A case study investigation of the indoor environmental noise in four urban South African hospitals.

by

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University of Pretoria

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Supervisor: Prof PT Vosloo

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Declaration

I declare that this research is entirely my own, unaided work, except where otherwise stated. All sources referred to are adequately acknowledged in the text and listed.

I accept the rules of assessment of the University of Pretoria and the consequences of transgressing them.

This dissertation is being submitted in partial fulfilment of the requirements for the degree of MSc (Applied Science Architecture) at the University of Pretoria.

It has not been submitted before for any degree or examination at any other university.

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Abstract

Dissertation title:	A case study investigation of the indoor environmental noise in four urban South African hospitals.
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The field of acoustics in architecture is often neglected by spatial designers, being thought of as a specialist field only applicable for complex acoustic requirements. However, research shows that environmental noise has a significant effect on humans and thus should be considered in all indoor environment design, no matter the occupancy type.

This case study research seeks to investigate acoustics within healthcare facilities, specifically in multi-bed general wards in four urban South African hospitals.

Sound can have either an auditory or non-auditory effect on humans, meaning it can either cause hearing damage or result in subjective responses that affect performance and physiology. This is an important consideration in a healthcare setting as the principle of 'do no harm' should apply to clinical treatment as well as the clinical environment.

Noise control in healthcare environments can be a challenge since most of the surface finishes are hard and smooth, making them easily cleanable but also acoustically reflective, which can potentially cause spaces to become very noisy. Guidelines have been developed internationally by the World Health Organisation (WHO) and nationally by the South African Bureau of Standards defining noise limits in various contexts, including hospitals.

Prior research in the area of evidence-based design has shown that a quiet environment is conducive to patient healing and has been shown to improve staff work performance and decrease stress, irritation and tiredness. However, numerous international studies have revealed that few hospitals world-wide, if any, comply with the WHO guidelines, highlighting the challenge that exists in designing quiet hospital environments.

Since the research in this regard is extremely limited in the South African context, the goal of this research is to investigate the acoustic environment of a selection of South African hospitals to determine whether there is a likely need to design hospitals for improved noise control.

This research project was designed as a multiple case study with the purpose of identifying possible areas for future research. The existing acoustic conditions in a ward of each of four urban hospitals were assessed in terms of sound levels, user opinions and architecture.

The research objective was firstly to establish whether the selected hospitals are too noisy according to national and international guidelines, and then to determine the cause of the noise, whether it is actual or perceived noise, and whether design factors have an influence on the noise.

Environmental noise was assessed by means of a Class 1 integrating sound level meter, questionnaires and direct observation.

It was found that the average sound levels exceeded both local and international guidelines. In spite of this, however, the overall opinion of users was that noise levels were not disturbing. A combined assessment of the data revealed that layout may influence the acoustic environment and is worthy of more extensive research, particularly with regard to the difference between patient and staff member perceptions of sound.

Other recommendations pertain to the establishment of design noise guidelines that address occupied noise levels in hospital wards, which would require an extensive study of human responses to noise exposure as well as factors that can either influence the response to noise or the noise level.

Abstrak

Verhandeling titel:	'n Gevallestudie van die binnenshuise omgewingsgeraas in vier stedelike Suid-Afrikaanse hospitale.
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	Universiteit van Pretoria
Datum:	Mei 2015

Akoestiese ontwerp in argitektuur word dikwels verwaarloos deur ontwerpers van gebouruimtes omdat dit beskou word as 'n spesialis dissipline wat net van toepassing is op projekte met gevorderde akoestiese ontwerpvereistes.

Hierdie gevallestudie poog om akoestiek in gesondheidsfasiliteite te ondersoek, spesifiek in multi-bed algemene sale in vier stedelike Suid Afrikaanse hospitale.

Klank kan 'n hoorbare en onhoorbare effek op mense hê. Dit beteken dat dit gehoorskade kan veroorsaak of aanleiding gee tot subjektiewe response wat produktiwiteit (werkverrigting) en fisiologie betref. Dit is 'n belangrike oorweging in 'n gesondheidversorgingsomgewing omdat die beginsel van 'vermy die aanrig van skade' op beide die kliniese behandeling as op die kliniese omgewing van toepassing behoort te wees.

Geraasbeheer in gesondheidsomgewings kan 'n uitdaging wees omdat die oppervlakke meestal hard en glad is. Dit maak dit maklik om skoon te maak maar terselfdertyd akoesties (klank) reflekterend. Dit kan aanleiding gee tot lawaaierige ruimtes. Die Wêreld Gesondheid Organisasie (World Health Organization, WHO) en die Nasionale Buro van Standaarde het geraaslimiete in verskeie omgewings gedefinieer, insluitend hospitale.

Vorige bewysgebaseerde navorsing het bevind dat 'n stil omgewing bevorderlik is vir die herstel van pasiënte. Dit bevorder ook personeel se produktiwiteit en verminder stres, irritasie en moegheid. Verskeie internasionale studies het bevind dat min hospitale wêreldwyd, indien enige, voldoen aan die WHO riglyne. Dit beklemtoon die uitdaging om stil hospitaalomgewings te ontwerp.

Omdat hierdie tipe navorsing baie beperk is in Suid Afrika, is die doel van hierdie studie om die akoestiese omgewing van 'n groep uitgesoekte hospitale te ondersoek ten einde vas te stel of dit nodig is om verbeterde geraasbeheer in hospitale toe te pas.

Die navorsingsprojek was ontwerp as 'n veelvuldige gevallestudie met die doel om verdere navorsingsaspekte te identifiseer. Die bestaande akoestiese toestande van hospitaalsale in vier stedelike hospitale is nagevors in terme van klankpeile, gebruikersopinies en die argitektoniese ontwerp.

Die navorsingsdoelwit was om eers vas te stel of die geselekteerde hospitale te lawaaierig is volgens nasionale en internasionale riglyne. Vervolgens is die bron van die geraas, werklik of waargeneem, vasgestel en of ontwerpfaktore 'n invloed op die geraas het.

Omgewingsgeraas was gemeet deur middel van 'n Klas 1 integrasie klankpeilmeter, vraelyste en direkte waarneming.

Die bevinding was dat die gemiddele klankpeile beide plaaslike en internasionale riglyne oorskry het. Desondanks was die algemene gebruikersopinie dat die klankpeile nie buitensporig was nie. 'n Gekombineerde evaluasie van die data toon aan dat uitleg die akoestiese omgewing beïnvloed; wat dit dan die moeite werd maak om verder na te vors; veral wat die verskil tussen pasiënt- en personeellid se persepsie van klank (geraas) betref.

Ander aanbevelings het te doen met die vestiging van geraasriglyne wat die geraasvlakke in okkupeerde hospitaalsale met pasiënte analiseer. Dit sal 'n uitgebreide studie van menslike reaksie ten opsigte van geraasblootstelling benodig, sowel as van ander faktore wat die reaksie op geraas en klankpeile beïnvloed.

Table of Contents

List of Tables

List of Figures

List of abbreviations

L_{eq}	Equivalent continuous sound pressure level [dBA]
LA_{max}	Maximum A-weighted sound level over a given time period
dB	decibel – unit of sound level measurement
dBA	A-weighted decibel level
SANS	South African National Standards
WHO	World Health Organisation

1. CHAPTER 1: INTRODUCTION AND BACKGROUND

Every space stimulates an acoustic response. This response can be manipulated by the designer to achieve a certain outcome. Different senses can be invoked to influence outcomes. While designers often tend to focus on visual responses, the impact of sound should not be overlooked in spatial design.

“Acoustics deals with the production, control, transmission, reception, and effects of sound” (Ching 2012:280). In architecture, this means designing a space in such a way that sound is either enhanced, reduced or directed in a particular manner.

The field of acoustics in architecture is often neglected by spatial designers, being seen as a specialist field, only to be employed when the space in question has very specific requirements to control the behaviour of sound. While it is true that specialist design is required for complex cases, such as a theatre, basic acoustic consideration should be afforded to every designed environment.

This dissertation sets out to explore the effect of sound in hopital indoor environments.

1.1. Background on acoustics

When considering acoustics in design, it is important to first understand the basic nature of sound, secondly to understand the difference between sound and noise and its behaviour in indoor space, and then thirdly, to understand the impact of sound on human subjects.

1.1.1. The nature of sound

Sound is energy propagated from a vibrating source, causing a series of pressure fluctuations in the surrounding medium. The air pressure fluctuation is measured in the Standard International unit for pressure, the Pascal (Pa). This motion can be represented graphically as a sine wave, the maximum compression being the apex and the maximum rarefaction being the negative apex as illustrated in Figure 1. The amplitude and wavelength influence the loudness and frequency of the resultant sound.

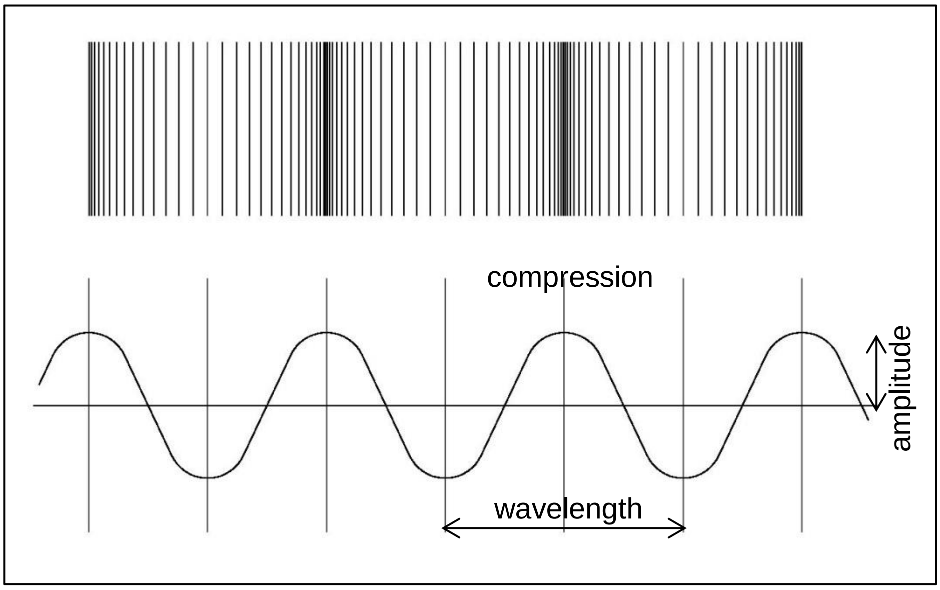

Figure 1: Representation of propagation of sound as wave motion.

Sound can be described in terms of its power (W/m^2), its pressure (Pa), or its frequency (Hz). Because the range of human hearing of sound power and pressure is extremely wide (10^{-12} to 10 W/m^2 and 0.0002 to 200 Pa respectively), these measurements are converted to a logarithmic scale giving a more comprehensible sound level range in decibels (dB). On this scale, 0 dB is the lowest threshold of human hearing, the upper threshold at which pain begins being at about 120 dB. Since the decibel scale is logarithmic, not linear, a doubling in the sound pressure results in an approximate 6 dB increase sound pressure level.

Since the human ear is not only sensitive to the sound pressure but also frequency, the frequency character of a sound needs to also be considered. The human ear can hear frequencies from 30 to 20 000Hz but is more sensitive to certain frequencies, perceiving them to be louder. Thus the sound level scale is weighted to compensate for the frequency component of a sound. The weighting that is most commonly used in architectural acoustics is called the A-weighting and the unit is dBA. The A-weighting is specifically adjusted for the frequency range of human speech.

In most natural contexts, sound pressure fluctuates constantly, making it difficult to determine a single figure for the sound level. It is common practice to express environmental sound in terms of the equivalent continuous sound pressure level (denoted by L_{eq}). This is a single value equivalent to the combined effect of fluctuating sound energy over a specified period of time. The equivalent continuous A-weighted sound pressure level is denoted by $LA_{eq}T$ in dBA.

When noise over a given time period contains of a number of discreet sound events, the A-weighted maximum level (denoted as LA_{max}) may be used rather than the continuous equivalent level as an indicator of the level of disturbance (Berglund, Lindvall & Schwela 1999:19).

Sound energy can be transmitted through materials, reflected, or absorbed. The amount of energy that is transmitted, reflected, or absorbed depends on the characteristics of the sound (frequency and energy content) and the properties of the materials encountered. This is of importance in design since the choice of materials in the architecture will influence the way sound behaves. Materials that are porous have the ability to absorb and transmit sound energy, converting it to heat or kinetic energy, thus extracting the sound from the space of origin. On the other hand, materials that are non-porous (usually rigid, hard and smooth) will typically reflect the energy back into the space with the result that sound takes longer to dissipate its energy and die down.

The amount of time it takes for a sound to die down by 60 dB is referred to as the reverberation time. A long reverberation time results in a noisy space and reduces the clarity of the sound.

1.1.2. The difference between sound and noise

Scientifically, there is no difference between sound and noise. However, noise is commonly defined simply as unwanted sound. This is very subjective, determined by any individual's response to sound. Noise can be a sound that is too loud, having an auditory impact, or it can be sound that has a particular frequency content or fluctuation pattern that is annoying or is simply distracting, having a non-auditory impact.

In spite of the subjective nature of noise, guidelines and standards have been established for environmental noise in various contexts. Some of these are based on auditory effects, such as *SANS 10083:2004 – The measurement and assessment of occupational noise for hearing conservation purposes* (South Africa 2004), which stipulates noise levels beyond which physical hearing damage is likely to occur. The noise limits stipulated in these standards are usually weighted for length of time exposure to the sound and frequency. These types of regulations are typically applicable to industrial settings, where loud noise is likely to occur.

Other guidelines and regulations, for example, *SANS 10103:2008 – The measurement and rating of environmental noise with respect to annoyance and to speech communication* (South Africa 2008), relate more to the subjective response of humans to sound, such as annoyance, and have much lower limits.

1.1.3. Background on the impact of noise on humans

It is important to remember that sound can have either an auditory or non-auditory effect on humans. Auditory effects relate to the human sense of hearing and, conversely, non-auditory effects relate to other aspects of human responses.

1.1.3.1. Auditory impact

Sound above certain levels and at certain frequencies can cause hearing damage. This is an auditory effect. Hearing loss is usually permanent due to acoustic trauma caused by either short term exposure to sound pressure levels above 120dB or long term exposure to levels above 90dB. The receptors (stereocilia) in the cochlea of the human ear can become permanently damaged and do not replace themselves. This usually occurs first in the high-frequency area of the cochlea, which is within the range of human speech.

Auditory effects can be measured by means of audiology tests. Because of the known and measurable effect of exposure to loud noise on one's hearing, safe and acceptable occupational noise levels have been established. *SANS 10083:2004 – The measurement and assessment of occupational noise for hearing conservation purposes* prescribes that in any occupational context where persons are exposed to equivalent continuous sound levels of 85dB and above for a period of 8 hours, hearing protection measures should be put in place (South Africa 2004). However, these regulations fail to recognise the non-auditory effects of noise.

1.1.3.2. Non-auditory impact

Non-auditory effects are those effects which cannot easily be empirically measured and result from exposure to noise which may not necessarily be excessively loud. This refers to the subjective response of humans to sounds that interfere with activities and disturb attitudes (Pohl 2011:158). These can then be divided into performance effects and physiological effects.

Performance effects result from noises that interfere with work activities, communication and rest, resulting in strain, fatigue, frustration and hindered personal effectiveness.

Physiological effects are often clinically presented in much the same way as stress. Unnecessary noise, even though it may not be very loud, can cause an increase in blood pressure and heart rate, muscle tension, change in breathing pattern and muscle startling response (Canadian Centre or Occupational Health and Safety 2008).

Both performance and physiological effects influence health and well-being and are as important to address as hearing damage.

1.1.4. The relevance of acoustics in healthcare

Considering both the auditory and the non-auditory impact of noise, it follows that noise control should be a significant consideration in indoor environment design, particularly in a healthcare setting where the philosophy of 'do no harm' should be extended to the environment and not only clinical practice. Research has shown that a quiet hospital environment is beneficial to both patient and staff outcomes (Joseph & Ulrich 2007). This is recognised by the World Health Organisation (WHO) in the document entitled *Guidelines on community noise* (Berglund, Lindvall & Schwela 1999).

In most settings, noise can be controlled by the application of sound-absorbing materials. Absorption of sound means that the sound energy is extracted from the space, preventing long reverberation times and the resultant noise. As mentioned previously, absorption materials are usually porous, however, in a healthcare setting materials are typically required to be non-porous and easy to clean in order to prevent bacterial growth on surfaces, potentially increasing the risk of acquiring hospital associated infections. These types of surfaces are typically acoustically reflective, resulting in a noisy environment. Thus, it seems infection-control principles are incongruous with a good acoustic environment.

Coupled with this, there is often a high level of noise generation from activities and equipment in a hospital such as trollies, monitors, foot traffic, alarms, staff conversation, etc. making hospitals generally very noisy. This is confirmed by numerous studies world-wide showing noise levels in hospitals to be 20-40 dB higher than the WHO recommendation (Busch-Vishniac, West, Barnhill, Hunter, Orellana & Chivukula 2005).

Thus there seems to be a challenge regarding noise control in hospitals.

1.1.5. Acoustic norms, standards and guidelines

Regulating bodies world-wide have set up various guidelines regarding the ideal noise levels to be maintained in hospitals.

The WHO, in their *Guideline for community noise,* gives a guideline continuous equivalent sound level (LA_{eq}) value for hospital ward rooms for the day and night time of 30 dBA, with a night time maximum (LA_{max}) of 40 dBA. In other areas of a hospital where patients are being treated the guideline value is 35 dBA (Berglund et al 1999:37-46).

The South African National Standard *SANS 10103:2008 - The measurement and rating of environmental noise with respect to annoyance and to speech communication* gives a value for recommended rating levels for ambient noise in different occupancy areas (South Africa 2008). The values represent the equivalent continuous sound pressure levels to be achieved when the area in question is under normal operation. With regard to healthcare facilities, it stipulates that in a single bed ward a level of 30 dBA is required and for a ward with two or more beds a level of 35dBA is to be achieved, with a maximum allowable for each being 35 and 40 dBA respectively.

At the time of writing, the design of hospitals in South Africa is governed by Regulation 158 of 1980, *Regulations Governing Private Hospitals and Unattached Operating Theatre Units*, as amended by Government Notice No R.434 of 1993. This regulation, however, is silent on the issue of room acoustics and noise control.

The South African National Department of Health has published a series of guidelines pertaining to the development of healthcare infrastructure, known as the Infrastructure Unit Systems Support (IUSS) Project. The IUSS guidelines refer briefly in various sections to considerations regarding noise control (IUSS N&S Task Team 2014), however, guideline values are not provided.

The Specialist Services Health Technical Memorandum of the United Kingdom sets out more detailed acoustic criteria for the design of healthcare facilities (United Kingdom 2008). This document includes criteria for noise levels in wards from both building services and external noise sources, sound insulation between rooms and room acoustics, paying attention to the need for confidentiality, privacy, quietness and speech intelligibility. The memorandum recommends an equivalent continuous sound level of 40 dB in single bed wards and 45 dB in multi-bed wards in the daytime, a higher and possibly more realistic guidance measure, which includes building services noise and external noise but excludes medical equipment.

1.2. **Goals and objectives**

Based on prior research showing both that hospitals should be quiet, on the one hand, and on the other hand, that hospitals have been found to be too noisy, the need to address noise in hospitals in South Africa has been identified.

The goal of this research is to determine, based on the selected case study sites, whether there is a likely need to address indoor environmental noise, through design, in South African hospitals. This study should be seen as a precursor to determining whether indoor environmental design needs to be improved to better address acoustic requirements.

The first objective in this study is to determine whether the noise levels in the selected hospitals are excessive, looking at empirical data and perceptions, bearing in mind that though sound levels can be scientifically measured, noise is subjective by definition.

Secondly, significant sources of noise, their regularity and their level of annoyance should be identified.

Thirdly, it must be established whether noise is propagated and the effect exaggerated due to design aspects in order to determine whether indoor noise should be addressed through design.

An evaluation of the facility layout and application of finishing materials will be conducted, paying attention to location of noises sources relative to the occupants and to the reverberation time resulting from acoustically reflective materials.

1.3. **Problem statement**

In recognising the benefits of quiet hospital environments juxtaposed by the reported common non-compliance with noise guidelines, it follows logically that there is a need to address noise control in hospitals. As an aspect of the indoor environment, this task falls, at least in part, to the designer.

Since research regarding hospital indoor environmental noise levels in South Africa is extremely limited, there is inadequate evidence of the need to address acoustics in indoor environmental design in South African hospitals. The body of research needs to be expanded to build an accurate picture of the acoustic environment in South African hospitals.

1.4. Research questions

The research objectives may be achieved by answering the following questions:

1. Does the continuous equivalent sound pressure level recorded in the assessed hospitals exceed the level recommended in the WHO Guidelines on community noise?
2. Does the continuous equivalent sound pressure level recorded in the assessed hospitals exceed the level recommended in the South African National Standard 10103: 2008?
3. Do the occupants find the indoor environment to be noisy?
4. Can the sources of noise be identified? (i.e. Why is it noisy?)
5. Is there a causal effect between the architecture and the noise levels?

In essence, the research sets out to determine if hospitals are noisy and whether the occupants mind the noise. If so, why is it noisy and can the noise be controlled by architectural interventions? If it is found that noise levels are high but perceived noise is low, then the validity or interpretation of the guidelines should be questioned. This process of questioning is illustrated in Figure 2.

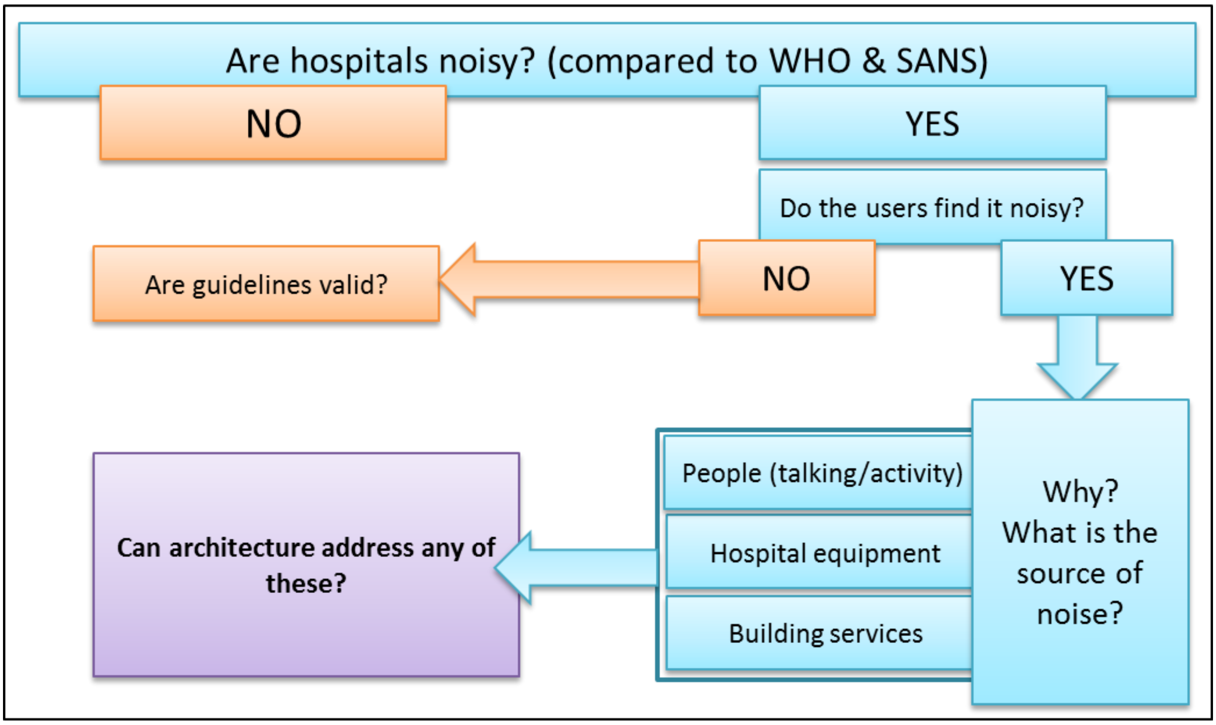

Figure 2: Flow diagram of research questions.

1.5. Supporting hypotheses

The primary hypothesis to be tested is that hospitals in South Africa are too noisy. The supporting hypotheses to this are:

1. Noise levels exceed recommended levels.
2. Noise levels are disturbing to the users.

The secondary hypothesis is that indoor environmental noise in hospitals is influenced by architectural design and finishes.

1.6. Research design

In order to achieve the set objectives, it was decided to conduct a case study investigation of the noise levels and acoustic environment in four urban hospitals.

Though case study research does not provide a large sample from which generalised conclusions may be drawn, it does contribute to the existing small pool of local research in this field and may provide insight into possible trends and avenues of further research.

This multiple case study will be both a comparative study and a cumulative study. Each site will be compared for similarities or differences that may provide insight into interpreting acoustic problems or solutions. The data will also be combined and integrated to obtain an overview of noise in urban South African hospitals.

The comparative research is exploratory, seeking possible explanations for differences or similarities that may emerge from the data. The cumulative study will be theory-testing, seeking to confirm, on a local scale, the hypothesis that hospitals in South Africa are too noisy.

Multiple sources of evidence will be used to build a picture of the acoustic environment of each site, as illustrated in Figure 3.

Firstly, noise levels will be assessed. This will be done through empirical means, measuring the actual sound levels using a sound level meter, and subjective means, measuring the perceived sound levels using a questionnaire.

Secondly noise sources will be identified and characterised through a questionnaire and direct observation.

Lastly, data regarding the architecture of each site will be gathered by direct observation and dimension measurement.

A statistical analysis of the collected data will be performed to detect associations.

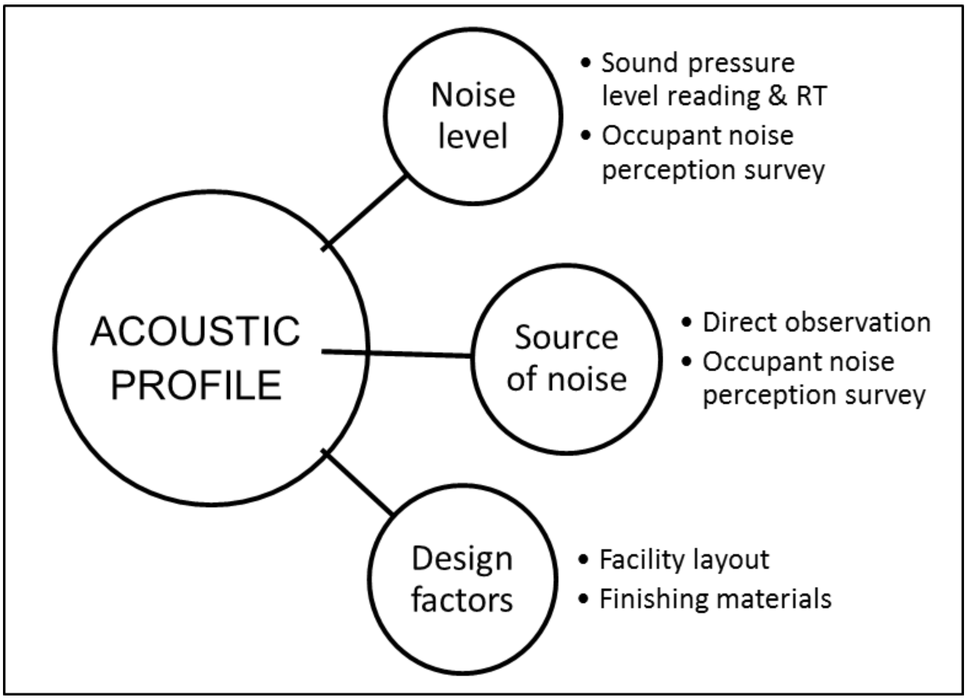

Figure 3: Sources of evidence building acoustic profile of hospital.

1.7. **Research delimitations and assumptions**

Since the research was designed as a case study, it is possible that the conditions recorded were uniquely influenced by circumstances specific to the time of the investigation, rather than being typical. However, even so, the data collected remains a true reflection of that particular case and gives insight into the acoustic conditions in the recorded circumstance and setting.

The questionnaire was designed only to assess perceived noise levels and sources, not the outcomes associated with noise. Thus the data will only be useful in concluding whether or not the hospitals are noisy and cannot be used to determine the impact of the noise.

A number of variables that could potentially impact findings could not be excluded. These include:

- The possible influence of gender, socio-economic background, age or medical condition on one's expectation and perception of noise could not be taken into consideration within the scope of this study, which is limited to noise levels and indoor environmental design aspects.
- The contribution of building services noise (such as mechanical ventilation) could not be neutralised. Continuity of these services is necessary for the functioning of the facility and indoor environmental control and thus could not be switched of in order to determine their contribution to the total noise level.

Though these two factors above may influence actual or perceived noise levels, it does not invalidate the measurements or perceptions recorded. The data can still be useful in answering the research questions in the context of the case study site.

It is possible that participants in the survey could be influenced by the Hawthorn effect, a subject effect resulting in participants consciously or unconsciously responding in a certain way to facilitate the confirmation of a known hypothesis (Kruger, Mitchell & Welman 2005:116). Participants may become more aware of noise levels due to being questioned in this regard. It was decided, though, that in spite of this possibility, results would still reflect the users' perceptions of noise, which is, in any case, subjective.

It is recognised that the survey, in respect of the source of noise, is based on subjective opinions and human observation, which is fallible, and that this may result in some noise incidents being either overlooked or exaggerated. It is argued that the subjective opinion is exactly what is required in order to determine user perceptions of noise and thus inconsistencies are inconsequential. Furthermore, since the research is conducted over at least a 48-hour period, it is unlikely that regular and common noise events will remain unnoticed.

1.8. **Importance of the research problem**

The World Health Organisation has recognised the impact on noise on the health and well-being of humans and the subsequent burden on the economy and healthcare system (World Health Orgnanisation 2011).

Since the evidence-based research points towards quietness having a significant impact on staff and patient outcomes (Joseph & Ulrich 2007), it seems reasonable to argue that quieter hospitals will benefit the healthcare system and economy of South Africa. Better patient outcomes should lead to a quicker turn-over of patients in over-crowded hospitals. This not only benefits the patient but also improves the economic outcomes of hospitals – a factor that is advantageous in public and private healthcare. Furthermore, improved recovery rates means that economically active patients can return to work sooner and thus contribute to the economy rather than remain a burden to it. Better staff outcomes should also lead to an improved level of service and better job satisfaction, making the system more stable and viable.

Currently, it can be argued that hospital design is largely shaped by engineering services, and rightly so since first and foremost hospital infrastructure must be functional. However, healthcare design in South Africa is on the brink of a paradigm shift as indoor environment quality and salutogenic principles are emerging as requirements for best practice rather than being mere luxuries. Knowledge and a practical understanding of the architectural implications of these requirements are necessary to carry designers into a new era of healthcare design.

The body of research regarding the state of the indoor acoustic environment in South African hospitals is too small to be able to make broad conclusions regarding noise in hospitals. The other South African case studies have been related to neonatal intensive care units (NICU) and conducted with a focus on the impact of noise on infants' hearing. Though these studies form part of the data base of noise levels in hospitals, the data are specific to NICU's. No data regarding the noise levels in general wards were found in peer-reviewed publications.

The proposed research will shed light on the current indoor environment conditions in South African hospitals. A better understanding of the conditions will enable designers to address the indoor environmental design more adequately.

Should it be found that hospitals in South Africa are indeed too noisy, the next step would be to determine the best way to address noise control in a healthcare environment, taking into consideration the unique requirements of finishing materials that need to be cleanable.

2. CHAPTER 2: REVIEW OF RELATED LITERATURE

It seems that existing research on the topic of noise in hospitals focusses on one of two points. On the one hand, there is a collection of evidence-based research discussing the significance and impact of maintaining a quiet environment in hospitals. On the other hand, there is a collection of case studies and reviews describing the acoustic environment in hospitals. When these two are held up together, it is apparent that there is a gap between the ideal and the actual noise levels.

2.1. The case for quietness in hospitals – the ideal

As mentioned in chapter 1, the non-auditory impact of noise can have a negative effect on the welfare of humans. The WHO concludes, in its document *Burden of disease from environmental noise*, that noise is not only a nuisance but a cause for concern in public health (World Health Orgnanisation 2011:xviii), linking exposure to environmental noise with adverse effects on health, including annoyance, cognitive impairment in children, cardiovascular disease, sleep disturbance and tinnitus. The WHO quantifies the effect of environmental noise in terms of healthy life-years and calculates that the number of disability-adjusted life-years (DALYs) lost every year due to the above-mentioned effects totals 1 685 000 years out of the life-expectancy of the population of western European countries. This is calculated by summing the potential years of life lost due to premature death and the equivalent years of healthy life lost to poor health of disability.

The WHO *Guidelines for community noise* also discusses the non-auditory effects and provides guideline values for equivalent continuous ambient noise levels are given for different contexts. For hospital ward rooms the guideline value for the day and night time is 30 dBA, with a night time maximum of 40 dBA. In other areas of a hospital where patients are being treated the guideline value is 35 dBA. These values are very low and are determined by the point of onset of health effects from noise exposure for the most exposed receiver (Berglund et al 1999:37-46).

In 2004 an in-depth study of hospital environments was conducted by a team led by Dr Roger Ulrich, a professor of architecture at the Centre for Healthcare Building Research at Chalmers University of Technology in Sweden. The study is a comprehensive review of a large collection of rigorous and high impact studies in which the impact of hospital design on clinical outcomes is established (Ulrich, Quan, Zimring, Joseph & Choudhary 2004:3).

The findings linked the physical environment to staff stress and effectiveness, patient safety, clinical outcomes and overall quality of healthcare. Though this particular study considered various aspects of the indoor environment, acoustics was identified amongst others (such as air quality and light quality) as a significant environmental factor influencing outcomes. Acoustics is relevant with regard to patient privacy and confidentiality (Ulrich et al 2004:13) and with regard to noise control, where evidence has shown that a noisy environment causes patient and staff stress, increases heart rate and blood pressure, affects patient sleep and healing, and impairs communication.

In the concluding statements of the study, it is claimed that noise levels in hospitals should be decreased “to reduce stress and improve sleep and other outcomes” (Ulrich et al 2004:26), highlighting the importance of designing hospitals with acoustics in mind.

This conclusion is backed up by individual studies in which specific outcomes were measured. For example, occupant impact was demonstrated in a pre-post case study conducted in 2003 at Huddinge University Hospital in Sweden on patients with coronary heart disease. It was hypothesised that a poor sound absorption condition is likely to produce a bad work environment and affect patients (Hagerman, Rasmanis, Blomkvist, Ulrich, Eriksen & Theorell 2005:267). The study extended over a period during which the ceiling tiles in the unit were changed from acoustically reflective tiles to sound-absorbing tiles.

The sound levels were monitored before and after the material change, giving an empirical indication of a noise reduction of up to 6dBA. Furthermore, the attitude of patients and staff were monitored as well as physiological outcomes of patients. It was found that staff felt less irritable under improved acoustic conditions. A data analysis of clinical characteristics of patients before and after the change showed a statistical association between acoustics and patient pulse amplitude as well as a significant association ($p<0.01$) between acoustics and rehospitalisation within 3 months.

Interestingly, this study measures both patient and staff outcomes. Though a hospital may be primarily thought of as a healing environment, it is equally a working environment. A paper presented at the 2011 Winter Conference of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) addressed the topic of hospital noise and occupant response, focussing on the concept that “hospitals should be conducive to patient recovery and safety as well as employee health and productivity” (Ryherd, Okcu, Hsu & Mahapatra 2011:248).

Apart from being a stressor, noise affects communication. Not only does speech need to be intelligible above background noise but it often also needs to be confidential. Discussions amongst medical professionals or medical staff and patients should be intelligible and yet should not be overheard by unintended listeners.

In a case study regarding patient privacy, it was found that up to 5% of patients in a hospital emergency department (ED) withheld private history or refused physical examination due to lack of privacy (Barlas, Sama, Ward & Lesser 2001). In another case study focused on privacy in a hospital ED, observers stationed in the ED recorded auditory and visual information gleaned. From these field notes, an assessment was made regarding the number of confidentiallity breaches, reporting that breaches in patient confidentiality in the triage and waiting area occurred for more than 53% of the patients (Mlinek & Pierce 1997:1142). While these studies were focused on emergency departments, it is easy to see that similar trends may be found in multi-bed general wards, further highlighting the importance of acoustic privacy and design.

These and other studies provide evidence of the impact of the environment on the user outcomes. This evidence, then, provides a reference resource for informing future designs. The idea of using research findings to inform design decisions is known as evidence-based design.

Based on the studies reported on in this section, as well as a host of others, the evidence seems clear that hospital environments should be designed in such a way as to provide quiet environments with appropriate acoustic privacy.

2.2. **A picture of noise in hospitals – the actual situation**

In spite of the evidence supporting the benefit of quietness in hospitals, it seems that very few hospitals, if any, comply with this ideal.

In a 2005 review of recorded noise levels in hospitals world-wide, it emerged that not a single case could be found in which noise levels were within the WHO guidelines of 35 dBA, with average levels recorded being in the region of 50 – 60 dBA. Furthermore, the data revealed an increase in noise levels over the years (Busch-Vishniac et al 2005).

In one of the few published studies in South Africa, the noise level in the NICU in athe Cape metropole hospital was measured. Not surprisingly, the noise levels exceeded both national and WHO guideline values, with actual levels ranging from 62.3 to 66.7 dBA, which is particularly dangerous for infant health and hearing (Nathan, Tuomi, Muller & Kirsten 2008:52). Significantly, not only the noise level but also the reverberation time was measured, providing useful information on which to base remedial design action.

The Australian Critical Care Journal published an article detailing an investigation into the noise levels in an Intensive Care Unit (ICU) (Stephens, Daffurn & Middleton 1995). It describes how the ICU is known to be one of the noisiest areas of a hospital and records sound level readings of up to 85dBA. As part of the investigation, a questionnaire survey was conducted using a Likert scale to determine staff, paitent and family members' attitude towards sound in the ICU. The results showed that 79% of the participants believed that there was a noise problem (causing headaches, stress, annoyance, loss of concentration, etc.).

The investigation also sought to identify the sources of noise by direct observation and sound meter measurements, detailing the appropriate measurement techniques. Findings were recorded and analysed, indicating clearly that most monitor alarms (eg. ventilator,humidifier, IVAC suction pump) regularly produced noises of around 80dB and machine noises (for example, suction equipment) produced noises of between 60dB and 80dB. The data collected from the investigation served to prove the importance of noise levels for occupant satisfaction, as well as the level of non-compliance with regulations.

These are only a few of many case studies world-wide, suggesting that few, if any, hospitals comply with the WHO guidelines.

2.3. **Noise mitigation in hospitals**

Noise mitigation can be approached from various angles, depending on the source of noise and available means of action.

The investigation team led by Daffurn (Stephens et al 1995) presented findings, recommending a facility and staff managerial approach to lowering noise levels. As suggested in this report, a good course of action to reduce noise levels is to firstly eliminate the sources as far as possible by lowering alarm signal settings where possible and practical, removing dustbin lids (a source of very high instantaneous noise) and training in staff awareness to lower voices.

Though a managerial approach, addressing staff conduct and equipment settings, for example, is valid, it is not necessarity sustainable as management or staff can change over time. A better approach, where possible, would be to 'design out' the noise, altering the architecture in such a way that noise is reduced or eliminated independently of human behaviour or actions.

A pre-post case study conducted at Johns Hopkins Hospital in Baltimore USA set out to observe the effect of sound absorbing materials. Even as one of the top ranked hospitals in the United States of America, the ambient sound levels were above the WHO guideline values of 35 dBA in treatment areas or 30 dBA in wards, particularly in the haematological oncology unit, where the average equivalent continuous sound level was 55 dBA. The specific physical design of the hallways and ceilings guided sound in such a way that conversation between staff was audible throughout the unit (MacLeod, Dunn, Busch-Vishniac & West 2007).

The application of sound absorbing materials was determined to be the best solution. However, most sound absorbing materials do not meet the requirements of infection control, being perfect for harbouring bacteria and not easily cleanable. It was thus decided that custom designed acoustically absorptive panels, composed of fibreglass with anti-bacterial fabric covering, were to be installed in the hallways. Sound level reading statistics showed a decrease in the ambient noise levels after the installation of about 5dBA as well as a decreased reverberation time. This is a significant result in favour of absorptive materials, provided the challenge of infection control can be overcome.

It should be noted that the Environmental Protection Agency discourages the use of surface treatments with antimicrobial properties as such materials "have not demonstrated a reduction in actual infections" (Facility Guidelines Institute 2010:96).

When a new Post Anaesthesia Care Unit (PACU) at Memorial Sloan Kettering Cancer Centre was designed, noise control was a given a high priority as high noise levels had been a major source of complaints in the old unit (Smykowski 2008:226). The outcomes of the new unit could be compared to that of the previous old unit, presenting a pre-post case study scenario. The results were highly significant for both patients and staff. Interestingly, acoustic privacy and quietness were achieved by a complete change in the actual layout of the facility and not only in installation of acoustically absorptive materials, setting a precedent for a paradigm shift in design thinking and facility work flow.

2.4. **Research review summary**

A preliminary investigation of previous case studies world-wide suggests that in practice noise levels in hospitals exceed the guideline levels given by the World Health Organisation.

It has been previously established by evidence-based research that noise levels have a significant influence on both staff and patient well-being, with high noise levels potentially increasing stress levels of staff, amongst other effects. The quality of patient care and privacy are at risk of being compromised due to high ambient noise levels, as well as effective healing.

There appears to be a disconnect between the noise level guidelines and what is practically achievable.

With the South African National Standards for noise levels in hospitals being closely aligned with the WHO guidelines, the indoor acoustic environment of South African hospitals is brought into question. Previous research regarding noise in South African hospitals is limited to only two studies, which showed a similar level of non-compliance as is found in international studies. However, both these studies focussed on the impact of sound on infants in neonatal intensive care units) (Neille, George & Khoza-Shangase, 2014; Nathan et al 2008).

There is a notable lack of information regarding the state of affairs regarding noise levels in South African hospitals. As part of a greater effort to improve healthcare environments, it will be valuable to have a better understanding of the acoustic environment and to compare that to the national and international norms and standards. Thus, the need to conduct an investigation of noise levels in general wards in South African hospitals was identified.

3. CHAPTER 3: IDENTIFICATION OF PERTINENT ISSUES

Based on the review of literature in Chapter 2, it is evident that noise has an influence on the healing process of patients in hospitals, as well as an impact on the performance of hospital staff. However, it is also documented that few hospitals, if any, are sufficiently quiet when ‘quietness’ is defined by the WHO guidelines (Busch-Vishniac et al 2005).

This situation raises a question as to how relevant or realistic the WHO guidelines are. Though the sound levels in hospitals are high, and in spite the evidence of negative outcomes of noisy environments, what is the perception of the users?

The problem statement in Chapter 1 highlights a lack of research regarding noise levels in South African hospitals. This void prevents an assessment of the performance of South African hospitals in the international arena with regard to the indoor acoustic environment.

The only research of this nature in South Africa is focussed on the NICU. No published research was found pertaining to noise in other areas of a hospital, such as waiting areas, circulation spaces, and general wards. This research is intended to begin to fill the knowledge void by investigating the current soundscape in general wards of four urban hospitals in South Africa.

Noise mitigation can be effected either through managerial intervention or design intervention. Since managerial intervention is dependent on human performance and compliance, which is fallible, it is valuable for a facility to be designed to be quiet. Though the South African National Standards prescribe sound levels to be achieved by design (South Africa 2008), there is a lack of guidance on how to achieve this.

This study therefore, sets out to investigate the actual and perceived noise levels in South African hospitals in light of national and international studies and guidelines and to investigate factors of design that potentially influence noise levels.

Actual and perceived noise levels in wards need to be assessed by empirical measurement and subjective surveys to build an image of the soundscape for comaprison with international guidelines and case studies and for assessment against local guidelines. This soundscape is to be analysed with reference to design features to determine whther design can influence the noise levels. To achieve this, four case study sites were selected for analysis as described in Chapter 4.

4. CHAPTER 4: THE RESEARCH: GATHERING AND REPORTING OF THE REQUIRED DATA

In order to gain insight regarding the noise levels in hospitals in South Africa and to determine whether there is a likely need to address indoor environmental noise in hospitals, it is necessary to survey hospitals regarding actual and perceived noise levels, the causes of noise and the indoor environment design.

Rather than conducting a resource-intensive country-wide survey of a large sample of hospitals, and since this is a relatively unexplored area of research in South Africa, it was deemed prudent to limit the study to a few case study sites, in which methodology could be confirmed and possible directions for future research detected.

4.1. Research methodology

In order to achieve the set objectives, it was decided to conduct a case study investigation of the indoor acoustic environment in four urban hospitals. Though the sample size is small, it is believed that the case studies will provide a valuable addition to the pool of local research in this field in South Africa.

Because sound is a complex topic, involving both objective and subjective data, the research methodology requires a combination of sources of evidence. This complexity makes the investigation extremely heavy on resources, contributing to the decision to limit the study to only four hospitals.

This multiple case study will provide an opportunity to compare the sites in terms of noise levels, user opinions, sources of noise, and architecture and test associations. This will be useful in yielding early insights into directions for future studies and appropriate methodologies for future studies.

An integration of the data averaged across all four sites will also give an indication of possible trends in South African hospitals

In spite of being theory-testing research, based on the hypothesis that hospitals are noisy, this research is also exploratory as the outcomes in terms of sources of noise, and the relationship between actual and perceived noise levels and architecture are not known in the context of hospitals in South Africa.

The evidence used in this study will be in the form of data collected from a Class 1 integrating sound level meter, questionnaires and direct observation. The data will be used to build a profile for each hospital in terms of indoor environmental noise, reflecting the actual noise levels, the perceived noise levels, the sources of noise and the architecture. These profiles, when compared, can be used to determine whether certain aspects or features of the indoor environment tend to result in a higher noise level.

The sound level readings and questionnaire results will answer the first three research questions, which are essentially designed to determine whether the environment is noisy and whether the noise is of any consequence to the users (is it noisy and does it matter?).

It is important to identify the source of noise as this will be useful supporting information when analysing possible reasons for differing responses from one site to another and in making recommendations regarding indoor environmental design interventions. The sources will be determined through a questionnaire completed by users and through direct observation of the investigator.

Data pertaining to the architecture of each site will be gathered by direct observation. The physical dimensions of the space under investigation will be recorded as well as distances to supporting services in the ward, such as the nurses' stations and sluice rooms. Other characteristics of the indoor environment will be noted by the investigator, such as the number of beds, type of ventilation system, and the finishing materials on the floor, walls and ceiling. These aspects may have an influence on the behaviour of sound in the environment and will be analysed for associations with the noise levels.

A statistical analysis of these sources of evidence will be used to conclude whether there is a likely need for indoor environmental noise in South African hospitals to be addressed through design.

4.2. **Choice of case study sites**

The sample group of hospitals chosen for this case study was a convenience sample. However, each site was required to meet certain criteria to suit the research design.

- The sites were to be in an urban area, with all the usual services associated with an urban hospital, such as running water and electricity, and accessed by motor vehicles. This was set as a criterion in order to, as far as possible, eliminate variables in the indoor and outdoor environment that could influence noise levels in the ward.
- Since one of the objectives of the research is to determine whether architecture can be associated with noise levels, it is necessary for design to be a variable. For this reason, one of the criteria for the selection of hospital sites for the case study was that there should be some degree of variation in the design of each.
- The specific wards selected for investigation at each site should accommodate clinically similar patients, thus eliminating the possibility that differing clinical treatments would render the noise levels at each site incomparable or that differing clinical conditions would influence the ability of users to answer the questionnaires accurately would render the subjective data collected at each site incomparable.
- The general activity level and work flow in the selected ward at each hospital should be comparable.
- Lastly, the hospitals must be willing to co-operate in the investigation.

Based on these criteria, four hospital sites were selected.

All four sites are located in the Tshwane Metropolitan area and will be referred to in this paper as Hospital A, B, C and D. Hospitals A and B are situated on the fringe of a densely-populated urban mixed-use area. Hospital C is situated on the outskirts of the city and Hospital D is situated in a medium-density suburban area. None of the sites are located on roads with high traffic volumes.

The general layouts of the ward selected at each hospital site are similar in concept, with patient beds grouped in bedrooms or cubicles, shared ablutions and a centralised nurses' station and other supporting services dedicated for the ward. However, the number of patients per room and the relative location of the specific area under investigation varied at each.

In each case, a general medical/surgery ward was identified for the study. Within each ward, a multi-bed bedroom was chosen to be the main measurement location (referred to as 'the measurement location'). Patients in the wards were either awaiting surgery or recovering from surgery.

The busiest normal working days of each hospital were identified by hospital management as being the three mid-week days (Tuesday, Wednesday and Thursday) and it was decided to conduct the investigation over these days at each site. Due to limited resources, the investigations at each site could not be conducted simultaneously but were conducted in corresponding time periods in consecutive weeks.

Permission and ethical clearance to conduct the investigation at each identified site was obtained from the relevant hospital management and academic institutions.

4.3. **Data gathering**

The case study investigation was conducted over a four week period. The sound level readings, questionnaire survey and observations were conducted over the identified period at each site in consecutive weeks.

4.3.1. Empirical data

Within each ward, a specific measurement location was identified. Each measurement location was in a bedroom or cubicle in which multiple patients were accommodated. A Class 1 integrating sound level meter was used to measure the equivalent continuous sound pressure level (L_{eq}) in each location.

The sound level meter was suspended from a strap that hung between the bed curtain rails in the centre of the measurement room above head height. In this way an overall sound reading of the room could be obtained without the meter obstructing activities or being tampered with by occupants in the room.

The meter was set to store data at one-second intervals and to calculate the L_{eq} at five-minute intervals for a twelve-hour recording period. After each recording period the data was downloaded and the battery changed before re-setting the meter to record the next period. Each recording period ran roughly from 6 am to 6 pm and 6 pm to 6 am over a 48 hour period. The data was used to calculate equivalent continuous sound levels for each 24-hour period, from which an average 24-hour L_{eq} was calculated. The spectral content of the sound was also recorded.

To ensure that the readings taken were a fair reflection of the normal sounds of each site, the readings for corresponding periods over two days were compared. If there was not a significant variation in the daily averages, the average was accepted as a fair reflection of 'normal' noise levels for that particular measurement location. If there was a difference in the averages of more than 3 dBA (an effective doubling of the sound level), the reading for the relevant corresponding period was recorded for a third day to verify the average. This was only necessary at Hospital B for the day period and values were adjusted accordingly.

Reference sound levels were taken in the corridor outside each measurement room and at an outdoor point within 2 m of the windows of the measurement room. The purpose of this was to establish if there were any significant surrounding noises that could be contributing to the noise experienced at the patient bed area.

Reverberation time measurements were taken in the measurement room as well as in the corridor near the doorway using the sound level meter. This was done in order to analyse the association, if any, between reverberation time and the noise levels (actual and perceived). Unfortunately, this data did not yield useful results. The readings obtained seemed unrealistic and were discarded, though direct observation of the reverberation effect was noted. The reason for the useless results could be that an appropriate signal noise could not be used for fear of alarming the occupants.

4.3.2. Direct observation

Though the sound level meter records sound pressure level at regular intervals on a timeline, no audio recordings could be made, as there was concern that recordings of conversations could be deemed a breach in doctor-patient confidentiality. Because of this, there could be no way of identifying the cause of peaks in the sound level data, other than to have an observer present for the entire time of the sound level recording. In order to maintain a level of patient privacy and confidentiality, the observer was stationed immediately outside the entrance to the measurement location in such a way that activities in the room could be observed but speech was not intelligible.

Timesheets were designed for the observer to record the time and cause of noise events (See Annexure 2 for an example timesheet). This was useful not only in identifying the cause of peaks but also as a source of information regarding activities and causes of sound in general. From the noted data, it was possible to characterise the type of noises and activities that are common/normal compared to unusual noise events, which should be excluded from averaging data.

4.3.3. Design data

The design of the indoor environment of the ward was analysed according to the following aspects:

- Dimensions of the measurement location area were taken, including the length, width and ceiling height. These measurements are significant because the geometry of the room will influence the reverberation time in the room, and thus the noise levels.
- The distances from the entrance to the measurement location to the nurse station, ward sluice room and ward kitchen were recorded. This was done in order be able to determine if noise from these service spaces had a possible influence on the noise in the measurement location.
- The general flow of work of the hospital relative to the position of the measurement location was observed to determine whether it is likely that the design of workflow of the hospital in general could impact on noise levels in patient areas.
- The floor, wall and ceiling finishes in the measurement location and passage were observed and noted to be used in determining the impact that the type of finishes may have on the behaviour of sound in the ward.
- The type of ventilation system was noted as this could possibly influence the sound level. Whether windows were open or closed, and whether mechanical cooling or heating systems were in place and switched on were noted.

4.3.4. Subjective data

In order to determine the perceived noise levels, both staff and patients were surveyed via questionnaires. Refer to Annexure 1 for a copy of the questionnaire.

- Section A of the questionnaire was used to profile the sample population. Participants were required to indicate whether they were a staff member or patient, whether they have hearing loss, their age, and their length of stay or hours on shift.

- Section B was designed to determine on a general level whether occupants perceived the noise level in the ward to be disturbing. A scale of “too quiet”, “fine”, or “too noisy” was used for this. This part of the questionnaire was completed by all participants.
- Section C was designed to help determine specific sources of noise, their level of disturbance, and when they are most noticeable. This would provide useful information for recommendations for corrective action.

The survey questionnaire was intended to be completed at regular intervals (once in the morning and once in the evening) by both staff and patients. This would ensure that both day and night shift staff opinions could be collected as well as patient opinions of noise perceived during the night and during the day. This would enable and analysis of when noise is more noticeable. However, since staff members were very busy, not all members made the time to complete the questionnaire, and since the patients were often sleeping or not feeling well, they often did not complete the questionnaires at the intended intervals, if at all. Because of this, the more detailed questions were not well answered with many questions missing. However, the general opinions were well-answered and could yield meaningful results.

In total, 83 questionnaires were collected from all four sites. Out of these participants, 33 (40%) were staff members (nurses working 12-hour shifts) and 50 (60%) were patients.

When the user groups are categorised at each hospital, it was recorded that at Hospital A 21 questionnaires were completed, 7 of which were by staff members and 14 of which were by patients. At Hospital B 17 questionnaires were completed, 9 of which were staff members and 8 of which were patients. At Hospital C 25 questionnaires were completed, 11 of which were staff members and 14 of which were patients. At Hospital D 20 questionnaires were completed, 6 of which were staff members and 14 of which were patients. The distribution of completed questionnaires is shown in Table 1.

Table 1: Summary of questionnaires completed.

Hospital ID	***Staff***		***Patient***		***Total***
	Number	%	Number	%	
A	7	35	14	67%	21
B	9	53%	8	47%	17
C	11	44%	14	56%	25
D	6	30%	14	70%	20
Combined Total	33	40%	50	60%	83

4.4. Report of findings

The data from each site was collected and analysed in terms of noise levels, sources of noise and architecture. The findings are recorded in the sections that follow.

4.5. Noise levels

The first objective was to establish whether the hospitals that were sampled are considered noisy. The means of assessing this was through measured sound levels as well as user opinions of perceived sound levels. The measured sound levels were analysed in terms of different time periods and characteristics and the relationship with the perceived noise levels.

4.5.1. 24-hour noise

The data from the sound level meter revealed that average equivalent continuous sound pressure level (L_{eq}) across all four hospitals over a 24-hour period was 53.4 dBA. This was calculated by averaging the 24-hour L_{eq} for each day at each site to obtain an average 24-hour value per site and then averaging those values over the four sites.

When the data from each individual site were analysed, there was found to be a noticeable difference between sites. Hospital A had the lowest 24-hour equivalent continuous sound pressure level of 49.4 dBA in comparison to the highest value which was found at Hospital C with a value of 56.8 dBA. This is a range of 7.4 dBA. Hospitals B and D had similar values at around 53 dBA, as shown in Figure 4.

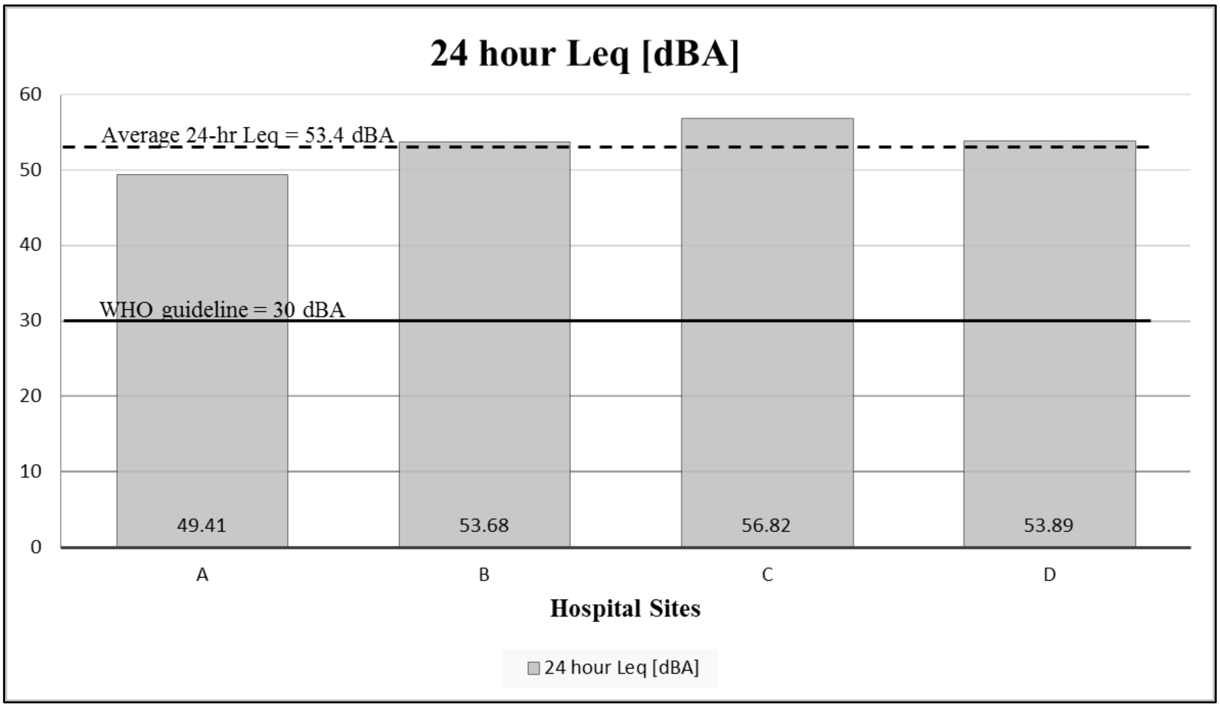

Figure 4: Bar chart comparison of average 24-hour L_{eq} values at each hospital.

When these values are compared to the design values prescribed by the WHO (30 dBA) and SANS 10103 (35 dBA), it is found that in all cases the 24-hour equivalent continuous sound pressure level exceeds these ratings by an average of 23.5 dBA and 18.5 dBA respectively. A summary of the 24-hour L_{eq} readings at each site in relation to the guidelines is given in Table 2.

Table 2: Comparison of average 24-hour L_{eq} to guideline values for each hospital.

Hospital ID	***Average 24-hour L_{eq}***	***Difference from guidelines***	
		WHO guideline (30 dBA)	***SANS 10103 rating (35 dBA)***
A	49.4	19.4	14.4
B	53.7	23.7	18.7
C	56.8	26.8	21.8
D	53.9	23.9	18.9
Average	53.4	23.5	18.5

4.5.2. Day-night noise

When the sound level data of each site were analysed for patterns, there was found to be a common quiet time each night between 11 pm and 5 am. At this time most patients are sleeping and the staff activity is low. Correspondingly, the active period of the day was commonly found to be from 5 am to 11 pm. This pattern of noise levels over a 48 hour period for each hospital is evident in the graph in Figure 5.

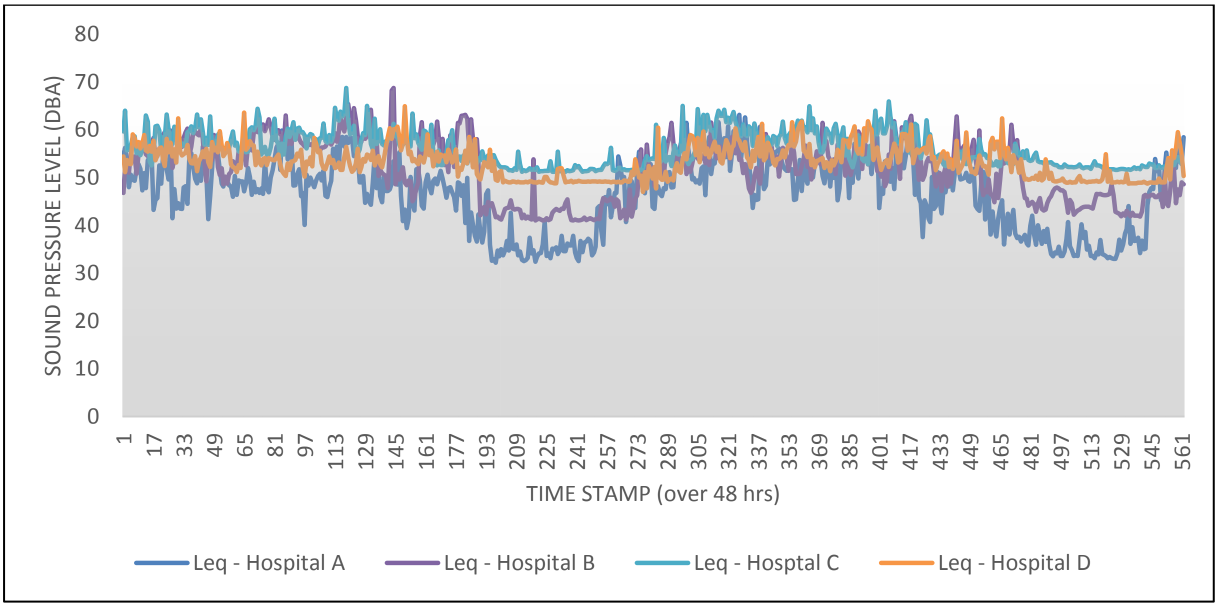

Figure 5: Overlay of sound level at each site over 48 hours.

The average equivalent continuous sound level across the four hospitals during the quiet night time period was 46 dBA, more than 10 dB above the WHO guideline value.

When the quiet period at each site was analysed individually, it was found that the lowest average level was at Hospital A, with a L_{eq} value of 38 dBA. The other hospitals fell within a range of 14 dBA above this, the highest level being recorded at Hospital C (52.1 dBA).

When specific noise events in the night were excluded (such as a bathroom door slamming) the calculated average values were lower and at Hospital A it was found to be as low as 34.8 dBA, which is within the South African requirements, though still above WHO requirements. The lowest recorded L_{eq} level at Hospital A over the pre-set five-minute measurement intervals was 32.6 dBA and when only minimum values were considered the lowest recorded was 29.7 dBA.

This exercise of extracting the lowest recorded levels was performed on the data set from each site, as shown in Table 3, however, only Hospital A revealed levels close to the WHO and SANS requirements.

Table 3: Sound recordings at each site during quiet period (11 pm to 5 am).

A	*B*	*C*	*D*	*E*
Hospital ID	***Quiet period average L_{eq} (dBA)***	***Quiet time average, excluding noise events (dBA)***	***Minimum recorded value (dBA)***	***Difference between average and value excluding noise events (dBA)*** ***(column B-C)***
A	38.0	34.8	29.7	3.2
B	44.4	42.8	39	1.6
C	52.1	51.8	49.9	0.3
D	49.6	49.2	44.9	0.4
Combined average	46.0	44.7	40.9	1.37

When considering active or daytime period from 5 am to 11 pm, the average equivalent continuous sound level across all four hospital sites was found to be 55.1 dBA.

Hospital A, once again, was found to have the lowest average equivalent continuous sound pressure level of 51.6 dBA and, once again, the highest value was found to be at Hospital C, with 58.1 dBA. Hospitals B and D had similar readings of 55.7 dBA and 54.9 dBA respectively.

Maximum and minimum five-minute equivalent continuous sound pressure levels were identified at each site, as recorded in Table 4. The maximum levels at each site were over 90 dBA, while the minimums ranged from 31.8 dBA (at Hospital A) to 49.9 dBA (at Hospital C). The maximums could be identified from the observation data to correlate with specific noise events, which involved furniture being moved or items dropping.

Table 4: A comparison of active period noise levels at each site.

A	*B*	*C*	*D*	*E*
Hospital ID	***Active period average L_{eq} (dBA)***	***Maximum recorded value (dBA)***	***Minimum recorded value (dBA)***	***Range (dBA)*** ***(column C-D)***
A	51.6	93.1 (bucket fell)	31.8	61.3
B	55.7	92.2 (item falling)	37.4	54.8
C	58.1	94 (chair scraping)	49.9	44.1
D	54.9	90.1 (furniture dragged)	44.3	45.8
Combined average	55.1	92.4	40.9	51.5

4.5.3. Surrounding readings

Fifteen-minute equivalent continuous sound pressure levels were measured in the passage outside each measurement room and outside the window of each measurement room. These readings were compared to the levels in the measurement location of an equivalent time period on a different day.

When compared to the readings in the measurement location, it was found that in all cases except Hospital C, the passage reading was higher than the reading in the measurement room. In all cases except Hospital B, the reading outside the window was lower than the reading in the measurement room.

On average, the difference between the level within the measurement location and the combined surrounding noise levels was 11.2 dB. As can be seen from the data in Table 5 and graphical illustration in Figure 6, there was a noticeably large difference between the surrounding noise level and the measurement location noise level at Hospital B, while there is hardly any difference (0.8 dB) between the location and surrounding noise levels at Hospital C. In spite of this, though, the noise levels in the measurement location at both these sites were very similar.

Table 5: Comparison of noise levels in the measurement location and surroundings.

A	*B*	*C*	*D*	*E*	*F*
Hospital ID	***Active period L_{eq} (dBA)***	***L_{eq} in passage (dBA)***	***L_{eq} outside window (dBA)***	***Combined surrounding level (dBA) (column C+D)***	***Differences (dB) (column E-B)***
A	50.74	55.45	47.53	56.1	5.4
B	55.38	69.18	85.46	85.56	30.2
C	55.9	53.5	53.88	56.7	0.8
D	53.18	61.17	51.9	61.65	8.5
Combined average	53.8	59.69	59.82	65	11.2

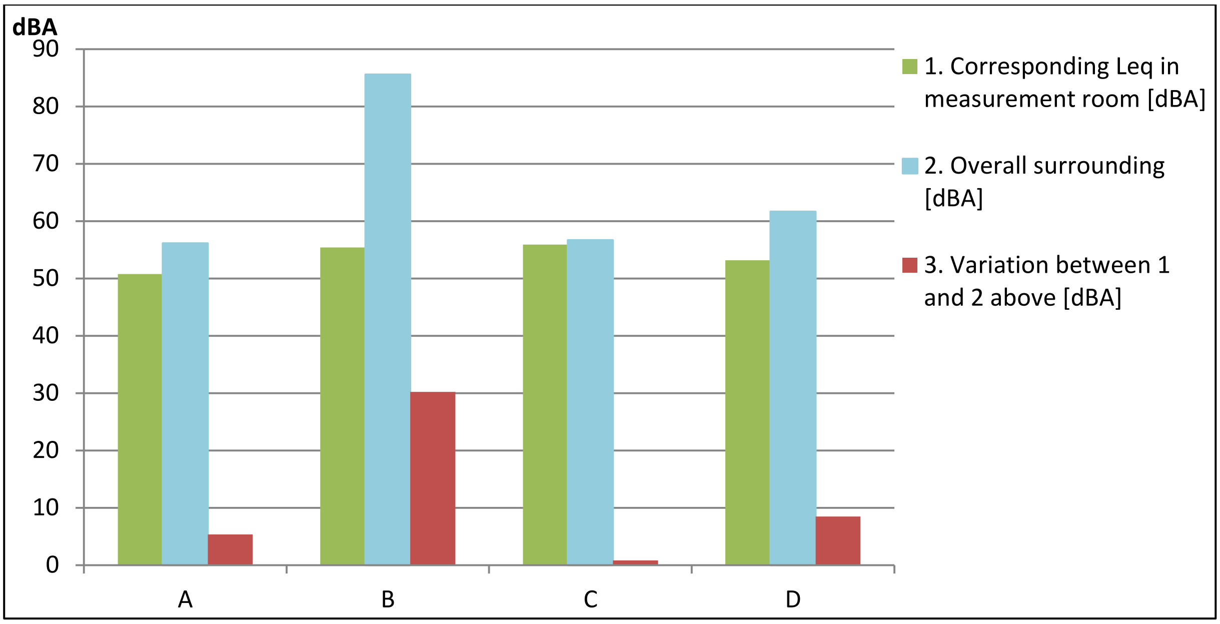

Figure 6: Comparison of surrounding environmental noise levels relative to daytime noise levels at each site.

4.5.4. Frequency spectrum

The dominant frequency bands at all sites was found to be between 400 and 1600 Hz, with maximum values being found between 500 and 800 Hz.

4.5.5. Perceived noise levels

Participants taking part in the questionnaire survey were users of the selected hospital wards. These participants consisted of staff members, who were nurses working 12-hour shifts, and patients.

Question 6 of the questionnaire (See Annexure 1) was designed to obtain a general opinion of noise levels at each site, requiring participants to indicate whether they found the noise level to be “too noisy”, “fine”, or “too quiet”. Combined data from the four hospital sites revealed that, out of the total of 83 participants, 22% of the participants found it “too noisy”, 74% found it “fine” and 4% found the hospital environment to be “too quiet”. Thus it is evident that the majority found the noise levels to be fine, as can be seen in Figure 7.

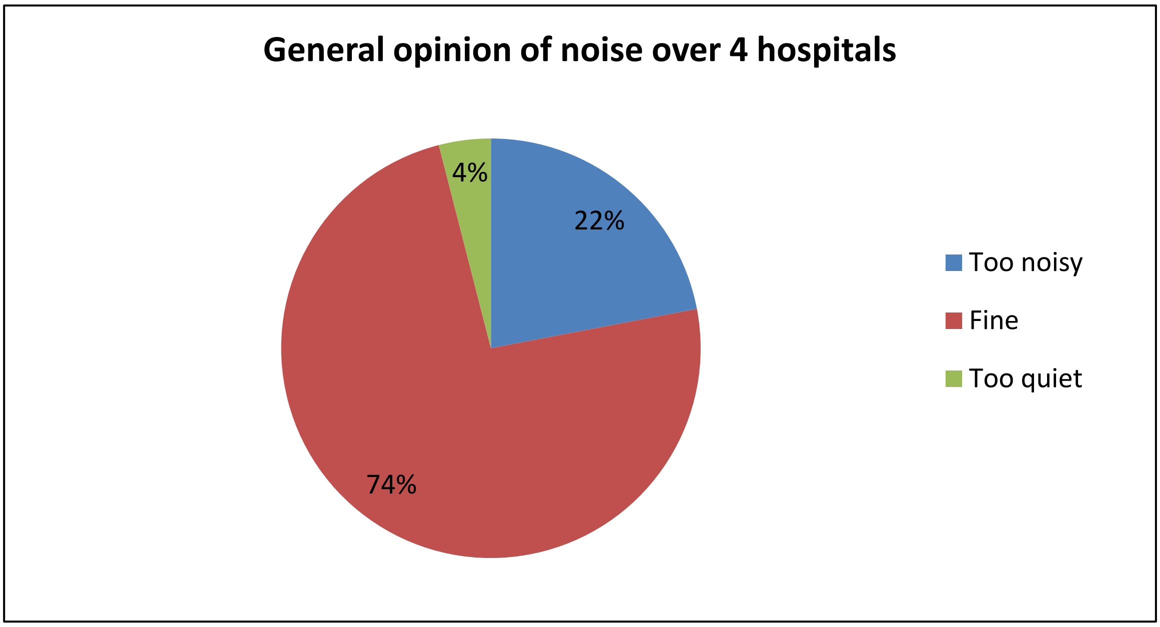

Figure 7: Distribution of general opinions over all hospitals.

When the results were analysed statistically, the categories for "fine" and "too quiet" were combined since there were very few in the "too quiet" category. Thus the analysis essentially addressed the question in terms of "too noisy" or "not too noisy". The results of this revealed that overall 22.2% of the participants found the hospital too noisy and a large majority of 77.8% found it not to be too noisy. This is displayed in visually in the chart in Figure 8.

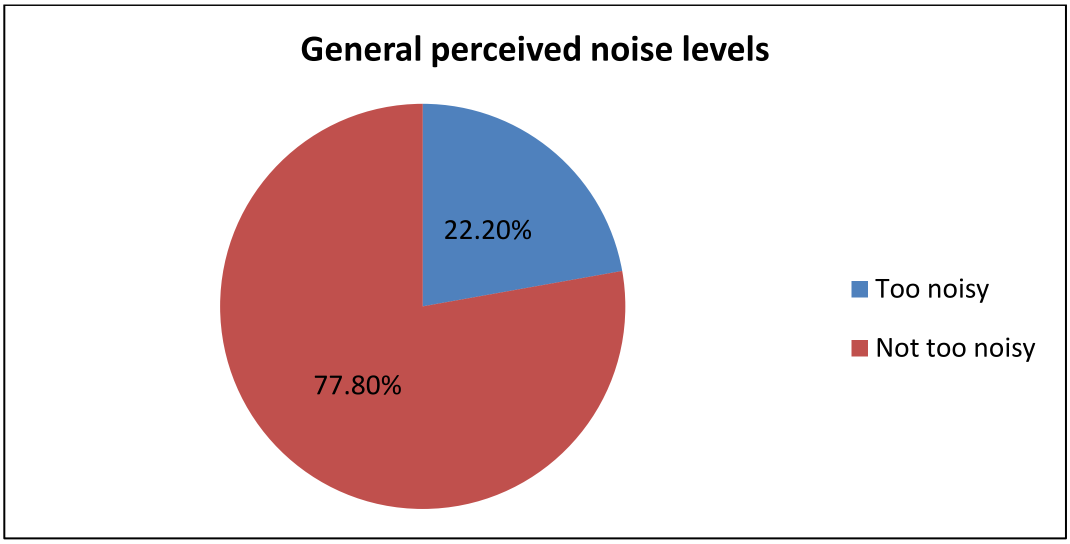

Figure 8: Distribution of general opinions over all hospitals with categories combined.

When the data set was analysed for each individual hospital site, a significant[1] difference of opinions was obtained for each site.

[1] Fisher's exact test: p = 0.0001

The breakdown of participant opinions at Hospital A was similar to the overall average of opinions, where, out of a valid number of 19 participants, a majority of 78.9% found the environment not to be too noisy. At Hospital B the opinions of the 17 participants were fairly evenly split with 52.9% finding it too noisy and 47.1% finding it not too noisy. In contrast, 100% of the 25 participants at Hospital C found it not to be too noisy. The data from Hospital D shows a similar distribution as that of Hospital A and the overall average of opinions, with 75% of the 20 participants indicating that it was not too noisy. Thus Hospitals B and D seem to be of interest. The distribution of user opinions is illustrated for each hospital in Figure 9.

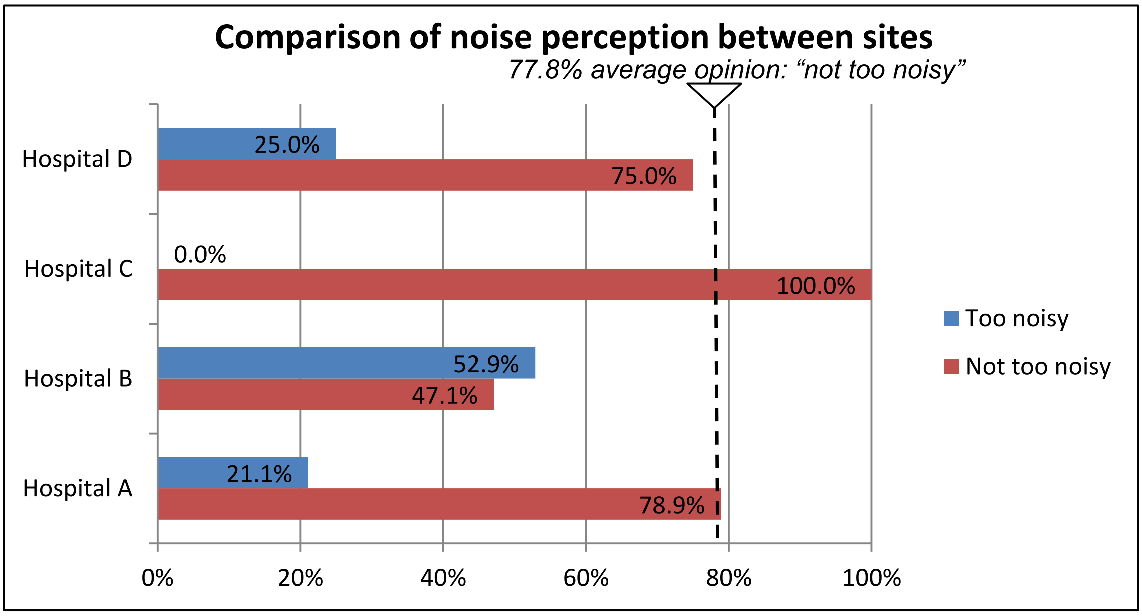

Figure 9: Graphical comparison of distribution of opinions at each site.

4.5.6. User categories

Based on the responses to question 1 of the questionnaire, the participants could be categorised into two user groups, namely staff and patients.

When this data was cross-tabulated with the responses to question 6, regarding the general opinion of noise levels, it was found that overall in the four hospitals most staff members (61% out of 33) and patients (89.6% out of 48) indicated that it was not too noisy. However, the statistical analysis reveals that there is a significant association[2] between the user group and noise opinions, with more staff members indicating that they found the noise level too noisy than was expected under the assumption of no association[3]. The comparison of the general opinions of staff and patient groups across all four hospitals is depicted in Figure 10.

[2] Pearson chi square value = 10.815; p = 0.004
[3] Expected number = 7.3; observed number = 13

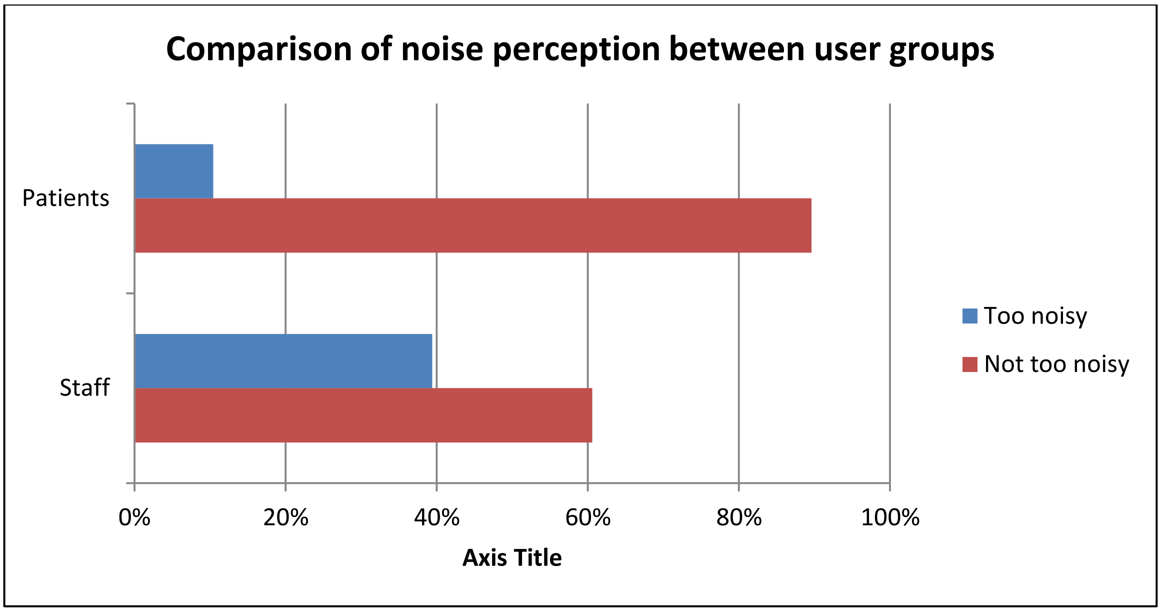

Figure 10: Distribution of general opinions between user groups across all four sites.

When this analysis was performed for each individual hospital site, there was found to be no significant association between perceived noise levels and the user group at Hospitals C and D. However, the data indicates a significant association[4] at Hospitals A and B, where the observed number of staff members finding it too noisy was higher than the expected number under assumption of no association. This distribution pattern is easily seen the graph in Figure 11.

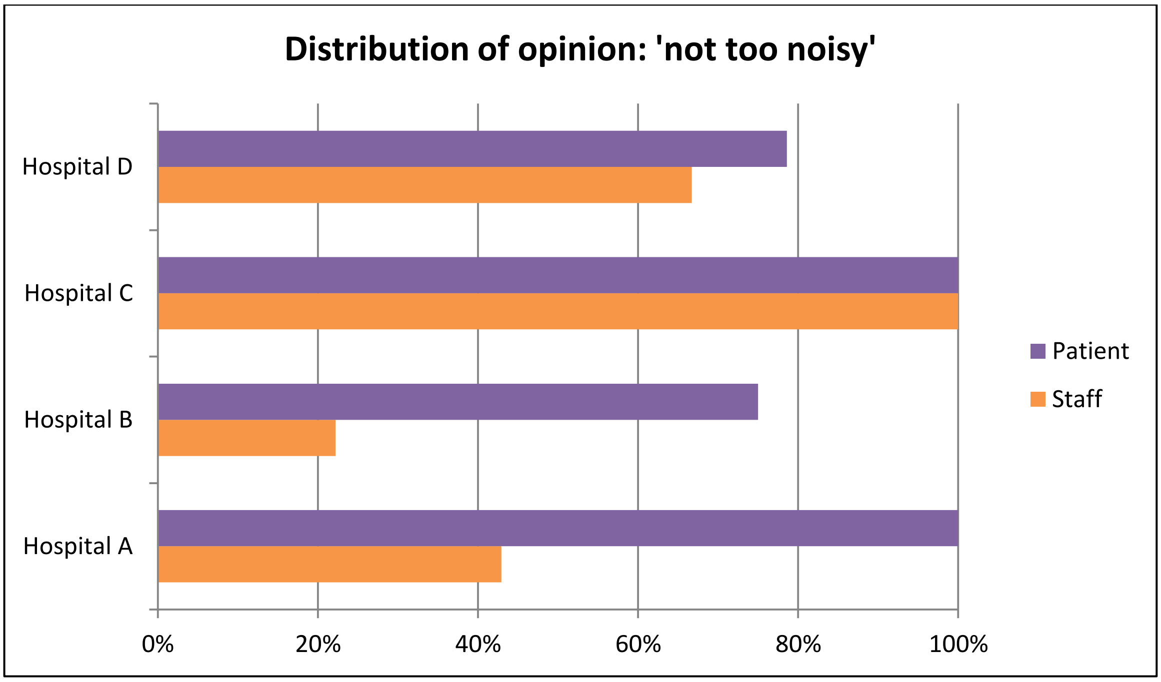

Figure 11: Comparison of the distribution of noise perception of staff and patients at each site.

[4] Fisher's exact test: $p = 0.009$ (Hospital A); $p = 0.044$ (Hospital B)

When participants were categorised according to their ages, based on question 3 of the questionnaire, it was found that there is no statistical significance between the perceived noise levels and the ages of the participants[5].

4.5.7. Actual and perceived noise levels

When the actual noise levels were compared to the perceived noise levels obtained from the questionnaires, it was found that there is not a direct association between the actual noise level and the perceived noise level.

The expectation was that the site with the highest equivalent continuous sound level would have the highest perceived sound level but this was not the case.

When arranged so that the highest noise is represented as number one and the lowest as number four, the ranking of the 24-hour equivalent continuous sound levels at each hospital compared to the ranking of the perceived noise level at each site indicates that there is a difference between actual and perceived noise. As can be seen in Table 6, Hospital C, which is ranked number one for the highest measured noise level, is ranked at number four for the lowest perceived noise level. Hospital A has the lowest actual sound level and a low perceived noise level. Hospitals B and D, while having similar sound levels have differing user opinions.

Table 6: Tabulation of average 24-hour L_{eq} values compared to perceived noise levels.

Hospital ID	Average 24-hour L_{eq}		Perceived noise	
	L_{eq} (dBA)	Rank L_{eq}	% 'too noisy'	Rank opinion
A	49.4	4	21	3
B	53.7	3	53	1
C	56.8	1	0	4
D	53.9	2	25	2

Likewise, there is no association when only the active or quiet periods are considered as indicated in Table 7 and Table 8.

Table 7: Tabulation of active period Leq values compared to perceived noise levels.

Hospital ID	Active period (day) L_{eq}		User opinion	
	L_{eq} (dBA)	Rank L_{eq}	% 'too noisy'	Rank opinion
A	51.6	4	21	3
B	55.6	2	53	1
C	58.1	1	0	4
D	54.9	3	25	2

[5] Fisher's exact test: p = 0.089

Table 8: Tabulation of quiet period Leq values compared to perceived noise levels.

Hospital ID	***Quiet period (night) L_{eq}***		***User opinion***	
	L_{eq} (dBA)	***Rank L_{eq}***	***% 'too noisy'***	***Rank opinion***
A	38.0	4	21	3
B	44.4	3	53	1
C	52.1	1	0	4
D	49.6	2	25	2

4.5.8. Type of noise – fluctuations

The average difference between the noise levels during the active period and the quiet period across all four sites was found to be 9 dB. As can be seen in Figure 12, the greatest variation was found at Hospital A, where the range was 13.7 dB, while the site with the lowest variation was Hospital D, with a range of 5.3 dBA.

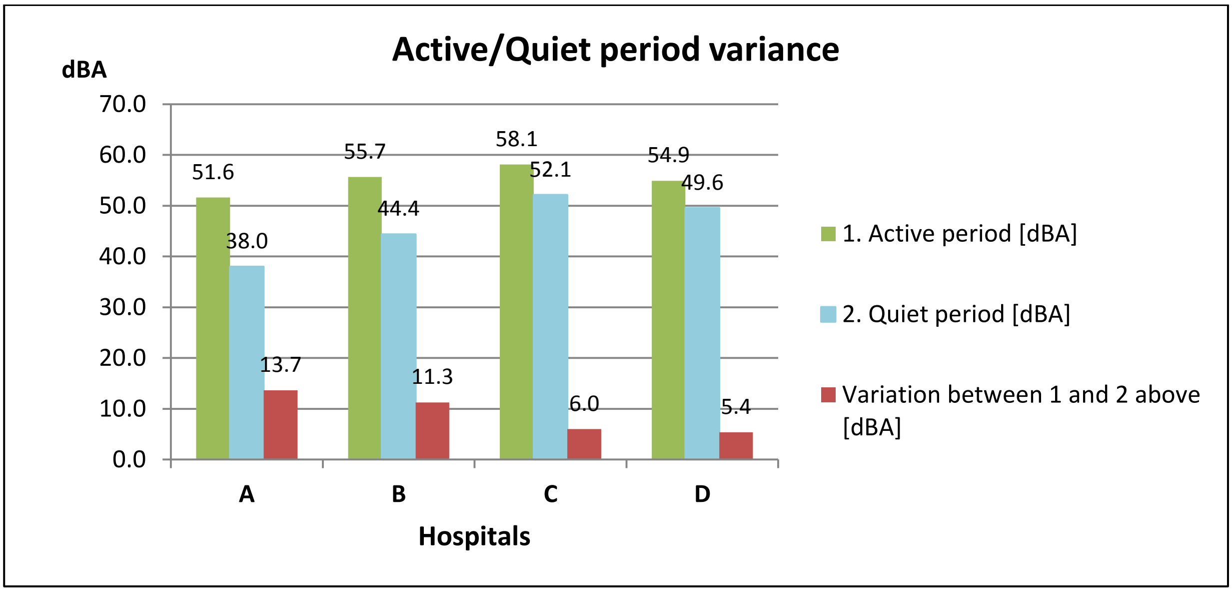

Figure 12: Variation between average noise levels during active and quiet periods.

The ranking of the perceived noise level, based on the percentage of users reporting it to be "too noisy", amongst the hospital sites and the ranking of the variation of sound level from the active to the quiet period at each site are tabulated in Table 9. No direct association was found between the ranking values.

Table 9: Tabulation of perceived noise levels compared to daily level of noise fluctuation.

Hospital ID	***Active/Quiet period difference in L_{eq} (dB)***		***User opinion***	
	Variance (dB)	***Rank Leq***	***% 'too noisy'***	***Rank opinion***
A	13.7	1	21	3
B	11.3	2	53	1
C	6	3	0	4
D	5.4	4	25	2

The continuous fluctuation of sound on a time scale throughout the day was analysed by comparing the standard deviation from the mean of the equivalent continuous sound levels taken at five-minute intervals at each hospital and calculating the coefficient of variance.

Based on the sound level values during the active period, it emerged that Hospital A had the highest variance, followed by Hospital B, C and D in that order. The quiet period calculations yielded similar results as can be seen in Table 10.

Table 10: Tabulation of perceived noise levels compared variance of noise levels.

Hospital ID	***Active period continuous fluctuation***		***Quiet period continuous fluctuation***		***User opinion***	
	Standard deviation	***Coefficient of variation***	***Standard deviation***	***Coefficient of variation***	***% 'too noisy'***	***Rank opinion***
A	4.35	8.45	6.82	16.34	21	3
B	3.68	6.64	5.8	12.09	53	1
C	2.9	4.96	2.2	4.12	0	4
D	2.59	4.7	2.99	5.81	25	2

The continuous fluctuation of sound was also assessed using the calculated percentile values of L90, L50 and L10, over 24 hours. The L90 value is the value above which 90% of the sound is and similarly the L10 value is the value above which 10% of the sound is. The calculated values for these at each site is recorded in Table 11.

Table 11: Recorded Ln values over 24 hours.

Hospital ID	***L10***	***L90***	***L50 (median)***	***L_{eq}***	***L10 – L50***	***L50 – L 90***
A	51.6	38.3	43.9	49.4	7.7	5.6
B	57.2	45.4	49.4	53.7	7.8	4
C	58.5	52.2	54.2	56.8	4.3	2
D	55.5	49.2	51.1	53.9	4.4	1.9

The value of L10 (24 hours) above the median, L50 (24 hours), gives an indication of how much the sound fluctuated. At Hospital C, though the equivalent continuous sound level (L_{eq}) was high, the L10 was only 4.3 dB above the median and the user perceptions here were that the indoor environment was generally not too noisy. In contrast, Hospital A, which had the lowest equivalent continuous sound level (L_{eq}), showed a large difference of 7.7 dB between the median and the L10 value, while the user perceptions of sound were normal.

The value of L90 is commonly used as an indicator of the ambient sound level. As can be seen in Table 11, the L90 (or ambient) sound level of Hospital A was the lowest and Hospital C was the highest. The difference between the L90 value and the L50 value at Hospital C was only 2 dB, while the difference between these values in Hospital A was 5.6 dB.

The momentary fluctuations, as well as the variance between the active and quiet periods at each hospital site can be seen in Figure 13.

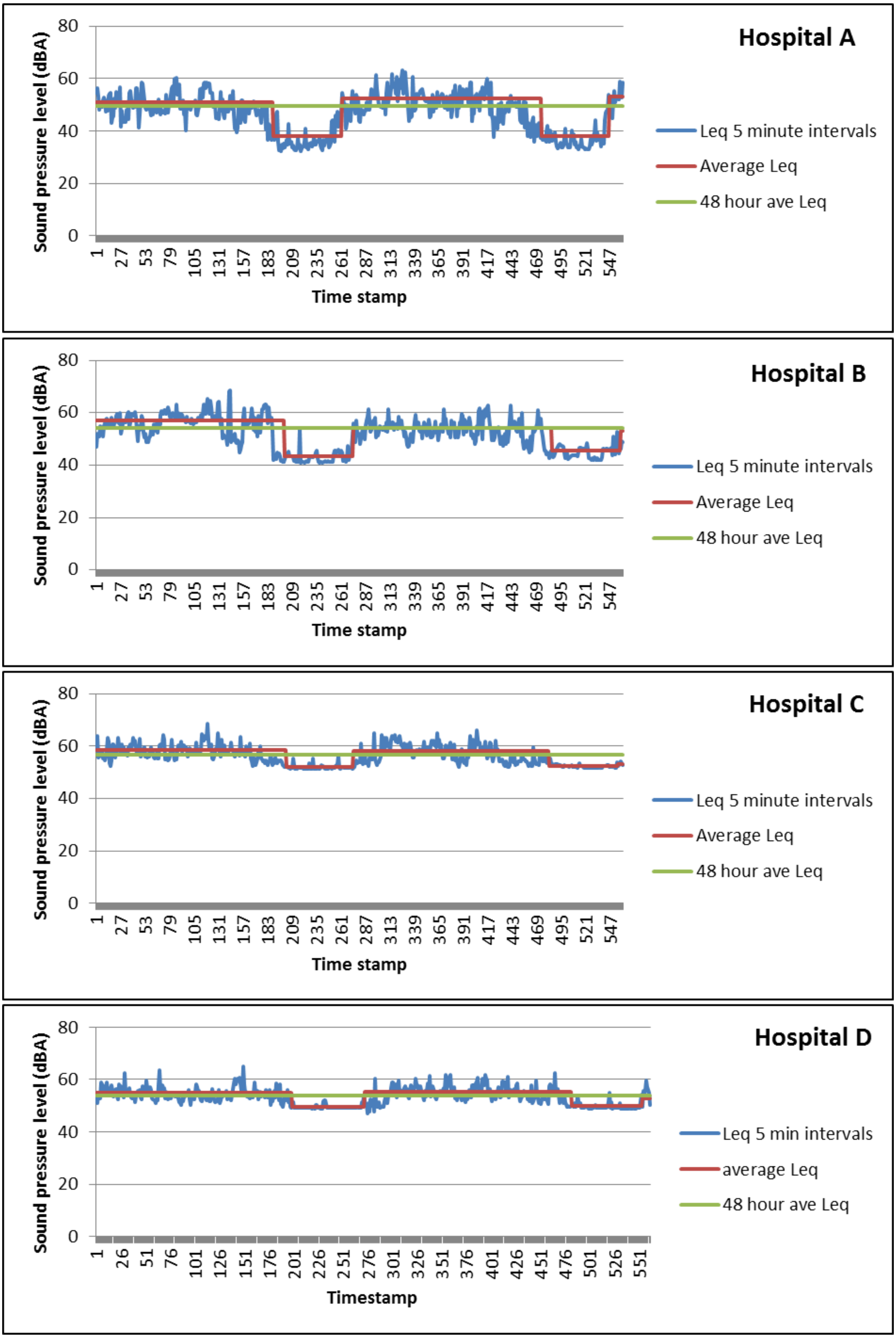

Figure 13: Sound level fluctuations over 48 hours at each site.

4.6. Observations

During the full period of sound level recording, an observer was present to note any specific noise events or observations pertaining to noise levels that could not be detected by the sound level meter, since there was no audio recording.

It was noted by the observer that Hospital B was particularly noisy, the passage outside the measurement location being very busy with a high volume of thoroughfare traffic and noise from the nearby main kitchen being noticeable. The joints between the tiles on the passage floor also seemed to contribute towards higher noise levels as wheeled equipment was rolled over the joints.

The long passage with high ceilings also seemed to contribute to a high apparent reverberation time.

Hospital C was noted to have a constant background noise of fans, though there was not a lot of activity in the ward.

4.7. Architecture

While it is relatively easy to obtain data regarding the actual and perceived noise levels from the sound level meter and questionnaires respectively, it is difficult to quantify and statistically analyse the architecture of each site. The architecture of each site was documented and compared with each other along with the actual and perceived noise levels.

While the detailed layouts of each site differed, the basic pattern, which is based largely on workflow, was similar throughout. Broadly speaking, all wards consist of patient spaces (containing beds) that are connected to ward service spaces, such as the nurses' station, ward kitchen and ward sluice room, via a corridor that also provides access between the ward and the rest of the hospital.

4.7.1. Physical description of sites

4.7.1.1 Hospital A

At Hospital A the particular measurement location was a 6-bed room within a general surgery ward. The room was located at the end of the ward corridor. The corridor serves as a circulation spine for the ward and also as a thoroughfare for hospital staff from the hospital to the management and administration block, as shown in Figure 15.

The room area was 50 m^2, being 6,98 m wide and 7,3 m in length, as illustrated in Figure 14, with a ceiling height of 3,2 m. Three beds lined opposite walls, there were windows opposite the entrance door facing onto a garden area and a dedicated ablution leading directly off the room. The floor was finished with vinyl sheeting, the walls were plastered and painted and ceiling was a flush plastered gypsum ceiling. The windows were covered with fabric drapes. The windows were kept closed and a split-unit air conditioning system was installed.

The centralised nurses' station was located along the corridor approximately 25 m from the door to the bedroom. The sluice room was also located along the corridor, its entrance door being approximately 10 m from the bed room door. These two areas were identified as potential sources of noise that could be heard from the measurement location.

The corridor was 2,4 m wide with a ceiling height of 2,64 m. The corridor floor was tiled with ceramic tiles, the walls were plastered and painted and the ceiling was a drop-in ceiling on a 600 x 600 mm grid with vinyl-clad ceiling tiles.

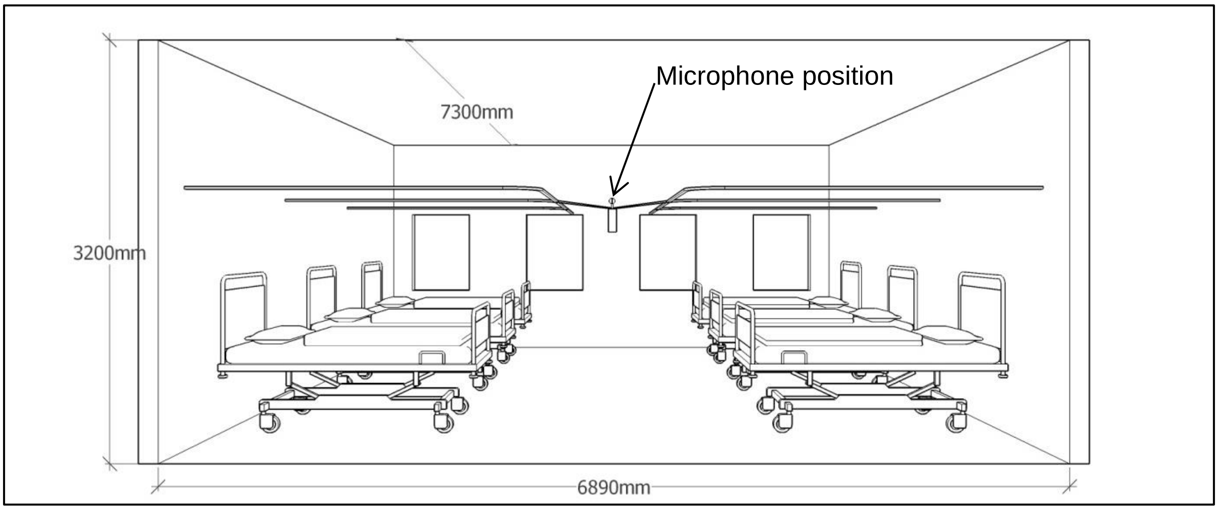

Figure 14: Illustration of measurement location - Hospital A.

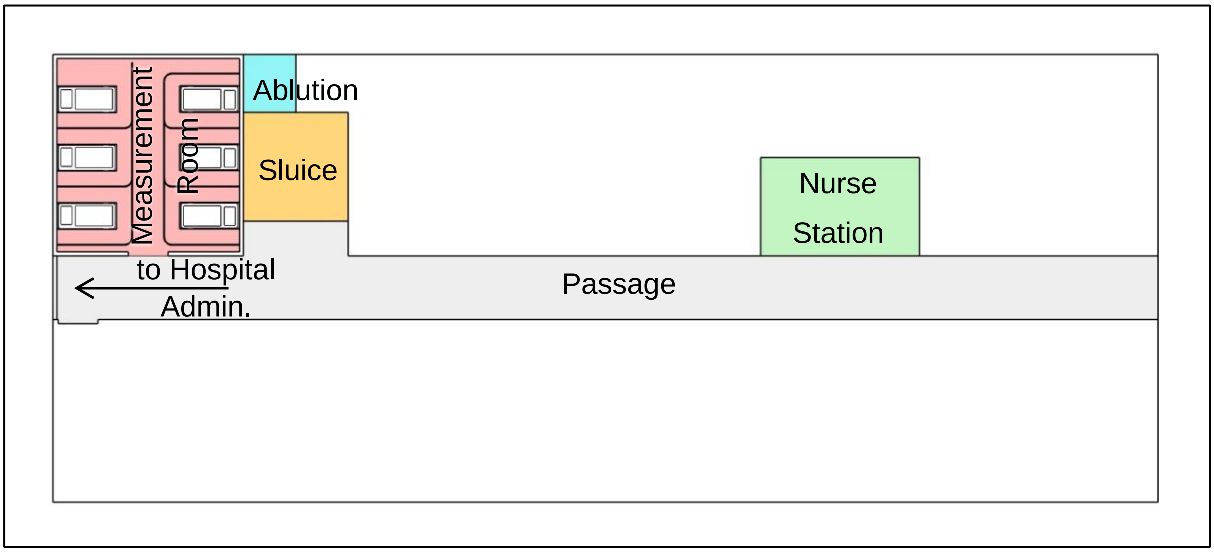

Figure 15: Plan layout of ward - Hospital A.

4.7.1.2 Hospital B

The measurement location at Hospital B was a 7-bed room within a ward, accessed by a central corridor serving the other ward rooms, as shown in the layout diagram in Figure 17. The corridor also served as a thoroughfare route to the theatre complex from other wings of the hospital. A corridor leading from other areas (particularly the paediatric ward) joined into the ward corridor directly adjacent to the measurement location room.

As illustrated in Figure 16, the room area was approximately 57 m^2, being 6,05 m wide and 9,39 m in length, with a ceiling height of 3,1 m. Three beds line one wall adjacent to the dedicated ablution room and four beds lined the opposite wall. The windows were opposite the entrance door facing onto a small paved courtyard. The windows were draped and openable providing natural ventilation supplemented by ceiling fans in the room. The floor was finished with polished vinyl sheeting, the walls were plastered and painted and ceiling was a 600 x 600 mm drop-in grid ceiling.

The nurses' station was located along the corridor approximately 8 m from the door to the room and the sluice and staff ablutions were located down a corridor that led into the main ward corridor at a distance of about 3 m from the room door. The main kitchen was located at the end of the corridor, approximately 18 m from the room door.

The corridor was 2,2 m wide with a ceiling height of 3,9 m. The corridor floor was tiled with ceramic tiles, the walls were plastered and painted and the ceiling was a nail-up gypsum ceiling.

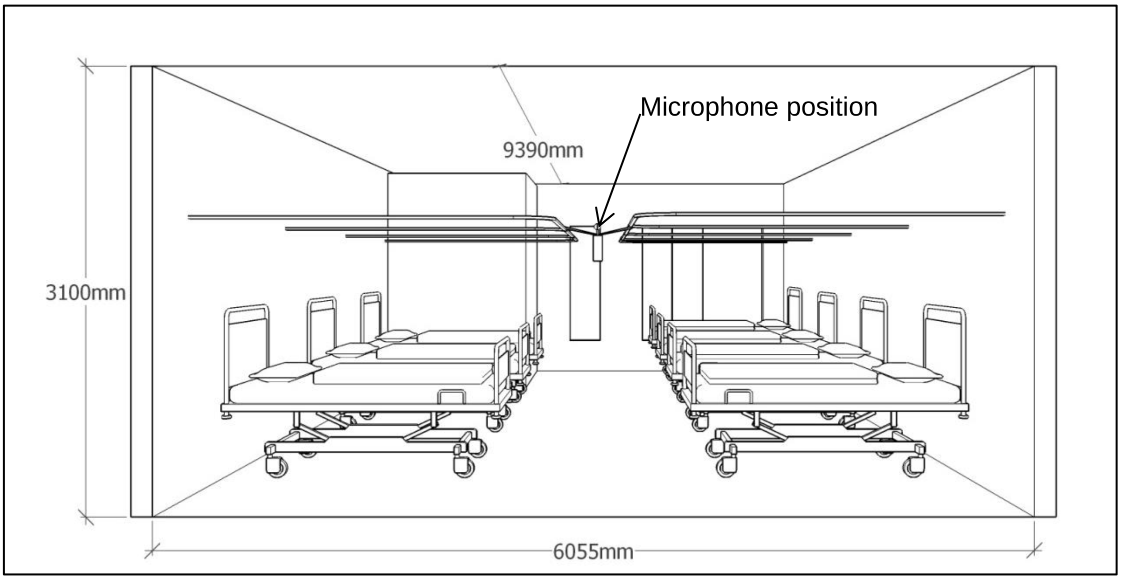

Figure 16: Measurement room in Hospital B.

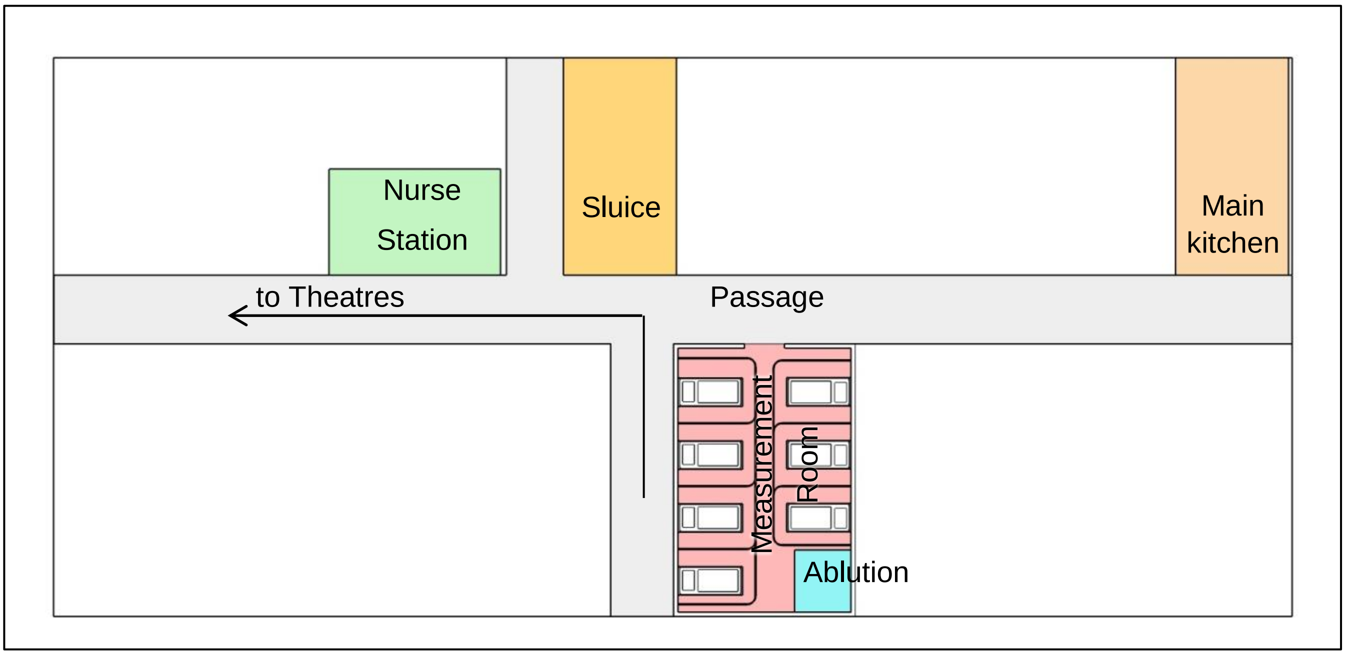

Figure 17: Layout of ward in Hospital B.

4.7.1.3 Hospital C

Hospital C was unique compared to the other sites in that the ward was linked to the hospital via an external covered walkway. The corridor space within the ward itself was used only by the occupants of the ward and did not serve as a thoroughfare to other wings.

The measurement location was a 9-bed cubicle within a 40-bed general ward. Four adjacent cubicles were open on one side facing onto a circulation passage with the nurses' station and supporting services rooms on the opposite side. A short entrance passage led from the ward to the external corridor.

The entire open plan ward area was approximately 350 m^2, while the measurement location cubicle was approximately 9,9 m wide and 10 m in length, as illustrated in Figure 18. The ceiling sloped from a height of 2,86 m above floor level at the back wall to 4,4 m above floor level over the passage area. Five beds lined one wall and four beds lined the opposite wall. There were high-level opening windows on the back wall with glazed doors in the centre opening out onto a large courtyard and high-level opening windows above the passage area, where the ceiling height was its maximum. There were no drapes on the windows. No functioning mechanical ventilation was present. The floor was finished with vinyl tiles, the walls were plastered and painted and ceiling a nail-up gypsum board ceiling.

The nurses' station was located approximately 10 m from the open side of the cubicle, the sluice room was approximately 25 m from the open side and the communal ablutions were about 20 m from the open side, as shown in Figure 19.

The passage area was 3 m wide beneath the highest part of the ceiling. The external corridor had a concrete floor and a sheet metal roof of approximately 2,2 m high.

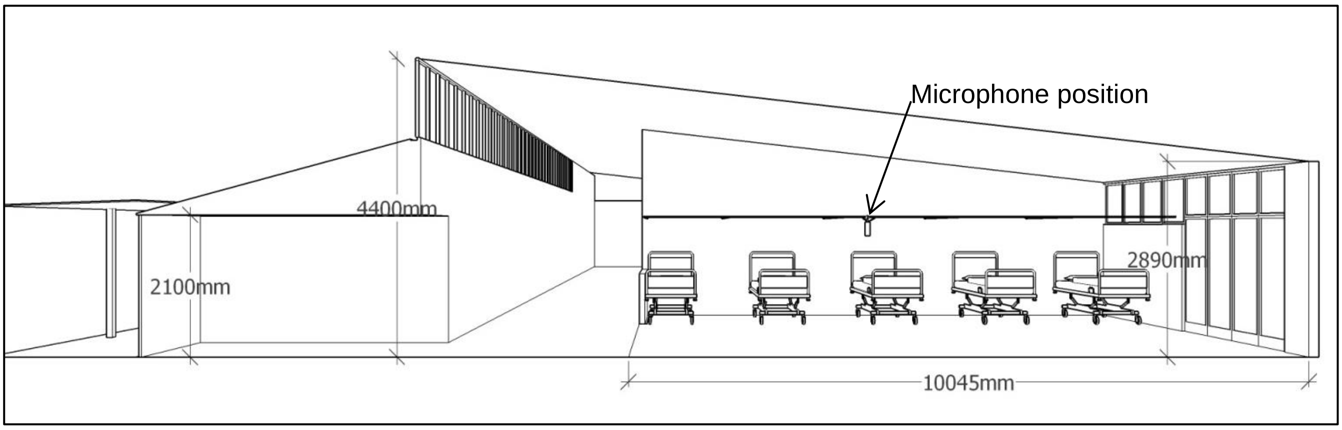

Figure 18: Measurement room in Hospital C.

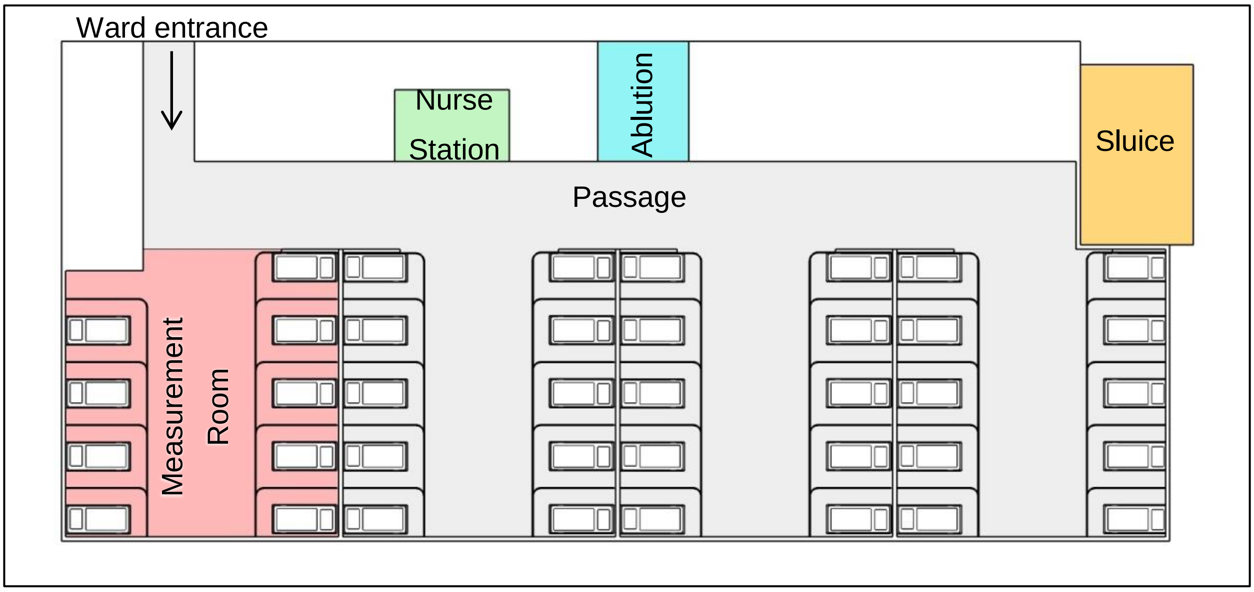

Figure 19: Layout plan of ward - Hospital C.

4.7.1.4 Hospital D

Hospital D provided the smallest measurement location - a 4-bed room within a general surgery ward. The room was located centrally along the ward corridor, as shown in Figure 21, which served as a circulation spine for the ward as well as one of the access routes from other areas of the hospital to the theatre complex.

The room area was measured to be 27 m^2, being 6,18 m wide and 4,4 m in length, as can be seen in Figure 20, with a ceiling height of 2,6 m. Two beds lined opposite walls, there were windows opposite the entrance door facing onto a paved courtyard and dedicated ablutions lead directly off the room at the entrance. The floor was finished with vinyl sheeting, the walls were plastered and painted and the ceiling was a non-acoustic drop-in tile in a 600 x 1200 mm grid. The windows were kept closed and had fabric drapes. A ducted air conditioning system was installed.

The centralised nurses' station was located along the corridor opposite the entrance to the measurement location room. The sluice room and tea kitchen were located along the corridor adjacent to the nurses' station, approximately 4 m from the room door.

The corridor was 2,05 m wide with a ceiling height of 2,6 m, finished with vinyl floor sheeting, the walls were plastered and painted and the ceiling was a drop-in ceiling on a 600 x 600 mm grid with non-acoustic ceiling tiles.

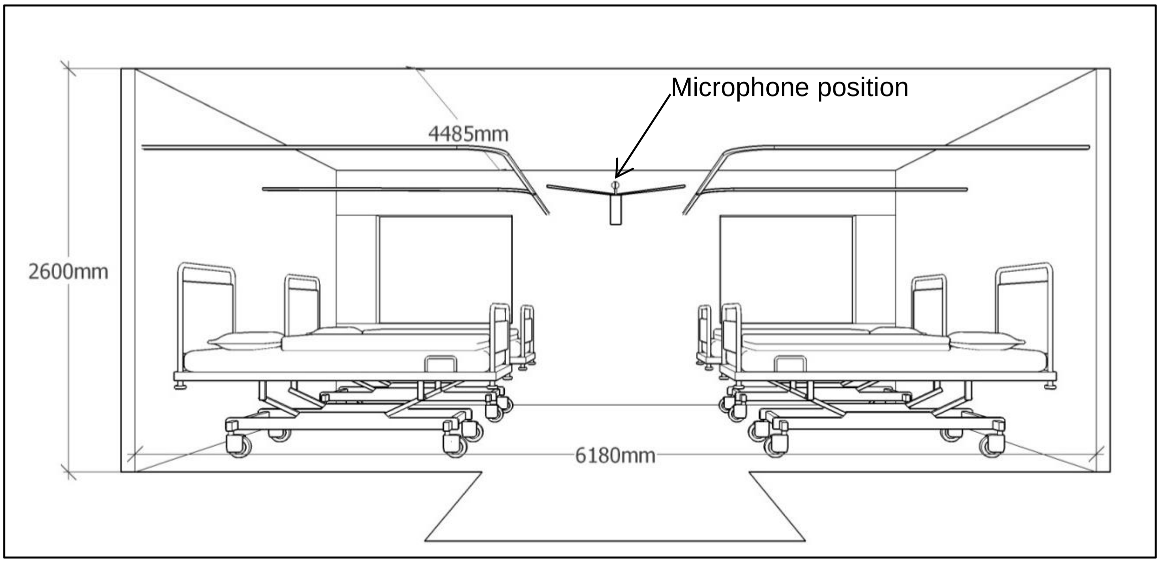

Figure 20: Measurement room in Hospital D.

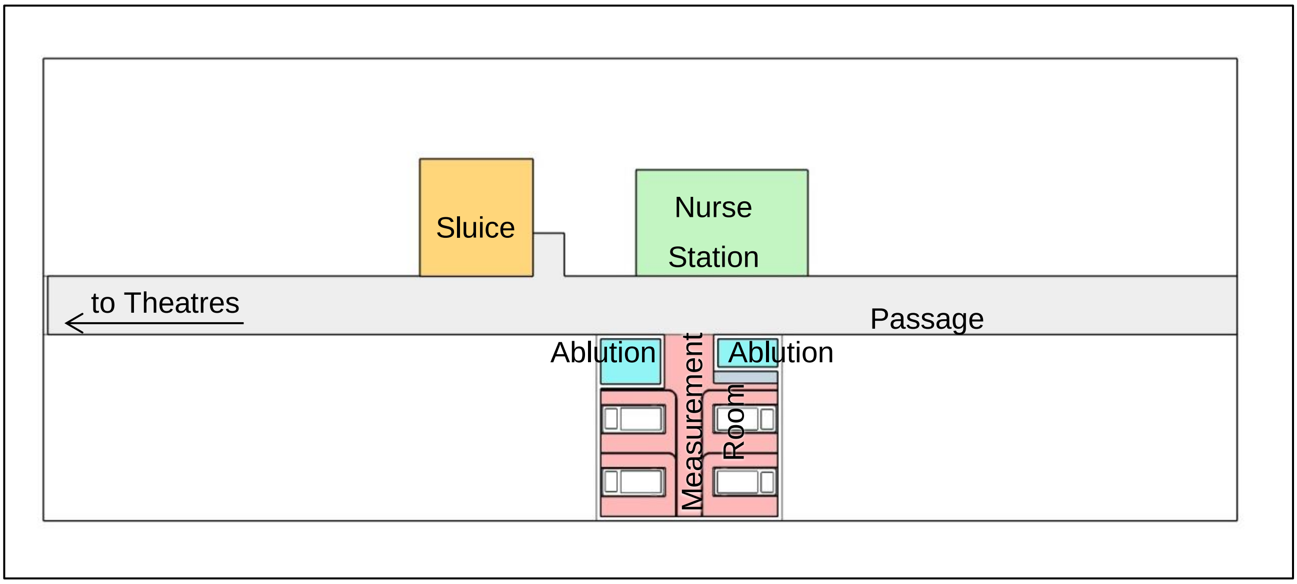

Figure 21: Layout of ward in Hospital D.

4.7.2. Analysis of the wards' architectural layout

The layout of the measurement sites was analysed in terms of the proximity to related service spaces and the relationship with the rest of the hospital.

When considering the distance from the measurement location to the nurses' station, Hospital A's location was the furthest, at 25 m, while Hospital D's location was the nearest, being directly across the corridor from the nurses station. When the distance from the nurses' station, the continuous equivalent sound pressure levels and the perceived noise levels, as tabulated in Table 12, are compared, it is found that there is no direct association between noise levels and proximity to the nurses station.

Table 12: Association between noise and distance from Nurse Station at each hospital

Hospital ID	***Distance to Nurse Station (m)***	***Average 24-hour L_{eq} (dBA)***	***Perceived noisiness (% users finding it noisy)***
A	25	49.4	21
B	8	53.5	53
C	10	56.8	0
D	2	53.8	25

Similarly, there was no association between the proximity of the measurement location to the ward sluice and the actual or perceived noise levels, as per the values tabulated in Table 13.

Table 13: Association between noise and distance from Ward Sluice at each hospital

Hospital ID	***Distance to Ward Sluice (m)***	***Average 24-hour L_{eq} (dBA)***	***Perceived noisiness (% users finding it noisy)***
A	10	49.4	21
B	3	53.5	53
C	25	56.8	0
D	4	53.8	25

In all cases, except Hospital C, the ward corridor also served as a general circulation route for the hospital. The corridor at Hospital A terminated at the entrance to the hospital administration block. This door was only used by staff and it was observed that the corridor outside the entrance to the measurement location was relatively quiet. Hospital B and D both had corridors that served as a thoroughfare from other hospital departments to the theatres.

The activity levels in the corridors are summarised in Table 14. There is no direct association between activity level in the corridor and noise levels across all four hospitals.

Table 14: Association between noise and activity level in corridor/busy circulation route

Hospital ID	***Thoroughfare***	***Activity level***	***Active period average L_{eq}***	
	Yes/No	***Rank/level (observed)***	***L_{eq} (dBA)***	***Rank***
A	Y	3	51.6	4
B	Y	1	55.7	2
C	N	4	58.1	1
D	Y	2	54.9	3

The size of each measurement location varied, the largest being Hospital C, which was an open-plan ward of 40 beds with cubicles of 10 beds each. The measurement location in this case was a 10-bed three-sided cubicle of approximately 10 m x 10 m with a sloping ceiling from 2.8 m to 4.4 m. In contrast, the smallest measurement room was in Hospital D, where the measurement location was a 4-bed room of with floor dimensions of 6.1 m x 4.5 m and a ceiling height of 2.6 m. When the overall dimensions of each measurement location, in terms of volume, were compared to the average 24-hour equivalent continuous sound levels, it was found that there is no direct association.

Table 15: Summary of room volume relative to L_{eq}

Hospital ID	***Volume (m^3)***	***Ave. 24-hour L_{eq} [dBA]***
A	161	49.4
B	176	53.5
C	361	56.8
D	72	53.8

4.7.3. Materials

The material finishes in each location were noted by the observers.

All four sites had very similar finishes in terms of their acoustic absorption coefficients. All sites had plastered and painted walls. The floor finishes in each measurement location was vinyl sheeting on a cement screed. The ceiling finishes differed in that Hospital A had flush plastered ceiling boards, while Hospital B had drop-in ceiling tiles that appeared to be non-acoustic. In Hospital C the ceiling was painted gypsum board and in Hospital D the ceiling was a suspended grid with drop-in tiles similar to those in Hospital B. Though the ceiling finishing materials differed, the difference in absorption coefficients between the ceiling materials is negligible.

The corridor materials were similar to the finishes in the measurement locations with the exception of Hospitals A and B, where the corridor floor was finished in ceramic tiles. It was observed that this was the cause of some noise as wheeled equipment passed over the joints between the tiles.

4.8. Source of noise

Section C of the questionnaire was designed to gain insight into the possible sources of noise in the selected hospitals. The questionnaire presented a list of possible noises and participants were required to indicate how disturbing they perceived each type of noise (if applicable) on a scale of “welcome” / “not noticeable” / “noticeable but not disturbing” / “slightly annoying” / “disturbing (can’t sleep/think/talk)”. They were also asked to indicate when (day or night) and how frequently (sometimes, always or never) they noticed the noise. Though the parts of the questionnaire relating to the frequency and time of noise was not well completed by the participants (only 23 and 14 respectively out of 83 completed these questions), the first part relating to the level of annoyance of noise yielded valid results.

When the source of noise was analysed based on the user opinions gleaned from the questionnaires, it was found that the highest disturbances reported were traffic in the corridor in the form of wheeled equipment, and the sound of medical equipment and alarms. A comparison of respondent opinions of the various noise sources can be seen in the chart in Figure 22.

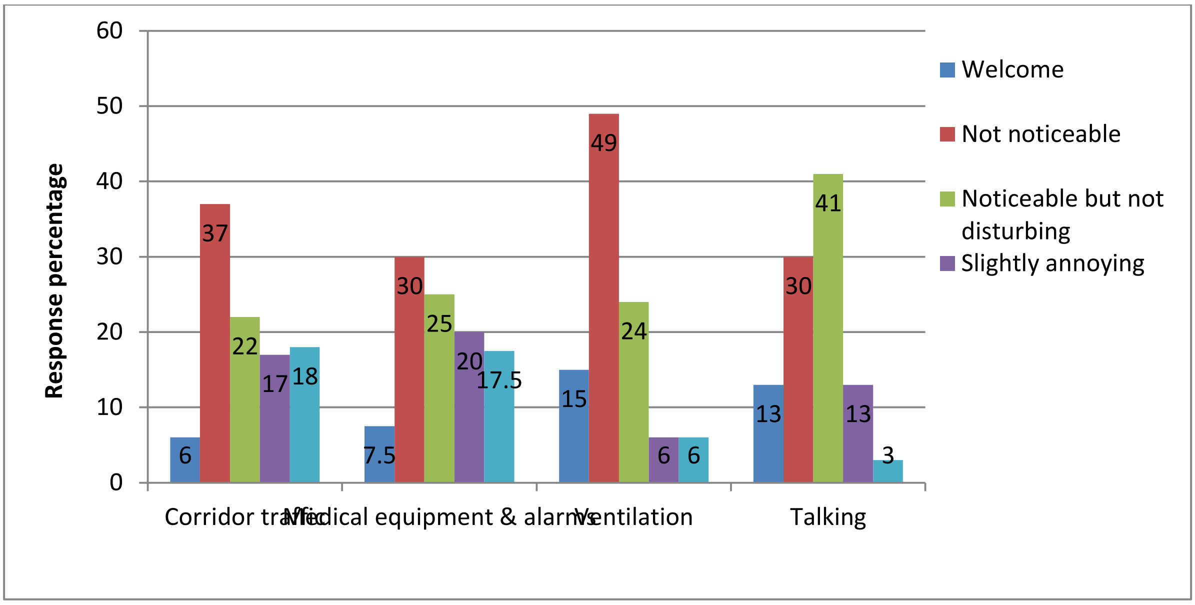

Figure 22: Responses to various noise sources (all sites combined).

4.8.1. Corridor traffic

In order to confirm whether activity in the corridor serving the patient area was perceived as noisy and disturbing, questions 18 and 20 of the questionnaire were combined. The noise sources to be rated were stated in the questionnaire as “Thoroughfare in the corridor outside the ward” and “Trollies in the passage”.

It was found that the majority found that 35% of the participants responded that the traffic noise was either slightly annoying or disturbing. When each site was analysed separately, it was found that corridor traffic was most disturbing in Hospital B, with 60% of the users finding it either annoying or disturbing, compared with Hospitals A, C and D where 36%, 27% and 23% of the participants found it annoying or disturbing, as can be seen in Figure 23.

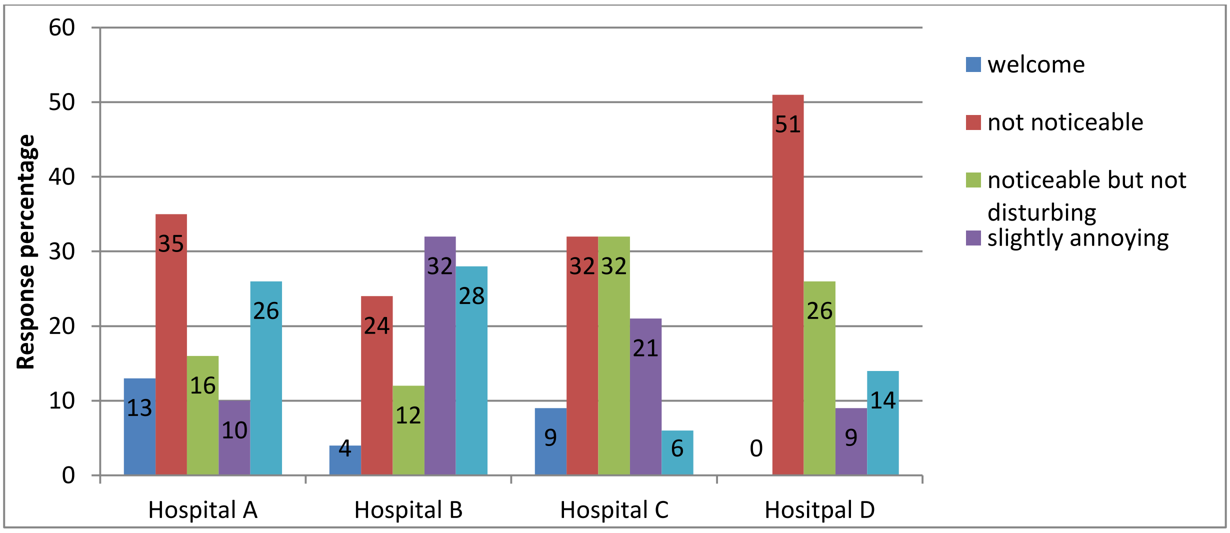

Figure 23: Perception of noise from corridor traffic

4.8.2. Medical equipment

The extent of possible disturbance due to noise from medical equipment and medical alarms was addressed in questions 9 and 10 respectively. Due to the low number of respondents, the data from questions 9 and 10 were combined. Overall, when data from all sites are combined, it is evident that most users do not find these sources of noise disturbing as is shown in the chart in Figure 24.

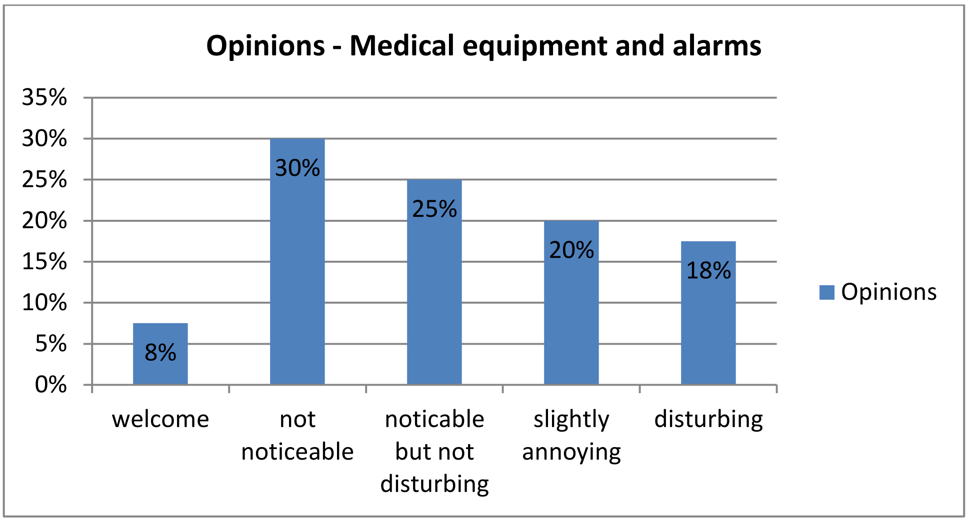

Figure 24: Overall user opinions of medical equipment and alarm noises at all sites combined.

When the data sets per site are analysed, it emerges that Hospital A has the largest percentage of users finding the noise level disturbing (though by only a small margin), while the majority of opinions at the other sites indicate that alarms and medical equipment are not disturbing, as shown in Table 16.

Table 16: Distribution of frequency of disturbance due to alarms and medical equipment.

ALARMS & MEDICAL EQUIPMENT	***Hospital A***	***Hospital B***	***Hospital C***	***Hospital D***
Welcome	11%	0%	14%	0%
Not noticeable	26%	**35%**	**32%**	30%
Noticeable but not disturbing	17%	29%	23%	**34%**
Slightly annoying	17%	18%	17%	27%
disturbing	**29%**	18%	14%	9%

4.8.3. Ventilation noise

Based on the hypothesis that noise from mechanical ventilation is disturbing, participants were asked in question 8 of the questionnaire to indicate their perception of noise from fans or air conditioners. The number of valid answers to this question was 66 out of 83. It emerged that the majority of participants, when all sites and user groups were combined, found the sound of mechanical ventilation to be not noticeable (valid of 48.5%). From one site to the next, it was found that ventilation noise was not disturbing.

When comparing the opinions of the different user groups, it was found at Hospital A, that patients were less disturbed by ventilation noise than staff; at Hospital B the majority of the staff indicated that ventilation noise was welcome (50%), while the majority of the patients found it ‘not noticeable’ (80%). No participants in either user group at Hospital B found the ventilation noise annoying or disturbing. At Hospital C, none found the noise disturbing, the majority of staff (56%) finding it noticeable but not disturbing and most patients (45%) finding it not noticeable. At Hospital D, the over-riding opinion of the patients was that ventilation noise is not noticeable (86%), while most staff (40%) found the noise noticeable but not disturbing.

The results of the combined user groups per hospital are displayed in Figure 25.

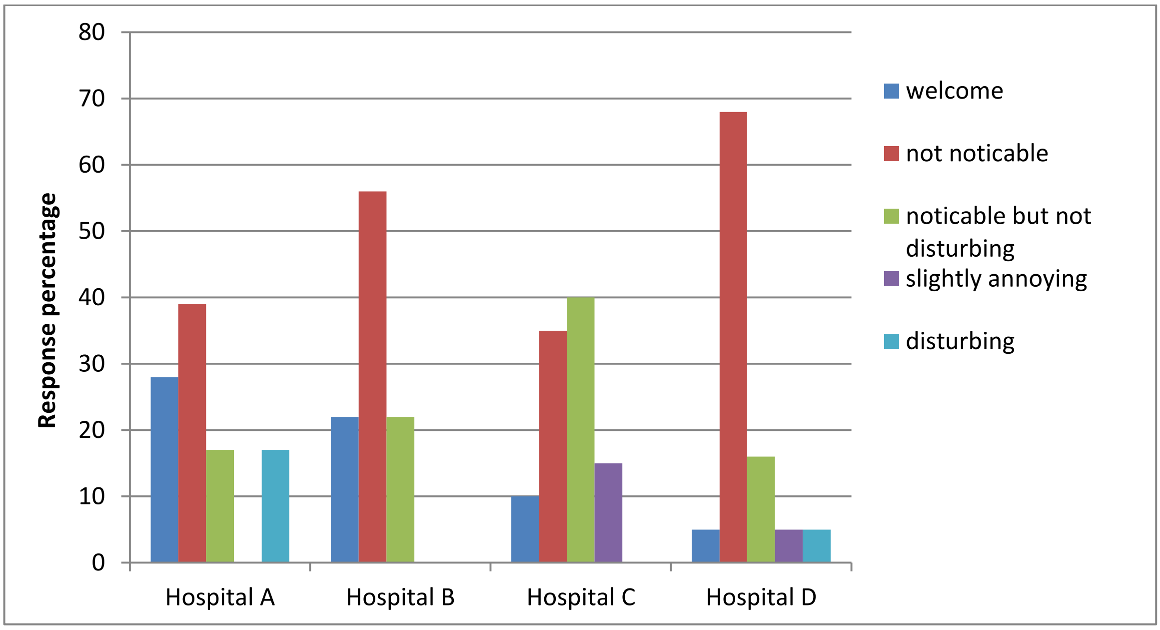

Figure 25: Graphic representation of user opinions of mechanical ventilation noise.

4.8.4. Talking

Questions 14 to 17 of the questionnaire all related to noise disturbance caused by talking – of either staff members, visitors or patients talking – and for statistical analysis were combined into one question to determine how much talking disturbed users. It was found that there is no statistically significant difference in the mean scores of opinions amongst hospitals[6] or amongst user groups[7], with the majority of the opinions lying in the categories of “not noticeable” or “noticeable but not disturbing”, as can be seen in Figure 26.

[6] $p = 0.188$
[7] $p = 0.197$

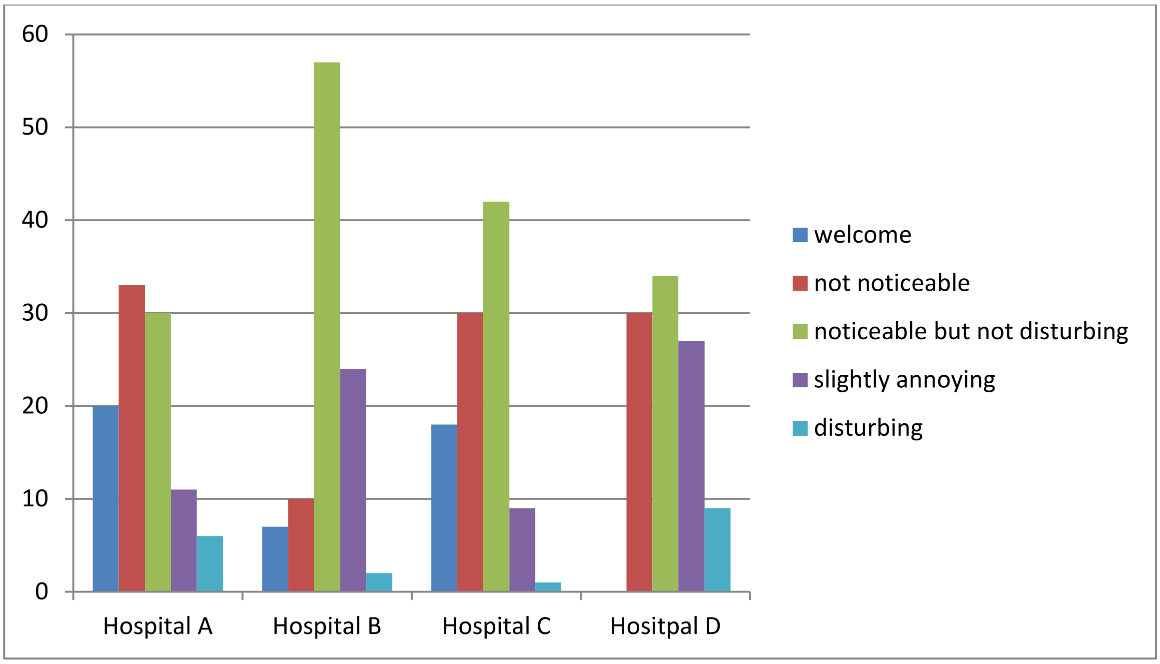

Figure 26: Distribution of user opinions of noise emanating from people talking

4.8.5. Other noises

A number of other noises were also listed on the questionnaire to determine the extent to which they could cause a disturbance. However, none of these emerged as significantly noticeable. The noises listed were: noise from outside the window, doors slamming, noise from the ablutions, noise from the kitchen, telephones and intercoms.

5. CHAPTER 5: DISCUSSION OF FINDINGS

5.1. Noise levels

5.1.1. Compliance with guidelines

With regard to the goal of determining whether there is a likely need to address indoor environmental noise in South African hospitals, the first two research questions to be addressed pertain to the international and national guidelines for noise levels in hospitals.

When the average 24-hour equivalent continuous sound levels across all four hospitals (53.4 dBA) are compared with the guidelines of the WHO (30 dBA) and the design rating given in the SANS 10103 (35 dBA), it is clear that the actual noise level exceeds the prescribed levels by 23.4 dBA and 18.4 dBA, respectively. This is significantly high, considering that the decibel scale is logarithmic. On this scale, a doubling of the sound pressure level will result in a 3 dB increase in the sound level, a ten-fold increase will result in a 10 dB increase and a 20 dB increase will be 100 times louder.

When compared to trends around the world, the hospitals surveyed for this research yield similar results. According to the Busch-Vishniac et al (2005) report, hospital noise levels world-wide are 20-40 dBA higher than the WHO guidelines. In comparison to this, the South African hospitals surveyed fare quite well as the deviation from the WHO guidelines was found to range from 19.4 – 26.8 dBA, which is at the lower end of the range reported internationally.

Since it seems that no hospitals can boast compliance with the WHO guidelines, it must be asked why this is. If the guidelines values are impossibly low, it can be argued that such guidelines need to be amended. Alternatively, it could be that the guidelines have been misunderstood or misinterpreted.

The WHO guidelines on community noise are commonly quoted in literature as a reference level in studies on noise levels in hospitals. The value used is either 30 dBA, if wards are in question, or 35 dBA for other patient areas. These are given as single equivalent continuous sound pressure levels for both day and night periods. Though these levels seem very low, a more detailed reading of the document reveals that the values are based on the lowest level at which health effects due to noise exposure may be expected for general populations. The guidelines are not on exposure-response relationships, which would have been preferable (Berglund 1999:38). Exposure-response relationships would give an indication of expected effects if standards were to be set above the guideline values. Since the lowest level at which a health effect can be expected in a hospital setting is sleep disturbance, the values reflect this and are thus very low.

With this explanation in mind, and an interrogation of minimum values recorded during the quiet period, it can be seen that Hospital A does in fact comply, with a minimum recorded value of 29.7 dBA. However, this value was found only in one of the five-minute recording intervals, proving it to be an unmaintainable level. None of the other hospitals were able to comply, still raising the argument that these levels are probably unrealistic for a functioning hospital.

Similarly, the design ratings stipulated in the SANS also need to be understood at more than just face value in order to determine their meaning and relevance. In Section 3 of the standards document the ambient sound is defined as the “totally encompassing sound in a given situation at a given time, and usually composed of sound from many sources, both near and far." (South Africa 2008:4) The introductory paragraph to Section 4 on guidelines explains that the levels stipulated are for ambient noise during the time periods when the areas are used for their intended purposes and with the building services under normal operation. However, a footnote to this section states that the "levels do not included the noise produced by the intended activities" (South Africa 2008:9) of the area in question. It seems then, that the stipulated values are for a building "at rest" when all building services are running but the building is unoccupied.

With this understanding, it is futile to assess an occupied functioning environment according to these SANS guidelines.

Though the SANS guidelines are valuable in ensuring that the building infrastructure does not contribute excessive noise to the ambient environment, there are no local standards addressing occupied noise levels. Based on the research evidence regarding the impact of noise on user outcomes, it seems there is a lack of practical guidance regarding noise levels in occupied spaces to ensure positive outcomes.

Considering that the SANS values refer to a building at rest, this condition is most closely simulated during the quiet hours of the night when there is virtually no occupant activity or noise. Once again, an analysis of the quiet times of the selected hospitals reveals that, when specific noise events are excluded, only Hospital A is able to comply with the SANS 10103 design rating of 35 dBA, with and ambient noise level of 34.8 dBA.

5.1.2. Discussion on Hospital A

The fact that none of the case study sites, except for Hospital A, complied with guideline values warrants a closer look at the environmental conditions at that site to see what factors could possibly set it apart from the others.

Hospital A does not have a particularly unique layout and the material finishes in the ward are very similar to those of the other sites. However, it can be noted that the measurement location in Hospital A was the furthest from the nurses' station when compared to the distances recorded at the other sites. Furthermore, though the ward corridor is a thoroughfare, it is only used by staff. Moreover, the measurement room is also located at the end of the corridor and thus no movement of staff or patients to other rooms raises activity at the doorway of the measurement location. It is thus a possible conclusion worth further investigation that patients should be located further from the activity of the nurses' station and passing traffic. It is worth noting, in relation to corridor traffic and talking, that most questionnaire participants at Hospital A found both talking and corridor traffic not noticeable.

It seems that the building services in Hospital A are adequately quiet and do not contribute noticeably to the ambient noise. The majority of the participants in Hospital A found ventilation 'not noticeable'. This, together with the low minimum values, indicates that building services at Hospital A are adequately quiet and do not contribute noticeably to the ambient noise levels, thus meeting the intended requirements of SANS 10103.

5.1.3. Perceived noise levels

Though Hospital A was unique in its low recorded noise levels, this did not correlate with the perceived noise levels. Rather, in Hospital C, where the 24-hour average equivalent continuous noise level was the highest (56.8 dBA), the perception of 100% of the users was that it was not too noisy.

Furthermore, the perceived noise levels in Hospitals A and D were very similar while the actual noise levels differed by almost 5 dB and while the actual noise levels at Hospitals B and D were almost the same, the perceived levels differed by 25%.

Clearly users are not disturbed by noise in relation to the actual noise levels. This is quite possible due to the complex and subjective nature of sound. Noise is not only dependent on amplitude but also the frequency and nature of sound.

Since the data recorded by the sound level meter revealed no difference in the dominant frequency range from one site to another, the influence of frequency on the perception of noise can be discounted.

However, an interesting observation can be made regarding the nature of the sound in terms of its continuous fluctuation or variance.

5.1.4. Discussion on noise variance

When the variability of sound fluctuations is considered, it is noticeable that Hospital C has the lowest amount of fluctuation, with a standard deviation of 2.2 during the quiet period and 2.9 during the active period. It is also notable that the day-night variance in noise levels at Hospital C is of the lowest, with a 6 dB difference between average day time noise levels and average night time noise levels.

By comparison, Hospitals A and B had the highest amount of variance, though the perceived and actual noise levels as these two sites differed from each other. Hospital A had very high variances, yet the average noise levels were very low and it was perceived not to be noisy. In this case the variance probably did not annoy users since in general the noise levels and activity levels were low. On the other hand, almost 50% of the users in Hospital B considered it to be too noisy and the actual noise levels were relatively high. Here is seems possible that the high variability in noise could have an impact on the perception of noise.

It could thus be concluded that the combination of ambient noise level and variance influence the perception of noise.

Considering the conditions at Hospital C, it was observed that there was a constant and noticeable noise generated by fans in the UVGI light fittings. This could have contributed to the high measured noise levels and yet possibly at the same time created a masking effect, keeping the ambient noise level high enough that noise events were relatively unnoticeable. Unfortunately, the UVGI lights could not be switched off to test this theory. However, the possible masking effect is a theory worth further investigation in a healthcare context.

5.1.5. User groups

When the type of users were categorised in staff and patient groups, it was found that a significant association between user group and noise perception exists with an unexpectedly high proportion of staff members finding noise to be disturbing, except in Hospital C where 100% of the staff indicated that the noise level was ‘fine’.

Though the critical health effect on which the WHO guidelines for noise in hospitals is based is sleep disturbance, it is important to note that the effect of annoyance on staff emerged as a significant factor to consider in this case study and that the patient perception of noise generally indicated less dissatisfaction. It should also be noted that a possible reason for this is the patients were recovering from surgery and were under the influence of anaesthetic or pain medication which aided sleep.

An interesting observation emerged from a case study at Padua Hopital, Italy, on measured and perceived indoor environment quality (De Giuli, Zecchin, Salmaso, Corain & De Carli 2013:223). It was found that there is a possible relationship between length of stay and acoustic comfort. Over 50% of short-stay patients did not perceive any environmental discomfort, while staff, who are long-term occupants, ranked acoustic discomfort as one of the highest concerns. This study may help provide an explaination for the difference in user group perceptions of noise since most of the patients were short-stay patients, while the nursing staff are exposed to the environmental noise on a constant daily basis.

Literature also tells us that noise is a stressor and if a person is already stressed, the impact of noise on stress levels will be greater. Members of medical staff need to communicate with each other and noise could interfere with this, while patients need to communicate less in a surgical ward setting. It is worth noting that this may not be same in a diagnostic environment, where staff-patient communication could be considered more important.

Though it was expected that patients require peace and quiet, it is significant to note that it is equally, if not more, important for staff. It could be concluded that staff areas need to be treated better acoustically to avoid frustration, stress or burn-out.

5.1.6. Source of noise

Based on the data gathered from the questionnaires, the main source of noise overall is trollies and medical equipment, including alarms. When analysed in terms of user groups, the highest ranking sources of observed noise amongst the patient group was firstly medical equipment and alarms, and secondly staff talking in the corridor. Amongst staff members, the highest ranking source of noise was trollies (corridor traffic) and medical equipment and alarms.

Thus it can be concluded that the most common source of noise in this study is medical equipment and alarms. However, it should be noted that though these sources ranked highly, the percentage of the total sample group finding these sources ‘not disturbing’ was higher.

Based on observations of the investigators, the noise of trollies in the corridors was the most noticeable noise.

The hospital with the highest noise due to trollies was Hospital B. It is theorised that there are two possible reasons for this. Firstly, the floor in the corridors is finished with ceramic tiles with 5 to 10mm joints between. The tiles are relatively small –250 mm x 250 mm – which means that the joints are very close together. Wheeled equipment being pushed over the tiles makes a noise passing over every a joint. Secondly, the corridor carried a high volume of traffic, being a route to the main kitchen, clinic, paediatric ward and theatre. Furthermore, though reverberation readings were not successfully taken, it was observed that there was a long reverberation time in the corridor, which had very high ceilings and was very long, possibly contributing to the reverberation.

Noise from the surrounding environment did not have a noticeable impact on the noise readings in the measurement locations. Even at Hospital B, where the external noise level was very high, the large variance between the surrounding noise level and the internal noise level suggests that the outdoor noise was not transmitted through the building envelope. The cause of the noise outside the window at Hospital B was air handling units on the nearby roof.

In Hospital C the surrounding sound levels were in fact lower than the internal readings, suggesting that most of the noise recorded in that location was generated from within the room rather than the surroundings. This is likely to be attributed to the fact that the activities that the hospital ward was open-plan to the supporting services, such as the nurses station, sluice room and ablutions, which in the other hospitals were located beyond the entrance to the measurement room leading off the circulation passage.

6. CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This research project set out to determine whether there is a likely need to address indoor environmental noise in South African hospitals through design interventions. The research was designed as a multiple case study, in which four South African urban hospitals were selected for investigation, laying the ground work for future studies of this nature.

The first objective was to establish whether the selected hospitals could be considered noisy. The empirical data measured with a Class 1 sound level meter revealed that the average 24-hour equivalent continuous sound level of the four hospitals was above the WHO guideline level as well as the South African National Standards guidelines for noise in hospital wards.

Juxtaposed on this finding, subjective data based on the users' perceptions of noise revealed that on average about three quarters of the participants did not find the hospitals to be noisy. It also highlights the complex nature of sound. Sound is perceived differently depending on its nature, pattern and frequency content and thus a single guideline value is difficult to quantify.

Though the data from the quietest period at Hospital A proved that the guideline values are achievable, the practicality of maintaining these levels over a 24-hour continuous period of operation seems unlikely. However, it was established that the guidelines should not necessarily be interpreted as levels to be maintained during active operation of the hospitals but rather refer to sleep disturbance levels, in the case of the WHO guidelines, and unoccupied building levels, in the case of the SANS guidelines.

The second objective was to establish the causes of the noise. Direct observations as well as participant responses to a questionnaire revealed that most noise was generated by activities in the ward corridor and by medical equipment and alarms. These sources are almost unavoidable functions of a hospital ward.

In order to address these issues of the general noise level and the main noise sources from an architectural perspective, the design of each site was analysed, fulfilling the third objective.

Though the general layout is similar in concept at all sites, being based on workflow, there are some differences potentially pointing to the impact of design on noise levels. These lead to conclude that patient bedrooms should be distanced from the central nurses' station and that ward circulation should be designed in such a way as to minimise traffic past patient bedrooms.

It was expected that the hospitals could be noisy due to reverberation as sound waves reflect off hard smooth surfaces. However, it was observed that the finished surfaces were treated in a very similar way at each hospital. The absorption coefficients of the applied materials were not found to be significantly different from one hospital to the next and thus it was not possible to draw a conclusion regarding finishing materials. However, this did mean that one possible design variable was excluded, with layout and the building envelope remaining as possible architectural influences.

A further observation was the potential benefit of sound masking. While it seems that sound masking could lead to a perception of lower noise levels, there would be the added benefit of masking doctor-patient conversations, thus increasing privacy. This would increase ambient noise levels but lower perceived noise levels and would require accurate quantification to prevent the ambient noise levels from being too high.

The findings of this case study cannot be extrapolated to have bearing on all hospitals in South Africa. However, the research has shown that the selected hospitals yield noise levels well above the guideline values, as currently applied, to the possible detriment of occupants, especially staff members. Noise control interventions would be beneficial to occupants, particularly in the form of the architectural layout of spaces and circulation routes.

6.2. **Recommendations**

In light of the apparent disconnect between actual and perceived noise levels, as well as the inadequacy of guidelines in addressing occupied, active spaces, it is recommended that acoustic guidelines for occupied and functioning hospital spaces should be established.

The fact that the perceived noise levels differed from the actual noise levels suggests that an in-depth study of human response to sound in a hospital environment would have to be conducted in order to inform such guidelines.

This case study raised a few observations that would need to be investigated in greater depth to establish their validity. These observations include:

- the benefit and effectiveness of sound masking,
- the value to be gained, in terms of quietness, by changing the current paradigm of layout and circulation in wards, and
- the possible benefit of separating staff and patient areas, treating them each according to their unique acoustic needs.

A broader-based study with a larger sample group would be required for this.

The current base of evidence used to argue the importance of quietness in hospitals consists of a collection of case studies, conducted under different methodologies, by different investigators with differing purposes, and at different times. There would be great value to be gained in the field of acoustics in healthcare environments from a combined co-ordinated world-wide effort to assess hospitals uniformly with the purpose of establishing practical guidelines for facilities in operation.

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8. ANNEXURE 1 – QUESTIONNAIRE

Questionnaire

A case study investigation to determine the extent to which noise in an urban South African hospital may be attributed to architectural design

our future through science

University of Pretoria

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For office use only	
Questionnaire number	
Hospital ward	
Bed number/Staff ID	
Date	
Time	
Number of occupants	

V0

Please answer Section A, B and C.

Section A

Please mark the applicable box with X.

1. Are you:

Staff [ ] or Patient [ ] — V1

2. Have you been diagnosed with hearing loss?

Yes [ ] No [ ] — V2

3. Age (years): — V3

18 - 34		35 - 45	
46 - 55		56 - 65	
66 - 75		76+	

4. If you are a patient, please indicate date of admission to this ward:
(MM/DD)

[/] — V4

5. If you are staff, please indicate the time your shift began:
(hh/mm)

[/] — V5

Section B

6. What is your opinion of the noise in the ward?

too noisy [ ] fine [ ] too quiet [ ] — V6

7. When does noise bother you the most? — V7

always		night	
day		never	

Please answer Section C on the next page

Section C

The following questions are designed to help determine the main cause of noise disturbance.

Please indicate how disturbing the following sounds are to you, and when you find them disturbing, by marking the appropriate column with a x.

If you are not sure, please don't answer the question.

		The sound is:					When the sound is noticable:									
							Frequency			Time						
		welcome	not noticable	noticable but not disturbing	slightly annoying	disturbing (can't sleep/think/talk)	Sometimes	Always	Never	Day	Night		a	b	c	d
8.	Fan/Air conditioner											V8				
9.	Alarms / beeping											V9				
10.	Medical equipment/machines											V10				
11.	Telephone											V11				
12.	Intercom											V12				
13.	Radio / TV											V13				
14.	Staff talking outside the ward											V14				
15.	Staff talking to patients in the ward											V15				
16.	Visitors talking to other patients											V16				
17.	Other patients talking/making noises											V17				
18.	Throughfare in the corridor outside the ward											V18				
19.	Noises outside the window											V19				
20.	Trollies in the passage											V20				
21.	Noise from the bathroom											V21				
22.	Noise from the kitchen											V22				
23.	Doors slamming											V23				
24.	Items falling on the ground											V24				
25.	Cleaning activities											V25				
26.	Other (please describe):											V26				
27.	Other (please describe):											V27				
28.	Other (please describe):											V28				

Thank you for your co-operation.

9. ANNEXURE 2 – OBSERVER'S TIMESHEET

A case study investigation to determine the extent to which noise in an urban South African hospital may be attributed to architectural design.

Site:	Office A350
Investigator:	
Date:	17 - 20 September
Time period:	8.35

Time stamp	Description of noise (cause, duration)