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Acoustical design criteria for hospitals

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This paper provides a case study of three new Finnish hospitals, which are currently under construction. We will discuss the acoustical design criteria in room acoustics of patient rooms and operation rooms. Solutions for structure borne noise insulation of MRI scanner devices will be discussed. We will also suggest some acoustical design criteria for sound insulation for different room types in healthcare facilities, such as patient rooms, hearing examination rooms and rooms for psychological therapy. Also, some thoughts are given on the need of sound insulation against sound sources from outside, such as emergency vehicles and helicopters.

1 Introduction

Room acoustical aspects of hospital sound environments have been of interest lately. Several recent studies discuss the importance of controlled and pleasant sound environments, from the point of view of health effects on the healing patients, as well as of working and communication circumstances of the staff [1, 2, 3, 4].

Rooms with poor sound absorption, with more than one patient or operation functions, can easily become acoustically chaotic. Besides control of the overall noisiness, speech intelligibility is a critical property from the point of view of the workers. For controlling speech intelligibility, reverberation time and the level of background noise are the significant acoustical parameters.

Reverberation time can be controlled by the amount, type, and placement of absorption materials. However, high requirements for the hygiene and maintenance of the interior materials set restrictions on the variety of materials and products that can be utilized in hospitals. Both measurements and user studies have been carried out for comparison.

In this article, we summon our up to now experiences in three major hospital construction projects in Finland, namely Carea Hospital, Keski-Suomen sairaala Nova Hospital, and Siltasairaala Hospital. Carea Hospital construction project in Kotka, Southern Finland, consists of renovation of the existing 47 600 m^2 facility, and a new extension building of 15 200 m^2. Currently, the extension building is in construction work phase, while the renovation part is in design phase. The new building will host emergency duty, intensive care, angiograph, 10 operation rooms for surgery, delivery ward and a datacenter.

Keski-Suomen sairaala Nova Hospital is a new hospital being built in Jyväskylä, Central Finland. The major acoustical challenges in this project have been a helicopter landing site on the roof of the hospital patient ward tower, a large 3-storey-high foyer with a restaurant and other functionalities, and a hearing examination unit involving a sound field room. The construction work began in 2016, and the hospital is planned to be taken into use in 2020.

Siltasairaala Hospital is a new hospital building to be built by the Hospital District of Helsinki and Uusimaa HUS in its main campus in Meilahti, Helsinki. Siltasairaala, 71 500 m^2, will include new emergency, trauma and cancer units with heavy modern technology. The construction work will begin during this year, and the facilities are planned to be taken into use in 2023.

Besides room acoustic solutions, the choices of sound reduction indices have major effect on the hospital's acoustic environment. The level of required airborne sound insulation between rooms in a hospital varies by the rooms' functions. Rooms like the psychological or psychiatric admittance, hearing examination, delivery rooms and rooms for special types of patients have a very high requirement for sound reduction index.

As for background noise level, modern hospitals are packed with noise-producing machines and operations. To give an example, a MRI scanner device is a very noisy, vibrating machine. Besides all operations in the surrounding facilities, also the machine itself is sensitive to noise and vibration: the quality of the produced image is dependent on the stability of the machine. In Siltasairaala Hospital, altogether 5 MRI devices are planned.

Large hospitals and hospital campuses involve heavy traffic due to catering and supplies logistics, ambulance service and other patient transport, even helicopter traffic. Sufficient façade sound insulation ensures undisturbed operations and peaceful life within the hospital building.

2 Government and standard requirements for acoustics in hospitals

Sound environment in hospitals in Finland is regulated at least with these documents:

- Ministry of environment statute YM 796/2017 Vaatimukset uuden rakennuksen ääneneristykselle (Regulations for sound insulation in new buildings) [5]
- SFS 5907 Rakennusten akustinen luokitus (Acoustical classification of buildings) [6]
- Suomen rakentamismääräyskokoelma (Finnish building regulations) parts C1:1998 [7] and D2:2012 [8]
- Valtioneuvoston päätös melutason ohjearvoista (Government Decree on noise level guidelines) (**993/92**). Helsinki 1992 [9]
- Asumisterveysohje (Health protection in dwellings) (**2003:1**). Ministry of social affairs and health, Helsinki 2003 [10]
- Ympäristöopas 108**:** Rakennuksen julkisivun ääneneristävyyden mitoittaminen (Dimensioning the sound insulation of building facades), Ministry of environment, Helsinki 2003 [11]
- ISO 8253-1:2010 Audiometric test methods [12]

Requirement values are given to the following quantities:

- Maximum permitted noise levels (equivalent and max) from HVAC-machines $L_{A,eq,T}$ and $L_{A,max}$ in rooms.
- Maximum permitted noise levels from noise sources outside the building (day and night) $L_{A,eq,07-22}$ and $L_{A,eq,22-07}$ in rooms.
- Minimum value for airborne sound reduction indices R'_w, $D_{nT,w}$ (YM 796/2017)
- Maximum permitted impact sound levels from tapping machine $L'_{n,w}$, $L'_{nT,w} + CI_{,50-2500}$ (YM 796/2017)
- Maximum value for reverberation time T (maximum octave band values 250 – 4000 Hz, 125 Hz can be 1,5 times higher).

3 Design criteria for room acoustics

The two most important factors of sound environment in rooms are background noise level and reverberation time (or amount of absorptive material).

3.1 Background noise levels

In the statute YM 796/2017 the maximum permitted background noise levels in patient rooms are $L_{A,eq,T}$ = 28 dB and $L_{A,max}$ = 33 dB, or if the noise is impulsive or tonal $L_{A,eq,T}$ = 25 dB and $L_{A,max}$ = 30 dB. However, since the statute was not yet in order during the design phase of our hospital cases, our design followed the SFS 5907 standard (class C), which is based on Finnish building regulations D2 and Government Decree 993/92.

These background noise level requirements are valid for elevators, HVAC-equipment, compressors, central vacuum equipment and machines for cleaning, to name a few. The requirements are not valid for machines (e.g. vacuum cleaner) used in the same room. The requirements are listed in Table 1.

Table 1. Maximum permitted background noise levels in different room types.

Room type	$L_{A,eq,T}$ (dB) **max**	$L_{A,max}$ (dB) **max**
Patient rooms, therapy rooms and resting rooms	28	33
Sound field room for hearing examination (ISO 8253)	16	
Inspection rooms, operation and treatment rooms rehabilitation rooms and children's waiting and play rooms	33	38
Offices and meeting rooms	33	38
Waiting rooms	33	38
Lobbies and corridors	40	45
Restaurant	38	43

3.2 Reverberation time

Requirements or target values for reverberation time are set in the SFS 5907 standard. In our design cases we have also dimensioned the requirement for class A absorption material. The amount of material is given as the ratio of the room floor surface area, and is dependent of the room height, since the reverberation time is in direct relation to the room volume. In our hospital cases, most rooms have normal 1 floor height 2,5 – 3,2 m. Table 2 lists the target reverberation time values and the corresponding quantities of class A absorption material for several different room types.

Table 2. Target values for reverberation time T and required amount of class A absorption material relative to the floor surface area.

Room type	T (s) **max**	Absorption % of floor area
Patient rooms	0,6 … 0,8	80 … 110
Inspection rooms, operation and treatment rooms, waiting rooms	0,8	80
Therapy rooms, children's waiting and play rooms resting rooms, audiometric rooms	0,5	120
Control room	0,4	150
Offices	0,7	90
Meeting rooms	0,5 … 0,7	100 … 120
Lobbies and corridors	0,8	80
Social rooms	0,7	90 …100
Restaurant and cafeterias	0,9	70 …100

4 Insulation of a MRI scanner device

Magnetic resonance imaging scanner (MRI) devices have become common for medical diagnosis and staging of diseases in hospitals. In our experience, a typical MRI device designed for hospital use weights around 7 tons and produces a noise level of about 80-90 dB. The mechanics within the MRI device involve gradient coils that are rapidly switched on and off, causing a loud hammering noise. This noise propagates efficiently in the structures of the building, unless it is carefully insulated from the structure frame.

Where possible, the MRI devices are typically planted well away from other facilities in the hospital. In Keski-Suomen sairaala Nova Hospital, we were able have an influence on the hospital facilities layout in an early enough design phase, so that the MRI unit was planted in a separate wing building. A preferable foundation for the MRI unit is on ground supported floor structure. In this case, the noise from the MRI device can be efficiently insulated by disjointing the concrete floor slab of the MRI space from the floor structures of the surrounding spaces.

In Siltasairaala Hospital however, one of the MRI devices is required to be placed within the emergency compartment of the hospital, having critical functions above, below and around the MRI room. In this case, a more sophisticated floor insulation is required, to enable concurrent operations in the neighbouring spaces. The concrete surface slab is disjointed from the floor structures of the adjacent spaces. Furthermore, the surface slab is required to be installed floating, typically on an elastic mat dimensioned to provide dampening over the range of relevant frequencies. The mat can either cover the area under the surface slab completely, or only the area where the weight of the MRI device is distributed by the surface slab. Alternatively, the mat can be installed under the surface slab in pre-sized strips / ribbons, allowing flexibility in selecting the elastic properties of the rug. Additional to the surface slab, also the device itself is typically insulated by foot pads pre-installed by the manufacturer. To avoid ending up with an uncontrolled multiple mass and springs system, a wise approach is to choose a concrete surface slab with a mass significantly larger than that of the device.

The choice of walls and ceiling structures and junctions is affected by the requirement of a Faraday cage to envelop the MRI room. The metallic cage structure can be installed right on the concrete floor, or alternatively on the floor surface slab. Following this resolution, the wall structure can similarly be based either on the floor slab, or on the surface slab. A sound insulating ceiling is required, typically a couple of gypsum boards suspended from the ceiling slab with vibration dampers.

Absorption in the MRI room helps regarding the airborne sound insulation but is not required from the point of the room operations: the patient under examination is armed with double hearing protection, and other people are not allowed in the room during the MRI operation.

5 Sound insulation of different room types

5.1 Airborne sound insulation

In the statute YM 796/2017 the minimum required sound insulation between patient rooms is $D_{nT,w}$ = 55 dB and between patient room and corridor $D_{nT,w}$ = 39 dB. This means that the airborne sound insulation requirements have become much tighter. As before, we have applied to our cases the sound reduction indices R'_w according to the earlier standard SFS 5907. The applied sound reduction indices are given in table 3.

Table 3. Requirements for sound reduction index R'_w (dB) for different room types according to SFS 5907 class C. For doors, a sound insulation category is given, along with a minimum laboratory-measured value for sound reduction index R_w (dB).

Room type	R'_w (dB) **minimum**	Doors [1]
Inspection, operation, treatment and therapy rooms	48	-
- from above to corridor	34	dB30, 37 dB
Patient rooms (multiple people)	48	-
- from above to corridor	34	dB30, 37 dB
Patient rooms (one person)	52	-
- from above to corridor	39	dB30, 37 dB
Resting rooms, Children's waiting rooms	48	-
- from above to corridor	34	dB30, 37 dB
Offices	40	dB25, 30 dB
Meeting rooms	48	dB30, 37 dB
Children's inspection, treatment, operation and hearing examination rooms	52	-
- from above to corridor	48	dB30+dB25, 37 dB+30 dB

[1] Akukon suggestion: equal to SFS 5907 class A and B

5.2 Impact sound insulation

In the new statute YM 796/2017 the maximum permitted sound level from tapping machine between patient rooms is $L'_{nT,w} + CI_{,\ 50\text{-}2500} = 53$ dB and from corridor to patient room $L'_{nT,w} + CI_{,\ 50\text{-}2500} = 63$ dB. In our cases the requirement is $L'_{n,w} = 63$ dB (SFS 5907).

6 Sound insulation against outdoor noise

In the new statute YM 796/2017 the minimum permitted façade sound insulation is 30 dB and maximum permitted noise level for narrow band or impulse sounds in the rooms used for sleeping is $L_{A,eq,T} = 25$ dB. In Asumisterveysohje (Health protection in dwellings) it is stated: [10] "*Disruption in sleeping begins to appear […] when single noise events, depending on length and frequency, exceed 40 – 65 dB(A). The lower limit is for long lasting or odd noises, and the upper limit is for short term, familiar noises, which happen only once or twice during the night, and the sleeper has adapted to them.*"

Potential outside noise sources in hospitals are general traffic, ambulance service and other patient transport, catering and supplies logistics, helicopter traffic, as well as HVAC noise. Table 4 lists the maximum noise levels according to standard SFS 5907 Class C. Different values are given for day (7-22) and night (22-7) time.

Table 4. Maximum noise levels from sound sources outside the building in different room types (SFS 5907, class C).

Room type	$L_{A,eq\ 07\text{-}22}$ (dB) **max**	$L_{A,eq,22\text{-}07}$ (dB) **max**
Patient rooms	35	30
Inspection, operation and treatment rooms	35	
Therapy and resting rooms	35	
Children's waiting and play rooms	35	
Offices	40	
Corridors, Lobbies	45	
Outside areas for people	55	50

References

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[8] Suomen rakentamismääräyskokoelma (Finnish building regulations) D2: Ventilation, Helsinki 2012

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[12] ISO 8253-1:2010 Audiometric test methods