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WELCOME TO ESPOO

On behalf of the organizing committee for BNAM2024, I would like to welcome you all to Hanasaari, Espoo.

We have attempted to change the concept of the Baltic-Nordic Acoustics Meeting a bit compared to previous conferences. Traditionally, BNAM gathers many acoustics consultants and practitioners, so we have organized numerous workshop with practical, hands on session for different topics which we think will be interesting. Naturally, we also have a scientific program with interesting papers, covering nearly all areas of acoustics.

We are all looking forward to seeing you at the conference and hope that we will have three fruitful days of presentations, workshop, tradeshow and of course perhaps most important, meeting colleagues, discussion and networking.

On behalf of the organizing committee

Henrik Möller

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BALTIC-NORDIC ACOUSTICS MEETING 2024 – PAPERS

KEYNOTES

ENVIRONMENTAL NOISE MEASUREMENTS AND SIMULATIONS + INDUSTRIAL NOISE

ROOM ACOUSTICS

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Acoustic comfort assessment in hospital wards: measuring procedures and parameters.

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Noise pollution is one of the most concerning environmental factors, as it can affect people's health. Especially the health of vulnerable people, such as children, the elderly, the sick, or hospitalized. For this reason, special attention must be paid to the design of hospital environments, within which noise from different activities and equipment can affect both the performance of healthcare staff and the quality of sleep of patients. In this context, patients are the most vulnerable users, as their extra-ordinary condition leads to less ability to cope with stress and greater sensitivity to noise. Despite numerous scientific studies showing that the noise levels detected within hospital environments are highly above those indicated by the World Health Organisation, there are few proposals for effective noise reduction in wards. Our research starts from the need to ensure the acoustic comfort of patients during their hospitalization. For this reason, the first purpose was to define a replicable survey method for assessing noise and acoustic quality in hospital wards, using acoustic characterization measurements, sound pressure levels long-time monitoring, and field observations. Specifically, the paper proposes the criteria applied in the selection of the case studies, the acoustic parameters analyzed, and the measurement techniques used. The survey, which can be easily applied to different contexts, has currently been experimented within some Italian University Hospitals.

1 Introduction

Noise pollution is one of the most worrying environmental factors, as it is increasing over time and can affect people's health [1]. Especially the health of vulnerable people, such as children, the elderly, the sick or hospitalized [2]. For this reason, special attention must be paid to the design of hospital environments, which is a complex organism that houses multiple spaces, functions, activities and equipment, but also different user groups - healthcare staff, patients, visiting relatives - with different needs and varying degrees of sensitivity to sound. For patients, excessive noise levels can affect stress levels, quality of sleep, and the recovery process [2, 3]. In addition, excessive noise can adversely affect healthcare personnel's quality of life and performance, causing stress, aggression and distraction, which can lead to medical errors [2, 4, 5]. Most of the noises complained about by patients come from the corridor. Specifically, most of the noises reported by patients during the night are of anthropogenic origin, such as the conversations of patients and healthcare personnel, and the movement of carts and stretchers [6].

The World Health Organization has expressed the values of desirable sound pressure levels for hospital environments, in order to protect people's well-being and health. Specifically, the A-weighted equivalent sound pressure level (L_{Aeq}) should not exceed 35 dBA during the day and 30 dBA during the night, while the A-weighted maximum sound pressure level (L_{AFmax}), for all anomalous events, should never exceed 40 dBA. Furthermore, in the case of areas frequented by patients, the 30 dBA L_{Aeq} should be maintained both at night and during the day [2]. Additionally, studies on the impact of noise

on sleep patterns, considering variables such as the variation of the duration and depth of the sleep phases by electroencephalography (EEG), has revealed that an equivalent sound level L_{Aeq} from 45 to 50 dBA can change EEG patterns in approximately 50% of exposed subjects [7].

In spite of this, scientific studies have revealed that sound levels inside most hospital spaces are very high [8]. Moreover, most studies focus only on highlighting the problem, giving little thought to possible solutions. A hospital environment design that takes into account both the acoustic performance, the ward layout and the user behavior could limit patient noise exposure [9].

The normative references on the acoustics of hospital environments in different European countries are various. The most commonly used parameters in national and international standards are airborne sound insulation, impact sound insulation, façade sound insulation, service equipment noise, and reverberation time [10, 11]. Despite this, noise disturbance within a hospital ward is mainly caused by the high sound pressure levels, produced by people's activities and equipment, propagating into the ward and consisting in short term events. In research, the most frequently used parameters to describe the indoor acoustic comfort of hospital environments are L_{Aeq}, L_{Amax}, L_{Amin}, or statistical indices as L_5, L_{10}, L_{50}, L_{90}, and L_{95} [2, 8, 12]. In Italy, the assessment of the acoustic performance of hospital building elements follows the standard UNI 11367 [13], which is mandatory under Ministerial Decree 23/06/2022 [14]. To date, the Italian reference for the interior acoustic quality of public buildings is the UNI EN 11532 series [15], part 4 of which, specific to hospitals, hasn't yet been published.

In the following we illustrate the method of investigation that has been carried out during a doctoral program, in order to assess the acoustic quality of in-patient wards and propose intervention strategies aimed at the acoustic comfort of all users. In particular, our research focuses on the comfort of the most vulnerable user, the patient, whose extra-ordinary condition leads to less ability to cope with stress and greater sensitivity to noise. The first part of the research focused on defining a replicable survey method for the assessment of the indoor acoustic quality, using acoustic characterization measurements, long-term and short-term monitoring of sound pressure levels and field observations. In addition, interviews were conducted with health personnel.

The paper proposes the criteria applied in the selection of the case studies, the acoustic parameters analyzed, and the measurement techniques used. This method was validated through measurement campaigns carried out in four Italian hospitals.

2 Case studies selection criteria

The first part of the research dealt with defining a process for selecting a typical hospital ward to carry out the survey. The selection can be based on the following two main aspects: first, type of care provided to patients; second, hospital ward configuration; third, patient bedroom layout.

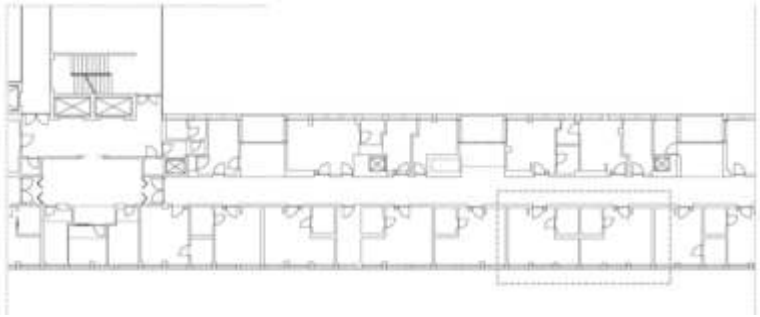

Figure 1: Example of one of the four case studies analysed: Ordinary inpatient care in the Surgical Department. Single corridor ward organization, with two-bed mirrored bedrooms.

Concerning the first topic, for the purpose of this study we propose to select only general low-intensity care wards, since high intensity care wards are characterized by very peculiar noise conditions, and within these specific spaces the acoustic comfort of patients usually has little importance compared with patients' general health conditions. Then, we focused on the most recurring ward configurations: a double corridor ward layout (two corridors with service in the middle area and bedrooms on the outer sides), and a single corridor ward layout (a single central corridor with rooms on both the left and right sides). Finally, among the wards with these typical configurations, we selected those with one- or two-bed mirrored

rooms, with a windowed façade on one side, and private toilets and access door to the other (Figure 1), which represent the most recurrent room type in the modern hospital [16].

For each case study, a representative sample room of the ward acoustics was selected, avoiding marginal locations or special acoustic conditions. Our investigation took place in four wards within the main hospitals of the Tuscan Region (Italy). The in-patient wards examined are of the Maternity, Surgery, Neurorehabilitation and Endocrine Surgery Department.

3 Indoor acoustic comfort evaluation

Since noise disturbance within a hospital ward is mainly caused by the presence of simultaneous sources, and their propagation in the ward, as a result of the performance of the building elements, our survey proposal for the indoor acoustic comfort evaluation is based on achieving the following objectives:

- measurement of Sound Pressure Levels (SPL) in the ward during the day and night;
- measurement of the acoustic performance of building elements;
- use of a qualitative survey to understand the hospital setting.

3.1 SPL measurements

Sound Pressure Levels within a hospital setting are highly variable over time and caused by a variety of sound sources, which is why this investigation is based on:

- Long-time monitoring within a sample room (24 hours minimum) in order to detect temporal and spectral history of noise during the day and night, and assess noise events that might cause disturbance and awakening in patients;
- Short-time monitoring along the ward (20/30 minutes) to detect specific sources of noise or particular activities during the day;
- Measurements at 1 meter from each specific sound source to analyze the specific sources' contribution to the overall noise.

Time and spectral history were sampled with a time constant of 100 ms, in the frequency range from 20 Hz to 20 kHz, by means of a 2-channel real time analyzer 01dB Symphonie, with two ½'' diffuse field microphones. In both long-time and short-time monitoring, the microphones were always positioned at a height of 1.50 m from the floor and at least 1.0 m from any reflective surface. Carrying out monitoring during weekdays (Monday to Friday) is essential, avoiding Saturdays and Sundays, when ward occupancy is reduced.

Three conditions for carrying out the monitoring were evaluated:

- one bedroom in the actual condition of use (occupied room, with the door open);
- one bedroom in an ideal condition (unoccupied room, with the door closed);
- two mirrored bedrooms, one in the actual condition, and one in an ideal condition.

In this way, sound pressure level can be evaluated in terms of L_{Aeq}, L_{AFmax} and statistical levels such as L_{10}, L_{50} and L_{90} during day and night; additionally nighttime noise disturbance can be evaluated in terms of the amount of potentially disturbing events above a fixed threshold.

In addition, short-term monitoring was conducted along the ward and in front of the sample bedroom door, as well as measurements at the specific sources detected during field observations.

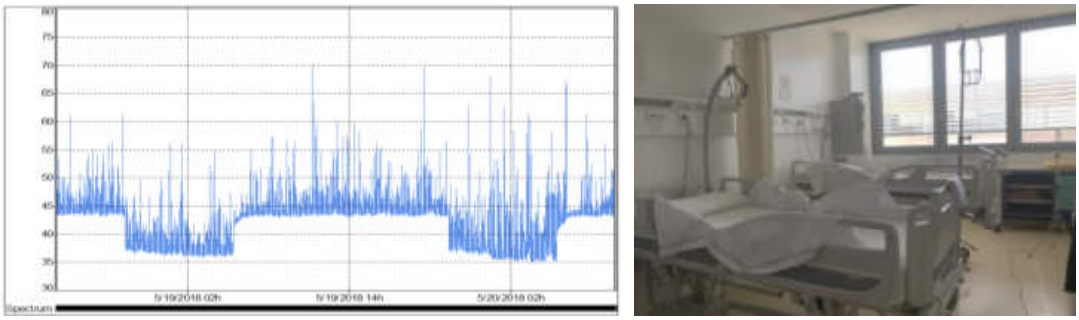

Figure 2: Example of one of the four case studies analysed: Maternity Ward. 48-h long-time monitoring within a typical bedroom in an unoccupied condition and door closed (on the left); photo of the typical bedroom during the long-time monitoring (on the right).

3.2 Measurement of acoustic performance of partitions and rooms

In order to assess the sound propagation within the ward, and patients' exposure to possible sound sources, the acoustic performance of the building elements must be evaluated in terms of reverberation time of the typical room and of the corridor [17], and normalized sound insulation of the partitions between adjacent rooms and between the bedroom and the corridor [18], (Figure 2). In our case studies, measurements were carried out by means of a 2-channel real time analyzer 01dB Symphonie, with two ½'' diffuse field microphones, using the MLS "Maximum Lenght Sequence" technique [19]. This technique was used to reduce excessive noise levels since measurements were carried out during normal activities in the hospital ward. These parameters can be compared with specific national standards. In the Italian context, the comparison was carried out with the 11367:2023 standards [13], referred to by the Italian Ministerial Decree of 23/06/2022 on Minimum Environmental Criteria [14].

Figure 2: Example of one of the four case studies analysed: Endocrine Surgery Ward. Sound insulation measurements of the partition between the bedroom and the corridor (on the left), and between two adjacent bedrooms (on the right).

3.3 A qualitative survey

During surveys, field observations were a valuable way to explore ward recurrences, practices and major sources of disturbance. At this purpose, during the 20/30-minutes short-time monitoring along the ward, noise sources were observed, grouped into seven categories and defined in time and space [20-22], Specifically, the seven groups of sound sources identified are:

- communication;
- anthropogenic noises (e.g., footsteps, coughing, etc...);
- personal electrical devices (e.g., cell phone ringing...);

- ward alarms; medical devices;
- equipment and/or furniture handling (e.g., carts, stretchers, etc...);
- electrical and mechanical systems.

In addition, semi-structured interviews were conducted with healthcare personnel to understand the actual use of ward spaces, functions, but also the needs and occupants' behavior [20, 21, 23].

4 Discussion and Conclusion

Noise pollution is one of the most worrying environmental factors, as it is increasing over time and as it is capable of having direct effects on human health, especially on the health of vulnerable people, including people who are sick or who are in the hospital. Indeed, the acoustic quality of hospital wards is a necessary condition for the comfort of patients and for the recovery process. Despite this, national and international standards usually give limit values for the building elements performances and for SPL values coming from outdoor, but not for the measurement procedure and for the selection of the case studies.

The aim of our research was to define intervention strategies to improve the acoustic quality inside in-patient wards. To do this, a survey protocol was structured which could be applied within general low-intensity care wards. The paper proposed the survey method, validated within four wards of four Italian hospitals, tracing its main phases: case study selection criteria, noise assessment, evaluation of the acoustic performance of the elements, and qualitative survey consisting of field observations and interviews with healthcare personnel.

The proposed survey was very effective in obtaining a large amount of data on the acoustic contexts of the wards, which are currently being processed. In addition, the hospitals involved in the project, as well as staff and patients, showed great interest and cooperation during the investigations, which is a sign of an actual issue that people really feel.

References

[1] European Environmental Agency, EEA Report No 22/2019, Environmental Noise in Europe. *Luxembourg: Publications Office of the European Union*, 2020.

[2] World Health Organization. Guidelines for Community Noise, *World Health Organization: Geneve*, Geneve, Switzerland, 1999.

[3] 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, *Crit. Care*, 13(2), 208, 2009.

[4] M. Basner, W. Babisch, A. Davis, M. Brink, C. Clark, S. Janssen, Auditory and non-auditory effects of noise on health, *The Lancet*, 383(9925), 2014, 1325–1332.

[5] E. E Ryherd, J. Ackerman, C. Zimring, S. Okcu, K. P. Waye, Noise pollution in hospitals: impacts on staff, *Journal of Clinical Outcomes Management*, 19(11), 2012, 491-500.

[6] S. Secchi, N. Setola, L. Marzi, V. Amodeo, Analysis of the Acoustic Comfort in Hospital: The Case of Maternity Rooms, *Buildings*, 12(8), 2022.

[7] P. Ander, B. Saletu, K. Kinsperger, H. Semlitsch, Topographic brain mapping of EEG in neuropsychopharmacology - Part I. Methodological aspects. Methods Find Exp, *Clin. Pharmacol*. 1987, 9, 371–384.

[8] E. De Lima Andrade, D. C. da Cunha e Silva, E. A. de Lima, R. A. de Oliveira, P. H. Trombetta Zannin, A. C. G. Martins, Environmental noise in hospital: a systematic review, *Environmental Science and Pollution Research*, 28(16), 2021, 19629–19642.

[9] S. Secchi, V. Amodeo, L. Marzi, R. Panichi, Analysis of bedroom distribution layouts to improve acoustic comfort in hospital wards, *forum acoustic 2023*, Turin, 2023.

[10] P. Fausti, A. Santoni, S. Secchi, Noise control in hospitals: considerations on regulations, design and real situations, Inter Noise 2019, Madrid, June 16-19, 2019, pp. 7952-7962.

[11] B. Rasmussen, T.C. García, S. Secchi, A comparative study of acoustic regulations for hospital bedrooms in selected countries in Europe, *Buildings*, 13(3), 578, 2022.

[12] V. Amodeo, S. Secchi, A survey methodology for noise in hospital wards, Proceedings of Forum Acusticum 2023 - Convention of the European Acoustics Association, Turin, Italy, 11-15 September 2023

[13] UNI 11367:2023, Building Acoustics - Acoustic Classification of Building Units - Evaluation Procedure and In Situ Measurements, *Ente Nazionale Italiano di Unificazione*, Italy, 2023.

[14] Ministerial Decree Italian Decree Minimum Environmental Criteria for the procurements of design and construction services for new construction, renovation and maintenance of public building, 2022.

[15] UNI 11532-1 Internal Acoustical Characteristics of Confined Spaces — Design Methods and Evaluation Techniques, Part 1: General Requirements, Ente *Nazionale Italiano di Unificazione*, Italy, 2018.

[16] W. Sunder, J. Moellmann, O. Zeise, L. A. Jurk, The Patient Room – Planning, Design, Layout, Basel, Switzerland, *Birkäuser*, 2019.

[17] EN ISO 3382-2:2008, Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms, *International Organization for Standardization*, 2008.

[18] ISO 16283-1:2014, Acoustics — Field measurement of sound insulation in buildings and of building elements — Part 1: Airborne sound insulation, *International Organization for Standardization*, 2014.

[19] ISO 18233:2006, Acoustics – Application of new measurement method in building and room acoustics, *International Organization for Standardization*, 2006.

[20] ISO/TS 12913-1 “Acoustics — Soundscape, Part 1: Definition and conceptual framework”, 2014.

[21] ISO/TS 12913-2 “Acoustics — Soundscape, Part 2: Data collection and reporting requirements”, 2018.

[22] D. Dawson, R. Barham, M. Hamilton, B. Philips, Sound in Time: An observational study to identify the sources of sound and their relative contribution to the sound environment of an intensive care unit, *Applied Acoustic*, 187, 2022.

[23] S. Tusini, La ricerca come relazione. L’intervista nelle scienze sociali (Research as a relationship. The interview in the social sciences), *Franco Angeli Editore*, Milano, 2006.