs containing up to six beds after the outbreak of Middle East respiratory syndrome (MERS), a huge reduction of noise due to the change of the layout was reported by medical staff [7]. Therefore, such separated layouts are proven to be beneficial not only in terms of noise, but also in terms of spread of contagious diseases. In addition to the separation of rooms, the doors can be either sliding or softly closing to reduce the noise. Automatically closing doors can block the noise transmission from one room to another effectively.

Separate entrances for specific purposes could help, as the noise emanating from the patients' arrival by ambulance is quite loud. Having more equipment available near the patients could be beneficial to avoid moving it back and forth through the ward. Electronic devices like printers should be re-located in separate rooms preferably with closed doors.

Admittedly, this study has some weaknesses. One weakness of this study is a small sample size only including three hospitals in Denmark. More data will certainly lead to clearer conclusions on the major noise sources and their contributions to the total noise levels in hospitals. Second, only one sound level meter was used to capture the noise level around the TRI area, and more measurement points are needed to fully capture the sound field in the emergency department. The observation study was conducted only for about 3.5 hours, which might not be sufficiently long time to capture the general work pattern in the hospital. Again, the microphone height was inconsistent, but it was hard to compromise the security of the device. The acoustic characteristics of the EDs have not been considered, which could influence the sound levels up to 3-4 dB depending on the acoustical treatments [26]. In hospitals, many walls and floors are acoustically hard to guarantee that appropriate cleaning and disinfection procedures can be applied. Therefore, there might be no big influence of the room acoustic treatments on the measured noise, but the EDs are different in size and degree of acoustic coupling to connected rooms. Finally, no subjective data were collected, such as staff satisfaction, stress, distraction, and fatigues. It is obvious that more meaningful conclusions could be drawn with correlating the subjective and objective measures, for example, which noise sources and activities affected the staff work significantly.

6. Conclusion

This study investigates the main noise sources and architectural layouts in three Danish hospitals' emergency departments and reports the noise data measured. The noise levels were measured for about three days, which are found be correlated with the noise exposure to communication noise and electronic / alarm noise in the hospital. Loud communication, un-optimized and unnecessarily loud patient transportation, unnecessary electronic devices and alarm noise were identified as the noise sources to be controlled. The largest difference among the A-weighted equivalent noise levels over 66 hours measured in three EDs was 9 dBA, which cannot be explained solely by the increased number of patients. To improve the noise condition in the emergency department, it is recommended to avoid a large open space not only for noise but also for preventing the spread of infectious disease, and not to use a hallway of about 10-15 meters long as a ward, which makes the medical staff tempted to communicate with raised voice in the hallway. Certain noise sources, such as unnecessary alarms / electronic devices and too loud footstep door slamming noise, must be minimized.

References

[1] F. Nightingale, *Notes on Nursing: What it is and what it is not*, Harrison and Sons, London, 1859.

[2] I. J. Busch-Vishniac, J. E.West, C. Barnhill, T. Hunter, D. Orellana, R. Chivukula R, Noise levels in Johns Hopkins hospital, J. Acoust. Soc. Am. 118 (2005) 3629-45.

[3] D. Orellana, I. J. Busch-Vishniac, J. E. West, Noise in the adult emergency department of Johns Hopkins hospital, J. Acoust. Soc. Am. 121 (2007) 1996-1999.

[4] W. Filus, A. B. Lacerda, E. Albizu, Ambient noise in emergency rooms and its health hazards, Int. Arch. Otorhinolaryngol. 19 (2015) 205-209.

[5] M. Buelow, Noise level measurements in four Phoenix emergency departments, J. Emerg. Nurs. 27 (2001) 23-26.

[6] A. E. Short, K. T. Short, A. Holdgate, N. Ahern, J. Morris, Noise levels in an Australian emergency department, Australas. Emerg. Nurs. J. 14 (2011) 26-31.

[7] W.-H. Cho, C.-H. Jeong, J.-H. Chang, S.-H. Lee, M. K. Park, M.-W. Suh, J. J. Han, Noise and room acoustic conditions in a tertiary referral hospital, Seoul National University Hospital, J. Audiol. Otol. 23 (2019) 76-82.

[8]. World Health Organization. WHO Guidelines for Community Noise. 1999.

[9] V. Blomkvist, C. A. Eriksen, T. Theorell, R. S. Ulrich and G. Rasmanis, Acoustics and psychosocial environment in coronary intensive care, Occup. Environ. Med. 62 (2005), e1.

[10] J. van Hoof, H. S. M. Kort, M. S. H. Duijnstee, P. G. S. Rutten, J. L. M. Hensen, The indoor environment and the integrated building design of homes for older people with dementia, Build Environ, 45 (2010), 1244-1261.

[11] R. S. Ulrich, C. Zimring, X. Zhu, J. DuBose, H.-B. Seo, Y.-S. Choi, X. Quan, A. Joseph, A Review of the research literature on evidence-based healthcare design, Health Env. Res. & Design J. 1 (2008) 61-125.

[12] E. A. Flynn, K. N. Barker, J. T. Gibson, R. E. Pearson, B. A. Berger, L. A. Smith,. Impact of interruptions and distractions on dispensing errors in an ambulatory care pharmacy, Amer. J. Health Sys. Pharm., 56 (1999) 1319–1325.

[13] M. V. Bayo, A.M. Garcia, A. Garcia, Noise levels in an urban hospital and workers’ subjective responses, Arch. Environ. Health, 50 (1995), 247-251.

[14] B. A. Hilton, Quantity and quality of patients’ sleep and sleep-disturbing factors in a respiratory intensive care unit, J Adv. Nurs., 1 (1976), 453-468.

[15] H. Xie, J. Kang, G. H. Mills, Clinical review: The impact of noise on patients' sleep and the effectiveness of noise reduction strategies in intensive care units, Critical Care, 13 (2009), 208-215.

[16] I. Busch-Vishniac, E. Ryherd, Hospital soundscapes: characterization, impacts, and interventions, by, Acoustics Today, 15 (2019), 11-18.

[17] T. M. Larsen, C.-H. Jeong, M-B. Beldam, J. Brunskog, C. A. Weitze, An investigation of room functions and acoustic demands in selected departments in three Danish Hospitals, Proc. of 23rd Int. Cong. Acoust. Aachen, Germany, 2019, September 09-13.

[18] S. Okcu, E. Shpuza, E. Ryherd, C. Zimring, Linking acoustics and floor-plate shape qualities of healthcare settings, Arch. Sci. Rev. 56 (2013), 315-332.

[19] S. Okcu, E. E. Ryherd, C. Zimring, O. Samuels, Soundscape evaluations in two critical healthcare settings with different designs, J. Acoust. Soc. Amer. 130 (2011), 1348-1358.

[20] J. M. Bliefnick, E. E. Ryherd, R. Jackson, Evaluating hospital soundscapes to improve patient experience, J. Acoust. Soc. Amer. 145 (2019), 1117-1128.

[21] H. Sbihi, M. Hodgson, G. Astrakianakis, P. Ratner, Measuring how acoustical environments affect staff in health-care facilities?, the 161st Meeting of the Acoustical Society of America, Seattle, WA, May 23-27, 2011.

[22] R. B. Way, S. A. Beer, S. J. Wilson, What’s that noise? Bedside monitoring in the Emergency Department, Int. Emerg. Nurs. 22 (2014) 197-201.

[23] H. Fastl, E. Zwicker, Psychoacoustics: facts and models, 3rd edition, Springer, Heidelberg, 2007.

[24] Z. Maekawa, Jens Rindel, P. Lord, Environmental and Architectural Acoustics, 2nd edition, CRC press, London, 2010.

[25] M. G. Kendall, A. Stuart, The Advanced Theory of Statistics, 4th edition, Macmillan, NewYork 1979.

[26] T. Cox, P. D'Antonio, Acoustic absorbers and diffusers: theory, design and application, 3rd edition, CRC press, London, 2017.

Highlights

- Measurement of three Danish emergency departments over 66 hours
- Identification of noisy activities and presentation of their noise levels and durations
- Correlation between sound exposure to individual noise sources and long-term noise measurement
- Suggestion of useful design and operation guidelines to reduce the noise level in emergency departments in hospitals

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: