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INVESTIGATION OF PATIENT PERCEPTION OF HOSPITAL NOISE AND SOUND LEVEL MEASUREMENTS: BEFORE, DURING, AND AFTER RENOVATIONS OF A HOSPITAL WING

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by

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INVESTIGATION OF PATIENT PERCEPTION OF HOSPITAL NOISE AND SOUND LEVEL MEASUREMENTS: BEFORE, DURING, AND AFTER RENOVATIONS OF A HOSPITAL WING

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Acoustic conditions in hospitals have been shown to influence a patient's physical and psychological health. Noise levels in an Omaha, Nebraska, hospital were measured and compared between various times: before, during, and after renovations of a hospital wing. The renovations included cosmetic changes and the installation of new in-room patient audio-visual systems. Sound pressure levels were logged every 10-seconds over a four-day period in three different locations: at the nurses' station, in the hallway, and in a nearby patient's room. The resulting data were analyzed in terms of the hourly A-weighted equivalent sound pressure levels ($L_{A\text{eq}}$) as well as various exceedence levels (L_n). Additionally, a subjective noise perception patient survey was conducted to record the impressions of patients in the ward regarding noise. The relationships between a patient's gender, age and responses to noise were examined. Results show that current noise level guidelines were exceeded regularly; despite this the surveys showed most patients were not very annoyed with the noise. Additionally, no relationships were found between a patient's gender or age to various noise responses. The survey also asked participants to rank the most bothersome noise sources in the hospital environment and showed that the number of people annoyed by TV noise doubled from the during

renovation to after renovation time periods. Overall this study did not find very large changes in sound levels or overall patient noise perception between the various time periods.

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LIST OF SYMBOLS

AHU = Air Handling Unit

AM = Ante Meridiem

ANOVA = Analysis of Variance

ASHRAE = American Society of Heating Refrigeration and Air-Conditioning Engineers

CCU = Critical Care Unit

CITI = Collaborative Institutional Training Initiative

CT5 = Clarkson Tower 5

CT6 = Clarkson Tower 6

cm = centimeter

dB = decibel

dBA = A-weighted decibel

df = degrees of freedom

ECG = Electrocardiogram

ECMO = Extracorporeal Membrane Oxygenation

EPA = Environmental Protection Agency

HIPAA = Health Insurance Portability and Accountability Act

HRV = Heart Rate Variability

HVAC = Heating, Ventilation, and Air Conditioning

Hz = Hertz, the unit of sound wave frequency

ICU = Intensive Care Unit

IRB = Institutional Review Board

kHz = kilohertz

L_{10} = level of sound exceeded 10% of the recorded time interval

L_{90} = level of sound exceeded 90% of the recorded time interval

L_{Aeq} = A-weighted equivalent continuous noise level, the constant level with the same sound energy as the time-varying sound for the given specified time interval of T

L_{AFmax} = the maximum noise level occurring during the measurement period, where F indicates the meter speed of fast

L_{AFmin} = the minimum noise level occurring during the measurement period, where F indicates the meter speed of fast

L_{Cpeak} = the C-weighted peak, C-weighted maximum level in a given specified time period

L_{dn} = the equivalent A-weighted sound level during a 24-hour time period with a 10 decibel weighting applied to the equivalent sound level during the nighttime hours of 10 p.m. to 7 a.m.

L_{eq} = equivalent steady sound level, the equivalent continuous sound level that contains the same total sound energy as the actual time-varying sound within a given specified time period

$L_{eq(24)}$ = an L_{eq} value taken over 24 hours

L_n = percentage of time the level is exceeded for n% of the given measurement time interval, T (Examples: see L_{10} or L_{90})

MICU = Medical Intensive Care Unit

mm = millimeter

NE = Nebraska

NICU = Neonatal Intensive Care Unit

NMC = Nebraska Medical Center

PM = Post Meridian

re = reference

REM = Rapid Eye Movement

s = second

SLM = Sound Level Meter

SPSS = Statistical Package for the Social Sciences

TV = Television

UHC = University Health-System Consortium

US = United States

USA = United States of America

UT5 = University Tower 5

UT6W = University Tower 6 West

WHO = World Health Organization

μPa = micro Pascal

χ^2 = Chi-square

CHAPTER 1: INTRODUCTION

The goal of this project was to determine if prescheduled changes to University Tower 6 West at Nebraska Medical Center influenced the patient perception of the hospital environment such as their annoyance, speech intelligibility, speech privacy, and their thoughts about noise sources. Three time periods existed: before, during, and after the changes. Sound level meter measurements were recorded during each of the time periods. Survey results were gathered for the during renovation and after renovation periods.

Hospitals want to give the best care possible. Numerous studies show noise impedes hospitals from giving the best care possible. The proven negative effects of noise are both physical and psychological. One way to assess a health care facility's quality and patient satisfaction is using the Press Ganey Inpatient Survey. To date, Press Ganey works with more than 10,000 health care facilities of which more than 40% are United States inpatient hospitals (Press Ganey Associates 2009). Eleven million surveys are processed yearly showing it draws upon a large survey population to make its assessments.

The point of the Press Ganey Inpatient Survey is to obtain feedback from patients so hospitals may improve their services. It has thirty-eight standard questions organized into ten sections: admission, room, meals, nurses, tests and treatments, visitors and family, physician, discharge, personal issues, and overall assessments. The survey responses are converted into a series of 100 point maximum scales in order to accommodate easy comparison between hospitals and to see a hospital's individual improvement. Items rated "very good" by patients receive 100 points, "good" 75 points, "fair" 50 points, "poor" 25 points, and "very poor" no points. The scores are done within each individual section listed above and the overall satisfaction score is taken to be the average of each individual section's score.

According to Press Ganey Associates data, overall patient satisfaction at the Nebraska Medical Center (NMC) has been increasing since January 2004 (2009). The control scores are based upon patient perceptions taken in surveys. For the September 2009 to March 2010 time period, the average pain control score for the Nebraska Medical Center was 86.6 with an average noise level control in and around the room score of 66.1. For the dates of January 2010 through March 2010, the Press Ganey whole database showed an average pain control score of 86.1 and an average noise level control in and around the room score of 76.0. A higher score indicates the hospital is doing a better job than a lower scored hospital. Consequently, the Nebraska Medical Center provides slightly higher pain control, although it has noisier rooms than the national average.

Additionally, the University Health-System Consortium (UHC), an alliance of 107 academic medical centers and 232 of their affiliated hospitals, which covers almost 90% of the United States non-profit academic medical centers, has their own scores (Press Ganey Associates 2009). During the same time period, the UHC peer group obtained a score of 85.8 for pain control and 75.6 for noise. The Nebraska Medical Center has a higher score for pain control indicating it controls pain the best when compared to the Press Ganey whole database and the UHC. However, the Nebraska Medical Center has a lower noise score when compared to the Press Ganey and UHC noise score. This shows that reducing noise levels is an area for improvement. Hence, the hospital has a desire to conduct the current study.

Many studies have shown that noise levels in hospitals are high. Busch-Vishniac et al. (2005) remarked that noise levels in hospitals have been increasing steadily since 1960. In earlier studies a mean noise level in hospitals of around 55 dBA with peaks reaching almost 80 dBA were found (Falk and Woods 1973, Bentley et al. 1977). Busch-Vishniac et al. (2005) stated that for hospitals the A-weighted equivalent sound levels (L_{eq}) has increased from 57 dBA in 1960 to 72 dBA in 2005 for the daytime hours and 42 dBA in 1960 to 60 dBA in 2005 for nighttime hours. These sound level values were taken from a variety of wards including intensive care units, operating rooms, and general wards. Intensive care units and operating rooms will have a higher noise level than general wards. However, what is most important about this study is it shows the general trend that hospital noise is increasing.

In the study presented in this thesis, the sound level meter measurements were taken before, during, and after renovations at three locations: nurses' station, patient room, and hallway. The expectation is to show how each of these location's noise levels were reduced by the changes made during the renovation. Surveys were distributed to measure patients' perceptions of noise annoyance and noise sources. A goal of the study is to connect the patient surveys and sound measurements recorded between the various time periods.

First a review of literature highlighting previous studies will be examined. Chapter 2 will explore the current guidelines hospitals follow when providing care. Next the variety of noise sources is reviewed. Many studies have followed the progression of noise level increase and these will be reviewed. Finally, three main categories of possible noise intervention and control are physical/architectural interventions, behavioral modifications for staff, and actions for patients as outlined in Chapter 2.

The administration of the Nebraska Medical Center commissioned a preliminary study to measure sound levels in various hospital wings with different material treatments. The results from that benchmarking study are presented in Chapter 3. Based on those results, a more extensive renovation of one of the NMC hospital wings, University Tower 6 West was undertaken. The renovations included cosmetic changes such as painting the rooms, installing decorative features, and installing new in-room patient audio-visual systems. Sound level measurements and patient perception of hospital noise in this wing prior, during, and after the renovation are the focus of this study.

In Chapter 4 the research methodology is discussed in more detail. Sound level measurements were taken before, during, and after renovations. A patient survey was utilized during and after renovations. Results are presented in Chapter 5. A conclusion of the study is presented in Chapter 6.

CHAPTER 2: REVIEW OF LITERATURE

Many studies have been undertaken to explore the various aspects of noise and healthcare. Below is a review of some selected studies to give an overview of perspectives involved in healthcare decisions and acoustical design of healthcare spaces. All these considerations need to be incorporated to provide the best care in these distinct spaces.

2.1 GUIDELINES

Current guidelines do not adequately reflect real world hospital environments. Despite the best efforts of organizations such as the World Health Organization and the United States Environmental Protection Agency, more needs to be done to address these current noise standards. As mentioned earlier, overall noise levels have continued to increase since 1960 for both daytime and nighttime values (Busch-Vishniac et al. 2005), and these are much higher than what is currently suggested in the assorted guidelines. Table 2.1 summarizes the current guidelines relating to noise in hospitals; these are discussed in greater detail below.

The World Health Organization (WHO) is an international organization that strives to improve healthcare and address healthcare concerns all over the world. The "Guidelines for Community Noise" (1999) discusses how for most hospital spaces the negative effects from noise are annoyance, sleep disturbance, and communication interference. In hospital wardrooms, the guidelines indoors are 30 dBA L_{Aeq} at night. The WHO guidelines stated that the $\mathrm{L_{AFmax}}$ of night sound events should not exceed 40 dBA indoors. A daytime value of 35 dBA L_{Aeq} for indoors is recommended for a wardroom. However, the WHO guidelines states that for patient treatment rooms the guidelines should be to keep the noise as low as possible. This would imply trying to keep it lower than 30 dBA. The WHO guidelines mention that patients have less ability to deal with the stress; therefore, the equivalent sound pressure level should not exceed 35 dBA L_{Aeq} in the rooms where patients are treated or observed. The guidelines continue that special attention needs to be given to the sound pressure levels in intensive care units and operating rooms.

The United States Environmental Protection Agency (EPA) works on enforcing regulations that protect human health and the natural environment that humanity relies on to sustain life such as air, water, and land. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety" (1974) gives its recommendations in L_{dn}. The day-night sound level (L_{dn}) is the equivalent A-weighted sound level during a 24-hour time period with a 10 decibel weighting applied to the equivalent sound level during the nighttime hours of 10 PM to 7 AM. These guidelines state that the sound levels indoors should not exceed 45 dBA during the day and 35 dBA during the night (for a maximum 24-hour L_{dn} of 45 dBA). The concerns listed in the document are noise negatively impacting sleep and adequate rest for the patient. The document also lists an L_{dn} of 55 dBA for outdoor areas surrounding the hospital space. This would ensure an adequate indoor level and would protect those patients who spent some time outdoors in perhaps a patient garden area. It continues with recommending an $L_{eq(24)}$ of 70 dBA to prevent hearing loss.

Additionally, an important note for both guidelines is that these are for occupied spaces, although this is not explicitly stated in either guideline. Both guidelines detail that measurements should be made using normal noise circumstances to include all possible sources. For a hospital space this would include ward noises, daily patient care, talking, and TV watching activities within a patient room.

The WHO guidelines are the values most frequently cited in other research literature; therefore, these guidelines will be the comparison guideline for this study.

2.2 NOISE IMPACT ON PATIENTS

Being in a healthcare unit is a stressful experience for patients. During their time in the hospital patients need to get enough sleep and rest. In a health care setting, patients can go into a sensory overload from all the various stimuli, nor is it stimuli with which they are familiar (Akansel and Kaymakci 2008). Both psychosocial and physiological effects of noise on patients are normally overlooked problems in the hospital environment, and most think of it as part of the hospitalization experience (Christensen 2002).

Many studies have revealed that hospital noise is a potential stressor for patients. High sound levels in health care facilities are known to: impair sleep, increase stress, delay post-illness rehabilitation, aggravate agitation, cause psychiatric symptoms, escalate restlessness, proliferate sleep disturbances, increase respiratory rates, increase heart rates, change blood pressure levels, instigate fatigue, produce headaches, cause hearing loss, increase plasma cortisol and hormone levels, increase blood cholesterol levels, cause cardiovascular response changes, instigate hypertension, cause acoustic neuromas, and cause vasoconstriction (Falk and Woods 1973, Topf 1983 and 1992a, Simpson et al. 1996, Topf et al. 1996, Wysocki 1996, Ragneskog et al. 1998, Dyson 1999, Holmberg and Coon 1999, Maschke et al. 2000, Topf 2000).

The following sections will outline in more detail the negative physical effects of noise on the cardiovascular system, other physical symptoms, wound healing rate, length of hospital stay, quality of sleep, and amount of medication. Next the psychological aspects of how noise can impact patients will be explored such as stressors, noise sensitivity, ability to control the noise source, and having a social support system.

2.2.1 Physical Effects

Physical maladies that patients suffer from in the hospital are varied. However, all patients require care to decrease their symptoms and keep their medical condition from worsening. The physical effects of noise have been well documented in many studies as outlined below. A noisy environment can cause a myriad of other physical problems regardless of the patient's original diagnosis.

2.2.1.A Cardiovascular

Various studies have found long-term effects of noise exposure on cardiovascular function, such as hypertension or heart rate increases when people were exposed to audio-taped critical care unit (CCU) noise such as an abrupt noise or staff conversation (Snyder-Helpern 1985, Topf 1988). This noise was a physiological stress the subject received while sleeping. Noise levels greater than 70 dBA raised the cardiovascular rates of the patients (Falk and Woods 1974).

Hagerman et al. (2005) had the goal of testing the effects of placing patients with coronary artery disease in a good acoustics environment versus a bad acoustics environment. One intensive coronary heart unit at Huddinge University Hospital was used for both environmental conditions. The study was done by creating two separate periods of good and bad acoustics in the same unit by changing the ceiling tiles from bad acoustical (sound reflecting) to good acoustical (sound absorbing) tiles. Each assessment period lasted four weeks. The tiles were changed in both patient rooms and common work area. The first change involved changing the original tiles to sound reflecting plaster ceiling tiles. Then these tiles were removed and replaced with sound absorbing tiles with an identical appearance to the reflecting tiles. Sound level meter measurements were taken only during the weekdays because of a change of staff on the weekends and other condition changes. Sound level meter measurements were taken for the good and bad acoustical periods but not for the original ceiling tile.

The test subjects were 94 coronary artery disease patients with chest pain admitted to an intensive coronary heart unit. Patients were removed from the environment for various lab tests. The patient's heart rate, heart rate variability (HRV), and blood pressure including pulse amplitude were monitored. Heart rate variability (HRV) is the influence of the autonomic nervous system at the sinus node resulting in beat to beat variation of the heart rate, and decreases in HRV can predict complications leading to death in patients with heart disease. Additionally, follow-ups were made at 1 and 3 month periods after their initial visit to see if they had been rehospitalized or died. Patients were asked to fill out a questionnaire at the end of their experience about the quality of care.

One important note is the high turnover rate in the unit; normally 6 or 7 patients were admitted to the unit each day with 17 hours of observation time. All patients were monitored with computerized electrocardiogram (ECG) and hemodynamics with a variety of alarms.

Hagerman et al. discovered that changing the acoustic tiles did make an impact (2005). The survey results were consistent with the proposed hypothesis. No differences in heart rates (HRV) were found between the two groups. A significant difference in pulse amplitude between the two groups existed though. Pulse amplitude is the difference between the systolic and diastolic blood pressure. During the good acoustics period at night, patients had lower "pulse amplitude in the acute myocardial infarction and unstable angina pectoris groups," (Hagerman et al. 2005). The bad acoustics environment may have extremely negative physiological effects on rehabilitation during an acute illness episode.

2.2.1.B Other Physical Symptoms

Other health concerns are headaches, hearing loss, and physical changes. Noise-induced stress seemed to instigate headaches (Topf 1988). Hearing loss was found to occur when peak values exceeding 100 dBA from orthopedic surgery instruments caused inner ear damage and long-term problematic tinnitus (Nott and West 2003). Additionally, hearing loss occurred when a normal individual experienced sudden intense noise and prolonged exposure to noise levels over 85-90 dB (Selfe 1982). The body may undergo some physical changes when startled including increased adrenaline, pupil dilation, and secretion (Falk and Woods 1973, McCarthy et al. 1991).

2.2.1.C Wound Healing

Higher noise levels appear to cause slower rates of wound healing. However, most of the wound healing work has been conducted on rats or mice, while human studies are limited.

In Toivanen et al.'s 1960 study, the effects of psychic stress on rats was examined to see how changing hormone levels from stress impacted wound healing. One-hundred and twenty-four male and female 5-month old albino rats were the test subjects. The stressors were flashes of light at repeated set intervals, along with the ringing of a bell, and a continuous steady not very loud noise made by the scraping of various metal wheels. The wounds were small incisions (900 mm^2 for males and 750 mm^2 for females) made on the back of each rat in the same location after administering anesthetic to expose the fascia of the dorsal muscles. Different combinations of hormones were given starting seven days before wound infliction and continued until the end of the study. The healing criterion was the size of the healed wound area that was taken once a week and the occurrence of the complete closing of the wound. Additionally, the weights, before and after, and gender were recorded for each subject.

Female rats' wounds healed quicker than the male rats with an average difference of approximately four days under control group conditions (Toivanen et al. 1960). Those male subjects who experienced the psychic stress had a slower healing time of eight days longer than control group rats while the female rats wound healing did not experience retardation.

This study showed a difference in results for each gender (Toivanen et al. 1960). In a similar study Cohen (1979) researched the effects of stressors such as cold, heat, and noise on wound activity and the rate of healing in 119 mice. The goal of the study was to compare the effects of different stressors on wound healing. Each of the mice was randomly assigned to one of seven groups: control, cold-before, cold-during, heat-before, heat-during, noise-before, and noise-during. Some of the subjects were exposed to noise before the wounding, while others were exposed during the wounding to noise or their respective variable. The wounds were made in the same location as the Toivanen et al. (1960) study and were measured once daily.

Cohen found no differences in gender in their study of rats but did find differences between the control group and test group (1979). Those exposed to noise prior to being wounded had a longer healing time than those exposed to noise as they were being wounded.

McCarthy et al. (1991) made a link connecting the normal processes of wound healing, endocrine aspects of the stress response, and the effects of stress hormones on the biological function of leukocytes involved in cell metabolism and tissue repair (wound healing). Noise exposure increases the levels of adrenaline and cortisol and induces the neuroendocrine changes typical of the stress response impacting the endocrine response for cell metabolism and tissue repair. Noise stress consequently affects the function of leukocytes involved in the cellular processes of wound healing. Noise causes sleep deprivation limiting the secretion of the growth hormone; in humans 70% of growth hormone is secreted during deep sleep periods, and secretion cannot occur if deep sleep does not occur. Stress also impacts insulin and people with a deficit in insulin have impaired protein synthesis such as wound healing and resistance to infection.

Other research shows that noise exposure can negatively modify the wound healing and weight in animals (Wysocki 1996). A study performed on rats using 40 male and female rats all given a 2.5 by 2.5 cm incision on their backs under anesthesia found that a group exposed to noise had slower wound healing and lower weight than the control group, even though food intake did not differ between the two groups.

The study wanted to resolve if intermittent noise exposure impedes wound healing. The treatment group was exposed to recorded 2-16 kHz white noise recorded from a random white noise generator. This noise sounds similar to television static and has no discernible qualities. Over a period of 19.5 days, the noise was played at intermittent intervals to decrease the likelihood of habituation for 15 minutes every hour. The noise levels used in the study were similar to those noise levels encountered in the hospital setting from ventilator alarms, bed movement, and equipment. The researchers believe that intermittent noise exposure is a closer representation of noise in an actual hospital environment than continuous noise exposure.

The Wysocki (1996) study did agree with the findings of the Cohen (1979) study. Gender did not have an impact on the results. Wysocki did note that there were no differences in the food intake between the control and treatment groups, indicating that the noise level utilized was not a severe enough stressor to impact the intake of food; nevertheless, the noise level was adequate enough to influence the healing and weight in the treatment group (1996).

2.2.1.D Length of Hospital Stay

In a few studies, the length of hospital stay was found to be impacted by noise exposure. Fife and Rappaport (1976) wanted to observe the physiological effect of construction noise on patients because very few clinical studies doing so existed. Noise sources were pile drivers, dump trucks, and tractors running outside the patients' room windows. The researchers found that construction noise altered the length of stay for those occupying the cataract surgery ward at three different time periods: one year prior to construction, one during construction, and one year after construction was completed.

Chosen subjects were those patients undergoing simple cataract surgery who would most likely not have any complications from preexisting conditions. The hospital stay was significantly longer for patients occupying the ward during the construction noise. Furthermore, in the Hagerman et al. (2005) study, the group exposed to worse acoustic conditions had higher rehospitalization rates at three months.

2.2.1.E Sleep

Sleep deprivation has been confirmed to change mood, alertness, and task performance; increase daytime fatigue; harmfully impact respiratory muscle function; and reduce ventilator control which delays removal of mechanical ventilation (White et al. 1983, Myles 1985, Bonnet 1989a, Bonnet 1989b, Chen and Tang 1989). Psychological factors as well as noise exposure influence sleep disturbance (Hatfield et al. 2002). Furthermore, studies on rats have found a link between excessive noise environments and distorted sleep wakefulness cycles (Wysocki 1996, Rabat et al. 2004).

In a hospital environment 10-50% of patient arousals from sleep are from the noisy ICU environment (Stanchina et al. 2005). The remaining arousals are from patient care activities, existing medical conditions already present, mechanical ventilation, or unidentified origin. Older people are particularly susceptible to sleep troubles due to extreme or troublesome noise (Williams 1989). Walder et al. (2000) conveyed that older patients woke up numerous times during their ICU stay because of noise.

Richardson et al. (2007) found the most critical care patients rate their health care facility sleep as less than average. Some dissent exists in the literature about whether peak noise or the change in noise level from baseline is more important in inducing sleep disruption. Some studies concluded that sleep disruption is produced by high-peak noise as reviewed by Stanchina et al. (2005). This idea was further explored and reinforced in another Richardson et al. (2009) study. Sleep for patients was promoted by reducing the peak noise levels in that investigation.

The Stanchina et al. (2005) study hoped to clarify the disagreements found in previous studies by looking at whether peak noise or the change in noise level from baseline was more important in inducing sleep disruption. They hypothesized that adding white noise to the environment would reduce arousals by reducing the magnitude of the changing noise levels. Their conclusion was that the peak noise was not the main factor in determining ICU noise sleep disruption, since adding white noise considerably reduced sleep arousals in normal individuals.

Therefore, despite the peak noise level, in the Stanchina et al. (2005) study, arousal from sleep was less likely to happen when the sound level changed less than 17.5 dB from baseline to peak. Earlier research by Roth et al. (1972) supports this conclusion, indicating that both the nature and frequency of sound peaks are important for sleep arousal.

2.2.1.F Medication

Greater noise-induced subjective stress has been connected with greater pain and more medication (Minckley 1968, Simpson et al. 1996, Hagerman et al. 2005). Minckley conducted a study to test the hypothesis that postoperative patients already in pain from surgery would have an increase in their discomfort as the noise in the space increased (1968). The patients had no control over this noise. It was hypothesized that pain medication dosages would be higher during the high noise time period than the low noise time period. Observations were made at half hour intervals during five random work days from 8:30 AM to 6:30 PM, of the sound levels, the source and character of the noise, the number of patients and staff present, and the amount of pain medication given.

Minckley's hypothesis that pain perception was enhanced by noise was supported by a chi-square analysis in the study. Of those patients requiring medication in a surgical recovery ward, 32% of those patients asked for analgesia when sound levels were above 60 dB compared an expected value of 17% of patients wanting the medication. Minckley further noted that patients are influenced by the sounds around them; an example is when someone else vomits, another patient can feel sick. Yet, some believe that noise can mask or distract a patient from the pain as well (Hilton 1987).

2.2.2 Psychological

Extensive research has been done that shows noise can cause physical problems; however, psychological problems stemming from the noisy hospital environment occur as well. The hospital and healthcare environment for most patients is unfamiliar, hectic, and associated with physical discomfort or unknown medical diagnosis. This stressful setting can take a toll on someone's state of mind. The following pages will discuss the psychological implications of the healthcare environment.

2.2.2.A Stressors

The Topf (2000) study showed that sociopolitical values, motivation for control over the problems, and technological advances all factored into the approach for reducing environmental pollution and supporting these changes over the long term. Characteristics unique to each individual are emphasized such as intrinsic sensitivity to specific pollutions, gender, stage of life, personality, limited capacities, stress, culture, personal preferences, personality predispositions, and perception of their social support system.

This study found that restricted capacity such as being ill, disabled or any other personal obstruction in reaching goals in a person's environment is a personal stressor. A specific stressor's ability to cause stress is influenced by its predictability, degree of intensity, duration, and controllability (Veitch and Arkkelin 1995). Additionally, anticipation of a stressful event can exacerbate and possibly cause the stress effect; sometimes the anticipation period was more stressful than the exposure to the stressor itself (Spacapan and Cohen 1983).

Tables 2.2-2.4 show the intervention categories discussed by Topf (2000). Table 2.2 describes changes that need to occur to the physical environment and equipment in everyday use at the hospital. Some of these elements involve decisions that need to be made in the design phase of a project or when making a product purchase. Table 2.3 outlines actions that need to be taken to retrofit an existing installation and involves behavior modifications as well. Table 2.4 lists patient aspects of noise reduction and actions each individual patient can take to help ensure a quiet environment. Topf concluded that nurses needed to acquire an environmental activist role using an interdisciplinary plan to implement noise abatement interventions (2000).

Furthermore, in another study by Hweidi, the principal physical and psychological stressors as perceived by Jordanian patients in a critical care unit were identified along with examining the impact of patients' characteristics on their perception of stress (2007). Data was collected from 165 patients, 2-3 days after being discharged from the ICU. An Environmental Stressor scale was used and the survey and corresponding results were translated from Arabic to English. A survey of patients in Jordan indicated that such things as age, income, education, and other factors impact the perception of stress in the ICU environment (Hweidi 2007).

Findings indicate that physical stressors are more of a concern than psychological stressors, while pain assessment and treatment of pain are of key importance. Hweidi recommends that critical care nurses empower patients and help them regain their autonomy (2007). Marriage status and income level were significantly statistically linked with how subjects perceived stress, although gender had no effect. Age and income also showed a correlation with stress perception; those who were older and with less income showed more stress.

Hweidi found the top five stressors overall for patients were: having tubes in their nose or mouth, being in pain, not being able to sleep, hearing buzzers and alarms from the machinery, being thirsty, and not being in control of their environment (2007). Those aspects concerning only noise are shown in Table 2.5. The top five of the noise stressors were: hearing alarms and buzzers from the machinery (in the top ten for overall stressors listed), hearing unfamiliar and unusual noises (in the top ten for overall stressors listed), being awakened by nurses, hearing your monitor alarm go off, and nurses and doctors talking too loudly. All of these noise stressors are in the top fifteen stressors overall. Therefore, noise is a considerable stressor that needs to be dealt with, even though one may concede that being awakened by nurses perhaps was not just related to noise and that having the nurse use words you cannot understand could involve more than speech intelligibility or speech interference. Some negative aspects with this study, however, are that the length of stay varies per patient in the critical care unit, and a convenience sample was used.

Akansel and Kaymakci (2008) looked at the effects of intensive care unit noise on coronary artery bypass graft surgery patients by measuring the noise levels in specific locations of the ICU to discover the disturbance levels of patients from noise. The investigation surveyed 35 coronary artery bypass graft surgery patients, while ICU noise levels were measured with a Bruel & Kjaer 2144 Model Frequency Analyzer located next to the each patient's bed. Each of the measurements was started at 9 AM the day after surgery and taken at 15-minute intervals during a 24-hour period at the selected bed's location. Measurements were taken Monday through Friday.

Socio-demographic information and self-assessed level of disturbance were obtained with a questionnaire filled out by one of the researchers during a face-to-face interview with the patient the day after the patient's operation. The mean patient age was 61 years old with males 82.9% (n = 29) and females 17.1% (n = 6). Also 28.6% (n =10) of the patients worked in noisy places for at least five years; 31.4% (n = 11) of patients had never been in the ICU before, 48.6% (n = 17) indicated having only one ICU experience, while 20% (n = 7) had two or more ICU experiences; and 65.7% (n = 23) of patients had least one operation previously.

Akansel and Kaymakci (2008) showed that patients with no ICU experience suffered more from the noise than those who were in the ICU two or more times. Previous experience in the ICU reduces the disturbance level from noise, perhaps because the prior experience helped teach patients how to cope with the noises they encountered during their stay.

Another conclusion by Akansel and Kaymakci (2008) was that the patients located in the bed closest to the nurses' station were most impacted by the ICU noise than the other patients. Those in the first bed were more bothered than those in the third or fifth bed despite the fact that the mean noise level measured at each bed location did not differ statistically at 64 dBA. Those who were closest to the nurses' station focused on noise creating activities carried out by the staff and conversations amongst the staff. This noise situation troubled a majority of patients regardless of the noise measurement levels.

2.2.2.B Noise Sensitivity

Weinstein hypothesized that certain patients were noise sensitive while others were noise-insensitive or less noise-sensitive (1978). This idea is supported by Hurst (1966) and Monjan and Collector (1977) who discuss the issue of slow adaptation to noise by some people. Postoperative patients, CCU nurses, and laboratory subjects who indicate that they have more sensitivity to noise showed significantly greater scores for noise-induced subjective stress from hospitals (Topf 1985a, 1985b, 1989, 1992b).

People may become conditioned to a noise and develop a lack of sensitivity over a period of time to a particular noise; however, overall these individuals may still be noise sensitive to new noises they are not conditioned to (Biley 1994). Furthermore, individuals may be unaware of a noise they are producing because of adaptation; they simply do not notice it after becoming used to it. Adaptation explains the tolerance some people have to the high levels of noise found in surgical wards and other units.

Topf (1985b) reported patients with intrinsic sensitivity to noise may display annoyance at several levels of objective noise while those with lower intrinsic sensitivity could possibly articulate annoyance only at high levels. Yet, Topf (1984) demonstrated no correlation between the concrete measured noise level and the sensitivity of patients to noise.

2.2.2.C Control

One's perception of control over the noise is a very important factor in noise-related impairments (Cohen et al. 1981, Job 1996). It is part of the patient's psychological experience at the hospital.

Hatfield et al. (2002) examined the perception that people have of environmental noise as being uncontrollable and the effects of such noise exposure. The research team used observational data to support the claim that "learned helplessness" does in fact contribute to the effect of noise exposure. To carry out the research the team used a socioacoustic survey to correlate the relationship between perceived control over aircraft noise and the effects of that noise. One thousand and fifteen residents living outside the Sydney Airport in Australia participated. A letter was sent to the targeted area homes, and a researcher went to each to the homes in the area to collect the data in person using a structured interview to fill out the socioacoustic questionnaire.

The Hatfield et al. (2002) study discussed "learned helplessness" as "the syndrome of deficits typically produced by exposure to uncontrollable events." This syndrome may come about in the hospital setting from the negative impact of noise exposure on health and performance.

The study states that four main psychological areas that are influenced by noise are: cognitive and motivational impairment (meaning in people and animals, exposure to uncontrollable outcomes impairs performance on subsequent controllable tasks), learned helplessness, mood effects, and physiological effects. Some people could perceive environmental noise to be uncontrollable, and many of the effects of noise exposure seem to parallel "learned helplessness" insufficiencies. The effects were more controlled by perceived control than by noise level. The study's results give some support for the assertion that some of the outcomes of noise exposure come from learned helplessness.

In lab animals, exposure to uncontrollable incidences decreased resistance to illnesses including cancer (Vinsintainer et al. 1982, Seligman and Vinsintainer, 1985). Most likely this occurs from negative effects of stress on immunity (Laudensager et al. 1983, Sklar and Anisman 1979), and plasma cholesterol level increases (Brennan et al. 1992). In one study residents on a floor in a nursing home who were given control of their surroundings outlived residents of another floor who did not receive control (Langer and Rodin 1976). The perception that noise is uncontrollable could cause an assortment of toxic consequences; one's perception of control appears to be a stronger predictor of several products of noise exposure than the noise exposure itself (Hatfield et al. 2002).

2.3 NOISE IMPACT ON STAFF

Healthcare workers experience much of the same noise exposure as patients. Therefore, they are at risk for many of the same health concerns as discussed in the above sections. Most previous research in this area is concerned with a staff or nurse's ability to perform their job; however, their individual health is also a matter for concern.

Noise-induced stress was positively connected to burnout especially for those working an eight-hour evening shift in a study of 100 critical care nurses using the Jones's Staff Burnout Scale for Health Professionals and the emotional exhaustion subscale of Maslach's Burnout Inventory (Topf and Dillon 1988). All the nurses volunteered for the study whose goal was to see the effect of noise on the nursing staff. An additional study that used a survey of 100 critical care nurses significantly linked a greater subjective disturbance from hospital noise to nurses having less commitment to work (Topf 1989).

The goal of West et al.'s (2004) research was to see how to overcome barriers to giving the best patient-focused care. The investigation explored the possible barriers to nurses giving the best quality care when nurses do not have the necessary resources. Nurses were asked to fill out a questionnaire to elicit their feedback; 2880 were returned out of 6160 distributed resulting with a response rate of 47%. Sixty-four percent of the nurses responding indicated that they felt overworked and did not have adequate time to execute vital nursing responsibilities which included tackling patients' fears, concerns, and anxieties, and dispensing information to patients and their respective families. Nurses also divulged that they did not have enough space, staff, or equipment, and a lack of cleanliness was present. They additionally felt no control over noise or temperature in their wards (West et al. 2004).

Additionally, another study by Blomkvist et al. (2005) looked at the influence of various acoustic conditions in the work environment and on the staff in the coronary critical care unit (CCU). A baseline period and two four-week periods with sound reflecting and sound absorbing tiles were examined. When the sound reflective tiles were in place, 31 patients, of whom 12 were women, occupied the space. When sound absorbing tiles were in place, 44 patients, of whom 13 were women, occupied the space. The patients had comparable patient diagnoses and severity between periods.

Blomkvist et al. (2005) distributed a survey to get feedback from nursing staff at the beginning and end of their respective shifts. The questions described: "pace of work (high or low), quantity of work (great or small), decision latitude (high or low), own competence (high or low), own hard decisions (seldom or often), self-determination (a lot or a little), information/education (a lot or a little), atmosphere at work (calm or unsettling), quality of care (easy to prioritize or hard to prioritize), and social support at work (good or poor)," (Blomkvist et al. 2005).

The participating staff consisted of 36 regular nurses, 21 daytime (morning or afternoon shift), 15 nighttime, with ages ranging from 24-53 years with a median age of 35 years (Blomkvist et al. 2005). No temporary staff participated in the questionnaire.

Blomkvist et al. (2005) found that a subject's perception of control in the environment was connected to their interpretation of a sound as negative or stressful as determined by the individual's psychological impression. When having high demands placed upon them, workers must feel in control of their decision-making, and supported by their superiors and workmates. Otherwise, the worker will have a negative impression of the work environment. When this negative environment continues for a long time, the physiological responses increase along with the risk of illness. Employee assessment of their work environment was influenced by their perception of the organization itself. Blomkvist et al. (2005) concluded that the psychosocial work environment in the healthcare system would get better by improving room acoustics, and those acoustical improvements can drastically make a difference in the work environment.

2.4 SPEECH INTELLIGIBILITY AND PRIVACY

Within an individual room or treatment space, patients need to be able to hear about their diagnosis while having secure sound isolation that restricts others from hearing about their malady. About one fifth of the nurses who responded to a staff questionnaire indicated that they did not have adequate space or well designed space for privacy to convey information to patients and their families, nor did they feel they had enough privacy for performing treatments of patients' symptoms and individual conditions (West et al. 2004).

The U.S. Department of Health and Human Services outlines laws and patients' rights. With the passage of the Health Insurance Portability and Accountability Act (HIPAA) in 1996, speech privacy has gained even greater importance. HIPAA applies to any organization that handles citizens' personal healthcare information (medical records, insurance, etc.).

Ryherd et al. (2008b) demonstrated the need for concern regarding oral communication in healthcare environments because the overall loudness and spectral shape of the background noise can make deciphering speech difficult. For unmistakable communication, the normal speech level for communication between two people should be about 50-55 dBA with a signal to noise ratio of 15 dB (Ryherd et al. 2008b). High background noise levels could mean that staff may need to raise their voices in order to be heard. This is important so as to not have medical errors.

Increased medical errors and speech interference are two potentially dangerous effects of hospital noise that has clear implications for patient safety. Indeed, there is a growing body of research on hospital noise and its impact on pharmaceutical name recognition (Berglund et al. 1976, Busch-Vishniac et al. 2005).

2.5 NOISE SOURCES

Noise is a well-documented source of stress in dynamic health care settings. Noise stress is not just the result of a noise being too loud; it involves the frequency, predictability, adaptation or habituation to the noise level (McCarthy 1991). Identifying the source of noise complaints can be subjective, and noises can be enhanced by cumulative sounds in the room. Many noise sources are active in the hospital setting. A sample of noise sources in hospitals includes those provided by daily care, human behavior, HVAC, medical equipment and alarms.

The noises most offensive to patients are high-pitched and loud noises according to a study by Akansel and Kaymakci (2008). An abrupt noise 30 dB over the background level can create a startling and more stressful effect than a high continuous background noise (Biley 1994). Perhaps constant low-pitched noise becomes part of the background noise, creating a soothing effect by masking or filtering other harsher sounds from reaching the patients (Akansel and Kaymakci 2008).

Busch-Vishniac et al. (2005) discusses research conducted at Johns Hopkins Hospital in Baltimore, MD. The results detailed the L_{eq} values as a function of location, frequency, and time of day. One-minute L_{eq} measurements were simultaneously taken at many locations on each of the units at the patient room, nurses' station, and an examination room or empty patient room. Then one-third octave band measurements were taken over a 24-hour period at a minimum of three places in each unit. All the staff, patients, and visitors followed their usual routine.

Overwhelmingly, the results indicated that at all locations and all times of day a problem exists. The researchers measured an average A-weighted L_{eq} of 50-60 dBA with corridors being the noisiest areas, then nurses' stations and occupied patient rooms as the next noisiest (Busch-Vishniac et al. 2005). Empty patient rooms were significantly quieter with significant variations in noise levels as a function of time of day; the other spaces were not as significantly varied depending on the time of day. Busch-Vishniac et al. (2005) measured relatively constant sound levels in areas that mainly influence patients, staff and visitors with higher spectra in the low frequencies less than 63 Hz, flat over 63-2000 Hz octave band, and having a rolling off above 2000 Hz.

Christensen (2007) conducted a small study to measure, analyze, and compare levels of acoustic noise in a nine bed general ICU using a sound level meter with A-weighting over 5 minute intervals throughout three consecutive days. The lowest noise level recorded was 50 dBA at random intervals during the 24-hour period. Christensen (2007) stated the importance of reducing the peak noise levels because patients who were continually exposed to low-level white noise eventually became familiarized to the noise but high pitched and irregular sounds stood out. This finding implies that actions to reduce these high peak levels are most needed since these noises are the most upsetting to patients. Location may also be a key factor for noise level.

Additionally, Christensen (2007) showed a positive relationship between the nursing shifts and the day of the week using parametric testing ANOVA ($p \leq 0.001$). The study utilized Scheffe multiple range testing that showed a significant noise level difference between the morning shift, and both the afternoon and night shift combined ($p \leq 0.05$) (Christensen 2007). The Scheffe test is a post-hoc test to help reduce the risk of type I error, where the null hypothesis is rejected when it is actually true (Pallant 2007). There was no statistical difference between the afternoon and night shift ($p \geq 0.05$) (Christensen 2007). Significant differences were not observed between the individual weekdays but a significant difference did occur between the weekdays and the weekend. The results can be used for strategic planning by confirming that ICU noise levels in the

ICU have decreased in line with universally accepted guidelines on noise control in the hospital regardless of time of day or day of the week (Christensen 2007).

Ryherd et al. (2008a) conducted research focused on the psychological and physiological elements of the sound environment, where dosimeters, stationary measurements, and a questionnaire survey of the staff were used. The three main goals of the project were to investigate the staff's perception of the sound environment, to identify acoustic descriptors for the intensive care unit environment, and to find areas for future research.

The effect of daytime versus nighttime was taken into consideration. Three shifts occur at the hospital: morning, afternoon, and evening. An average value during each shift was then calculated as well. All the measurements were taken over a five-day time period at various staff and patient locations.

The descriptors measured or interpolated in the article are: A-weighted equivalent sound pressure level ($L_{A\mathrm{eq}}$), A-weighted minimum ($\mathrm{L}_{\mathrm{AFmin}}$), A-weighted maximum ($\mathrm{L}_{\mathrm{AFmax}}$), and C-weighted peak ($\mathrm{L}_{\mathrm{Cpeak}}$). The stationary result showed no large differences between the day and night or depending on which day the measurements were taken. The measurements close to the patients resulted in 53-58 dBA for average L_{Aeq}. The dosimeters worn by nursing staff members showed higher levels which the staff perceived as contributing to their stress.

2.5.1 Daily Care

Seemingly innocuous daily care activities can easily produce bothersome noise. Morning is when most patients are having daily care such as baths, getting dressed, bed linen changing, and when most visitors and staff arrive (Dube et al. 2008). A dropped plastic kidney dish produces a noise of about 85 dB when recorded at a distance of 2 m (Hodge and Thompson 1990). Other noises heard include noise from staff footsteps (89 dBA), vacuum cleaners (74 dBA), and telephone rings (68 dBA) (Akansel and Kaymakci 2008). Additionally, other noise sources are flushing toilets (44-76 dBA) and bed making (56-66 dBA) (Hilton 1987). Rolling carts are frequently heard moving through the hallway. Noise measurements for trolley cart sides being lowered have been documented at 85 dBA (Hodge and Thompson 1990). Note: besides the plastic kidney dish listed above, the other references did not indicate the distance at which these measurements were recorded.

Akansel and Kaymakci (2008) showed that the number of staff working in the ICU is directly related to the noise level. The staff levels are the highest in the mornings and during shift changes; therefore, the patients are the most disturbed by the noise levels in the morning and during shift changes. Additionally, ward rounds, equipment replacement activities, patient care activities, and patient transfers took place during the morning hours, contributing further to the noise. The patients did not think noises from treatment and caring activities such as massage, oxygen supplies and respirators were troubling, because these tend to produce a constant rhythmic low-level noise.

2.5.2 Talking/Human Behavior

Talking, socializing, or entertainment devices such as the TV cause distractions or upset in the healthcare environment for some patients. Conversations may be beneficial for the intended conversational partner; however, when overheard by someone else they can contribute to the noise level. Additionally, visitors and in-room entertainment devices can cause distress for those who want or need quiet to recuperate.

Hilton (1985) documented that as the number of nurses around a patient's bed increased, the noise levels increased. Sicker patients need more urgent and consistent nursing and medical care, contributing to more noise production (Kahn et al. 1998). The presence of staff has a significant positive correlation with the measured noise levels; therefore the staff needed to be cognizant of noise producing activities and be concerned with means to reduce them (Akansel and Kaymakci 2008). Akansel and Kaymakci (2008) stated staff conversations were the fourth most disturbing noise source for patients. These conversations and laughter often concerned patients because they assumed they are the subject of these conversations; however, two out of the 35 patients in the study stated that the staff conversations they overheard were interesting and did not cause them concern (Akansel and Kaymakci 2008). In Kahn et al.'s study, more than 50% of noises were attributed to human behavior, such as talking, and watching TV, meaning they are potentially modifiable (1998).

Staff conversations happen at levels that can be heard by the patients, and the patients affirmed these staff conversations to be the most annoying noise (Topf 1985a, Kahn et al. 1998, Russel 1999). The nurses' station is a spot where both personal and professional issues can be conversed by staff (Elliot and Wright 1999, Russel 1999). The measured noise levels by the nurses' station were reported as 50 dBA (Hilton 1985) and 60 dBA (Moore et al. 1998). Conversations among ICU staff measured 74 dBA (Akansel and Kaymakci 2008).

It is difficult to compare the results of all the previous studies as they have different experimental designs. Yet, a consistent finding is that staff behavior could be modified to accommodate to patients' needs for a restful environment.

2.5.3 Heating, Ventilation, & Air-Conditioning (HVAC)

The main functions and concerns of HVAC systems are energy efficiency, condensation control, indoor air quality, noise control, temperature control, air pressure control, humidity control, and thermal comfort. HVAC systems and their corresponding control systems are the primary method of containing contaminants in one area from entering to another (Babineau 2008). Hospitals operated continuously place continuous high work demands on HVAC systems, increasing noise issues from HVAC systems. Low frequency noise is more likely to stem from the mechanical equipment while high frequency energy corresponds more often to the high velocity airflow through the heating ventilation air conditioning (HVAC) systems (Ryherd et al. 2008b).

Babineau (2008) discussed the various HVAC needs for each individual type of space within a hospital setting. Some of those needs are as follows: operating rooms, ICU nurseries, and protective-environment rooms require a positive pressure in regards to the surrounding areas; airborne-infection-isolation environments require a negative pressure compared to surrounding areas; and autopsy, sterilization, and soiled laundry rooms need air vented to the outdoors.

2.5.4 Alarms/Medical Equipment

Another source of noise in hospitals is in-room medical equipment noise. High frequency energy often corresponds to alarms and mobile medical equipment (Ryherd et al. 2008b). One aspect to keep in mind is the close proximity of these devices to the patient throughout their stay making these noise sources a particular concern that needs to be addressed.

Biley (1994) and Akansel and Kaymakci (2008) found that equipment alarms and the bleeping of monitoring equipment are the most commonly described causes of stressful noise to patients. Standards require that medical equipment alarms, such as the mechanical ventilator alarms, have preset volumes that cannot be modified to guarantee patient safety and to audibly alert staff consistently to problems in all areas of the unit (Kahn et al. 1998, Taylor-Ford et al. 2008). However, monitors in the ICU are frequently false alarms (Walder et al. 2000). This could be from the monitor alarms not being set correctly or the staff not quickly reacting to the alarms.

Some common noise levels are telemetry alarm levels at over 70 dB, electrocardiogram (ECG) alarms at 75 dBA, intravenous infusion alarms between 44-80 dBA, measured infusion pump alarms at 61 dBA, and monitor alarms at 68 dBA (Hilton 1987, Hodge and Thompson 1990, Akansel and Kaymakci 2008, Taylor-Ford et al. 2008). Evidence exists, though, that patients develop a tolerance of the noise from noisy mechanical equipment because of their trust in doctors and their understanding that staff need to use the equipment for their own greater good (Topf 1984,1985a, Akansel and Kaymakci 2008).

2.6 NOISE CONTROL STRATEGIES

Controlling the noise in hospitals greatly increases patient's perception of care, and low-noise environments improve staff attitude and sleep. Reducing the impacts of noise should be a priority and could be accomplished in many ways. Consideration of architectural design, facilities and equipment, engineering, and people are extremely important when examining the noise levels in medical facilities (Hilton 1985). In this section, the methods and results from a number of studies aimed at reducing noise impact on patients and staff are reviewed. The methods fall into three broad categories: physical/architectural, staff behavioral modifications, and patient actions.

2.6.1 Physical/Architectural Improvements

Administrative noise controls such as closing doors and asking staff to speak softly as recommended by Biley (1994) and Cmiel et al. (2004) have limited success in deterring noise (Ryherd et al. 2008b). Walder et al. (2000) stated that the noise levels measured approximately 43.2 dBA even with the doors closed and with peaks at 70 dBA, which disturbed 50% of healthy subjects. Ryherd et al. (2008b) believes it is imperative to consider the design of healthcare spaces and their distinctive variety, in terms of architecture, types of equipment, and activities in the particular ward. One suggestion would be to locate staff workstations outside of patient rooms and forming conference areas appropriate for holding group discussions (Kahn et al. 1998).

Another suggestion is utilizing sound absorbing materials in the hospital's physical structure to effectively reduce sound level in the hospital setting (Philbin and Gray 2002, Taylor-Ford et al. 2008). There is evidence that using more acoustically absorptive materials may improve perception of noise in spaces. In the Hagerman et al. (2005) study discussed earlier in Section 2.2.1.A, the two patient rooms where the measurements took place had a drop in equivalent sound pressure level of 5-6 dB between using acoustically absorptive versus reflective ceiling material. In the main work area the L_{eq} only showed a difference of 1dB. The sound absorbing ceiling tile caused the reverberation in both the patient room and work area to decrease to 0.4 s from 0.8 s in the work area and 0.9 s in the patient room. Speech intelligibility improved drastically in both the patient rooms and main work area. The staff stated they felt fewer demands and not as much irritation during the period with good acoustics.

MacLeod et al. (2007) conducted a study at Johns Hopkins involving a hematological cancer unit and the different types of materials present. This study examined if adding new sound absorbing panels with special anti-bacterial fabric, Xorel purchased from Carnegie Fabrics, and 2" thick fiberglass would decrease the noise. Two metrics were used: one objective and one subjective.

The objective measurement MacLeod et al. (2005) took was the sound pressure levels in various rooms as a function of time of day and frequency. Additionally, the A-weighted equivalent sound pressure level was recorded. The reverberation time in the unit was measured using a B&K Pulse system to generate broadband noise amplified and played through a single speaker and two monitoring microphones to observe sound decay from the rapid turn off of the source. This was done for three trials using third octave bands from 400 Hz to 20 kHz. The subjective measure consisted of fourteen patient surveys taken before and eleven patient surveys after adding the absorbing material, with an overlap of eight patients; results indicated that people noticed a change from being very noisy to relatively quiet. The same twelve nurses also participated in the survey before and after the changes with the same response as the patients.

The ward tested had a reflective solid ceiling because of concern that the typical small holes in acoustical ceiling tiles might harbor bacteria. Three of its four corners were outfitted with corner cabinets at 45-degree angles. The hard cabinets created a waveguide with sound traveling down one hall then reflecting into the orthogonal hall at the corner. The unit had two decorative circular ceiling architectural features creating echoes. Both of these channeled sound into the hallways and throughout the unit. Typical walls and floors for hospitals are made for durability and cleanliness with no sound absorbing material. The L_{eq} decreased by 5 dBA from installation of the material and the reverberation time dropped by a factor of 2. Moreover, the researchers discovered the staff cared a great deal about the appearance of the materials on the surfaces, since they removed some of the panels after the study because of appearance.

Babineau (2008) mentioned some design methods and ideas to control noise from the HVAC system. Standard design ideas of centralized equipment plants, low-velocity airflow, and large duct sections help reduce the noise produced from HVAC systems. Other suggested ideas were duct liners which are insulation materials wrapped around the outside of the components. However, concern exists about the porous nature of the material and the absorption of dirt and germs. Another idea was silencers, which are mechanical muffler devices that are located within sections of ducts. Most silencers include an internal filler or baffles; however, one type of silencer, a pack-less silencer, uses honeycomb backing behind perforated metal. This would cut down on concerns about absorption of dirt and germs because it is not a porous material.

2.6.2 Staff Behavioral Modifications

Nurses are in critical positions where they can identify psychological, physical, and social stressors that concern patients during their hospital stay (Akansel and Kaymakci 2008). Educating staff, planned nursing activities, and proper design of intensive care unit can consequently help prevent noise problems. Akansel and Kaymakci (2008) state that improving staff knowledge decreased the noise levels and can help reduce the annoyance from the noise, along with planning noise-creating activities ahead of time to decrease the disturbance level, and informing patients about the character of the hospital environment.

In the Webber (1984) study, a 314 bed tertiary teaching hospital at Presbyterian Hospital in San Francisco set out to introduce a noise control campaign after moving into its new facility and realizing patient questionnaires indicated that noise complaints had risen 20-30 percent. The questionnaire identified two main sources of noise: machine noise and people noise. The goal of the project was to have every employee become committed to participating in the noise reeducation and to reduce the noise. The staff incorporated such changes as dimming the lights at night, reducing the glare from light by using parabolic lenses on light bulbs, using automatic door closers, adding more absorptive materials, and giving patients headsets to use with their TVs. The total cost of the project was $5,000. Returned patient questionnaires were the only feedback. A total percentage of noise complaints were calculated from the returned questionnaires on a monthly basis. These results were then graphed and tracked over a year's time. Overall, the behavior modification program and other changes reported a 6% decrease in noise-related complaints after implementation (Webber 1984).

Kahn et al. (1998) reported sound peaks greater than 80 dBA in the medical intensive care unit (MICU) and tried to explore how to reduce the 80 dBA through a behavior modification program. The study had two phases: identification of noise and behavior modification based upon the identified sources. Kahn et al.'s modifications included setting beepers to vibrate mode, allowing intercoms to be used in emergencies only, turning off the main television, and reducing talking in patient care areas to a minimum (1998). The research team recommended providing in-service training for staff including nurses, ward secretaries, managers, therapists, housekeeping, and consulting services. With these measures, Kahn et al. was able to significantly decrease the 24-hour peak noise level ($p=0.0001$) and the number of sound peaks greater than 80 dBA ($p=0.0001$) (1998). Television and talking accounted for 49% of the sound peaks greater than 80 dBA.

The Kahn et al. (1998) study concluded many noise sources in the hospital setting, particularly those producing peaks greater than 80 dBA, are amenable to behavior modification and effective noise reduction. Kahn et al. noted that setting an official noise control policy would be favorable in addition to designing physical features such as private rooms, built with walls and ceiling panels that minimize noise reflection and intensity along with small bedside televisions or pillow speakers to lower noise levels (1998).

Taylor-Ford et al. (2008) conducted a study to test intervention treatments to decrease the sound levels in an acute care hospital. Both a pre-intervention and post-intervention study with a control group was designed. Patients and staff filled out the Topf Adapted Sound Disturbance Scales, and the environmental sound levels were recorded. The research team implemented interventions that included an educational PowerPoint presentation for employees, minor environmental acoustical alterations, and installing a Quest 261 Sound Detector/Controller.

The study had more than 95% of staff attend the power point presentation. The Quest 261 Sound Detector/Controller alerted staff to when the noise level rose above a certain preset decibel by flashing a lighted “Quiet Please” sign in the nurses’ station for one month. Environmental alterations included repairing or replacing hydraulics and rubber stripping in doorways, adjusting patient furniture to eliminate unwanted noise, fixing alarms on mobile equipment away from patients' heads, decreasing the volume on patient and nursing station telephones and padding a pneumatic tube system. These particular interventions did not yield statistically significant changes in sound levels, but patients and employees reported fewer disturbances after the interventions.

Patients also received earplugs. The study reported that a successful part of the intervention program was the use of earplugs. Both patients and staff reported being satisfied with the earplugs. Employees expressed that they enjoyed being able to offer a solution to the noise problem that was not pharmacological in nature.

However, some difficulties were incurred during the study that indicated immediate and potential future problems. Staff tampered with the detector/controller in the nurses' station on at least four occasions. Additionally, the staff became used to the device, ignoring it after a few weeks. Other studies have had similar episodes of resistance to the reduction programs or changes (Schnelle et al. 1999, Bailey and Timmons 2005). Moreover, these techniques are expensive when employee wages for training and purchasing the devices are considered, as well as the cost for overseeing the whole project.

Dube et al. (2008) conducted sound level measurements and a patient and staff survey both before and after an intervention. The study was conducted at two Mayo Clinic hospitals in a ward with 57 units with a wide range of focus, with the intent of identifying and reducing the noise sources about which patients complained. The researchers looked at the before and after noise levels for noise reduction techniques such as closing the patient door at night, dimming lights at night, limiting overhead paging, lowering speaking voices, turning alarms and ringers on phones down at night, posting quiet signs, and introducing white noise.

The study investigated what time of day and which noises were most bothersome, while describing the noise control interventions, comparing noise levels, and determining noise control methods that could easily be reproduced in other settings. They took dosimeter and sound level meter (SLM) measurements supplemented by subjective patient and staff surveys. A sample of 30 patients participated from each unit with pre-intervention and post-intervention assessments. The sample patients had no self-reported hearing problems, spoke English, were there for at least 12 hours minimum and were alert and orientated as identified by nursing staff. Response rates were 47% and 43% for patients before and after intervention, while the response rates for staff were 53% and 43% respectively. The survey used a 5 point Likert response scale of very quiet to very loud for four times of day: morning (7AM-noon), afternoon (noon-5PM), evening (5PM-10PM), night (10PM-7AM). The respondents picked the time they thought the noise was worst, indicated the types of noises present, and gave comments for noise control suggestions.

Dosimeters recorded the noise levels in 31 units for 24 hours. Four SLMs were placed next to the dosimeter area in order to have a comparison between the two data devices. Staff recorded any unusual circumstances in a journal next to the dosimeter station. The data was then shared with the staff who implemented at least one noise reduction method in their respective units 2-4 weeks after being provided with the pre-intervention data. Post-intervention measurements were taken 6 months after the pre-intervention data. Staff did a web-based survey accessed through their corporate e-mail; patients completed theirs with paper and pen.

Common tasks such as soft voices, closing doors, dimming lights, and limiting overhead paging reduced noise levels and the perception of the noises as being seen as bothersome. Additionally, the sleep enhancement protocols and awareness of environmental noise created a positive impact. Results showed that the noise reduction techniques worked in all shifts except for the night shift. Nighttime was found to be not statistically significant because it was seen as already being quiet by patients and staff. The authors stated that the location of the noise, such as hallway or patient room, may impact the perception of that noise. One interesting thing to note is that the actual noise level readings increased 4 dBA from pre-intervention (32 dBA) to post-intervention measurements (36 dBA); however, the perception of bothersome noise was decreased as reported both by patients and staff (Dube et al. 2008).

Richardson et al. (2009) did a similar study as Dube et al. (2008); however, this investigation focused on the staff's perception of noise only and sound level measurements in three wards within one hospital. The researchers utilized three phases similar to Dube et al. (2008) with a pre-intervention, intervention, and post-intervention. The main focus was on improving the patients' sleep.

The design of the experiment was to change staff's behavior by making them go through awareness and education programs (Richardson et al. 2009). The most significant finding was the reduction in peak noise levels on all three wards ($p = <0.001$) from approximately 96 dBA to 77 dBA. Ward 1 had no change in the overall noise levels while ward 2 and ward 3 had levels that increased. This was a result echoed in the Dube et al. (2008) research that also noted the measured values increased from pre-intervention to post-intervention. Richardson et al. (2009) suggested this could be from the fact that general background noise in such a hospital environment is unavoidable and hard to reduce since patient care and activities will naturally produce some levels of noise. A secondary reason comes from staff's efforts and attempts to reduce the peak high noise levels, with activities that have lower noise levels remaining unchanged.

A key idea was the need to develop a staff education and awareness program. The program was administered during activities such as emptying trash and changing bed linens because of the limitations on nurses' time, plus suggestions could be given as the work was being performed. Only 50% of staff received the training program but changes in noise levels were accomplished. The other two methods used were following up with messages for staff through e-mail and posting sleep promotion posters to be viewed by everyone. The study did not conclusively decide that any one factor had the most impact.

Other behavior modifications that have been suggested to reduce noise are wearing soft-soled shoes, closing doors to spots with disproportionate amounts of noise from either the television or sluice rooms, choosing equipment with quieter alarms in an effort to improve patient results, and creating a better work place for hospital staff (Biley 1994). Biley continues with other suggestions of ensuring telephones or personal bleeps are adjustable in volume, speaking softly and notifying others to do the same, and moving noisy equipment away from the patients or at least the head of the patient (1994).

2.6.3 Patient Actions

Finally, another way to achieve noise reduction is by asking the patient to actively intervene, for example by using earplugs. Some previous studies have shown that using earplugs can decrease the negative effects of noise by improving rapid eye movement (REM) sleep and sleep efficiency; however, they are not regularly used. Scotto et al. (2009) studied the effect of earplugs in the critical care setting by using valid and reliable measures to demonstrate that earplugs improve the subjective experience of sleep in unmedicated patients in the critical care unit. The 100 subjects were non-ventilated, non-sedated adults who were in the critical care. Earplugs were utilized during sleeping hours at night. Subjects completed a subjective survey response to record their impressions. For the intervention group total sleep satisfaction scores were significantly better ($p = .002$). Additionally, the earplugs did not interfere with health care delivery to each individual patient.

Scotto et al. (2009) concluded that most critically ill patients with earplugs reported satisfaction with their sleep compared to the control group without the earplugs. Some potential difficulties mentioned in the study are patients having sensitivity to the earplugs, inserting earplugs improperly, patients feeling uncomfortable when wearing them, the earplugs falling out during sleep, or patients experiencing anxious feelings from not hearing background noise. Chisholm et al. (2004) study rated six different types of earplugs in their study and found the foam kind to be comfortable and the easiest to insert. Having nurses help or trying different earplugs may make them more comfortable for each individual patient (Scotto et al. 2009).

Some benefits of the earplugs are that they are easy to use, low cost to purchase, have low level of invasiveness, and do not require sedative medications making patients more alert to their surroundings and communicative allowing for faster care (Scotto et al. 2009). The earplugs improve sleep effectiveness and satisfaction; therefore, this low cost easy method should be offered to all patients. Other studies have recommended patients should dress in earmuffs and staff should use some kind of hearing protection to alleviate potential hearing loss problems from noisy medical instruments (Lusk and Tyler 1987, Nott and West 2003). Biley encouraged patients to use personal headphones when using personal entertainment devices (1994).

Table 2.1

Organizations and their corresponding standards regarding noise.

Organization	**Abbreviation**	**Guideline**	**Details**
World Health Organization	WHO	Guidelines for Community Noise (1999)	Daytime noise levels should not exceed 35 dBA L_{Aeq} in patient treatment rooms. Nighttime noise levels should not exceed 30 dBA L_{Aeq} in patient treatment rooms. The L_{AFmax} equals no more than 40 dBA re 20 μPa at night when the sound level meter is set on the fast setting.
United States Environmental Protection Agency	EPA	Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety (1974)	Daytime noise levels should not exceed 45 dBA during the day and 35 dBA during the night. Both values are L_{Aeq} values. However, the overall guidelines are based on L_{dn} values.

Table 2.2

Unit redesign recommendations utilizing acoustical improvements in the physical structure and equipment.

Physical Structure	**Equipment**
- A more spacious unit	- Alphanumeric paging system to replace equipment alarms and rings of telephones
- Private patient rooms with insulated walls	- Computers for entry of nurses' notes
- Carpet in areas where there is heavy traffic (i.e. nurses' desk)	- Light plastic covers for charts
-Acoustical ceiling and floor tiles	- Electric (quieter) addressograph machine
- Wide hallway between patient rooms and nurses' station	- Laser (quieter) printer
- Acoustical barrier around nurses' station up to eye level of staff seated at desk	- Quieter vacuum cleaner and other electric cleaning equipment
- Insulated nurses' desk and counter surfaces	- Divert overhead paging system to personal pagers
- Rooms (conference, chart) for activities involving staff conversations	- Headphones for television and radio
- Separate rooms for noisier equipment (computer printer, ice machine)	- Medical carts and chairs with large, plastic wheels and rubber bumpers
- Swinging, latch free doors with windows when possible	- Beds with heavy plastic rails
- Rubber stripping in doorways	- Carts and patient furniture (nightstands) with silicone (quieter) parts for drawers
- Rubber/heavy plastic door latches	- Rubber trash barrels
- Insulated utility room surfaces (e.g. washable rubber counter surface)	- Rubber/heavy plastic eating utensils

Source: Topf (2000)

Table 2.3

After unit redesign noise reduction recommendations.

Physical Structure	**Equipment**
- Turn bellow of ventilators and necessary equipment away from patient heads	- Oil/repair squeaky equipment (e.g. chair wheels)
- Assign patients to available beds furthest from nurses' desk	- Reduce sudden/sharp sounds when taking vital signs
- Limit the number of visitors at the bedside at any one time	- Secure equipment and carts
- Measure sound level for staff to compare to an ideal standard	- Use caution closing doors and drawers
- Lower unit lights to keep noise level down	- Process night admissions in a separate area
- Discontinue radio and television or provide headphones	- Unwrap supplies/prepare treatments away from bedside
- Turn off unused suctioning and oxygen equipment	- Redirect some foot traffic with signs if two entrances are available
- Restrict unnecessary louder bedside communication with signs	- Keep remaining necessary alarm volumes as low as is safely possible
- Organize care so patients have fewer nighttime sounds at one time	- Combine treatments involving equipment
- Isolate patients who emit disturbing verbal sounds: snoring, groaning, loud talking crying	- Reschedule noisier activities (stamping charts) for the daytime
- Close patient and utility room doors	- Wear rubber heeled footwear
	- Close patient and utility room doors

Source: Topf (2000)

Table 2.4

Patients' actions that will help control noise after unit redesign.

<table>
<tr><th><u>Cognitive control</u></th><th><u>Behavioral control</u></th></tr>
<tr><td>- Label sounds for patients
- Give patients a rationale for necessary sounds</td><td rowspan="3">- Teach patients progressive muscle relaxation
- Provide patients with music or synchronized white noise to block out noise
- Give patients earplugs to use
- Teach patients assertive verbal responses to quiet others
- Instruct patients to ask for sleep medication</td></tr>
<tr><td><u>Decisional control</u></td></tr>
<tr><td>- Offer patients choices regarding sound reductions and coping strategies</td></tr>
</table>

Source: Topf (2000)

Table 2.5

Partial listing of Hweidi's ranking of stressors specifically related to noise. The ranking of stressors as perceived by critically ill Jordanian patients are listed according to their mean score.

Rank	**Stressor**
4	Hearing alarms and buzzers from the machinery
7	Unfamiliar and unusual noises
11	Being awakened by nurses
13	Hearing your heart monitor alarm go off
15	Nurse and doctors talking too loudly
20	Hearing other patients cry out
30	Having nurse use words you cannot understand
36	Having nurses constantly doing things around your bed
38	Hearing the telephone ring

Source: Hweidi (2007)

CHAPTER 3: NOISE LEVEL MEASUREMENTS COMPARISON BETWEEN FOUR HOSPITAL WINGS WITH DIFFERENT MATERIAL TREATMENTS

The review of literature in Chapter 2 clearly indicates that noise is a problem in hospitals. Noise can negatively impact both patients and staff. In order to combat noise's negative effects, Nebraska Medical Center decided to undertake a preliminary study to determine the best course of action including potential renovations and material changes. Material changes appear to have made positive impacts in some previous studies reviewed in Section 2.6.1, but the administration at the Nebraska Medical Center were interested in learning how materials used in four different wings at their facility impacted noise levels.

Baseline noise level measurements were made in four wings at the Nebraska Medical Center: Clarkson Tower Level 5, Clarkson Tower Level 6, University Tower 5 West, and the Neonatal Intensive Care Unit (NICU) (Wiese et al. 2009). The goal was to study the relationship between materials present in different hospital wings and the resulting noise levels. The measurement locations at each area were the main nurses' station, hallway by the ward's main entrance, and a typical patient room. An ambient noise level baseline was determined.

Each wing and location within that area has different finished surfaces as outlined in Table 3.1. These surfaces can also be seen in Figures 3.1 to 3.4. In the NICU sound level meter measurements were taken in two patient rooms due to the very different material finishes and due to the one room containing more medical equipment for the individual patient. Three of the wings, labeled as Cases 1 through 3 in Table 3.1, have traditional atmospheres, meaning these wards do not have dim lighting at night and do not have visual noise monitoring alarms that indicate when talkers talk above a specified level. The NICU incorporated more specific environmental controls such as dim lights at night and visual noise alarm monitors when a specified noise level has been exceeded.

Cases 2 through 4 have standard acoustic ceiling tile in the hallway. Cases 1 and 2 have a hard linoleum floor while Cases 3 and 4 have a more absorptive carpet floor for the hallway. The patient rooms in all four cases were of similar room volume and all had hard ceilings. The patient room floors were hard linoleum except for in one of the NICU patient's rooms which had carpet in the most critical patient room.

A centralized nurses' station means that all the nurses are located in one main area of the ward. A distributed nurses' station means that there were a number of smaller workstations. The distributed nurses' station spreads people around, allowing the socializing between nurses to be reduced and decreasing the unnecessary conversations throughout the ward. Additionally, occupancy needs to be mentioned as well. University Tower 5 (UT5) housed double occupancy patient rooms; the other three, Clarkson Tower 5 (CT5) Clarkson Tower 6 (CT6), and both NICU patient rooms were single occupancy.

Larson Davis sound level meters were used to take logging measurements of the A-weighted equivalent sound pressure levels (L_{Aeq}) over 24-hours in ten second increments. From these measurements, the L_{90} and L_{10} values were calculated using Microsoft Excel spreadsheets. L_{90} is the sound pressure level that is exceeded 90% of the time. L_{10} is the sound pressure level that is exceeded 10% of the time. The results of this study revealed that ambient noise levels were decreased by absorptive material treatments like absorptive ceiling tile and carpet. The peak levels did not show large variation, though, except in the NICU. Figures 3.5, 3.9, 3.13, and 3.17 show the hourly L_{eq} for each ward for each location. Moreover, Figures 3.6 to 3.8, 3.10 to 3.12, 3.14 to 3.16, and 3.18 to 3.21 plot the levels across the 10-second intervals, showing the ambient and peak levels for each individual location for each of the wards.

The L_{90} and L_{10} results can be seen in Table 3.2. L_{10} is the level of sound exceeded 10% of the recorded time interval and corresponds to the peak values. The peak level is the maximum instantaneous level in a given specified time period. L_{90} is the level of sound exceeded 90% of the recorded time interval and corresponds to the ambient values. The ambient sound is similar to the background noise level which would occur for most of the measurement time period.

Material finishes were found to affect the ambient sound levels within the nurses' station and hallway. The more absorptive materials did lower ambient levels, but peak levels remained similar in most of the areas. The NICU peaks were not as high, apparently because of the darker light levels and visual alarms. Sound levels in the patient rooms were less correlated to materials in the hallway and nurses' station and more impacted by the peak levels coming from those spaces and patient equipment. The patient equipment produced peaks in a few of the rooms, as indicated in Table 3.2. The measurement with the monitor icon indicates that these spaces had medical equipment. The patient rooms in UT5 and CT5 each had a tracheotomy unit and kin air bed with motor. The NICU critical care room had an ECMO pump and ventilator oscillator. The CT6 patient room did not have medical equipment that produced high in-room levels as in CT5 and UT5.

CT6 had more absorptive materials so ambient, L_{90}, values were lower than in the other spaces. However, the more absorptive materials did not bring down the peak values. Peaks in the patient rooms were impacted by noise coming from outside the room because the doors were left open. Noise transmitted into the patient room is a primary problem. The NICU had the second lowest measured noise levels, and this is attributed to the atmosphere changes.

Both the ambient and peak noise levels need to be tackled to improve the acoustical environment in hospitals. Moreover, the two sources of main concern in patient rooms were found to be occasional intrusive peaks originating from the hallway and common work areas and the patient's own medical equipment.

Peak levels remained similar in most of the areas. It may be better to reduce noise peaks than to shift all of the ambient levels down by a small amount because the peaks could be perceived to be more annoying, but patient surveys on noise perception should be taken to verify this. Sound levels in the patient rooms seemed less correlated to the materials in the hallway and nurses' station and more impacted by the peak levels coming from those spaces as well as patient equipment.

Some possible general improvements are to utilize absorptive materials to lower ambient L_{90}, or to create positive atmosphere changes similar to the NICU in other wards to attempt to minimize peak levels (L_{10}) that intrude on patient's perception. More absorptive materials such as carpet lowered ambient levels. Adding acoustic materials to either the hallway or nurses' station may decrease the range of noise in that area by 2-4 dB which is just perceptible but it will not impact sound levels in the patient room.

In conclusion, the measured data showed that the measured L_{90} was higher than the recommended guidelines which confirmed other studies that stated that the noise levels were rising. The two biggest problems in patient rooms are considered to be the occasional intrusive peaks coming from the hallway and common work areas and then the patient's own medical equipment. The ambient noise level in the patient room could be reduced by using quieter medical equipment. Creating positive atmosphere changes similar to the NICU in all the wards may lower peak values, while incorporating more absorptive materials is advised to help to lower the ambient L_{90} but such a change may not have a perceptible effect on occupants.

Table 3.1

Nebraska Medical Center surface treatments in each hospital wing studied.

Ward	**Hallway Ceiling**	**Hallway Floor**	**Nurses' Station Type**	**Patient Room Ceiling**	**Patient Room Floor**	**Other Remarks**
Case 1: University Tower 5 West (UT5)	Older absorptive treatment	Hard linoleum	Centralized	Hard ceiling	Hard linoleum	Traditional atmosphere
Case 2: Clarkson Tower 5 (CT5)	Absorptive treatment	Hard linoleum	Distributed	Hard ceiling	Hard linoleum	Traditional atmosphere
Case 3: Clarkson Tower 6 (CT6)	Absorptive treatment	Carpet	Distributed	Hard ceiling	Hard linoleum	Traditional atmosphere
Case 4: Neonatal Intensive Care Unit (NICU)	Absorptive treatment	Carpet	Centralized	Hard ceiling	Hard linoleum or Carpet	Visual alarms, Dim lighting

Table 3.2

Approximate peak and ambient sound levels for the three locations in each of the four wards.

Location	L_{10} **(dBA) peaks**	L_{90} **(dBA) ambient**
UT5 Nurses' Station	63	50
Patient Room 	66	61
Hallway	60	49
CT5 Nurses' Station	62	45
Patient Room 	63	58
Hallway	59	47
CT6 Nurses' Station	60	41
Patient Room	54	48
Hallway 	58	49
NICU Nurses' Station 	54	44
Critical Patient Room E48267 	64	55
Patient Room E48260	46	41
Hallway	54	46

a. Monitor symbol in table represents in room medical equipment occupying space close to the sound level meter.

(a)

(b)

(c)

Figures 3.1. Measurement locations in University Tower 5 West (UT5) (a) nurses' station, (b) patient room, and (c) hallway.

(a)

(b)

(c)

Figures 3.2. Measurement locations in Clarkson Tower Level 5 (CT5) (a) nurses' station, (b) patient room, and (c) hallway.

(a)

(b) (c)

Figures 3.3. Measurement locations in Clarkson Tower Level 6 (CT6) (a) nurses' station, (b) patient room, and (c) hallway.

(a)

(b)

(c)

Figures 3.4. Measurement locations in Hixson Lied neonatal intensive care unit (NICU) (a) nurses' station, (b) patient rooms, and (c) hallway.

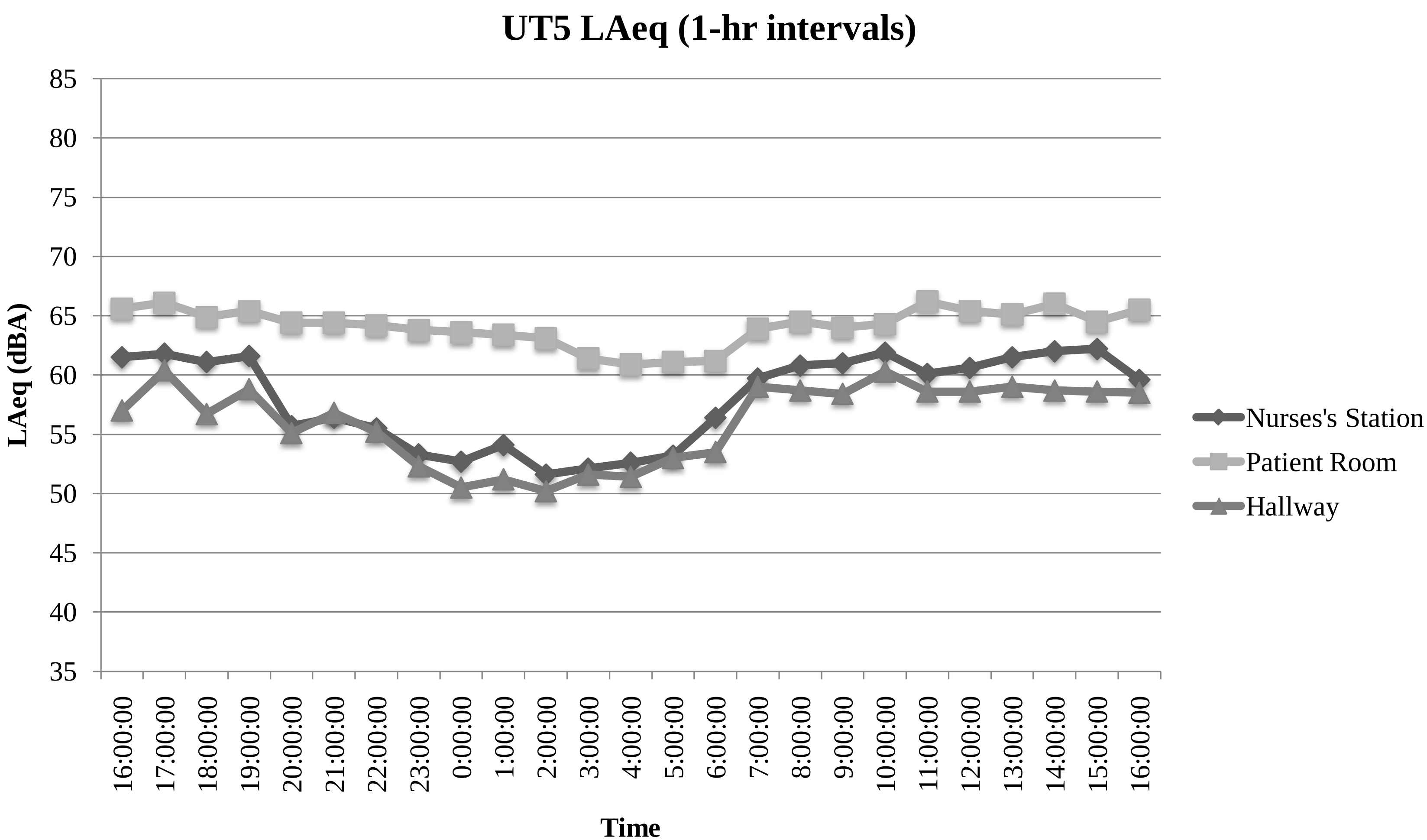


Figure 3.5. Hourly equivalent sound levels (L_{Aeq}) measured in University Tower 5 for the three locations.

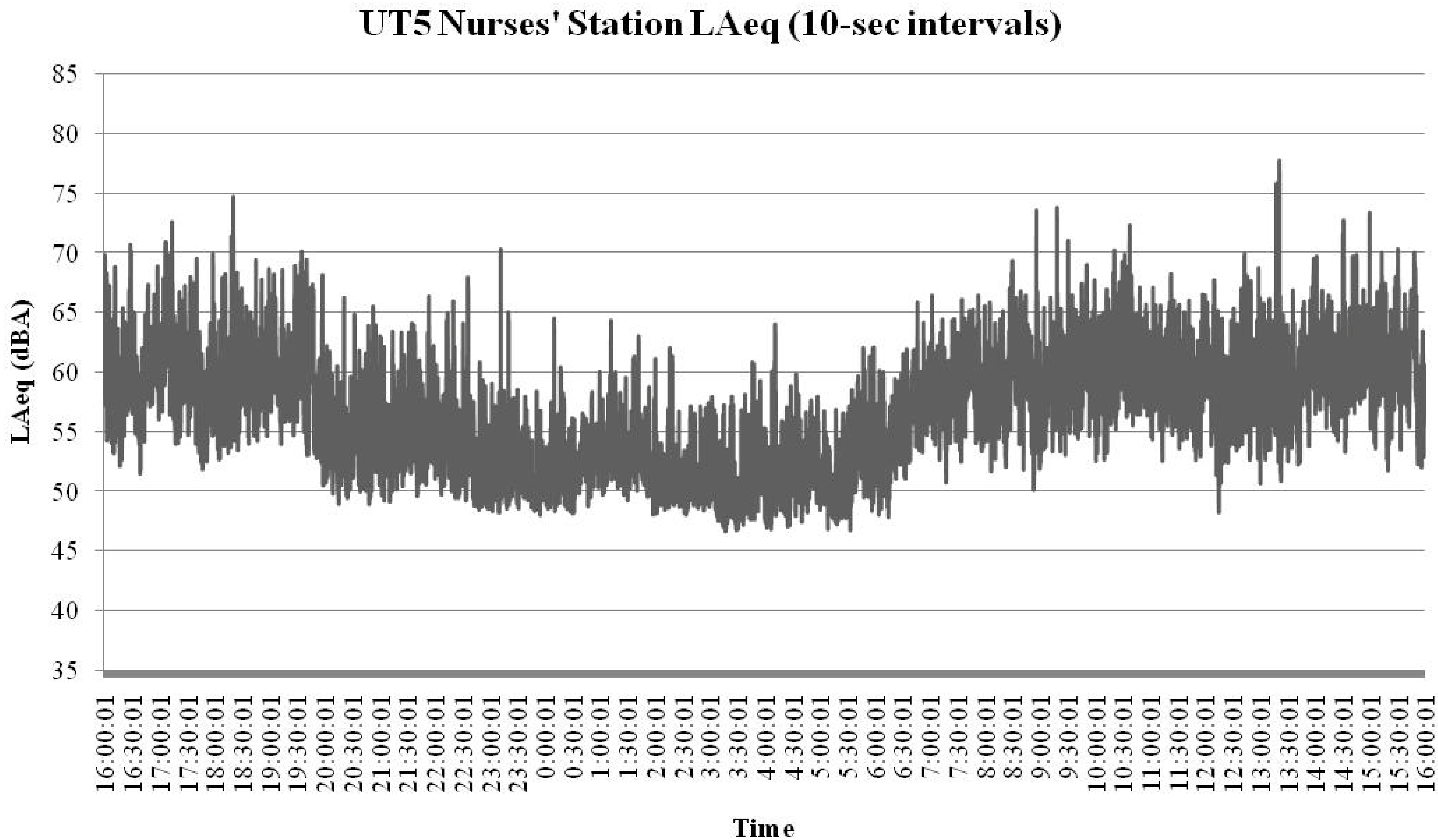


Figure 3.6. L_{Aeq} for each 10-second interval measured in University Tower 5 at the nurses' station.

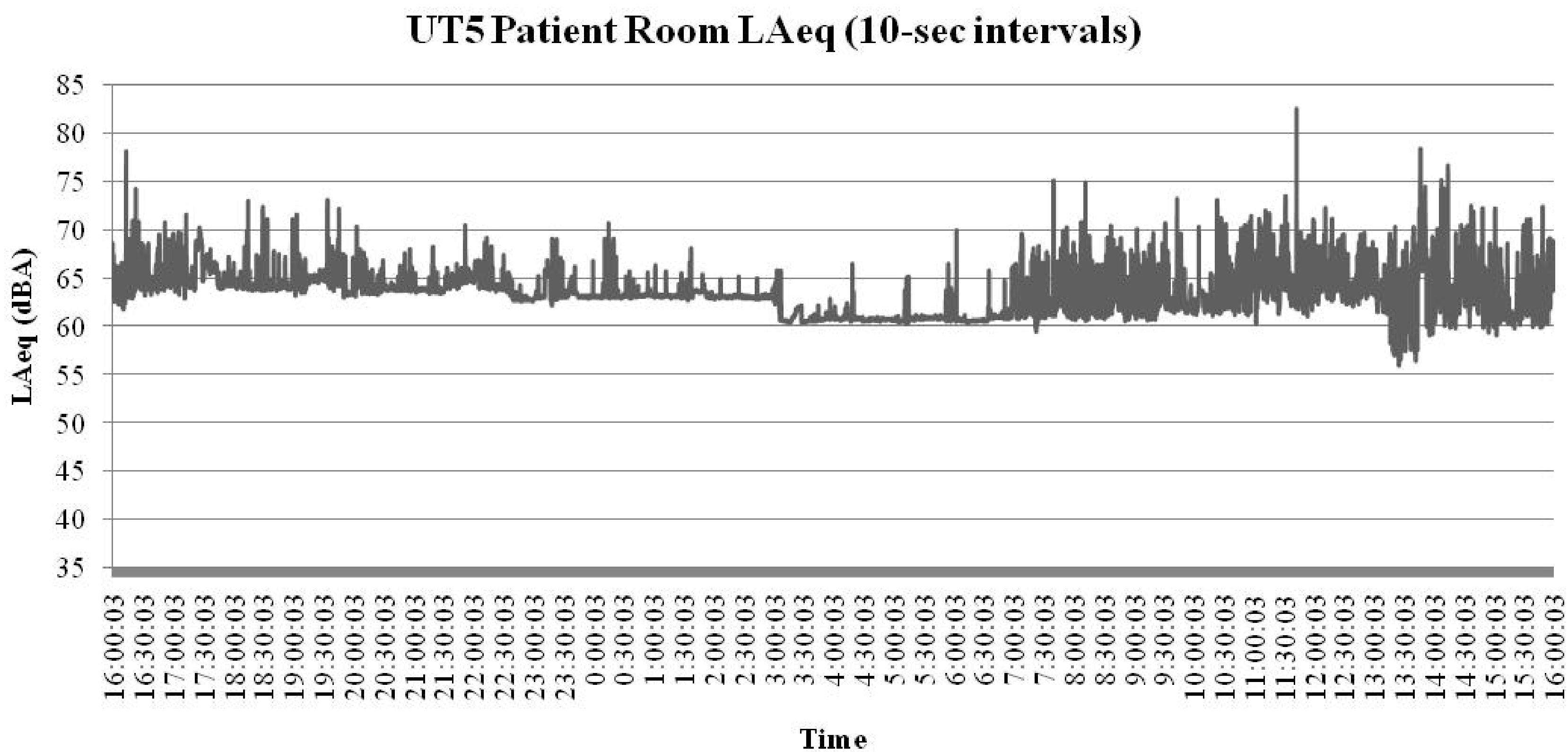


Figure 3.7. L_{Aeq} for each 10-second interval measured in University Tower 5 at the patient room.

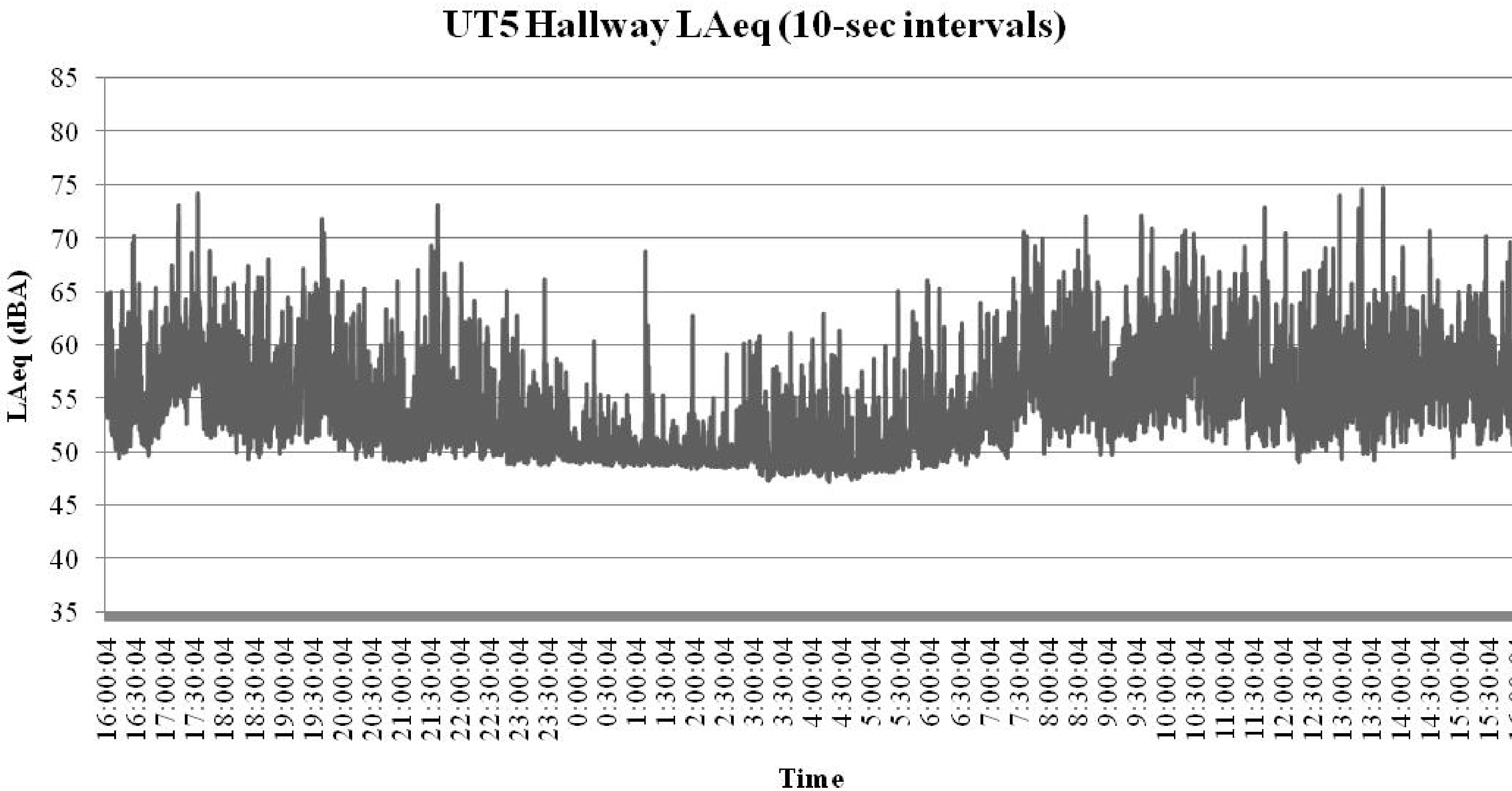


Figure 3.8. L_{Aeq} for each 10-second interval measured in University Tower 5 for the hallway.

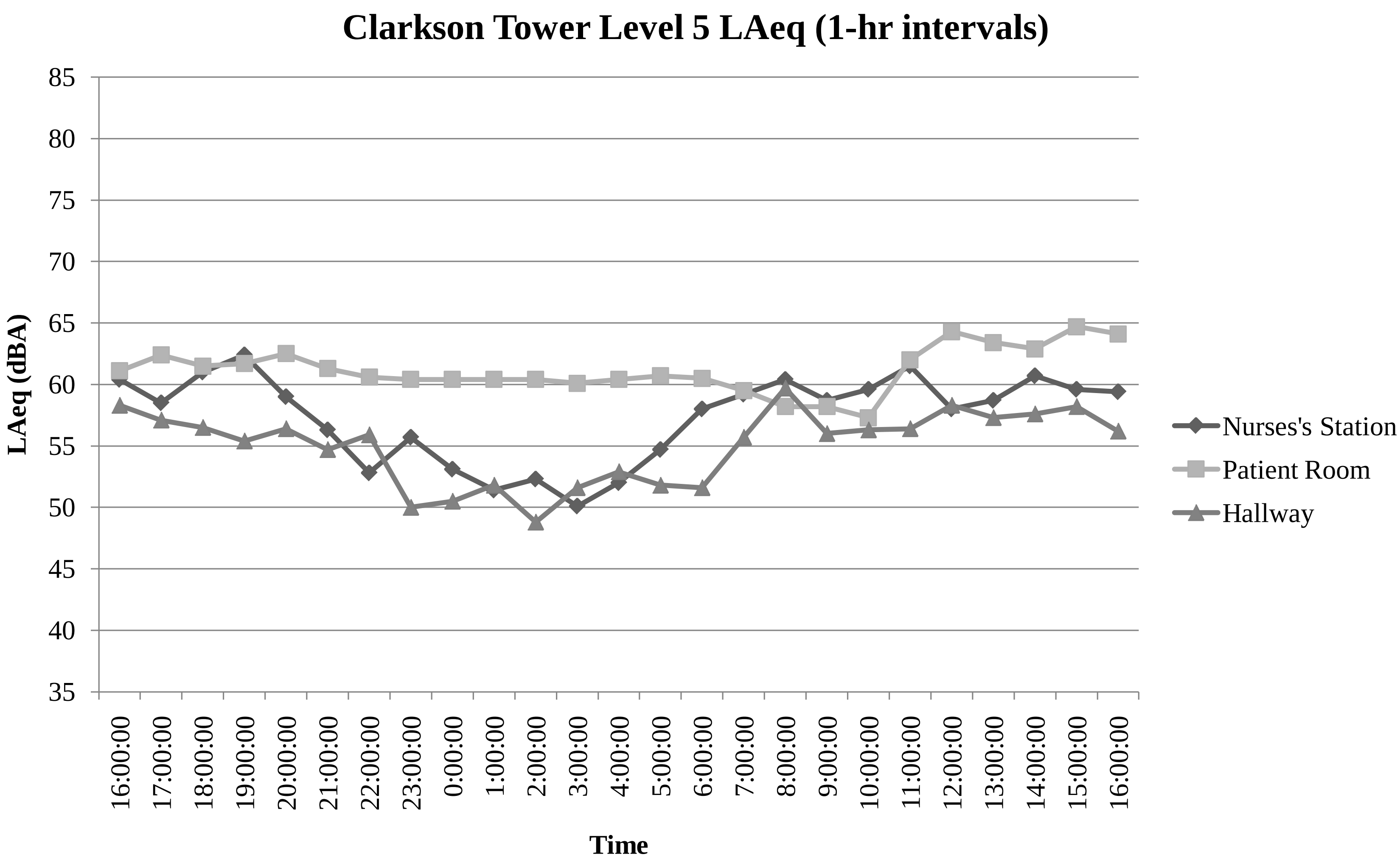


Figure 3.9. Hourly equivalent sound levels (L_{Aeq}) measured in Clarkson Tower 5 for the three locations.

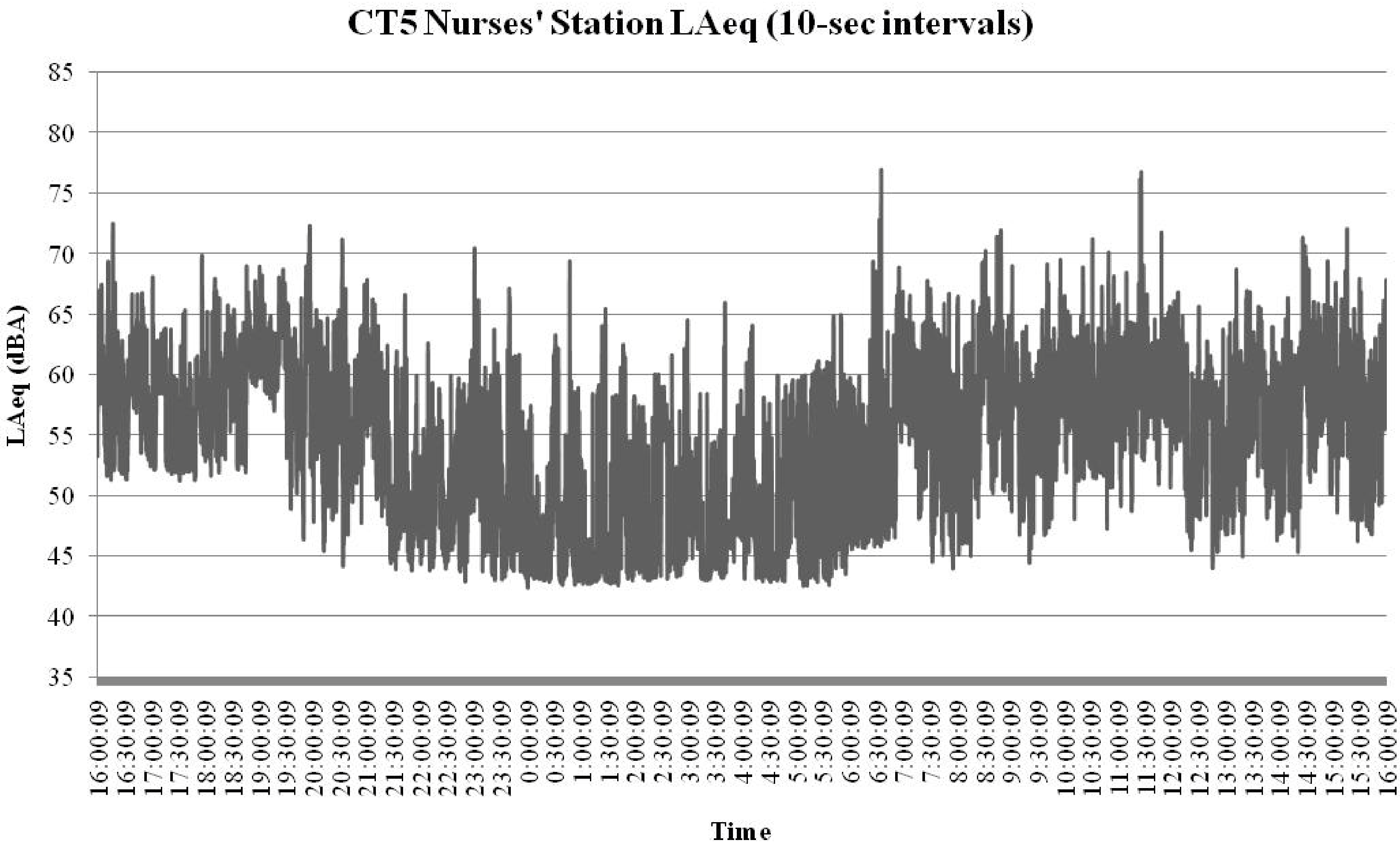


Figure 3.10. L_{Aeq} for each 10-second interval measured in Clarkson Tower 5 at the nurses' station.

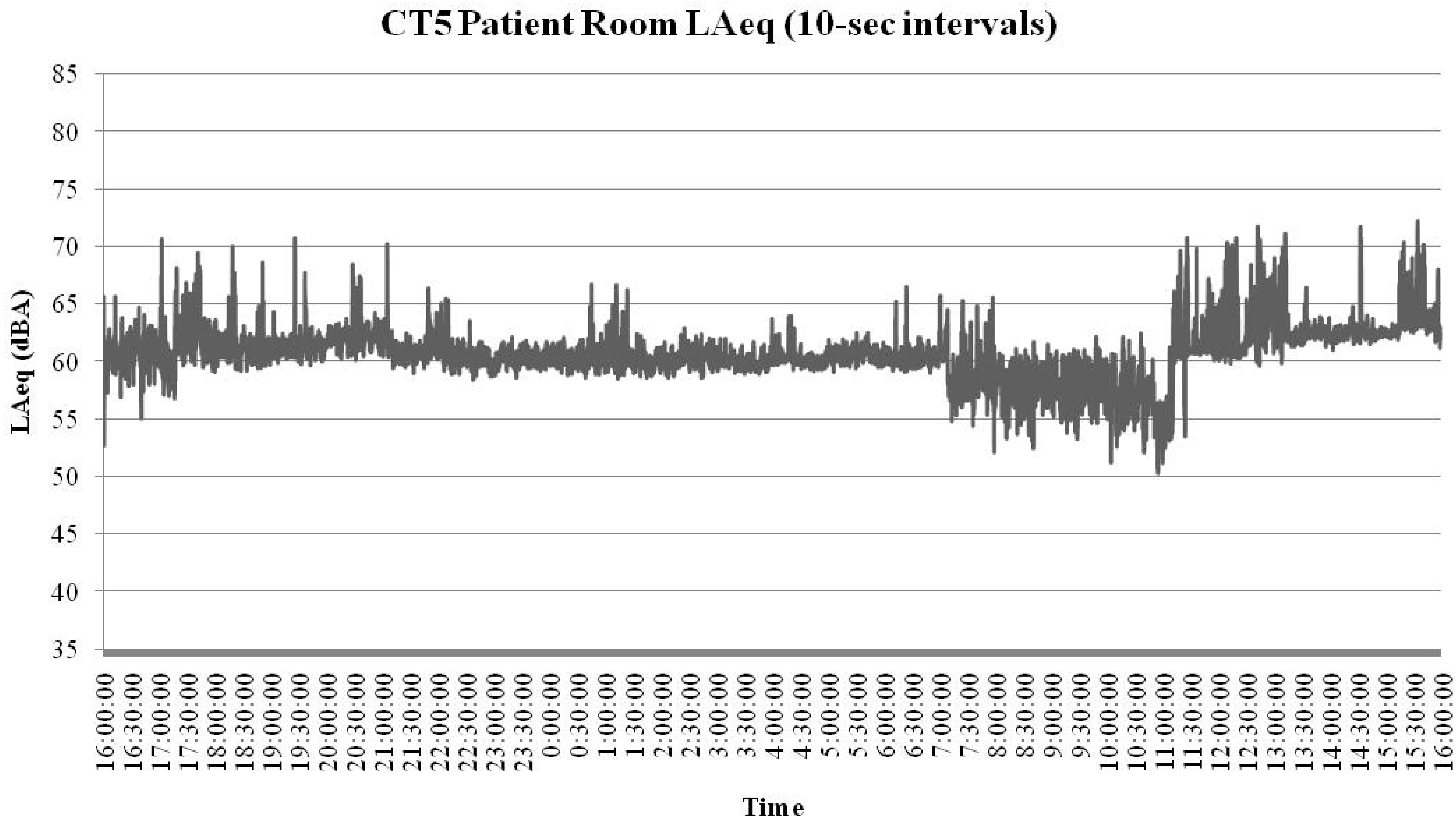


Figure 3.11. L_{Aeq} for each 10-second interval measured in Clarkson Tower 5 at the patient room.

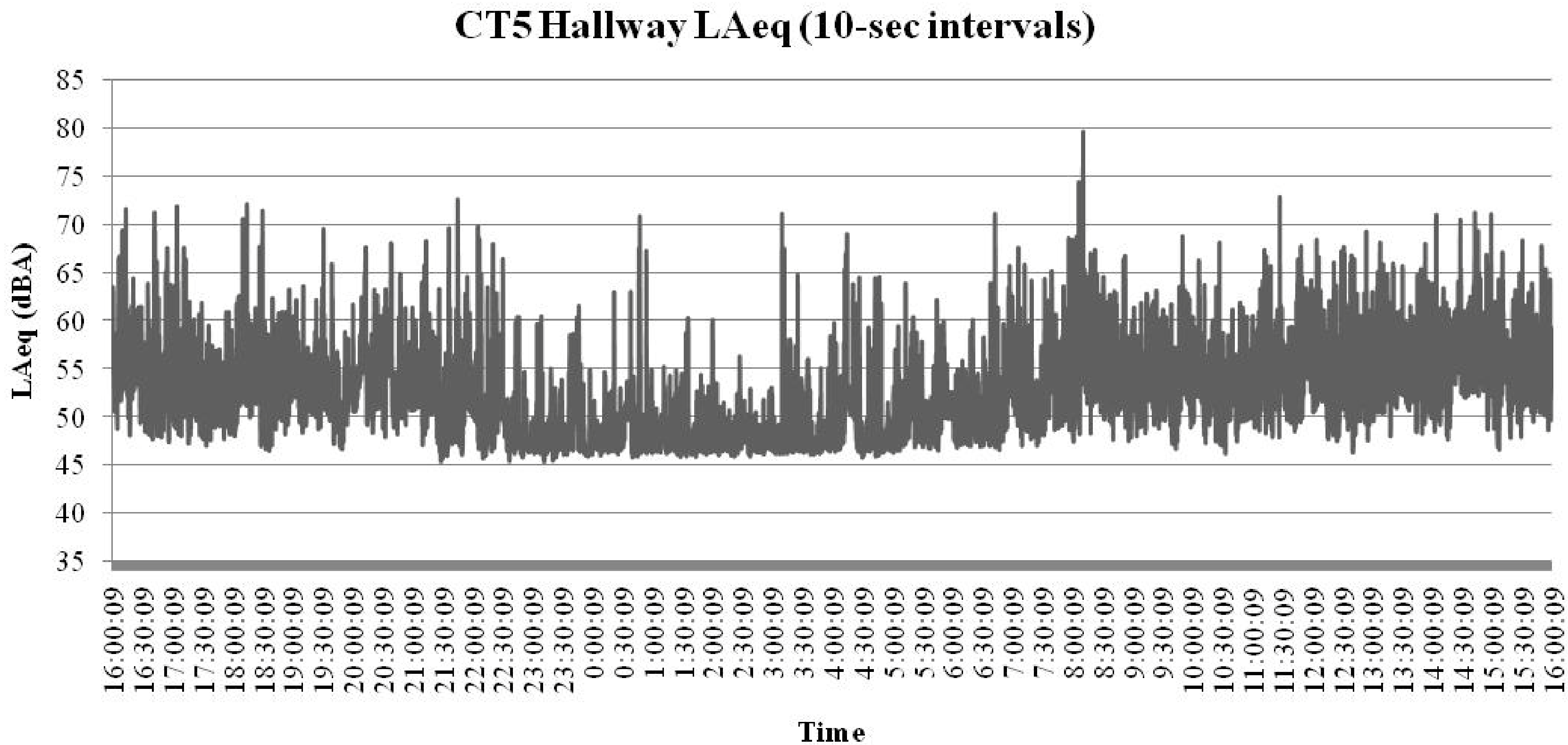


Figure 3.12. L_{Aeq} for each 10-second interval measured in Clarkson Tower 5 at the hallway.

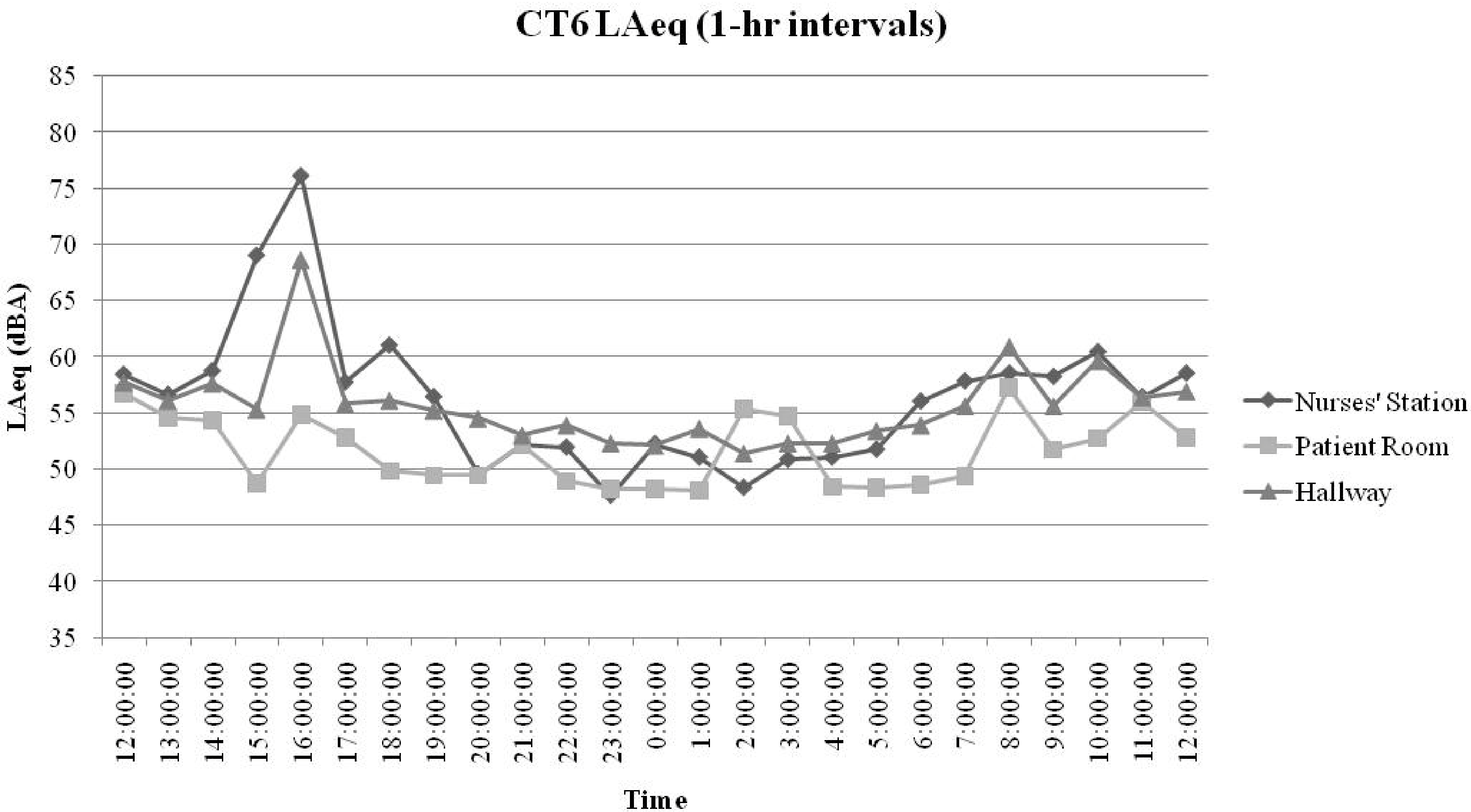


Figure 3.13. Hourly equivalent sound levels (L_{Aeq}) measured in Clarkson Tower 6 for the three locations.

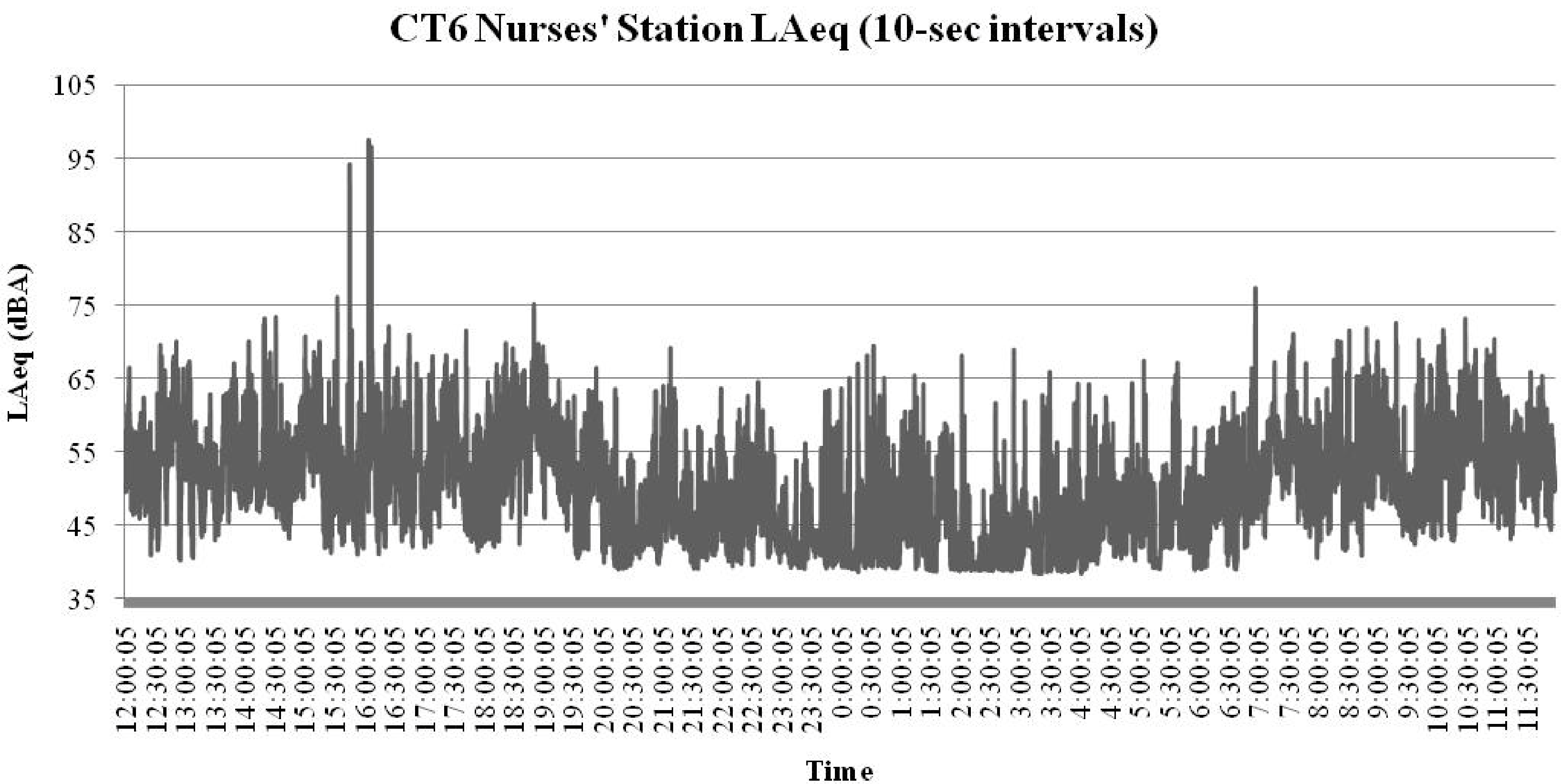


Figure 3.14. L_{Aeq} for each 10-second interval measured in Clarkson Tower 6 at the nurses' station.

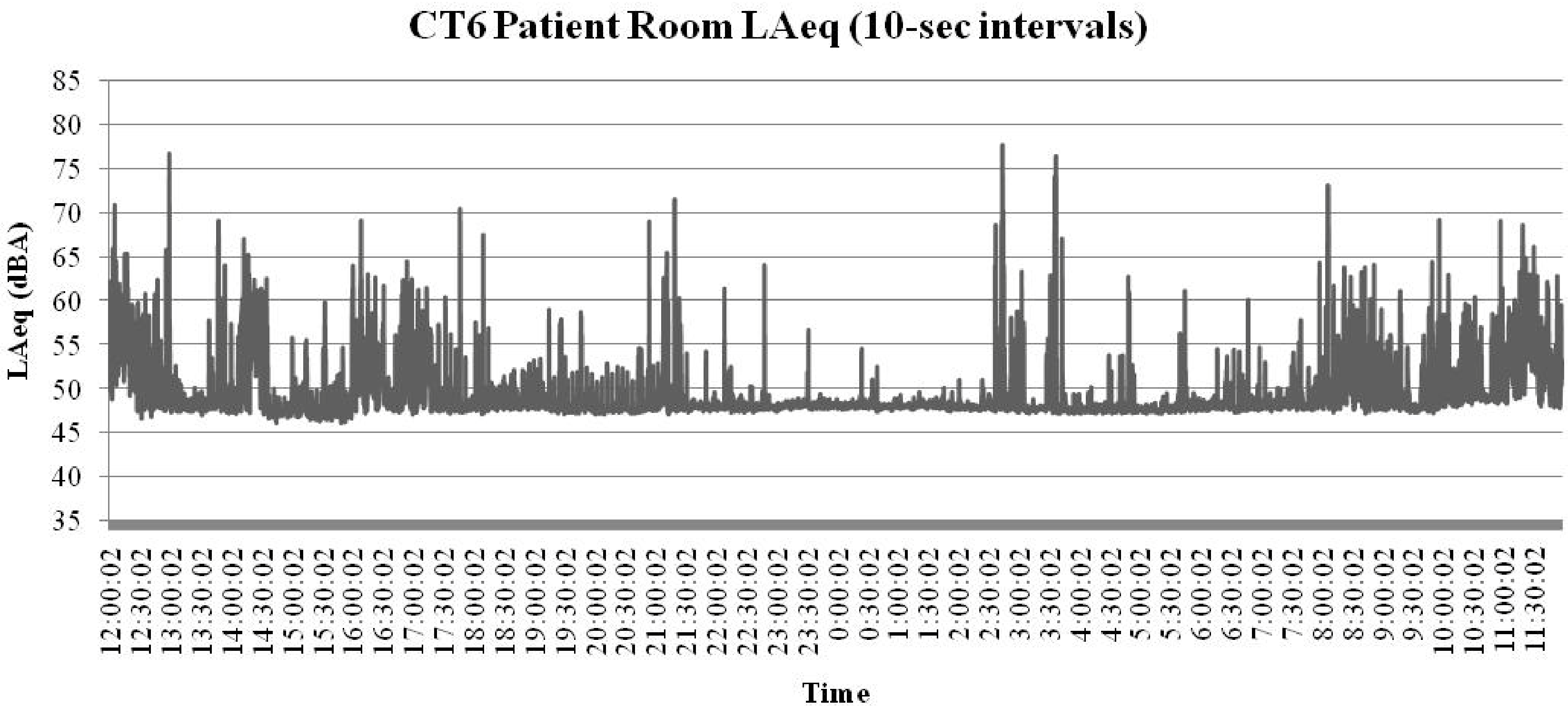


Figure 3.15. L_{Aeq} for each 10-second interval measured in Clarkson Tower 6 at the patient room.

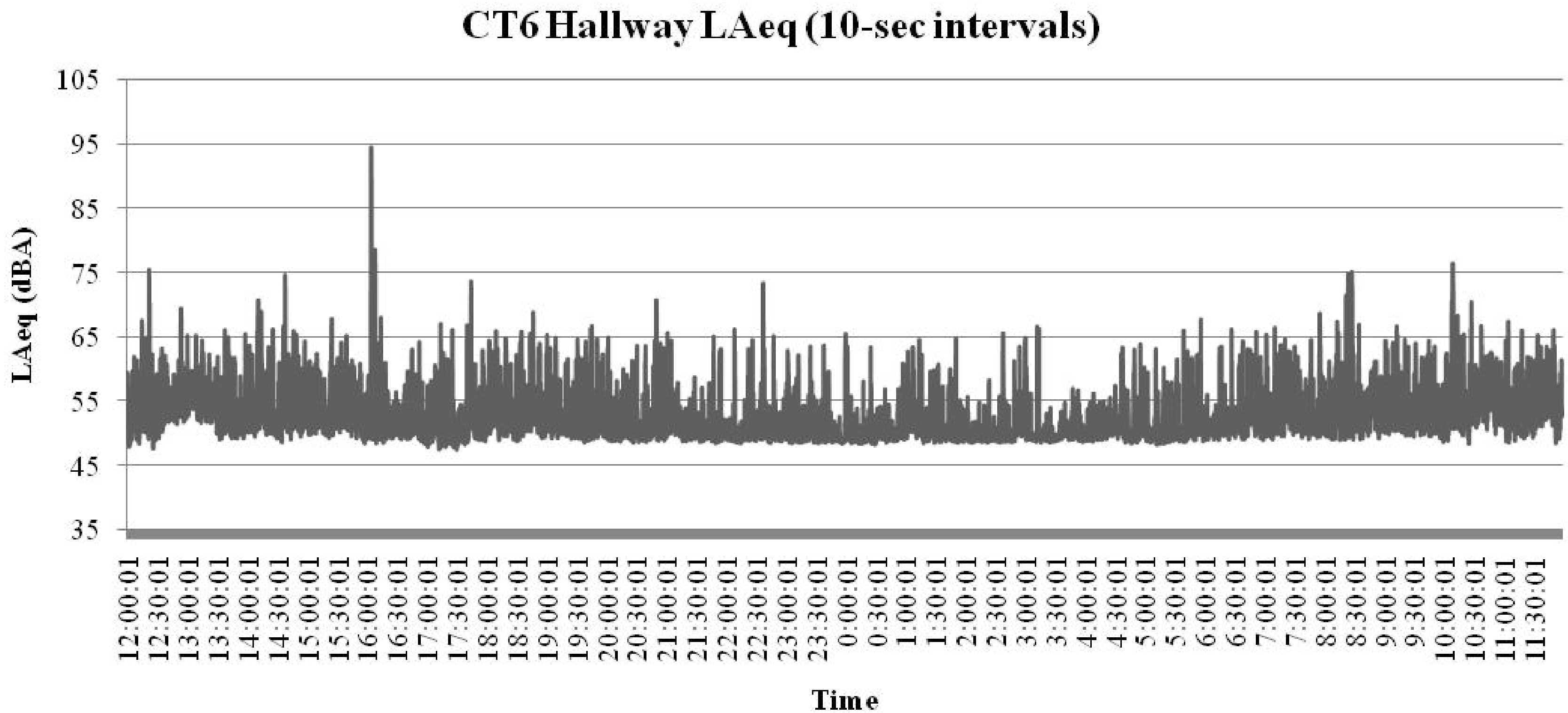


Figure 3.16. L_{Aeq} for each 10-second interval measured in Clarkson Tower 6 at the hallway.

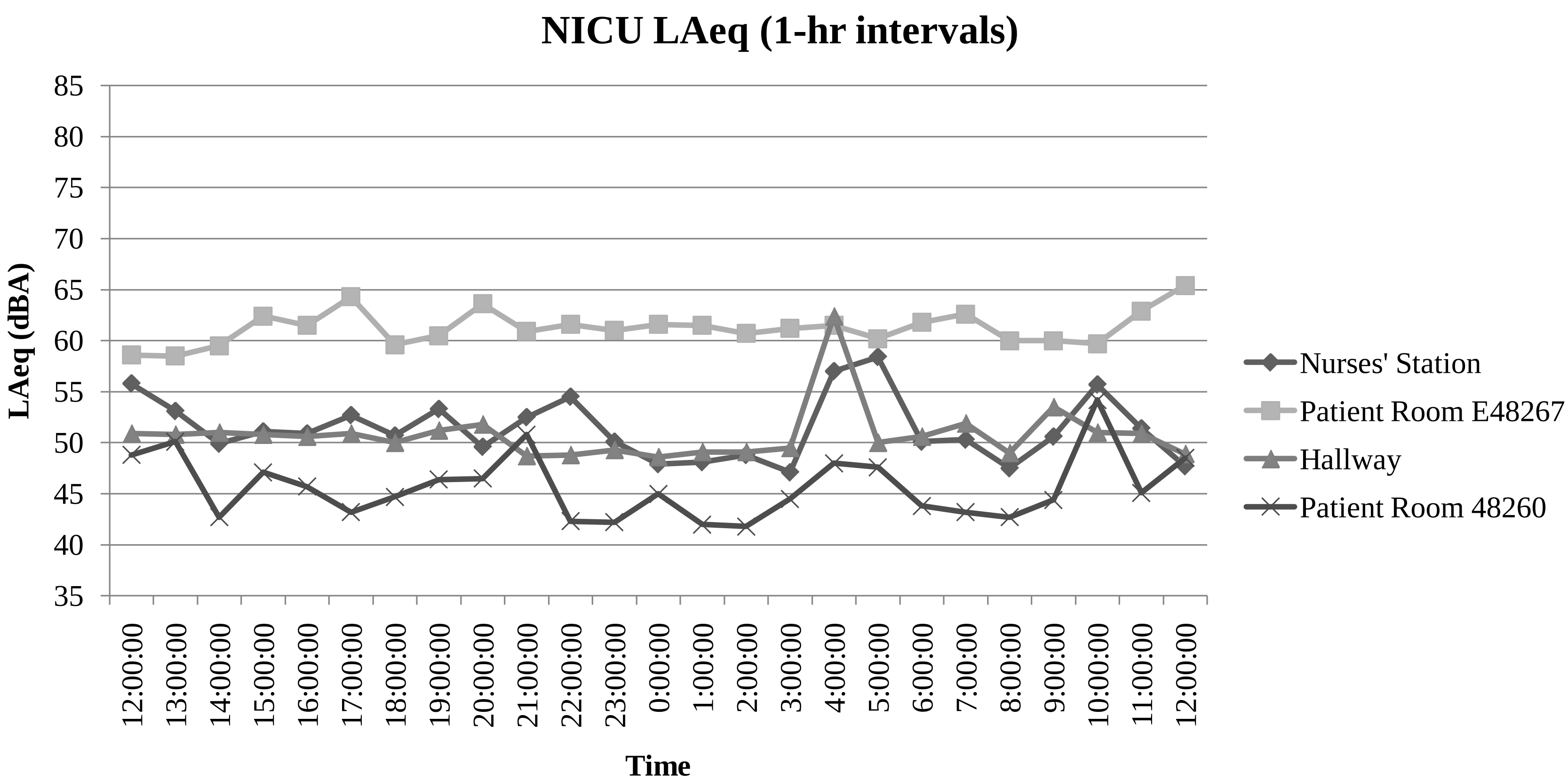


Figure 3.17. Hourly equivalent sound levels (L_{Aeq}) measured in Hixson Lied neonatal intensive care unit for the four locations.

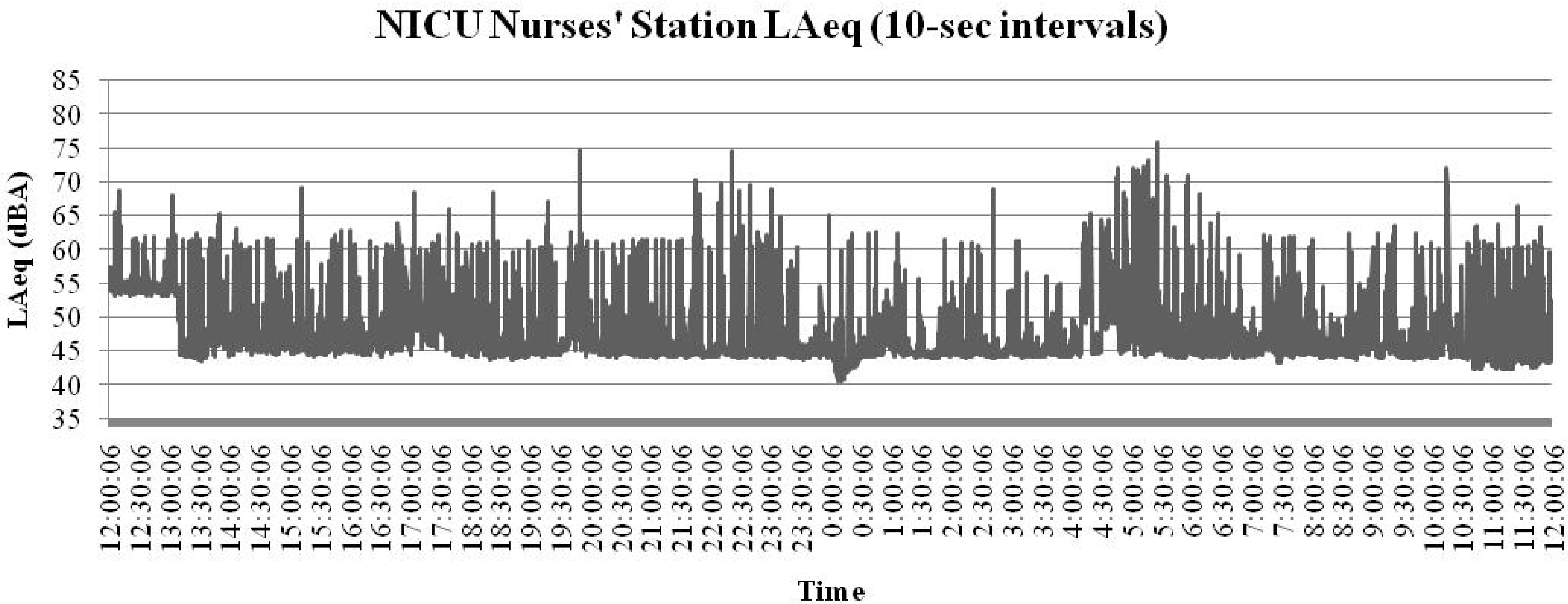


Figure 3.18. L_{Aeq} for each 10-second interval measured in neonatal intensive care unit at the nurses' station.

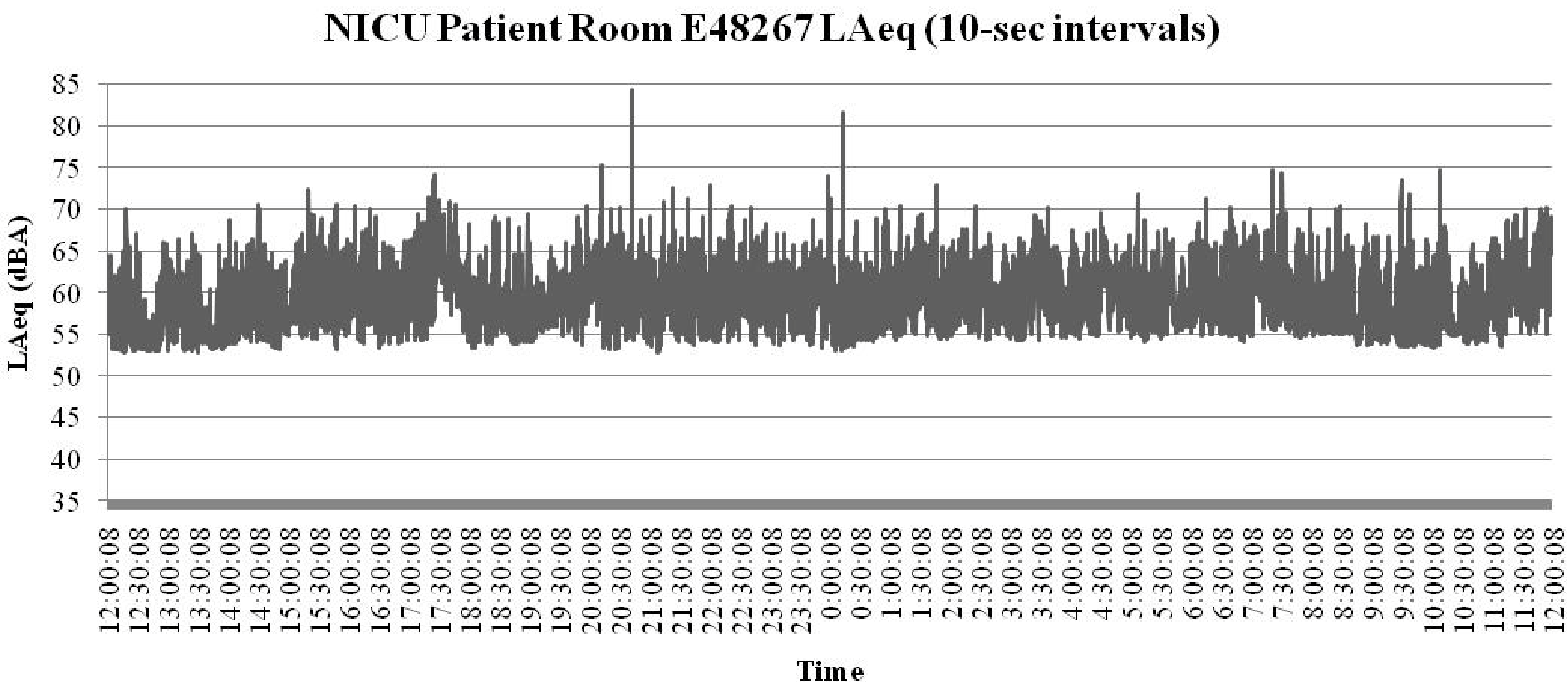


Figure 3.19. L_{Aeq} for each 10-second interval measured in neonatal intensive care unit at the patient room E48267.

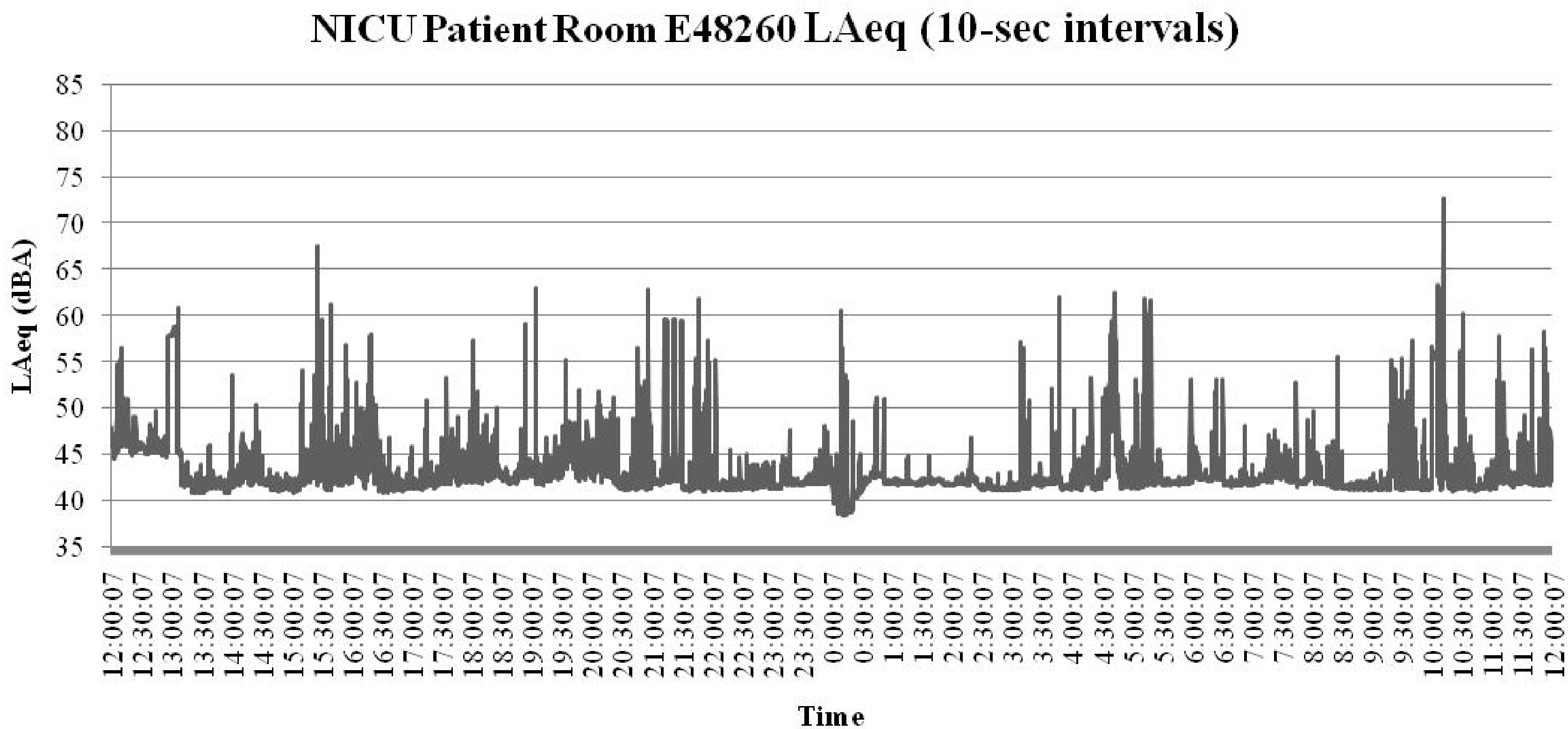


Figure 3.20. L_{Aeq} for each 10-second interval measured in neonatal intensive care unit at the patient room E48260.

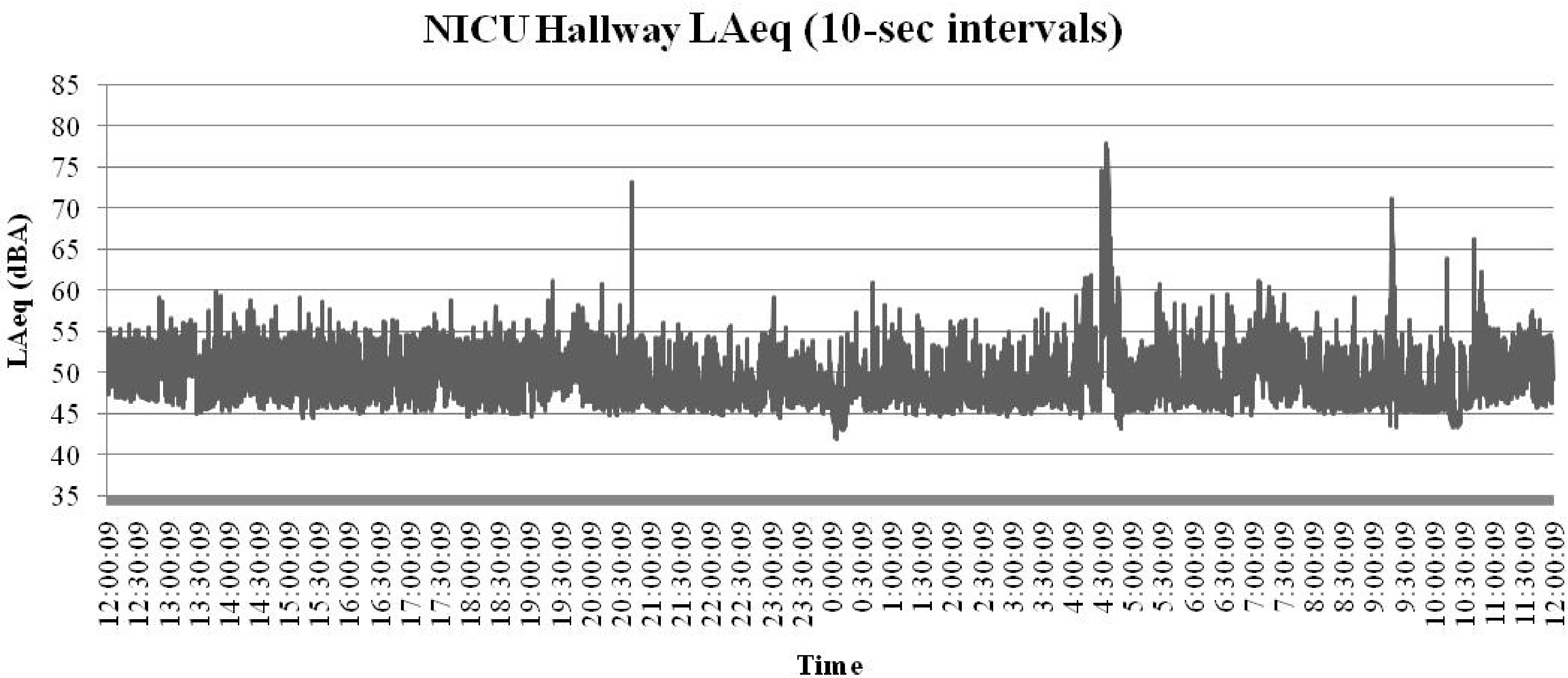


Figure 3.21. L_{Aeq} for each 10-second interval measured in neonatal intensive care unit at the hallway.

CHAPTER 4: RESEARCH METHODOLOGY

From the study presented in Chapter 3 and the literature reviewed in Chapter 2, a conclusion can be made that other research needs to be implemented to further the advancement of hospital design and healthcare. Patients are at the center of the healthcare system. Therefore, research into patient perception of the care they are provided is necessary. Based on the results of the baseline study in Chapter 3, the Nebraska Medical Center was interested in implementing some changes to determine how these may impact the sound levels and patient perception.

4.1 OVERVIEW

The investigation was conducted in the Nebraska Medical Center, a hospital located in Omaha, NE. University Tower 6 West, a general ward with patients suffering from a variety of ailments, was used. The objectives of the study were:

I. To determine if the patients' perception of care was impacted by the improvements.
II. To objectively measure sound levels changed before, during, and after renovation.
III. To make suggestions for further improvements based upon the results.

4.2 SPACE DESCRIPTION

The floor plan of University Tower 6 West is shown in Figure 4.1. The patient rooms are along the outside corridor, while a centralized nurses' station and storage areas are in the center. There are twenty double occupancy patient rooms on the floor. The materials are hard linoleum flooring in the hallway and patient rooms, and carpet in the nurses' station. Standard absorptive acoustical ceiling tile treatments are found in the hallway and nurses' station, while the patient rooms have hard drywall ceilings. All spaces have standard painted drywall walls. Figures 4.2 and 4.3 show images of each area with the materials present in each space. A large variety of equipment is present, particularly in the patient rooms depending upon the individual patient's needs.

4.3 PROCEDURE

Two types of techniques were used to obtain the results. One was objective sound level meter measurements that recorded the sound levels in the hospital ward. The other was a subjective survey taken by qualified patients that met predetermined specifications and gave consent to participate. While objective measurements can tell us one aspect of the study, it is necessary to assess patient perception data as well. In order to accurately obtain patient perception data, specific questions need to be asked as supported by the following described studies.

The National Health Service of the United Kingdom found a large disparity in patient satisfaction within key areas such as coordination of care, emotional support, and physical comfort (West et al. 2004). Jenkinson et al. (2002 a,b) conducted a patient survey that found a similar difficulty, showing a discrepancy between what people report in answering detailed questions to their overall impressions of their experience. In both of these studies, nurses and patients preserved a positive image of the quality of care while maintaining a disapproving opinion of many of the specific aspects of care.

In the Jenkinson et al. (2002 a,b) study, patients were extremely positive and optimistic about their overall satisfaction with care; however, this was not carried over into their answers to more detailed specific questions about their experiences. Therefore, detailed questions and answers need to be obtained from both patients and staff for the information to be the most useful for watching and improving hospital care and operation. The need to portray one's self in a socially positive manner as gauged by Crowne and Marlowe (1964) sometimes leads to people not venting their concerns or complaints openly when initially asked.

Yet, acoustical changes can impact patients' perceptions, as reviewed in Section 2.2.2. Additionally, physiological measures of recovery and patient perceptions of well-being are positively impacted from attempts to promote patient relaxation: music therapy, biofeedback, progressive muscle relaxation (McCarthy 1991). Methods need to be devised to create a positive impression upon patients and to make their environment more comfortable.

4.3.1 Ethical Considerations

The research proposal was submitted to and approved by the Nebraska Medical Center's Institutional Review Board (IRB) at the end of December 2009 and beginning of January 2010. All investigators completed Collaborative Institutional Training Initiative (CITI) online courses and received certification in the CITI program. Hospital staff who participated in the project were trained and certified by this program as well. All measures and procedures in the study were compliant with ethical standards, particularly regarding informed consent and privacy of patients' information.

4.3.2 Sound Level Meter Measurements

Sound level meter (SLM) measurements were made with calibrated Larson Davis 824 sound level meters at three time periods: before (December 2009), during (March 2010), and after (May 2010) renovations. Spectral and equivalent sound level (L_{eq}) measurements were taken during each time frame in University Tower 6 West, at each of three locations: the nurses' station, a patient room and the hallway. These locations are marked in Figure 4.1.

Measurements were logged every 10-seconds continuously over a four-day workweek from Monday through Thursday, at each location. The work week was chosen with the assumption that the schedule and usage of the space would remain consistent during those days while the weekend may have a different shift schedule or usage of the space. Additionally, the sound level meters have limitations in regards to the amount of internal memory space for storing data during a measurement period so a time frame of four days was chosen. The resulting data was analyzed in terms of the hourly A-weighted equivalent sound levels ($L_{A\text{eq}}$) as well as various exceedence levels (L_n).

4.3.3 Patient Survey Measurements

Subjective voluntary surveys were given to patients to determine their perceptions, thoughts, and experiences with noise during their hospital stay. Ideally, the survey would have been distributed before, during, and after renovations. However, due to the time constraints of the IRB process, the survey was only distributed during and after renovations.

The sample involved patients who met the following criteria. Subjects were at least 19 years old or older, able to read English, able to cognitively understand the survey as determined by the distributing staff, and must have stayed at least one night in the University Tower 6 West unit between February and June 2010.

Potential subjects that met the above criteria were asked to fill out the survey and return it. No patient identifiers were collected. The surveys were brought to the hospital in batches of 100 which aided in keeping track of the number of completed surveys returned. A cover letter attached to each individual survey described the project (see Appendices A and B). If the patient completed the survey, then informed consent was implied.

CITI-trained hospital staff oversaw the process for distribution and collection of the surveys, which were kept at the central nurses' station desk. The dismissal nurse for each particular case handled the distribution and was aware of the inclusion criteria. If completed, the survey was then returned and placed in the envelope at the main desk. The author then collected these. The number of dismissals, number of surveys distributed, and number of surveys returned were tracked on a separate sheet.

4.3.4 Data Evaluation/Analysis

The following discussion uses information from the Levin, Field, and Pallant statistics books. Two divisions (broad categories) of statistics exist. Descriptive statistics describe the data such as a mean. Inferential statistics infers properties of a specific population based on sample data. Variables can be either independent (factor that is manipulated or changed, not more than three) or dependent variables (factor that is measured). Variables are either discrete or continuous and one of four scales: nominal, ordinal, interval, and ratio.

Discrete variables are finite or countable with a certain number of possible values. Continuous variables are infinite and can be measured with varying degrees of precision since intermediate values are possible. The four scales have each of the preceding levels properties as well as more properties inherent to that particular division. Nominal variables are the lowest division. Names, labels, and categories with no specific order are all examples of nominal variables. Subjects of a study are sorted into a specific mutually exclusive and exhaustive category based upon some shared characteristic. Ordinal division assigns an order or rank to cases based upon degree to which they share some quantity; however, the distances between values are unknown and not necessarily constant. Interval scale has an order and meaningful distance between the measurement values and needs to have an established common standard measurement unit. Ratio scale is the highest level in the hierarchy. It has a non-arbitrary zero point and the values can be compared according to ratios and proportions. The nature of the measurement collected will impact the researcher's choice of statistics to apply.

The patient survey gathered demographic data such as age and gender as well as results of response on subjective noise perception during the subject's hospital stay. See Table 4.1 for information on the variables in this study. Descriptive results are given in frequency figures and percentage figures in Chapter 5. The frequency shown on the survey charts or graphs is the count of how often an event or circumstance occurs. As the descriptive statistics indicate in Table 5.1, the continuous variables: *Age, Awakened and Annoyed at Night, Disturbed and Annoyed During the Day, Hard Time Understanding Spoken Comments and Able to Hear Patient Private Info Being Discussed* do not have a normal distribution as their Kologorov-Smirnov Sig. Values are less than 0.05.

Some of the data are displayed as counts as well as percentages to indicate the precision of the data. For example, 2 out of 10 and 20 out of 100 both represent 20% but the larger count has more significance. A review of the continuous variable properties indicated that age is skewed to the left; that variable is not normally distributed. Due to a lack of a normal distribution, or even a symmetric distribution, it is not possible to use the standard parametric tests. Instead, non-parametric tests were used in analyzing the data (see Table 4.3).

A between subjects study design was used because it involved different independent groups of subjects for each time period of renovation, during the renovation and after the renovation. Subject variables may impact results but selecting subjects that meet the above-specified criteria can reduce error.

Microsoft Excel and Statistical Package for the Social Sciences 18 (SPSS) were used to analyze the survey data. $L_{A\mathrm{eq}}$, L_{10}, and L_{90} values were compiled using Excel for each location over a number of timeframes: the overall 4-day values; the daily daytime values between the hours 7AM-10PM; and the daily nighttime values between the hours of 10PM-7AM. Spectral data were also analyzed.

Each patient's survey responses were inputted into Microsoft Excel for analysis using number coded variables. The survey questions and the exact coding values used for the survey responses are shown in Table 4.2. SPSS was utilized to determine the significance of the survey results and to determine the relationships between age, gender, noise sensitivity, and annoyance. Patient responses to questions 1 and 2 were converted to a 13-point annoyance scale (0 to 12). This interval scale was used to gauge the patient's individual experience, similar to a Likert scale. Responses to questions 4 and 5 likewise were converted to a four point (0, 1, 2, 3) interval scale. Missing responses were left "blank" for purposes of evaluation of results.

Two different types of statistical techniques exist: parametric and non-parametric. Parametric tests, such as t-test and analysis of variance (ANOVA), make certain assumptions about the population like the population is normally distributed (Pallant

2007) with kurtosis and skew values equal to 0.0. Non-parametric techniques do not make such assumptions about the population. Non-parametric techniques are ideal when using nominal (categorical) data and ordinal (ranked) scales. Assumptions for the non-parametric tests are random samples and independent observations. Independent observations mean that each person or case is only counted once; it does not appear in another category or group. Additionally, the data from one subject does not influence the data from another subject.

One non-parametric statistical technique used in this investigation is the chi-square test for goodness of fit to compare the hypothetical count of the after renovation group with the count received for various subjective responses. The hypothetical count is based on the proportions of the during renovation group. With one degree of freedom, values smaller than 3.84 for $p=0.05$ could be attributed to chance alone.

Chi-square test for independence determines if two categorical variables are related. A comparison between the frequency of cases found in the various categories of one particular variable with the variety of categories of another variable is calculated. Two or more categories are needed for each of the variables. The test compared observed frequencies that happen in each of the categories with the value that would be expected if no association between the two variables being measured existed.

A chi-square for independence test was used for the independent variables *Age* and *Gender* and categorical dependent variables *Awaken and Annoyed at Night, Disturbed and Annoyed During the Day, Sensitive to Noise* and *Hard Time Understanding Spoken Discussions*. This analysis can determine the relationships among the variables. The accepted level of significance for all analogies was $p < 0.05$.

Another analysis technique, which is used in the case of normally distributed variables, is the independent t-test which explores the differences between small groups. This is accomplished by testing the hypotheses about the equality of the two sample means. However in order to use this test the variables need to exhibit a normal distribution which did not occur in the survey results obtained. This also applies to using any type of ANOVA analysis procedures. So for this study it was not possible to use these analysis procedures. It was noted that as the number of surveys increased that the age variable did approach a normal distribution. It is expected that the distribution will be normal around 250 or more surveys.

Kruskal-Wallis is a non-parametric technique that is an alternative to the one-way between-groups ANOVA test. With the Kruskal-Wallis test, a comparison of the scores can be made on some of the continuous variable for three or more groups. The Mann-Whitney U test and Kruskal-Wallis test are similar but the Kruskal-Wallis test allows the comparison of more than just two groups. With this test, scores are converted into ranks; then the mean rank for each group is compared in a between-groups analysis. Different people need to be used in each of the different groups because it is a between-groups analysis.

Mann-Whitney U test is a technique used to test for differences between two independent groups on a continuous measure. This is the non-parametric alternative test to the t-test for independent samples. This test compares medians. Across the two groups, it converts the scores on the continuous variable to specific ranks. The test then assesses if the ranks for the two groups vary significantly. When the scores are changed into ranks, the actual distribution of the scores no longer matters.

Previous studies have found that age and gender can play a role in a patient's experience with noise, as reviewed in Chapter 2. These variables could influence and cause bias to the results but as will be shown in Chapter 5, no relationship between gender or age were found with the patient's surveys with noise in this investigation. The most important determination in this research is to determine if a statistical significance exists between before, during, and after renovations, as well as what noise sources were reduced and which still need to be addressed.

Table 4.1

Variable descriptors.

Survey Variable	Variable Name	Discrete or Continuous	Category Type	Values
Gender	*Gender*	Discrete	Nominal (Categorical)	0,1
Age	*Age*	Discrete	Interval	1 to 12
Hard of Hearing	*Hardhear*	Discrete	Nominal (Categorical)	0,1
Awake Annoyance PM	*AwakeannoyPM*	Continuous	Interval	0 to 12
Awake Annoyance AM	*AwakeannoyAM*	Continuous	Interval	0 to 12
Noise Source *Medical Equipment in Patient Room*	*NoizMEIR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Alarms in Patient Room*	*NoizAIPR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Talking in Patient Room*	*NoizTIPR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Rolling Carts in Hallway*	*NoizRCIH*	Discrete	Nominal (Categorical)	0,1
Noise Source *TVs*	*NoizTVIR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Other Entertainment Devices*	*NoizOEDS*	Discrete	Nominal (Categorical)	0,1
Noise Source *Medical Equipment outside Patient Room*	*NoizMEOR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Alarms outside Patient Room*	*NoizAOPR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Talking outside of Patient Room*	*NoizTOPR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Office Equipment outside of Patient Room*	*NoizOEOR*	Discrete	Nominal (Categorical)	0,1
Noise Source *Heating, Ventilation, Air-conditioning*	*NoizHVAC*	Discrete	Nominal (Categorical)	0,1
Noise Source *Other (see comments)*	*NoizOTHR*	Discrete	Nominal (Categorical)	0,1
Speech Intelligibility	*Hardundr*	Continuous	Interval	0 to 3
Speech Privacy	*Heardisz*	Continuous	Interval	0 to 3
Noise Sensitivity	*Noizsenz*	Discrete	Nominal (Categorical)	0,1

Table 4.2

Selected survey questions and response values (in parenthesis) for SPSS analysis.

Question	**Response Options and Values in Parenthesis**
Gender	Male (0), Female (1)
Age	19 to 25 (1), 26 to 30 (2), 31 to 35 (3), 36 to 40 (4), 41 to 45 (5), 46 to 50 (6), 51 to 55 (7), 56 to 60 (8), 61 to 65 (9), 66 to 70 (10), 71 to 75 (11), 76 and older (12)
Do you, the patient, have any known hearing impairments?	Yes(1), No(0)
#1. How often were you awakened at night by sounds during your hospital stay, other than by a nurse for a required activity?	Never – Did Not Wake (0), Rarely - Not At All (1), Sometimes - Not At All (2), Often - Not At All (3), Rarely – Slightly (4), Sometimes – Slightly (5), Often – Slightly (6), Rarely – Moderately (7), Sometimes - Moderately (8), Often – Moderately (9), Rarely – Extremely (10), Sometimes – Extremely (11), Often – Extremely (12)
#2. How often were you disturbed during the day by sound, other than by a nurse for a required activity?	Never – Did Not Wake (0), Rarely - Not At All (1), Sometimes - Not At All (2), Often - Not At All (3), Rarely – Slightly (4), Sometimes – Slightly (5), Often – Slightly (6), Rarely – Moderately (7), Sometimes - Moderately (8), Often – Moderately (9), Rarely – Extremely (10), Sometimes – Extremely (11), Often – Extremely (12)
#3. Noise sources - (1) if selected, otherwise (0):	Medical Equipment in Patient Room, Alarms in Patient Room, Talking In Patient Room, Rolling Carts in Hallway, TV Noise, Other Entertainment Devices, Medical Equipment Outside Patient Room, Alarms Outside Patient Room, Talking Outside Patient Room, Office Equipment Outside Patient Room, HVAC, Other Comments
#4a. and 4b., Did you ever have a hard time hearing or understanding the comments from staff because of noise? If so, how often?	No – Never (0), Yes – Rarely (1), Yes – Sometimes (2), Yes – Often (3)
#5a. and 5b., Were you able to hear other patients, guests or staff discussing private information that did not pertain to you in the areas around you? If so, how often?	No – Never (0), Yes – Rarely (1), Yes – Sometimes (2), Yes – Often (3)
#6. Would you describe yourself as being sensitive to noise?	Yes(1), No(0)

Table 4.3

Non-parametric tests used to analyze data in this study.

Statistical Test	**Definition**	**Variables Required**	**Assumptions/Conditions**
Chi-square, χ^2	A test for independence to see if two categorical variables are related	two categorical variables with two or more categories each	Independent observations that fall into mutually exclusive and exhaustive categories, each person or case contributes to only one cell, cannot use with repeated measures design, random sample, independent observations, not normally distributed population
Chi-square, χ^2	A test for goodness of fit to project expected values for a variable	one categorical variable with two or more categories each (Yes/No)	Independent observations that fall into mutually exclusive and exhaustive categories, each person or case contributes to only one cell, cannot use with repeated measures design, random sample, independent observations, not normally distributed population
Kruskal-Wallis	A test to compare the scores on some continuous variable for three or more groups	one categorical independent variable with three or more categories and one continuous dependent variable	random sample, independent observations, not normally distributed population
Mann-Whitney U	A test for differences between two independent groups on a continuous measure	one categorical variable with two groups and one continuous variable	random sample, independent observations, not normally distributed population

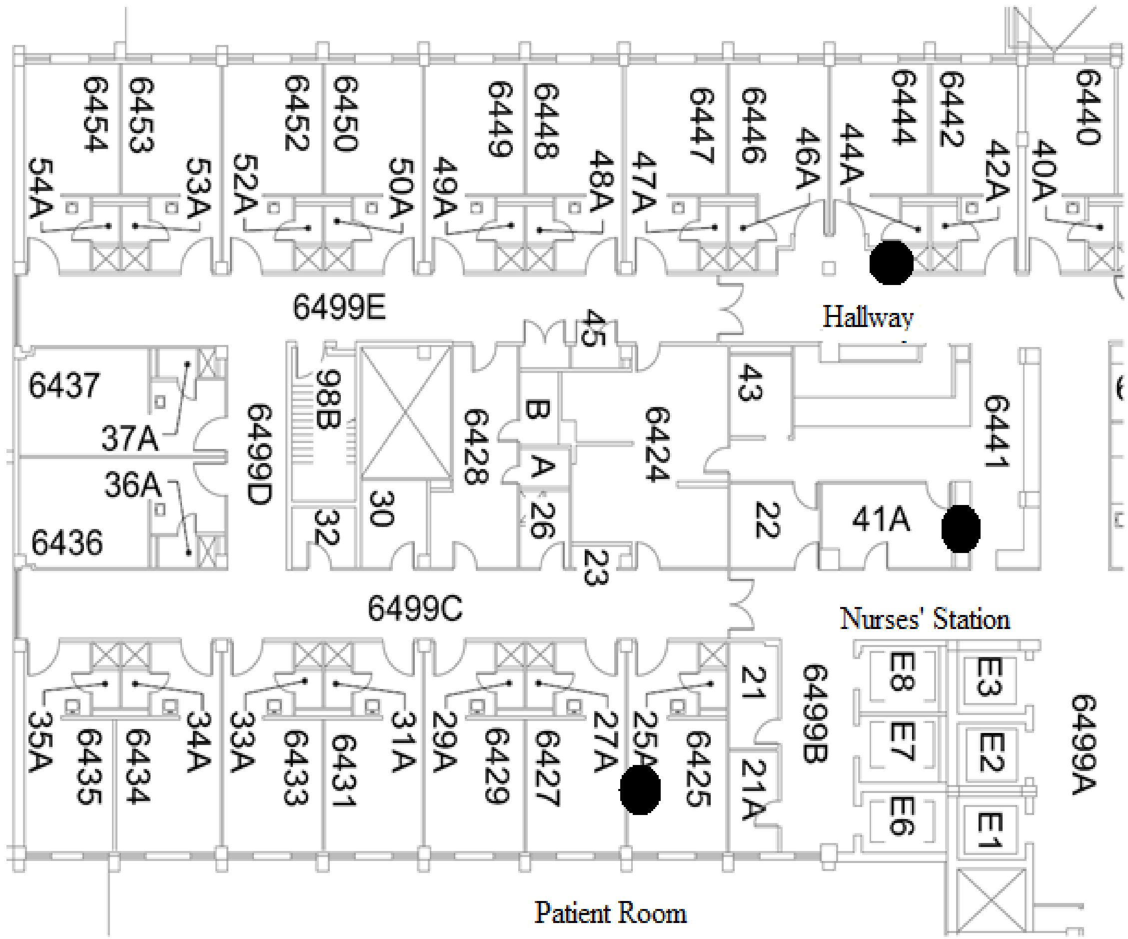
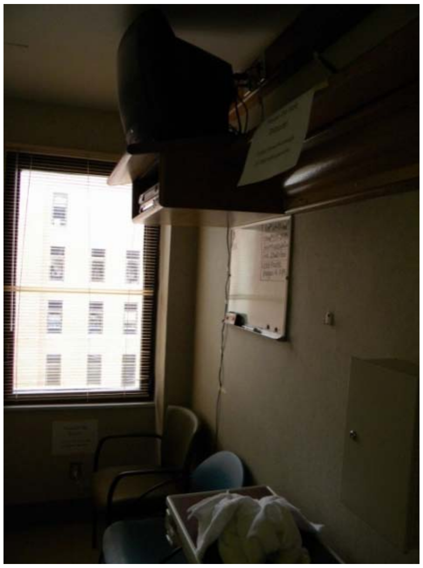


Figure 4.1. Floor plan of Nebraska Medical Center University Tower 6 West. Black dots indicate location of sound level meters.

(a)

(b)



(c)

Figure 4.2: Views of the before renovation material finishes and sound level meter set-up in University Tower 6 West. (a) the nurses' station, (b) the patient room, and (c) the hallway.

(a)

(b)

(c)

Figure 4.3: Views of the after renovation material finishes and sound level meter set-up in University Tower 6 West. (a) the nurses' station, (b) the patient room, and (c) the hallway.

CHAPTER 5: RESULTS

Chapter 4 outlines the procedures used to obtain the data. Chapter 5 will discuss the results of these measurements in detail. First the objective sound level meter measurements will be discussed; then the subjective survey results will be examined. Next Chapter 6 will state the conclusions to the study drawing upon the findings stated below.

5.1 Objective Measurements

Measurements using the sound level meter were recorded for three time periods. The three time periods are as follows: before renovation time period (December 2009), during renovation time period (March 2010), and after renovation time period (May 2010). All the measurement periods lasted for four workdays starting on Monday of each respective week.

A comparison of all these values can be found in Figure 5.1 where the average overall L_{Aeq}, average night L_{Aeq}, and average day L_{Aeq} can be seen. The hours for the daytime measurements were 7AM to 10PM, and the hours for nighttime measurements were 10PM to 7 AM. Here it can be seen that the nighttime values are quieter than the daytime ones at all three locations during each time period. The during renovation overall levels had no noticeable difference between the locations. The before renovation values for the three locations shows the hallway does have a 5 dBA higher sound level than the other two locations which is a noticeable difference. The patient room's night before value drops then increases in the during renovation period. The hallway location in Figure 5.1(a) indicates a sound level of 63 dBA for the daytime; however upon careful examination of Figure 5.4(a) and Figure 5.12 this is most likely due to a piece of equipment being left in the space near the sound level meter for a prolonged period of time. This would increase the sound level.

From Figure 5.1(c), the hallway is the quietest of all three locations during both daytime and nighttime periods. The hallway values had the greatest change between the before renovation period and during renovation period with a decrease of 8 dBA. The overall L_{Aeq} after renovation values show just noticeable differences in sound level with a decrease of 3 dBA when comparing the hallway location to the patient room and the nurses' station.

Figure 5.2 shows the L_{Aeq} for the nurses' station during the day and night for each day of the week for before, during, and after renovations. The lowest L_{Aeq} value is 57 dBA for the nurses' station and the highest L_{Aeq} is 60 dBA. Figure 5.2(a) shows a 10 dBA difference between the day and night average. Both values are higher than WHO guidelines. Monday and Wednesday do have a just noticeable difference; however, the night values are consistent with each other. Figure 5.2(b) shows either no noticeable difference or a just noticeable difference between days and nights of the week. Figure 5.2(c) indicates no noticeable difference between the before and after renovation values.

Figure 5.3 shows the L_{Aeq} for the patient room during the day and night for each day of the week for before, during, and after renovations. Part (a) of Figure 5.3 shows that the day values increased as the week went on with a difference of 6 dBA from Monday to Thursday. Figure 5.3(b) shows only a just noticeable difference between the days of the week but no noticeable difference for the night values. Figure 5.3(c) has the most difference between values when compared to the other two locations for nights of the week. However, the average values are in line with the overall average values.

Figure 5.4 shows the L_{Aeq} for the hallway during the day and night for each day of the week for before, during, and after renovations. These figures show that very little difference occurs between each day of the week and values were fairly consistent from the three different periods. Part (a) of Figure 5.4 indicates an 11 dBA increase from Monday to Tuesday then a 13 dBA drop from Tuesday to Wednesday for the day values. This is the most dramatic change of decibel values between days and nights of the week. Tuesday stands out from the other days and must have had some significant noise. Part (b) of Figure 5.4 shows that overall values for night decrease. The before renovation to during renovation values increased by 6 dBA for the day measurement. Figure 5.4(c) indicates that something happened on Tuesday for the before period in the hall because the day L_{Aeq} went down significantly when compared to the during renovation and after renovation time periods. This is most likely due to equipment noise from a piece of equipment left in that location for a long duration of time, as supported by the spectral plot in Figure 5.12 which shows a clear peak at 1200 Hz.

Overall, the L_{Aeq} values for each of the different locations for each of the different time periods did not change significantly. All the values are above the recommended guidelines, though. The A-weighted L_{eq} is 51 to 63 dBA for all three measurement locations: nurses' station, patient room, and hallway for all three time periods: before renovation, during renovation, and after renovation. These values are similar to the ones obtained in the Busch-Vishniac et al. (2005) study. However, in the current study no specific ranking of which location was loudest could be determined since each location's values were numerically close to each other.

Next, comparisons of L_{10} and L_{90} values are presented in Figure 5.5, where L_{10} values are taken to correspond to peak noise levels while L_{90} values correspond to ambient noise levels. The patient room seems to have the greatest range in peak values for each of the different days of the week. The hallway has smaller variations in the L_{10} peak values for each day of the week. During the day ambient L_{90} levels typically fall below 50 dBA for all locations with most in the range of 45-50 dBA. However, this range is still 5 to 10 dBA or more, above the given guidelines by WHO.

Figure 5.5 shows average L_{10} and L_{90} values for each location for the whole measurement time period. It indicates what would be expected, that the L_{10} peak values are greater than the L_{90} ambient values for each location. Overall both the L_{10} and L_{90} are over the WHO guidelines as presented earlier in Section 2.1. Additionally, the values are consistent and do not show much variation even on the order of a just noticeable difference. The nurses' station L_{90} stayed about the same sound level from before renovation, during renovation, and after renovation. The patient room L_{90} went down 5 dBA from before to after renovation. The hallway L_{90} went down 3 dBA from before renovation to after renovation. For the L_{10} measurement, the nurses' station sound values did not change from before renovation, during renovation, to after renovation. The patient room L_{10} increased by 2 dBA from before renovation to after renovation. The hallway L_{10} increased by 5 dBA from before renovation to after renovation.

Figures 5.6-5.11 show the L_{10} and L_{90} daytime values and nighttime values for all three locations for each of the time periods. The hallway and the nurses' station have high peak values for each day of the week when compared to the patient room. Therefore, these would have a greater range of noise fluctuations throughout the night.

This would indicate that during what is supposed to be a restful period the patients' room is relatively quiet when compared to the hallway and nurses' station because there is not as many high dBA L_{10} values or variations in the peak noise levels. The hallway has the highest nighttime ambient level.

Figures 5.12-5.14 show the spectral data. Lower frequencies have higher sound levels for all three locations with some small peaks, especially for the patient room at the middle frequencies. Other peaks around 63 Hz and its harmonics are most likely from electrical equipment. These peaks appear in all the spectral plots. The peaks in the middle frequency ranges may be attributed more likely to human speech. In Figure 5.12, a peak around 1200 Hz is visible for the before renovation hallway location. This would indicate that a piece of equipment was left near the sound level meter at the hallway location for a large portion of Tuesday during that particular measurement week. This would lead to the higher L_{Aeq} values seen in Figure 5.1 for the average day and overall L_{Aeq} values.

5.2 Subjective Survey Results

The purpose of the survey was to measure people's perceptions of the noise in the hospital and determine what the most offensive sound sources were in the during renovation and after renovation time periods. The number of discharged patients from University Tower 6 West eligible to participate in the survey between March 2 and June 11, 2010, was 210. Of the 158 patients who responded, 108 were in the during renovation period from March 2 to April 30 and 50 were in the after renovation period from May 1 to June 11; for an overall response rate of 75%. A response rate of 83% for the during renovation time period was obtained. A response rate of 62.5% for the after renovation time period was obtained. There were a few missing responses for gender or age, and twenty-one responders who did not indicate whether they considered themselves hard of hearing while 4 did not answer the *Sensitive to Noise* question.

The survey analysis involved a statistical approach. As the descriptive statistics indicate in Tables 5.1 and 5.2, the continuous variables: *Age, Awakened and Annoyed at Night, Disturbed and Annoyed During the Day, Hard Time Understanding Spoken Comments* and *Able to Hear Patient Private Info Being Discussed* do not have a normal distribution, as the Test of Normality section lists the Kolmorgorov-Smirnov Significance value =0.00 << 0.05 indicating that this is a non-normal distribution. The various histograms shown in the respective sections discussing the results of each variable also show the non-normal distribution. For example, Figure 5.15 is a histogram of the age levels of the people who took the survey. Although the distribution began to approach a normal distribution as the after renovation responders were added to the during renovation responses, it is still not sufficient as is to use parametric analysis methods (see Tables 5.1 and 5.2). Since *Gender, Describe Yourself as Hard of Hearing,* and *Sensitive to Noise* are non-continuous variables with only two answers (male/female or yes/no) they do not have a distribution.

The distribution of *Ag*e is given in Figure 5.15 as counts and Figures 5.16 to 5.17 as percentages: during renovation, after renovation, and of total respondents. In most instances, as described below, age was not a factor in the responses received.

Females were the majority of the responders (99 females to 56 males), with 3 respondents not reporting gender (Figures 5.18 to 5.19). Based upon further analysis presented below, gender itself was not a factor in the responses received.

The results of the survey question "Would you describe yourself as hard of hearing" are shown in Table 5.3. The lower response percentage of this portion of the survey makes the overall results questionable. The Mann-Whitney Test indicates that *Gender* has no statistically significant relationship to the responses regarding hard of hearing (during renovation p=0.40, after renovation p=0.08 and total p=0.06). The Kruskal-Wallis Test also found no statistical significance between *Age* and *Describe Yourself as Hard of Hearing* (during renovation p=0.05, after renovation p=0.70 and total p=0.10).

Responses to the annoyance questions are summarized in Figures 5.20 and 5.21. The survey results show that over 80%, of the patients were not annoyed at all or only slightly annoyed by the noise in the daytime for either time phase of the survey (Figures 5.22 and 5.23). Figures 5.24 and 5.25 indicate that the number who reported being awakened and annoyed increased slightly for the nighttime period with approximately 72% of patients not being annoyed or slightly annoyed. For both daytime and nighttime and during renovation and after renovation periods almost 60% of patients were not annoyed at all by noise. Overall despite the noise levels exceeding the recommendations, the majority of respondents did not report any significant level of annoyance at the noise. One reason could be their ailments were not as severe as those who were more annoyed. Another reason could be they are naturally less noise sensitive.

A chi-square analysis was run for the expected after renovation group responses of the variables *Awakened and Annoyed at Night* and *Disturbed and Annoyed During the Day* based on the during renovation group responses for these variables. As shown in Table 5.4, there is no statistical difference between the responses concerning *Awakened* *and Annoyed at Night* (p=0.80) or *Disturbed and Annoyed During the Day* (p=0.76) from the during renovation to after renovation periods. However, these results are weak statistically speaking because the large degree of freedom for each variable (9 for night annoyance, 10 for day annoyance) requires a much larger survey in order to eliminate just chance for the numbers received in the survey for the after renovation group. Chi-square degrees of freedom of 9, 10 or 11 would require a number of results equal or greater than 17, 19, or 20 respectively in the cells of the possible variable outcomes to eliminate chance alone as the cause. A survey population of 50 is not large enough for this result.

Since the *Awaked and Annoyed at Night, Disturbed and Annoyed During the Day* and *Age* variables are not normally distributed or homogeneous, a Kruskal-Wallis analysis was run to determine if there was a relationship. This test compares two groups of continuous variables, in this case *Disturbed and Annoyed During the Day* or *Awaked and Annoyed at Night* and *Age*. This was used instead of ANOVA because a normal distribution is required for ANOVA analysis. The results in Table 5.5 for the during renovation group (p=0.09 for night and 0.34 for day) indicate no statistical relationship. For the after renovation group a weak relationship is indicated between *Age* and *Awakened and Annoyed at Night* (p=0.05) and no significance between *Age* and *Disturbed and Annoyed During the Day* (p=0.46). The results shown in Table 5.5 for the total group indicate that there is no relationship between *Age* and level of *Disturbed and Annoyed During the Day* (p=0.30). A possible relationship was found for the *Awakened and Annoyed at Night* (p = 0.03). Using additional Mann-Whitney U tests with two selected age groups at a time, Table 5.6 shows that there was a slight difference at night between the 46-50 and 51-55 years age groups.

Using the Mann-Whitney U test, no relationship was found between *Gender* and *Awakened and Annoyed at Night* or *Disturbed and Annoyed During the Day* as indicated in Table 5.7 (p values range from 0.12 to 0.83 > 0.05). Table 5.8 provides a more detailed breakdown of *Gender* and *Awakened and Annoyed at Night* and *Gender* and *Disturbed and Annoyed During the Day* for the total patient group.

From the survey results shown in Figure 5.26 very few patients (9%) of the total group had a hard time hearing what was said to them. A chi-square analysis (Table 5.9) determined that there was no statistical difference between the during renovation *Hard Time Understanding Spoken Comments* count and the after renovation *Hard Time Understanding Spoken Comments* count with a p=0.57.

The Kruskal-Wallis analysis determined that there was no relationship between *Age* and *Hard Time Understanding Spoken Comments* (during renovation p=0.86, after renovation p= 0.34, total p= 0.47). A Mann-Whitney U test determined *Gender* did not influence responses on having a *Hard Time Understanding Spoken Comments* (during renovation p=0.16, after renovation p= 0.91, total p= 0.32) either, as shown in Table 5.10. Table 5.11 provides more detailed information concerning *Gender* and *Hard Time Understanding Spoken Comments* and *Able to Hear Patient Private Info Being Discussed* for the total group of patients.

A greater concern was being able to overhear other private conversations (Figure 5.27). Indeed some of the patients noted that they were able to hear the discussions between other patients and their care providers which prompted concerns of privacy. One respondent even stated that the private conversations that they overheard were a source of entertainment. Of those surveyed, 33% of each of the all three groups could overhear private conversations (see Figure 5.30).

The chi-square information, shown in Table 5.12, for *Able to Hear Patient Private Info Being Discussed* determined no statistical significance between the during and after renovation responses (p= 0.21).

A Mann-Whitney U test determined that there was no relationship between *Gender* and *Able to Hear Patient Private Info Being Discussed* (during renovation p=0.64, after renovation p=0.26, total p=0.81), Table 5.13. This table also has the results of the Kruskal-Wallis Test which indicate no statistical significance between *Age* and *Able to Hear Patient Private Info Being Discussed* (during renovation p=0.52, after renovation p=0.35, total p=0.25).

Figures 5.28 and 5.29 show the *Sensitive to Noise* results. Figure 5.28 is the frequency of number of respondents. Of the 158 respondents indicated that 116 respondents were not sensitive to noise, 38 respondents said they were sensitive, and 4 people did not answer the question. Then Figure 5.29 shows the percentages. A large majority, 73%, of the total did not have a self-reported noise sensitivity.

The chi-square results shown in Table 5.14 found no significant statistical relationship between the during renovation and after renovation counts for the *Sensitive to Noise* variable (p=0.12).

The Kruskal-Wallis analysis of Table 5.15 indicates no relationship between *Age* and *Sensitive to Noise* (during renovation p=0.87, after renovation p=0.39 and total p=0.69). The Mann-Whitney U test, Table 5.15, indicates no relationship between *Gender* and *Sensitive to Noise* (during renovation p=0.76, after p=0.46 and total p=0.59). Table 5.16 provides a more detailed breakdown of *Gender* and *Sensitive to Noise* for the total group.

Some additional Mann-Whitney Tests were run to determine if any relationships existed among other variables. Table 5.17 indicates that some statistical relationships exist between *Describe Yourself as Hard of Hearing* and *Awaked and Annoyed at Night* or *Disturbed and Annoyed During the Day*. Per Table 5.18 those patients who responded to the survey question that they were more sensitive to noise were more annoyed during the night (p=0.03) and day (p=0.002) during the renovation. Also those patients who responded to the survey question that they were more sensitive to noise were more annoyed at night (p=0.001) after the renovation, than those who did not indicate they were more sensitive to noise.

5.3 Noise Sources

Table 5.19 has the survey counts for the sources of noise in this study. The list is in order of ranking based upon the count each item received: *Alarms Inside the Patient Room, Medical Equipment in the Patient Room, Talking in Patient Room, Rolling Carts, Alarms Outside Patient Room*, etc. For example *Talking in Patient Room* was listed as a source of noise from 45 people in the during renovation group and 12 from the after renovation group, for a total of 57 people. The percentage is based on the count within each group, during or after renovation. The total count for the during renovation group was 343, so for *Talking in Patient Room* 45 of 343 is 13.1%. Note that this percent is not the percentage of people who checked this item but rather the percentage of total check marks for all the items in the rankings. Figures 5.30, 5.31, and 5.32 depict the percentages of each noise source, during renovation, after renovation and total respectively.

Part of the challenge in analyzing the survey data was that the question regarding noise sources was marked inconsistently. A few respondents ranked the sources as requested from one through five, while others just marked all the noise sources that bothered them with check marks. Others marked several items with number one or two, etc., and did not clearly indicate which was their top choice. To use the results of the survey, every item checked was counted one time in calculating the total count; the total count was used to establish the order of ranking for the noise source items. If 45 people out of 108 people marked a particular noise source, then the data is interpreted as having 41% of people list this item based on the total count of all noise source items.

Figure 5.30 shows the top noise sources during the renovation. The top complaints seem to be consistent both during and after the renovation even though they may have moved up or down a position or two within the list. After the renovations, the new ranking of noise sources listed from most to least: *Alarms in Patient Room, Rolling Carts in Hall*, *Medical Equipment in Patient Room, Other Noise* (based upon comments this mostly stems from roommate issues), *TV Noise,* and *Talking in Patient Room,* as shown in Fig. 5.31. Figure 5.32 shows the overall ranking of noise sources.

The noise from *HVAC* equipment only accounted for 2% of the total tally, same as the percentage for the *Other Entertainment Devices.*

The chi-square "goodness of fit" analysis was run for all noise sources to obtain the expected after renovation group count number for the noise sources based on the during renovation group responses. Each noise source has been treated as a separate variable with a yes or no answer, and has therefore 1 degree of freedom which for p=0.05 have an expected value of 3.84; so the counts which are greater than 4 are statistically valid and not due to chance alone. For example, the chi-square method predicts that of the 50 people in the after renovation group, 21 people would be expected to select *Talking in Patient Room* as a source of noise. Since only 12 people selected this option, this represents a decrease of 42% from the expected value, hence –42% is listed in Table 5.6. Since the $p=0.02 < 0.05$, this is a statistically significant result.

The most noticeable difference is that *TV Noise* complaints doubled from during renovation (at 5%) to after renovation (10%). The chi-square analysis indicates that there was a 100% increase from the expected count with a p value of $0.002 < 0.05$. This could be due to an increase in usage of the new audio-visual system. Perhaps patients wanted to try out a new device that they do not have at home or because the item itself was new. Based on the change in percentages, five noise sources seemed to decrease significantly from the during renovation to after renovation surveys. These were *Talking in Patient Room* (-42%), *Talking Outside Patient Room* (-28%), *Alarms Outside Patient Room* (-30%), *Office Equipment Outside Patient Room* (-40%) and *Other Entertainment Devices Noise* (-33%). However based on the p value having to be less than 0.05, only *Talking in Patient Room* and *TV Noise* discussed above can be consider statistically significant. See Table 5.11.

In terms of what noise sources the subjects were most concerned with, the most bothersome ones were from the equipment needed for the patient's care and the behavior of other people such as roommates watching TV, roommates having visitors, or staff treating the roommates. Medical equipment in a patient's room has alarms that may bother patients; however, not much can be done about this since alarm sound levels are regulated to ensure patient's safety. Based on previous research, distributing earplugs to individual patients could help with this by allowing patients an option to help block out the noise.

5.4 Comments from Patients and Other Suggestions

One suggestion made by many patients is the need for private hospital rooms. Having individual rooms would address many of the patients' concerns gathered from the survey. However, this may not be financially feasible.

Other ideas could be to remove the TVs from patient rooms to decrease the amount of discord over the TV and provide a quieter environment. While many of the devices and equipment in the patient's room are necessary for patients' health, the TV's only function is entertainment and is consequently not necessary. If this is not an option, then limiting TV watching to certain hours of the day (like visiting hours) or giving patients earphones for their individual TV may help.

There were a number of comments about the noise created by people accessing the supply or equipment rooms; these could be resolved by relocating the rooms or limiting the hours they can be entered. Several people also noted that the floor cleaning machines were a source of noise. Perhaps different machines or method of cleaning could be instituted.

Another major concern expressed by subjects involved privacy of their personal information. Many survey respondents indicated their disapproval over having their diagnosis given out and discussed in front of others or at having to hear the diagnosis of other patients, who shared the same room as them. Doctors should use patient consultation rooms, keep their voices lower when giving diagnosis, and incorporate a white noise generator into the environment to help mask their private discussions with patients.

Table 5.1

Continuous variable descriptive statistics information.

		Age		***Awakened and Annoyed at PM***		***Disturbed and Annoyed During the AM***		***Hard Time Understanding Spoken Comments***		***Able to Hear Patient Private Info Being Discussed***	
		Statistic	**Std. Error**	**Statistic**	**Std. Error**	**Statistic**	**Std. Error**	**Statistic**	**Std. Error**	**Statistic**	**Std. Error**
Mean		6.13	0.224	3.58	0.286	3.11	0.255	0.28	0.056	0.89	0.089
95% Confidence Interval for Mean	**Lower Bound**	5.69		3.02		2.6		0.17		0.72	
	Upper Bound	6.57		4.15		3.61		0.4		1.07	
5% Trimmed Mean		6.1		3.33		2.83		0.18		0.82	
Median		6		2		2		0		0	
Variance		7.803		12.907		10.262		0.498		1.251	
Std. Deviation		2.793		3.593		3.203		0.706		1.118	
Minimum		1		0		0		0		0	
Maximum		12		12		12		3		3	
Range		11		12		12		3		3	
Interquartile Range		3		6		5		0		2	
Skewness		0.025	0.194	0.741	0.193	1.034	0.193	2.507	0.193	0.745	0.194
Kurtosis		-0.532	0.386	-0.626	0.384	0.305	0.384	5.384	0.384	-1.012	0.385

a. Skewness = 0.0 and kurtosis = 0.0 would indicate a normal distribution. Positive skew indicates scores clustered to the left of the graph; negative scores cluster to the right of the graph. Positive kurtosis indicates the distribution has a peak; negative kurtosis indicates a flat distribution.

Table 5.2

Test of normality for variables.

Variables	**Kolmorgorov-Smirnov[a]**			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.b**	**Statistic**	**df**	**Sig.c**
Age	.100	156	.001	.969	156	.001
Awakened and Annoyed at Night	.232	158	.000	.860	158	.000
Disturbed and Annoyed During the Day	.205	158	.000	.854	158	.000
Hard Time Understanding Spoken Comments	.492	158	.000	.458	158	.000
Able to Hear Patient Private Info Being Discussed	.348	157	.000	.738	157	.000

a. Lilliefors Significance Correction.
b. Sig. < .05 signifies non-normal distribution.
c. Sig. <.05 signifies non-normal distribution.

Table 5.3

Information and tests for *Describe Yourself as Hard of Hearing*.

		During Renovation			**After Renovation**			**Total**		
			N	**Percent**		**N**	**Percent**		**N**	**Percent**
Describe Yourself as Being Hard of Hearing	No		86	79.6		39	78.0		125	79.1
	Yes		7	6.5		5	10.0		12	7.6
	Subtotal		93	86.1		44	88.0		137	86.7
	Missing		15	13.9		6	12.0		21	13.3
	Total		108	100.0		50	100.0		158	100.0
Mann-Whitney Test										
	Gender	**N**	**Mean**	**Sum of Ranks**	**N**	**Mean**	**Sum of Ranks**	**N**	**Mean**	**Sum of Ranks**
Describe Yourself as Being Hard of Hearing	Males	31	47.40	1469.50	19	24.63	468.00	50	71.95	3597.50
	Females	60	45.28	2716.50	25	20.88	522.00	85	65.68	5582.50
	Total	91			44			135		
Test Statistics[a]										
Mann-Whitney U				886.50			197.00			1927.50
Wilcoxon W				2716.50			522.00			5582.50
Z				-0.85			-1.75			-1.90
p value				0.40			0.08			0.06
Kruskal-Wallis Test										
	Age		**N**	**Mean Rank**		**N**	**Mean Rank**		**N**	**Mean Rank**
Describe Yourself as Being Hard of Hearing	19 to 25		5	43.50		2	19.50		7	62.50
	26 to 30		9	43.50		1	19.50		10	62.50
	31 to 35		4	43.50		0	.00		4	62.50
	36 to 40		6	51.25		2	19.50		8	71.00
	41 to 45		19	45.95		6	19.50		25	65.22
	46 to 50		12	47.38		5	19.50		17	66.50
	51 to 55		10	48.15		9	21.89		19	69.66
	56 to 60		11	43.50		7	22.57		18	66.28
	61 to 65		6	51.25		2	19.50		8	71.00
	66 to 70		6	43.50		6	26.67		12	73.83
	71 to 75		2	43.50		0	.00		2	62.50
	76 +		3	74.50		3	26.67		6	96.50
	Total		93			43			136	
Test Statistics[b,c]										
Chi-square				19.553			6.393			17.144
df				11			9			11
p value				.052			.700			.104

a. Grouping Variable: Gender.
b. Kruskal Wallis Test.
c. Grouping Variable: Age.

Table 5.4

Annoyance chi-square count predictions.

Awakened and Annoyed at Night	**Observed N**	**Ratio**	**Expected N**	**Residual**
Never Awakened or annoyed	16	0.2222	11.5	4.5
Rarely Awakened, Not at all annoyed	12	0.2037	10.6	1.4
Sometimes Awakened, Not at all annoyed	3	0.0555	2.9	0.1
Often Awakened, Not at all annoyed	1	0.0185	1	0
Rarely Awakened, Slightly annoyed	2	0.0648	3.4	-1.4
Sometimes Awakened, Slightly annoyed	4	0.1203	6.2	-2.2
Often Awakened, Slightly annoyed	3	0.1018	5.3	-2.3
Sometimes Awakened, Moderately annoyed	1	0.0462	2.4	-1.4
Often Awakened, Moderately Annoyed	6	0.0925	4.8	1.2
Often Awakened, Extremely Annoyed	2	0.037	1.9	0.1
Total	50	0.9625		
Chi-square	5.389[a]			
df	9			
p value	0.799			

Disturbed and Annoyed During the Day	**Observed N**	**Ratio**	**Expected N**	**Residual**
Never Disturbed or annoyed	12	0.2592	13	-1
Rarely Disturbed, Not at all annoyed	11	0.1944	9.7	1.3
Sometimes Disturbed, Not at all annoyed	8	0.0925	4.6	3.4
Often Disturbed, not at all annoyed	1	0.0092	0.5	0.5
Rarely Disturbed, Slightly annoyed	3	0.1111	5.6	-2.6
Sometimes Disturbed, Slightly annoyed	6	0.1574	7.9	-1.9
Often Awakened, Slightly annoyed	1	0.0462	2.3	-1.3
Sometimes Disturbed, Moderately annoyed	4	0.0555	2.8	1.2
Often Disturbed, Moderately Annoyed	2	0.0277	1.4	0.6
Sometimes Disturbed, Extremely Annoyed	1	0.0185	0.9	0.1
Often Disturbed, Extremely Annoyed	1	0.0277	1.4	-0.4
Total	50	0.9994		
Chi-square	6.622[b]			
df	10			
p value	0.761			

a. 6 cells (60.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.0.
b. 7 cells (63.6%) have expected frequencies less than 5. The minimum expected cell frequency is .5.

Table 5.5

Kruskal-Wallis test for *Age* and *Awakened and Annoyed at Night* and *Age* and *Disturbed and Annoyed During the Day*.

	Awakened and Annoyed at Night						*Disturbed and Annoyed During the Day*					
Age	**During N**	**During Mean Rank**	**After N**	**After Mean Rank**	**Total N**	**Total Mean Rank**	**During N**	**During Mean Rank**	**After N**	**After Mean Rank**	**Total N**	**Total Mean Rank**
19 to 25	7	33.93	2	8.50	9	45.28	7	32.43	2	16.50	9	47.78
26 to 30	10	58.85	3	30.67	13	90.04	10	39.90	3	16.83	13	57.08
31 to 35	6	44.08	1	41.00	7	76.64	6	49.33	1	43.50	7	81.50
36 to 40	7	56.86	2	15.25	9	75.28	7	64.14	2	17.50	9	85.28
41 to 45	20	59.55	8	13.56	28	74.30	20	61.63	8	21.44	28	82.86
46 to 50	15	60.83	5	35.00	20	93.85	15	61.87	5	31.40	20	92.00
51 to 55	11	43.18	10	20.55	21	62.36	11	55.86	10	21.85	21	75.14
56 to 60	12	65.75	7	28.21	19	91.42	12	59.50	7	27.93	19	86.71
61 to 65	7	27.00	2	28.75	9	51.00	7	44.50	2	40.50	9	79.06
66 to 70	7	53.36	6	32.42	13	88.12	7	47.07	6	29.67	13	80.00
71 to 75	2	96.00	0	.00	2	140.00	2	79.75	0	.00	2	117.00
76 +	3	55.83	3	35.33	6	94.25	3	39.17	3	20.50	6	60.83
Total	107		49		156		107		49		156	

Test Statistics[a,b]

Chi-square		17.672		18.445		21.562		12.358		9.778		12.873
Degrees of Freedom		11		10		11		11		10		11
p value		0.09		0.05		0.03		0.34		0.46		0.30

Table 5.6

Mann-Whitney U test of *Age* and *Annoyance*.

Annoyance	***Age***	**N**	**Mean Rank**	**Sum of Ranks**	**Mann-Whitney U**	**Wilcoxon W**	**Z**	**Asymp. Sig. (2-tailed) p value**	**Exact Sig. [2*(1-tailed Sig.)]**
Awakened and Annoyed at Night	19 to 25	9	5.11	46.0	1	46	-2.056	0.04	.073[a]
	71 to 75	2	10	20.0					
	Total	11							
Awakened and Annoyed at Night	31 to 35	7	16.5	115.5	59.5	290.5	-0.767	0.443	.466[a]
	51 to 55	21	13.83	290.5					
	total	28							
Awakened and Annoyed at Night	46 to 50	20	25.28	505.5	124.5	355.5	-2.267	0.023	---
	51 to 55	21	16.93	355.5					
	Total	41							
Awakened and Annoyed at Night	41 to 45	28	26.71	748.0	246	477	-0.994	0.32	---
	51 to 55	21	22.71	477.0					
	Total	49							
Awakened and Annoyed at Night	31 to 35	7	6.29	44.0	16	44	-0.721	0.471	0.534
	76+	6	7.83	47.0					
	Total	13							

a. For all groups except 46-50/51-55 the sig. Is > 0.05 (Exact sig. for groups less than 30), therefore no significance. For the 46-50/51-55 the 46-50 group exhibited higher annoyance at night.

Table 5.7

Gender and *Annoyance* p values of Mann-Whitney U test.

Null Hypothesis	**During Renovation**	**After Renovation**	**Total**
The distribution of *Awakened and Annoyed at Night* is the same across all categories of *Gender*.	0.456	0.118	0.831
The distribution of *Disturbed and Annoyed During the Day* is the same across all categories of *Gender*.	0.751	0.439	0.447
Since all p>0.05 retain the null hypothesis. Distribution is the same across all categories of *Gender* for AM and PM *Annoyance*.			

Table 5.8

Mann-Whitney U test of *Gender* and *Annoyance* for total group.

Ranks and Test Statistics

Annoyance	***Gender***	**N**	**Mean Rank**	**Sum of Ranks**	**Mann-Whitney U**	**Wilcoxon W**	**Asymp. Sig. (2-tailed)** **p value**	**Z**
Awakened and Annoyed at Night	Males	56	79.01	4424.5				
	Females	99	77.43	7665.5				
	Total	155						
	Statistics				2715.5	7665.5	0.831	-0.214
Disturbed and Annoyed During the Day	Males	56	81.59	4569				
	Females	99	75.97	7521				
	Total	155						
	Statistics				2571	7521	0.447	-0.761

a. The rankings indicate that there was slightly more annoyance at night than during the day. Since 0.83 and 0.45 > 0.05 there is no difference between male and females for annoyance levels day or night.

Table 5.9

Chi-square prediction for expected counts of *Hard Time Understanding Spoken Comments*.

Hard Time Understanding Spoken Comments

	Ratio	**Observed N**	**Expected N**	**Residual**
No hard time hearing at any time	0.843	41	42.1	-1.1
Rarely hard time hearing	0.074	3	3.7	-.7
Sometimes hard time hearing	0.056	5	2.8	2.2
Often hard time hearing	0.028	1	1.4	-.4
Total	1.001	50		

Test Statistics

	Hard Time Understanding Spoken Comments
Chi-square	2.009[a]
df	3
p value	.571

> 0.05 Not significant

a. 3 cells (75.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.4.

Table 5.10

Tests of *Hard Time Understanding Spoken Comments* and *Gender* and *Age*.

Mann-Whitney U Test p values

	During Renovation	**After Renovation**	**Total**
The distribution of *Hard Time Understanding Spoken Comments* is the same across categories of *Gender*	0.16	0.91	0.32
Since p> 0.05 retain the null hypothesis that the distribution of *Hard Time Understanding Spoken Comments* is the same across categories of *Gender*			

Kruskal-Wallis Test

	Age	**During N**	**During Mean Rank**	**After N**	**After Mean Rank**	**Total N**	**Total Mean Rank**
Hard Time Understanding Spoken Comments	19 to 25	7	46.00	2	20.50	9	66.00
	26 to 30	10	50.95	3	27.67	13	76.92
	31 to 35	6	54.25	1	20.50	7	76.14
	36 to 40	7	61.71	2	31.25	9	91.67
	41 to 45	20	51.30	8	20.50	28	71.46
	46 to 50	15	57.10	5	20.50	20	78.10
	51 to 55	11	55.64	10	30.60	21	88.71
	56 to 60	12	54.83	7	24.14	19	78.37
	61 to 65	7	53.07	2	33.25	9	83.00
	66 to 70	7	54.07	6	20.50	13	72.31
	71 to 75	2	74.25	0	.00	2	107.00
	76 +	3	46.00	3	29.00	6	79.67
	Total	107		49		156	

Test Statistics[a,b]

Chi-square			6.226		11.282		10.748
df			11		10		11
p value			.858		.336		.465

a. Kruskal Wallis test.
b. Grouping Variable: *Age.*
c. Since p> 0.05 the distribution of *Sensitive to Noise* is the same across categories of *Age.*

Table 5.11

Gender and *Hard Time Understanding Spoken Comments* and *Able to Hear Patient Private Info Being Discussed*-total group.

		Do you have a hard time understanding spoken comments			**Were you able to hear patient private info being discussed**		
		No	**Yes**	**Total**	**No**	**Yes**	**Total**
Males	Count	49	7	56	33	23	56
	% within *Gender*	87.5%	12.5%	100.0%	58.9%	41.1%	100.0%
	% within *Hard Time Understanding Spoken Comments*	37.7%	28.0%	36.1%	---	---	---
	% within *Able to Hear Patient Private Info Being Discussed*	---	---	---	38.4%	33.8%	36.4%
	% of Total	31.6%	4.5%	36.1%	21.4%	14.9%	36.4%
Females	Count	81	18	99	53	45	98
	% within *Gender*	81.8%	18.2%	100.0%	54.1%	45.9%	100.0%
	% within *Hard Time Understanding Spoken Comments*	62.3%	72.0%	63.9%	---	---	---
	% within *Able to Hear Patient Private Info Being Discussed*	---	---	---	61.6%	66.2%	63.6%
	% of Total	52.3%	11.6%	63.9%	34.4%	29.2%	63.6%
Total	Count	130	25	155	86	68	154
	% within *Gender*	83.9%	16.1%	100.0%	55.8%	44.2%	100.0%
	% within *Hard Time Understanding Spoken Comments*	100.0 %	100.0%	100.0%	---	---	---
	% within *Able to Hear Patient Private Info Being Discussed*	---	---	---	100.0%	100.0%	100.0%
	% of Total	83.9%	16.1%	100.0%	55.8%	44.2%	100.0%
df		**Value**	**Asymp. Sig. (2-sided)**	**Approx. Sig.**	**Value**	**Asymp. Sig. (2-sided)**	**Approx. Sig.**
1	Pearson Chi-Square	.85[a]	0.36		.34[b]	0.56	
1	Continuity Correction[c] p value	0.49	0.49		0.17	0.68	
	N of Valid Cases	155			154		
	Phi[d]	0.07		0.36	0.05		0.56

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 9.03.
b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 24.73.
c. Yates Correction for 2x2 table results not significant since 0.49 and 0.68 >> 0.05.
d. Phi of 0.07 and 0.05 << 0.10; therefore no strong association.

Table 5.12

Chi-square count predictions for *Able to Hear Patient Private Info Being Discussed.*

Able to Hear Patient Private Info Being Discussed

	Ratio	Observed N	Expected N	Residual
Never heard other private patient info discussed	0.574	26	29.0	-3.0
Rarely heard other private patient info discussed	0.0833	8	4.2	3.8
Sometimes heard other private patient info discussed	0.2222	9	11.2	-2.2
Often heard other private patient info discussed	0.1111	7	5.6	1.4
Total		50		

Test Statistics

Able to Hear Patient Private Info Being Discussed	
Chi-square	4.514[a]
Degree of Freedom	3
p value	.211

a. 1 cells (25.0%) have expected frequencies less than 5. The minimum expected cell frequency is 4.2.

Table 5.13

Tests of *Able to Hear Patient Private Info Being Discussed* and *Gender* and *Age*.

Mann-Whitney U Test P values

	During Renovation	**After Renovation**	**Total**
The distribution of *Able to Hear Patient Private Info Being Discussed* is the same across categories of *Gender*	0.64	0.26	0.81

Since p>0.05 retain the null hypothesis that the distribution of *Able to Hear Patient Private Info Being Discussed* is the same across categories of *Gender*.

Kruskal-Wallis Test

	Age	**During N**	**During Mean Rank**	**After N**	**After Mean Rank**	**Total N**	**Total Mean Rank**
Able to Hear Patient Private Info Being Discussed	19 to 25	7	58.29	2	21.25	9	80.56
	26 to 30	10	51.75	3	37.83	13	84.85
	31 to 35	6	48.17	1	46.00	7	80.00
	36 to 40	7	38.36	2	13.00	9	52.00
	41 to 45	20	55.98	8	23.38	28	79.09
	46 to 50	15	64.40	5	24.60	20	89.53
	51 to 55	11	46.68	10	20.45	21	66.67
	56 to 60	12	59.92	7	26.00	19	85.29
	61 to 65	6	51.17	2	25.50	8	75.44
	66 to 70	7	58.29	6	32.33	13	92.73
	71 to 75	2	31.00	0	.00	2	43.50
	76 +	3	31.00	3	18.50	6	52.08
	Total	106		49		155	

Test Statistics[a,b]

Chi-square	10.105	11.109	13.653
Degrees of Freedom	11	10	11
p value	.521	.349	.253

a. Kruskal Wallis Test
b. Grouping Variable: Age

Table 5.14

Chi-square count predictions for *Sensitive to Noise*.

Sensitive to Noise

	Ratio	**Observed N**	**Expected N**	**Residual**
No	0.72	41	36.0	5.0
Yes	0.28	9	14.0	-5.0
Total	1.00	50		

Test Statistics

	Describe yourself as being sensitive to noise
Chi-square	2.480[a]
df	1
p value	.115

> 0.05 Not significant

a. 3 cells (75.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.4.

Table 5.15

Tests for *Sensitive to Noise* and *Gender* and *Age*.

Mann-Whitney U Test p values

	During Renovation	**After Renovation**	**Total**
The distribution of *Sensitive to Noise* is the same across categories of *Gender*	0.76	0.46	0.59
Since p> 0.05 retain the null hypothesis that the distribution of *Sensitive to Noise* is the same across categories of *Gender*			

Kruskal-Wallis Test

	Age	**During N**	**During Mean Rank**	**After N**	**After Mean Rank**	**Total N**	**Total Mean Rank**
Describe yourself as being sensitive to noise	19 to 25	7	45.43	2	20.50	9	66.50
	26 to 30	10	58.80	3	36.83	13	93.31
	31 to 35	6	55.33	1	20.50	7	79.86
	36 to 40	7	67.71	2	20.50	9	92.00
	41 to 45	20	51.00	8	20.50	28	71.66
	46 to 50	14	49.14	5	25.40	19	74.11
	51 to 55	11	52.18	10	22.95	21	72.57
	56 to 60	12	51.00	7	24.00	19	74.11
	61 to 65	6	46.67	2	32.75	8	77.13
	66 to 70	6	46.67	6	28.67	12	77.13
	71 to 75	2	64.00	0	.00	2	96.25
	76 +	3	55.33	3	28.67	6	83.50
	Total	104		49		153	

Test Statistics[a,b]

	During	After	Total
Chi-square	6.089	10.604	8.234
df	11	10	11
p value	.867	.389	.692

a. Kruskal Wallis Test

Since p> 0.05 the distribution of *Sensitive to Noise* is the same across categories of *Age*

b. Grouping Variable: *Age*

Table 5.16

Gender and *Sensitive to Noise*-total group.

		Do you describe yourself as being sensitive to noise		
		No	**Yes**	**Total**
Males	Count	41	15	56
	% within *Gender*	73.2%	26.8%	100.0%
	% within Describe yourself as being sensitive to noise	35.7%	40.5%	36.8%
	% of Total	27.0%	9.9%	36.8%
Females	Count	74	22	96
	% within *Gender*	77.1%	22.9%	100.0%
	% within Describe yourself as being sensitive to noise	64.3%	59.5%	63.2%
	% of Total	48.7%	14.5%	63.2%
Total	Count	115	37	152
	% within *Gender*	75.7%	24.3%	100.0%
	% within Describe yourself as being sensitive to noise	100.0%	100.0%	100.0%
	% of Total	75.7%	24.3%	100.0%
df		**Value**	**Asymp. Sig. (2-sided)**	**Approx. Sig.**
1	Pearson Chi-square	.29[a]	0.59	
1	Continuity Correction[b]	0.12	0.73	
1	Likelihood Ratio	0.29	0.59	
	N of Valid Cases	152.00		
	Phi[c]	-0.04		0.59

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 13.63.
b. Yates Correction for 2x2 table results not significant since 0.73 >> 0.05.
c. Phi of -0.04 << 0.10; therefore no strong association.

Table 5.17

Describe Yourself as Hard of Hearing and *Annoyance* p values of Mann-Whitney U test.

Mann-Whitney U Test p values			
	During Renovation	**After Renovation**	**Total**
The distribution of *Awakened and Annoyed at Night* is the same across categories of *Describe Yourself as Hard of Hearing*	0.57	0.05	0.46
The distribution of *Disturbed and Annoyed During the Day* is the same across categories of *Describe Yourself as Hard of Hearing*	0.10	0.75	0.15
Since p> 0.05 retain the null hypothesis that the distribution of *Awakened and Annoyed at Night* and *Disturbed and Annoyed During the Day* is the same across categories of D*escribe Yourself as Hard of Hearing*			

Table 5.18

Mann-Whitney Tests *Sensitive to Noise* and *Annoyance* during day and night.

Variable	**Describe yourself as being sensitive to noise**	**During Renovation** N	**During Renovation** Mean Rank	**During Renovation** Sum of Ranks	**After Renovation** N	**After Renovation** Mean Rank	**After Renovation** Sum of Ranks	**Total Group** N	**Total Group** Mean Rank	**Total Group** Sum of Ranks
Awakened and Annoyed at Night	No	75	48.45	3633.50	41	22.28	913.50	116	69.53	8065.00
	Yes	29	62.98	1826.50	9	40.17	361.50	38	101.84	3870.00
	Total	104			50			154		
Disturbed and Annoyed During the Day	No	75	46.97	3522.50	41	24.06	986.50	116	70.49	8176.50
	Yes	29	66.81	1937.50	9	32.06	288.50	38	98.91	3758.50
	Total	104			50			154		

Test Statistics[a]	***Awakened and Annoyed at Night***	***Disturbed and Annoyed During the Day***	***Awakened and Annoyed at Night***	***Disturbed and Annoyed During the Day***	***Awakened and Annoyed at Night***	***Disturbed and Annoyed During the Day***
Mann-Whitney U	783.500	672.500	52.500	125.500	1279.000	1390.500
Wilcoxon W	3633.500	3522.500	913.500	986.500	8065.000	8176.500
Z	-2.231	-3.056	-3.418	-1.513	-3.937	-3.461
Asymp. Sig. (2-tailed) p value	.026	.002	.001	.130	.000	.001
Exact Sig. [2*(1-tailed Sig.)]	---	---	.000[b]	.138[b]	---	---
Those who describe themselves as more sensitive to noise are more annoyed (with p=0.05)	yes	yes	yes	no	yes	yes

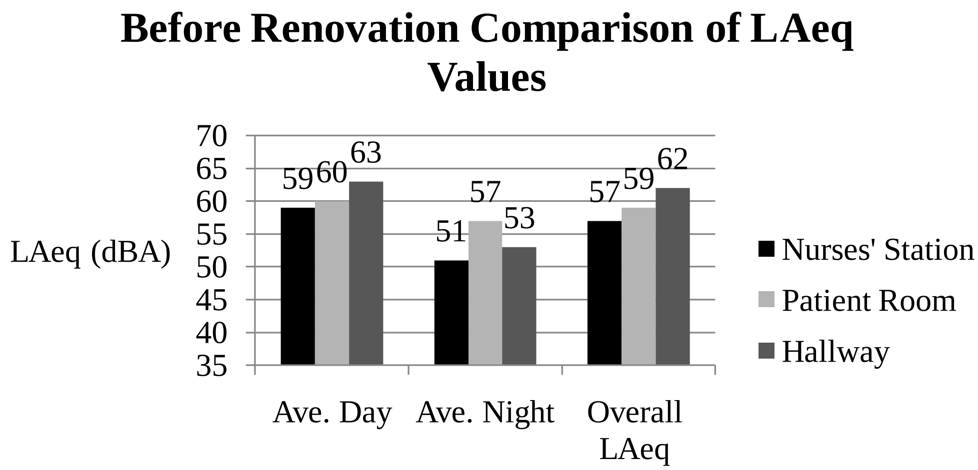
a. Grouping Variable: describe yourself as being sensitive to noise.
b. Not corrected for ties.

Table 5.19

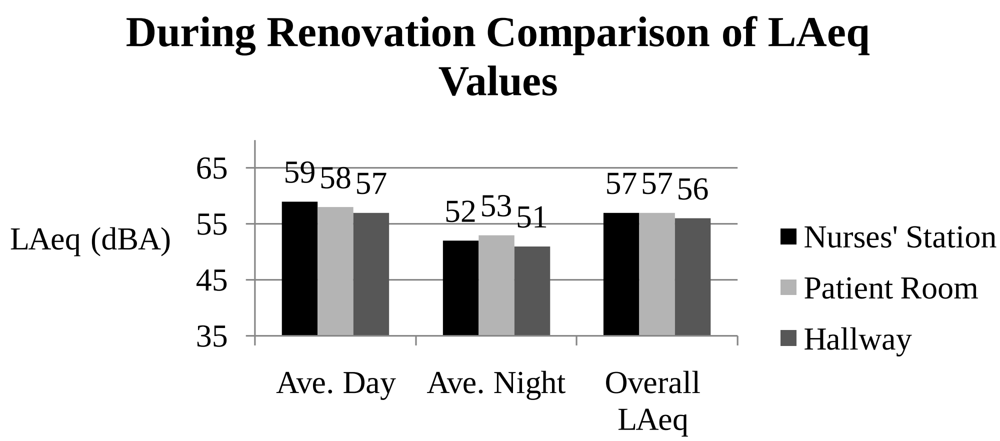
Noise source rankings, counts, and percentages.

Noise Source	Total Percent	Total Count	During Renovation Percent	During Renovation Count	After Renovation Percent	After Renovation Count	Expected	p value	diff	%diff
Alarms in Patient Room	18.0%	88	16.6%	57	21.1%	31	26	0.16	5	19%
Medical Equipment in Patient Room	13.1%	64	13.1%	45	12.9%	19	21	0.67	-2	-9%
Rolling Carts in Hallway	12.0%	59	12.0%	41	12.2%	18	19	0.88	-1	-5%
Talking in Patient Room	11.6%	57	13.1%	45	8.2%	12	21	0.02	-9	-42%
Other Noise Comments	9.8%	48	9.0%	31	11.6%	17	14	0.35	3	21%
Talking Outside Patient Room	8.4%	41	9.0%	31	6.8%	10	14	0.21	-4	-28%
Alarms Outside Patient Room	7.3%	36	7.9%	27	6.1%	9	13	0.21	-4	-30%
Medical Equipment Outside Patient Room	6.9%	34	7.3%	25	6.1%	9	12	0.4	-3	-25%
TV Noise	5.9%	29	4.4%	15	9.5%	14	7	0.002	7	100%
Office Equipment Outside of Patient Room	3.1%	15	3.5%	12	2.0%	3	2	0.21	1	50%
HVAC Noise	2.0%	10	2.0%	7	2.0%	3	2	0.21	1	50%
Other Entertainment Devices	1.8%	9	2.0%	7	1.4%	2	1	0.31	1	50%
	100.0%	490	100.0%	343	100.0%	147				

a)



(b)



(c)

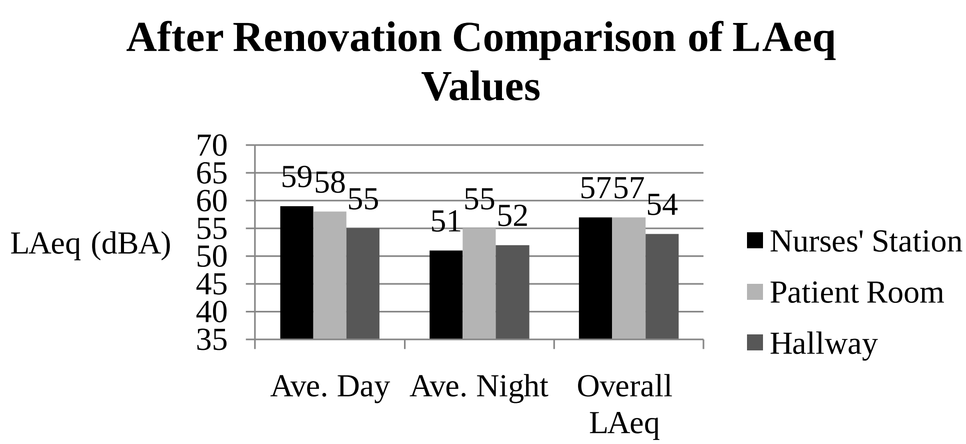
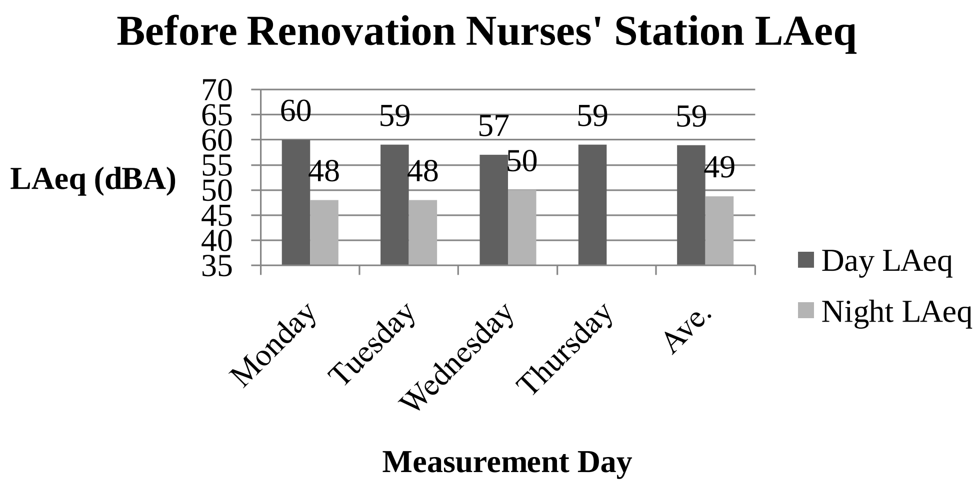
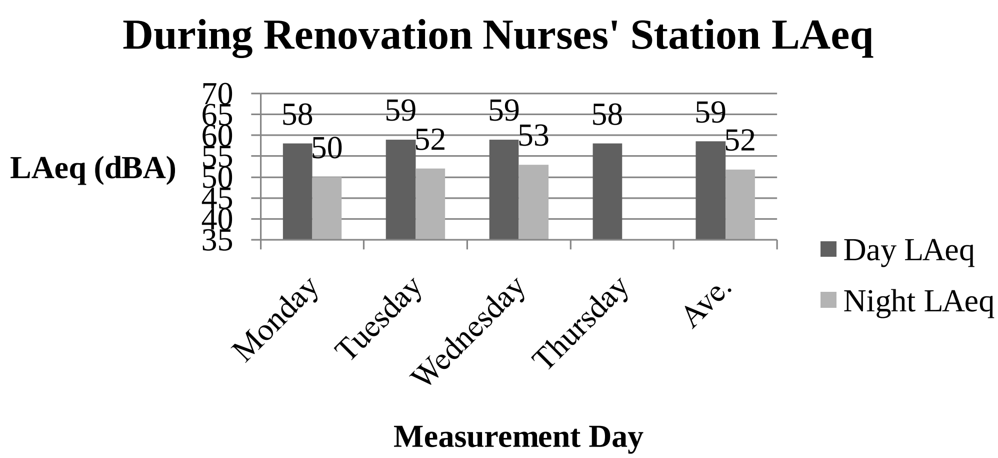


Figure 5.1. A comparison of equivalent sound level values for all three locations (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

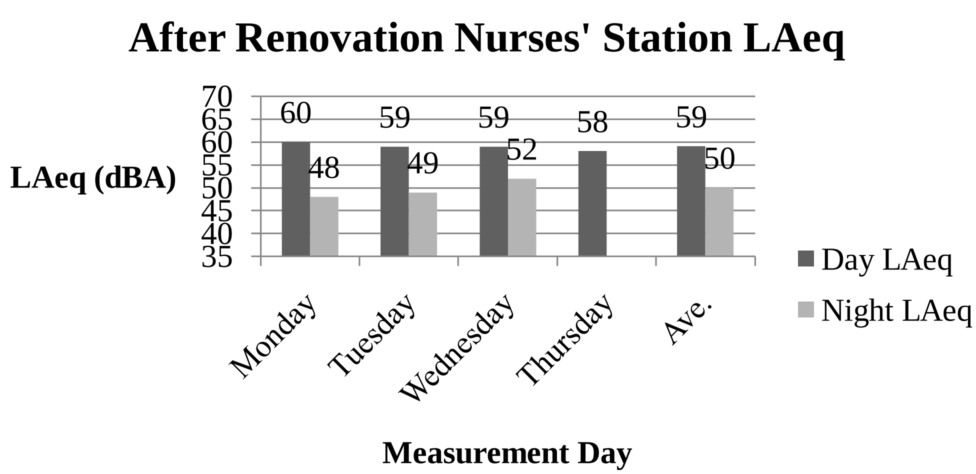
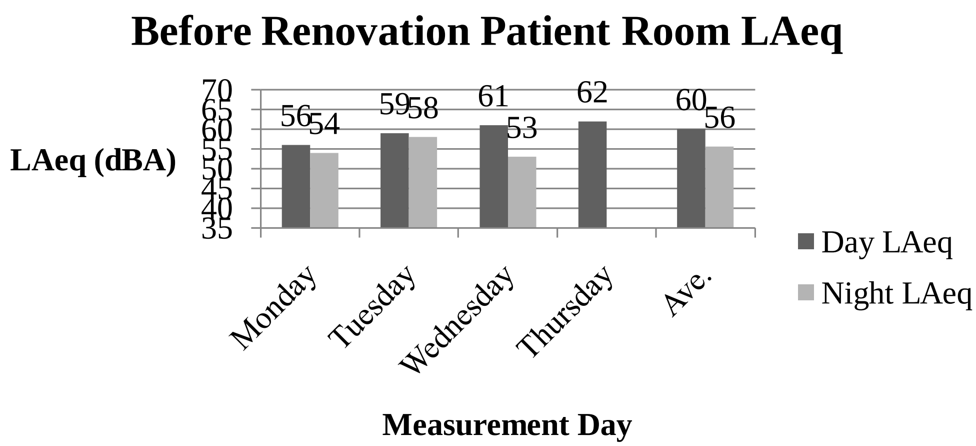
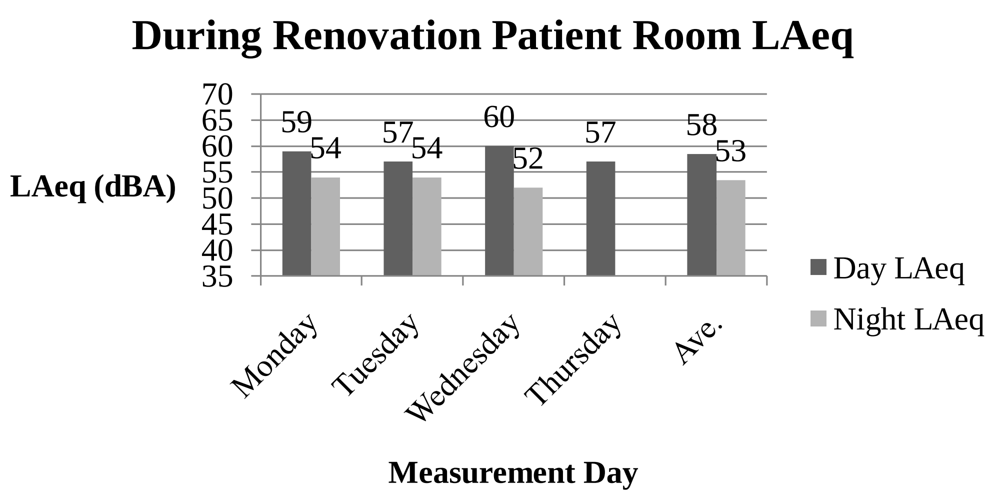


Figure 5.2. A day of the week comparison of equivalent sound level values for nurses' station (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

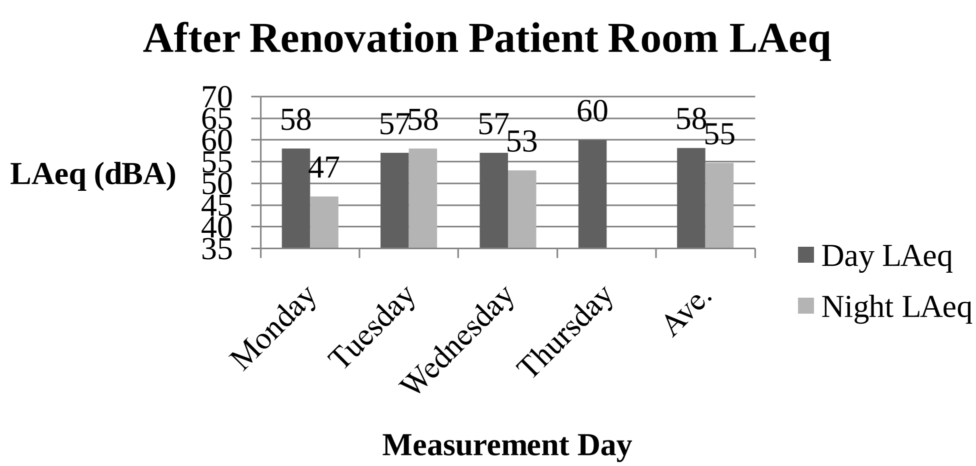
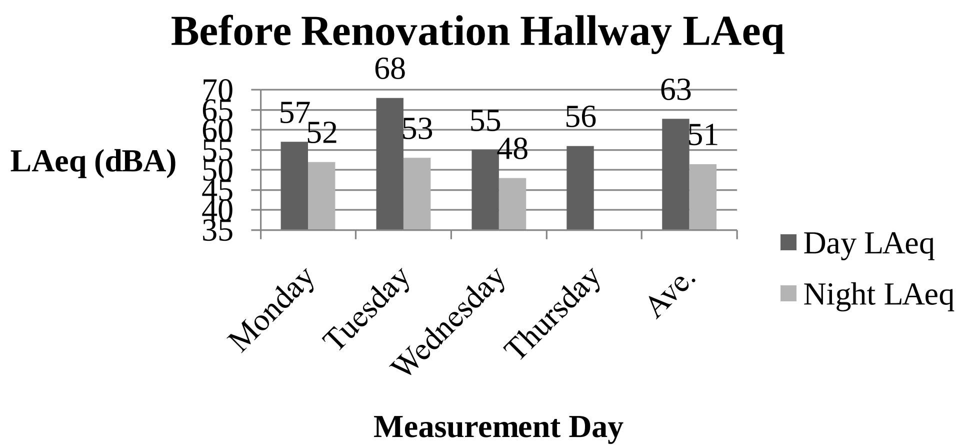
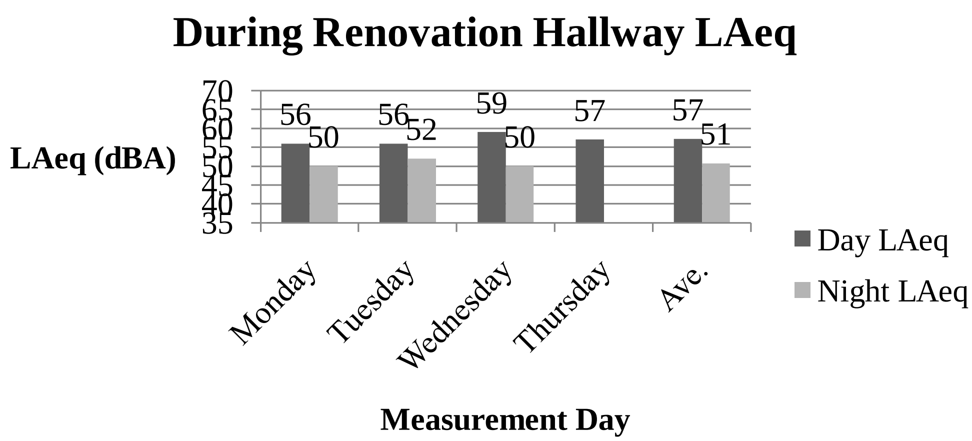


Figure 5.3. A day of the week comparison of equivalent sound level values for patient room (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

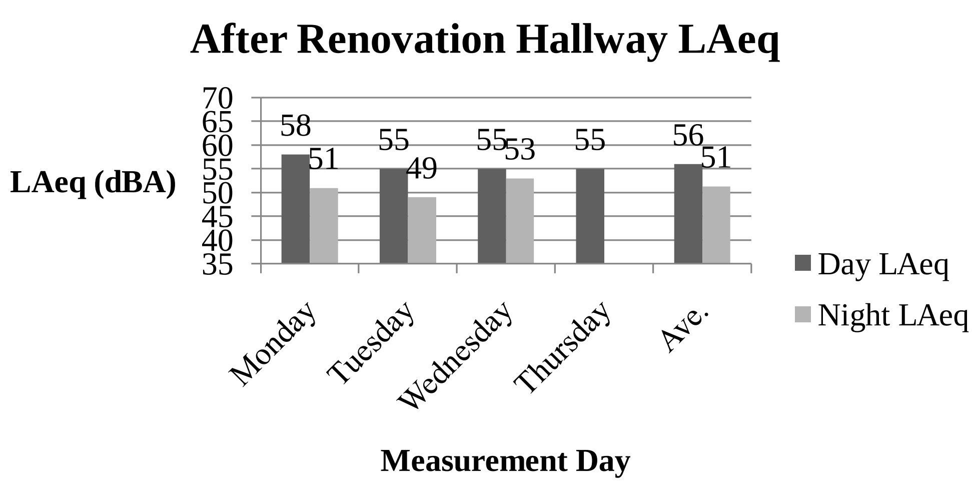


Figure 5.4. A day of the week comparison of equivalent sound level values for hallway (a) before, (b) during, and (c) after renovations.

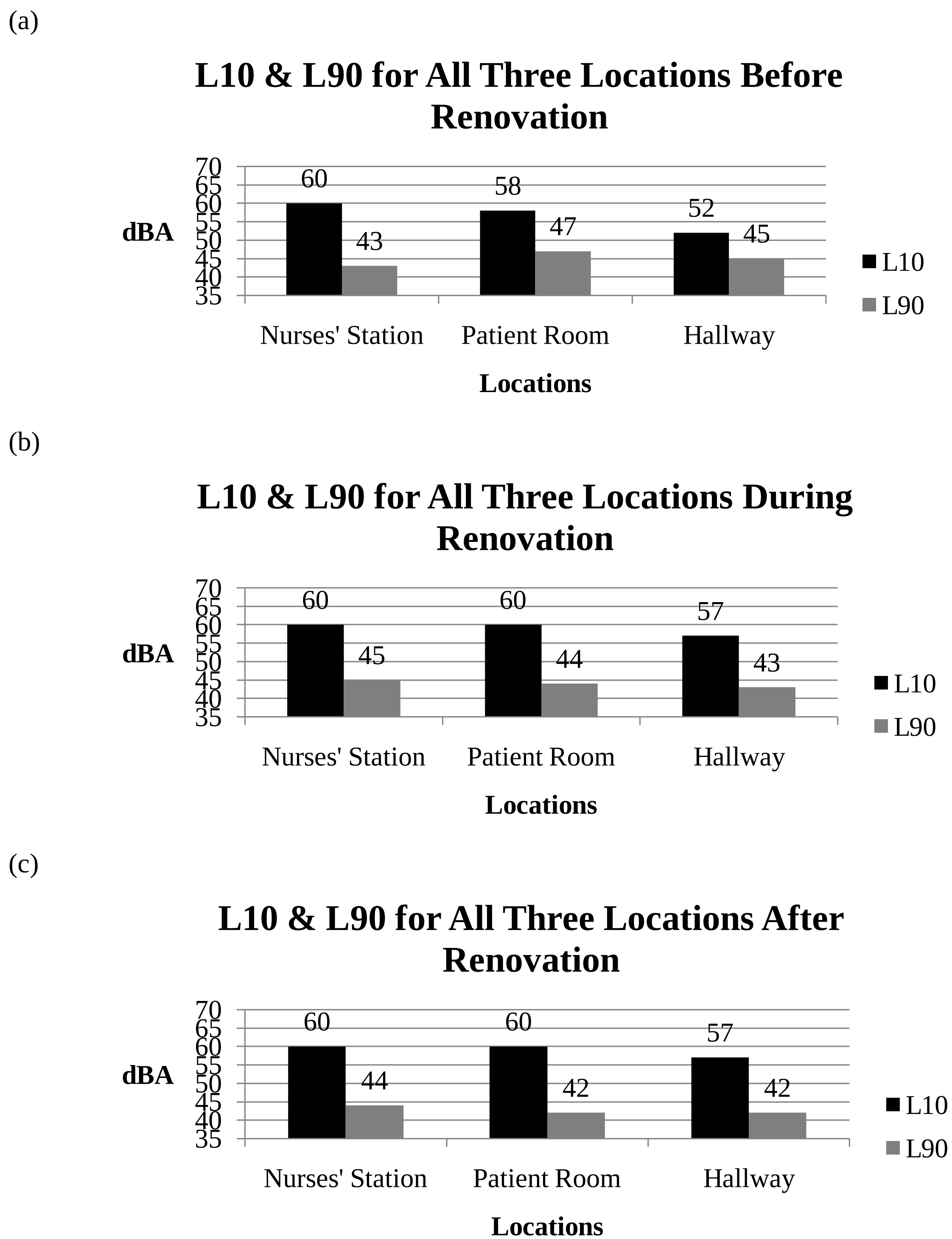


Figure 5.5. A comparison of values for percentage of exceedence over a certain level, L_{10} and L_{90}, for all three locations (a) before, (b) during, and (c) after renovations.

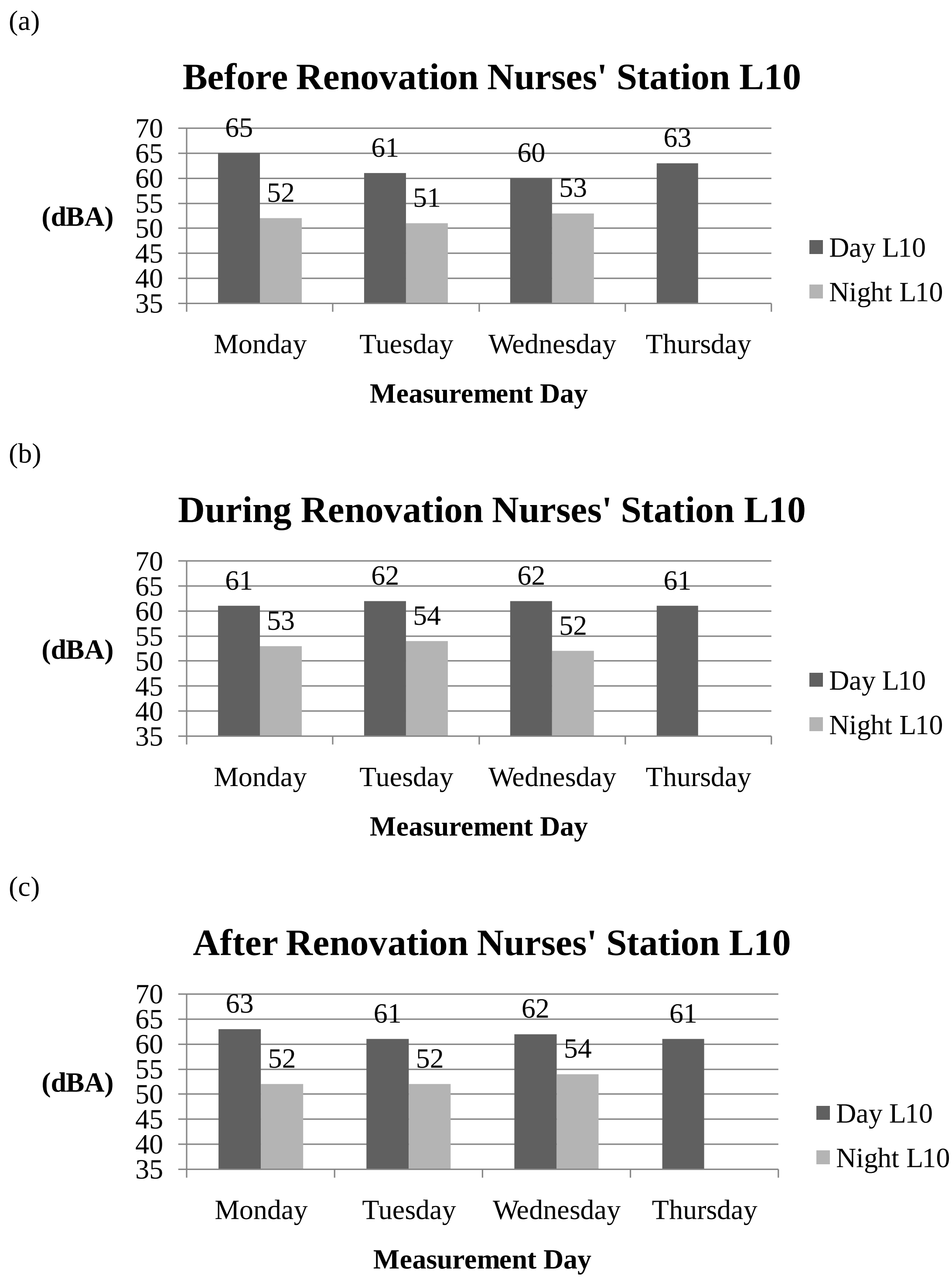
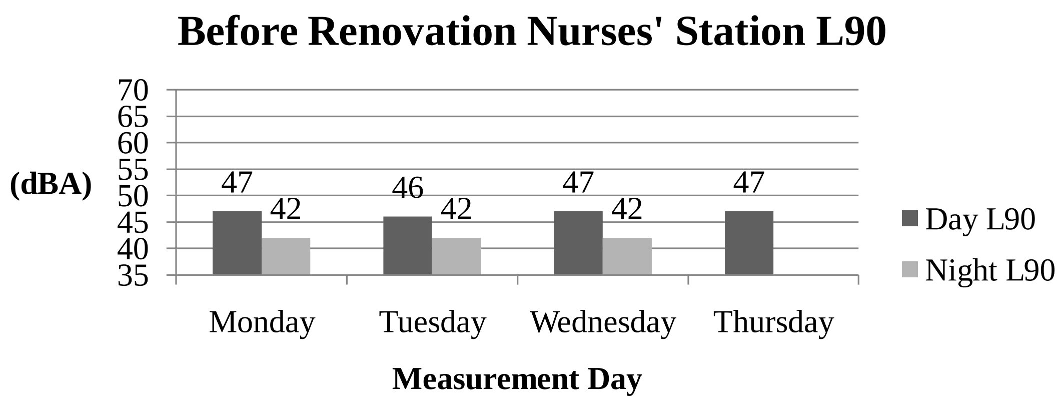
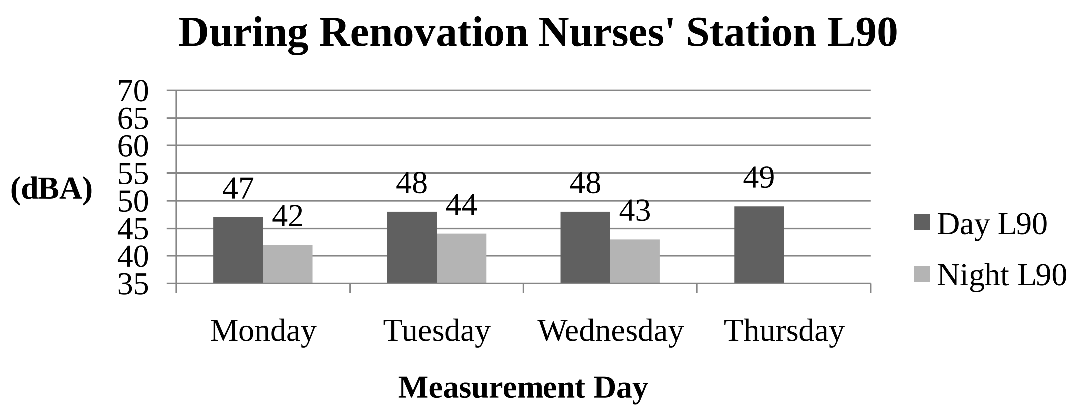


Figure 5.6. A comparison of values for percentage of exceedence over a certain level, L_{10}, for the nurses' station (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

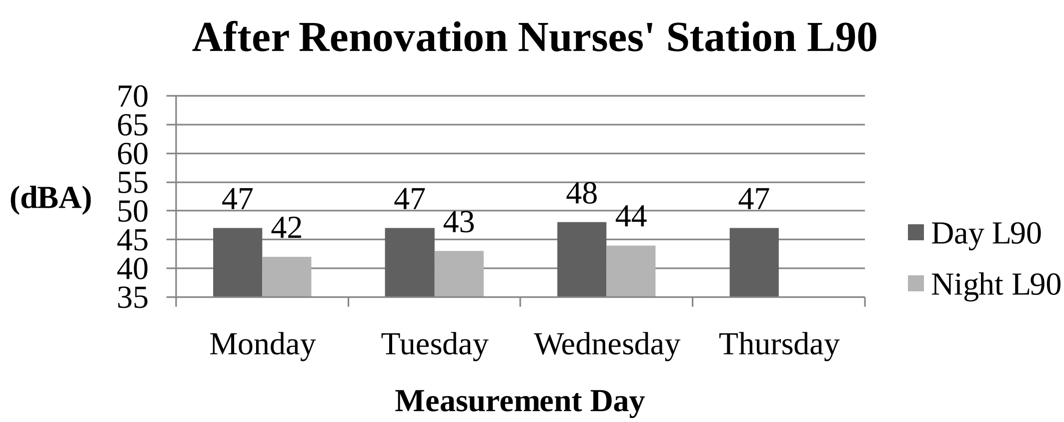
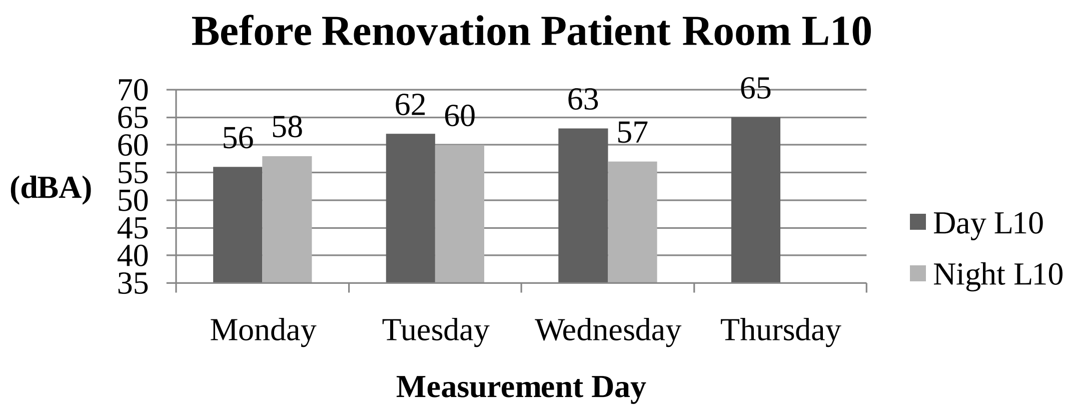
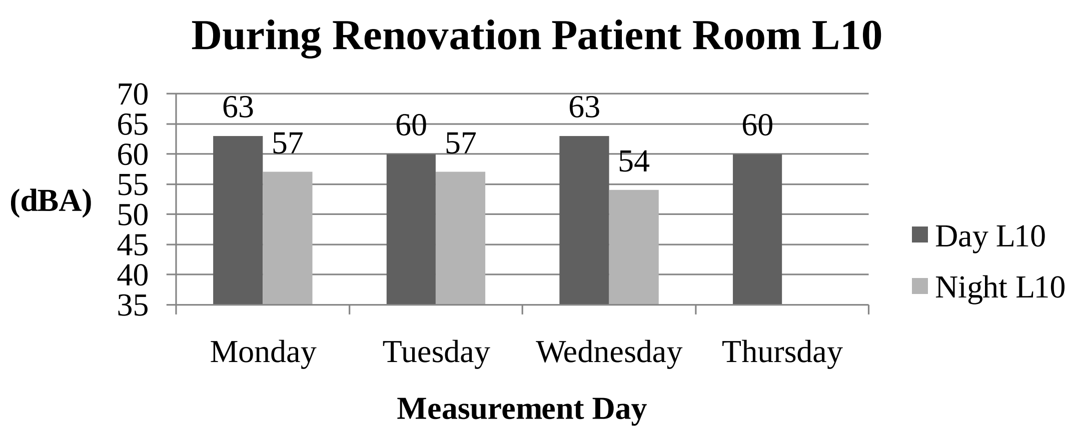


Figure 5.7. A comparison of values for percentage of exceedence over a certain level, L_{90}, for the nurses' station (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

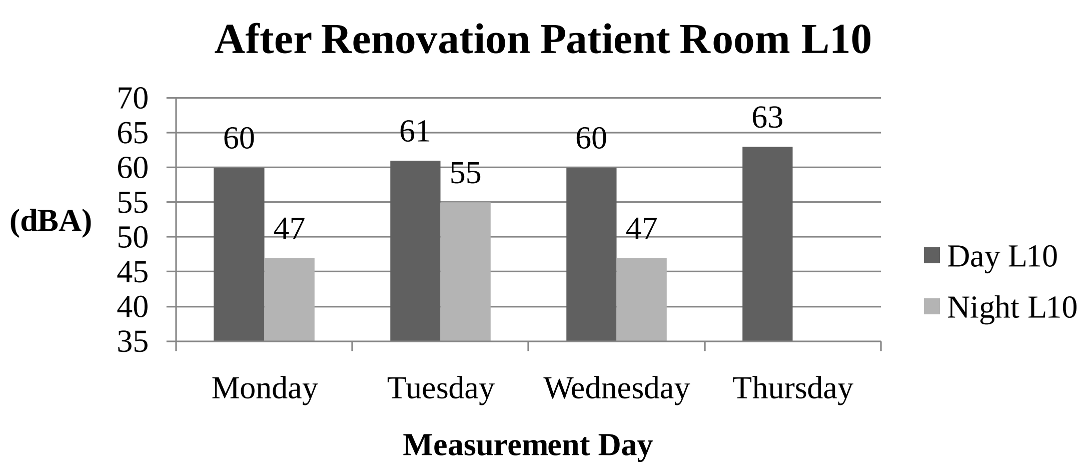
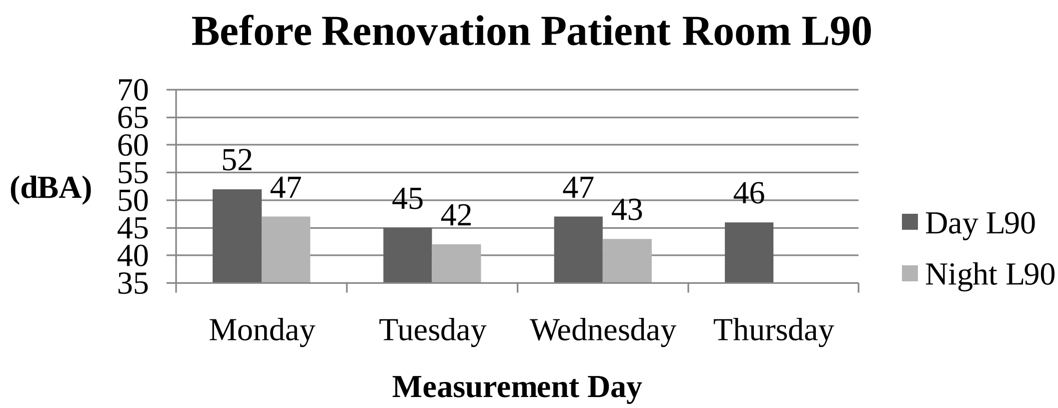
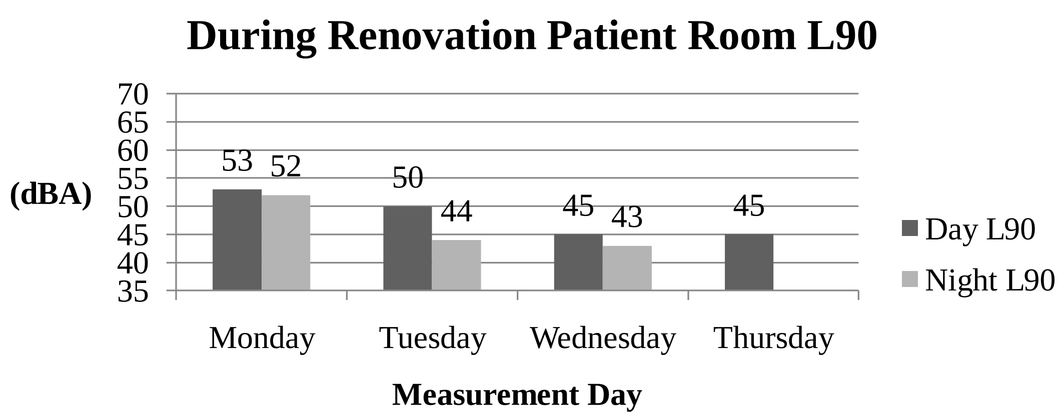


Figure 5.8. A comparison of values for percentage of exceedence over a certain level, L_{10}, for the patient room (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

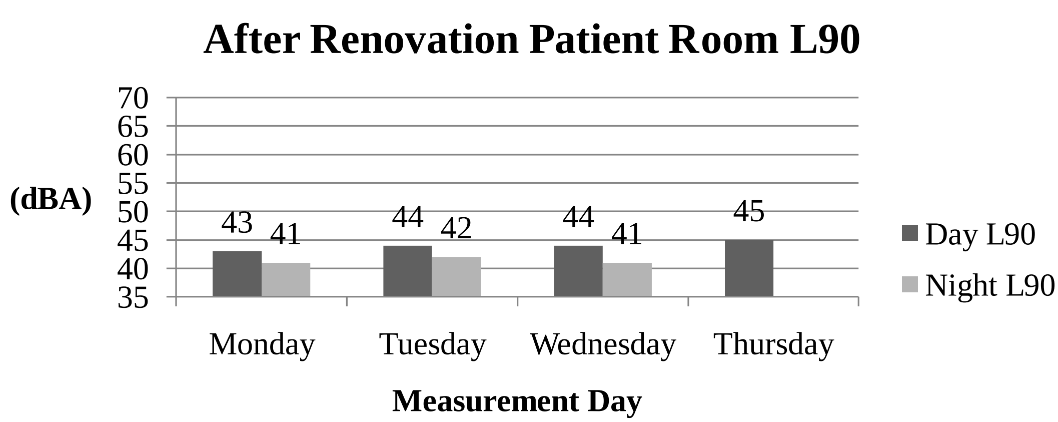
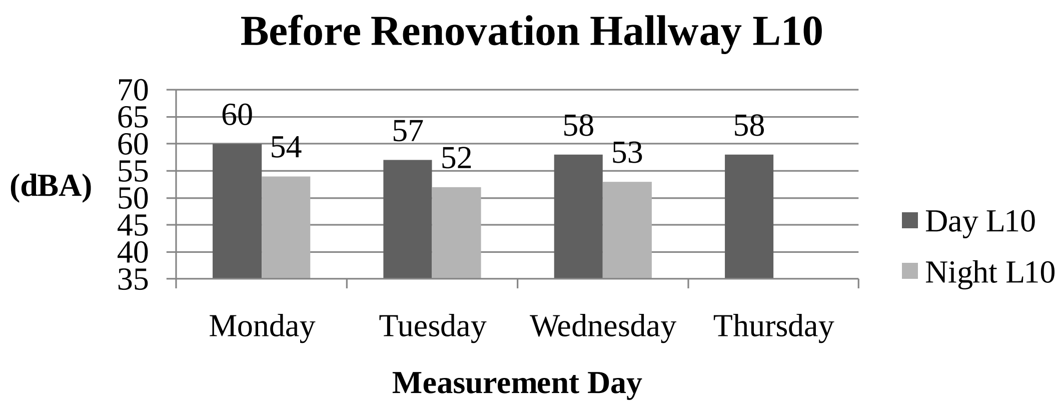
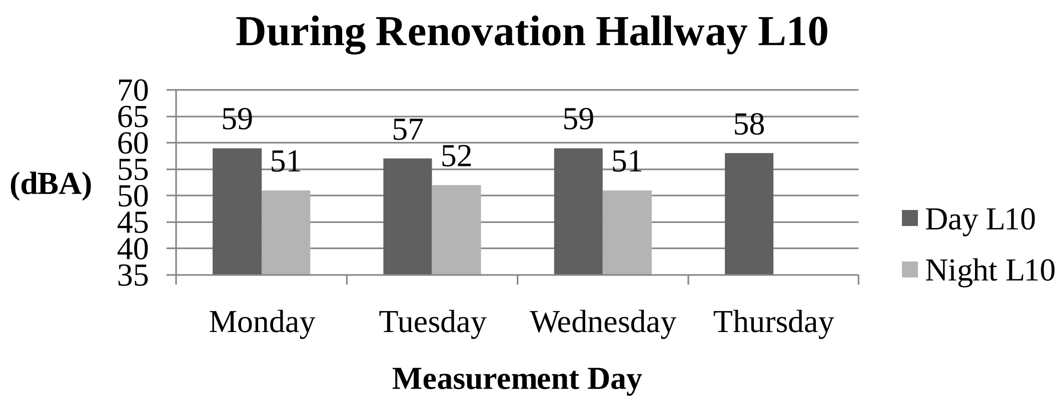


Figure 5.9. A comparison of values for percentage of exceedence over a certain level, L_{90}, for the patient room (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

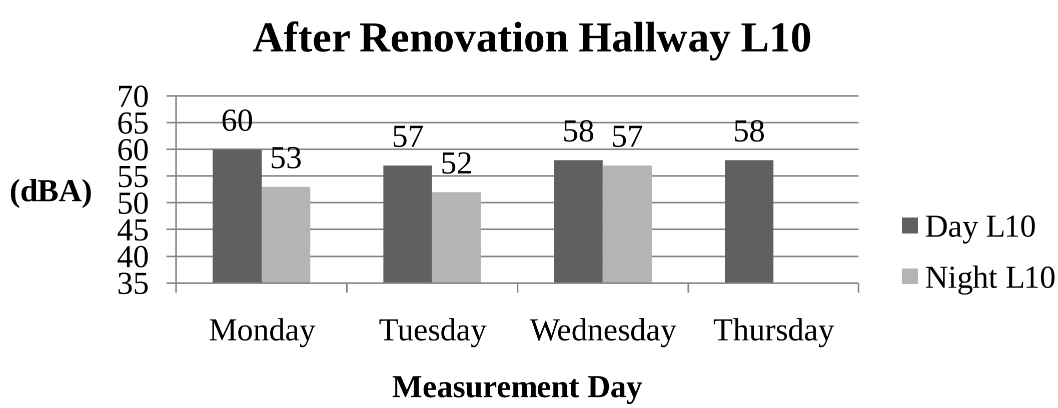
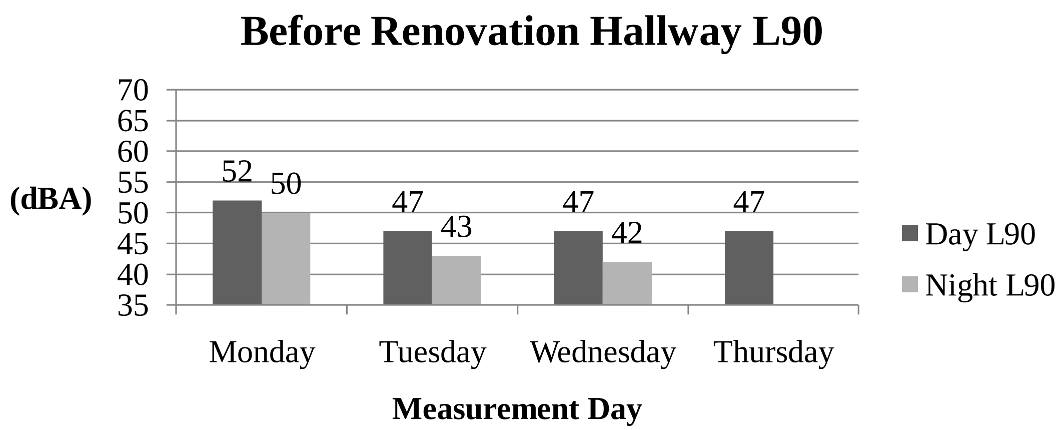
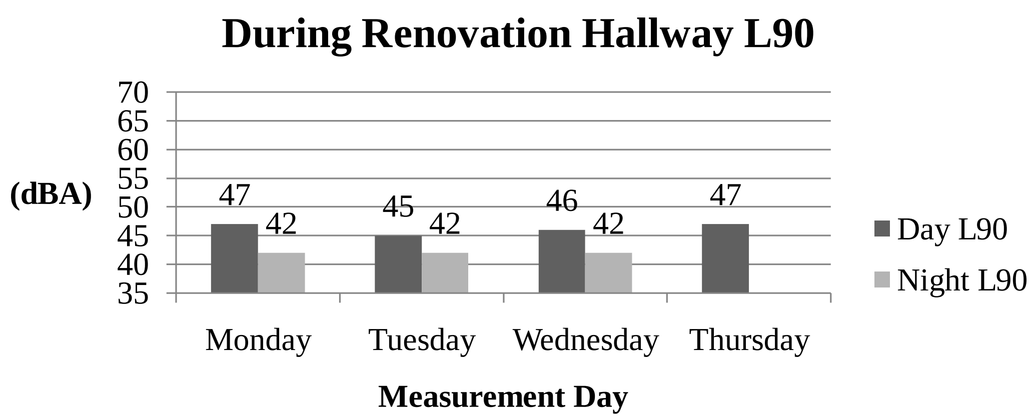


Figure 5.10. A comparison of values for percentage of exceedence over a certain level, L_{10}, for the hallway (a) before, (b) during, and (c) after renovations.

(a)



(b)



(c)

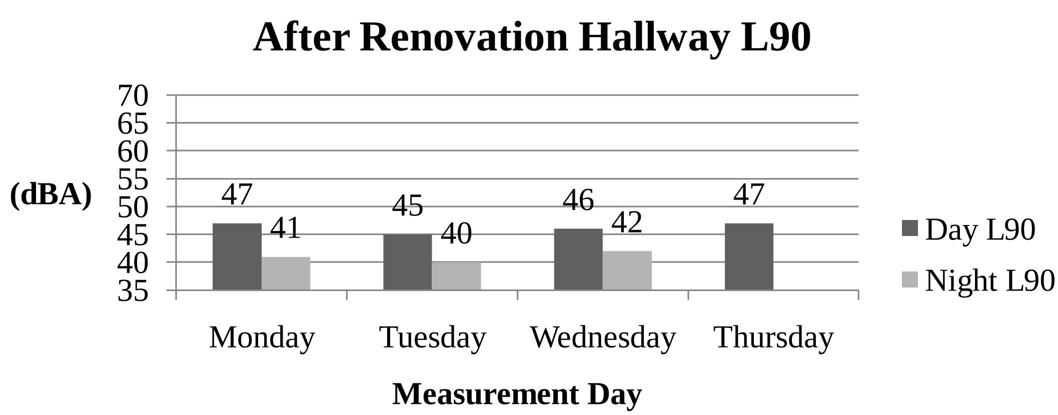


Figure 5.11. A comparison of values for percentage of exceedence over a certain level, L_{90}, for the hallway (a) before, (b) during, and (c) after renovations.

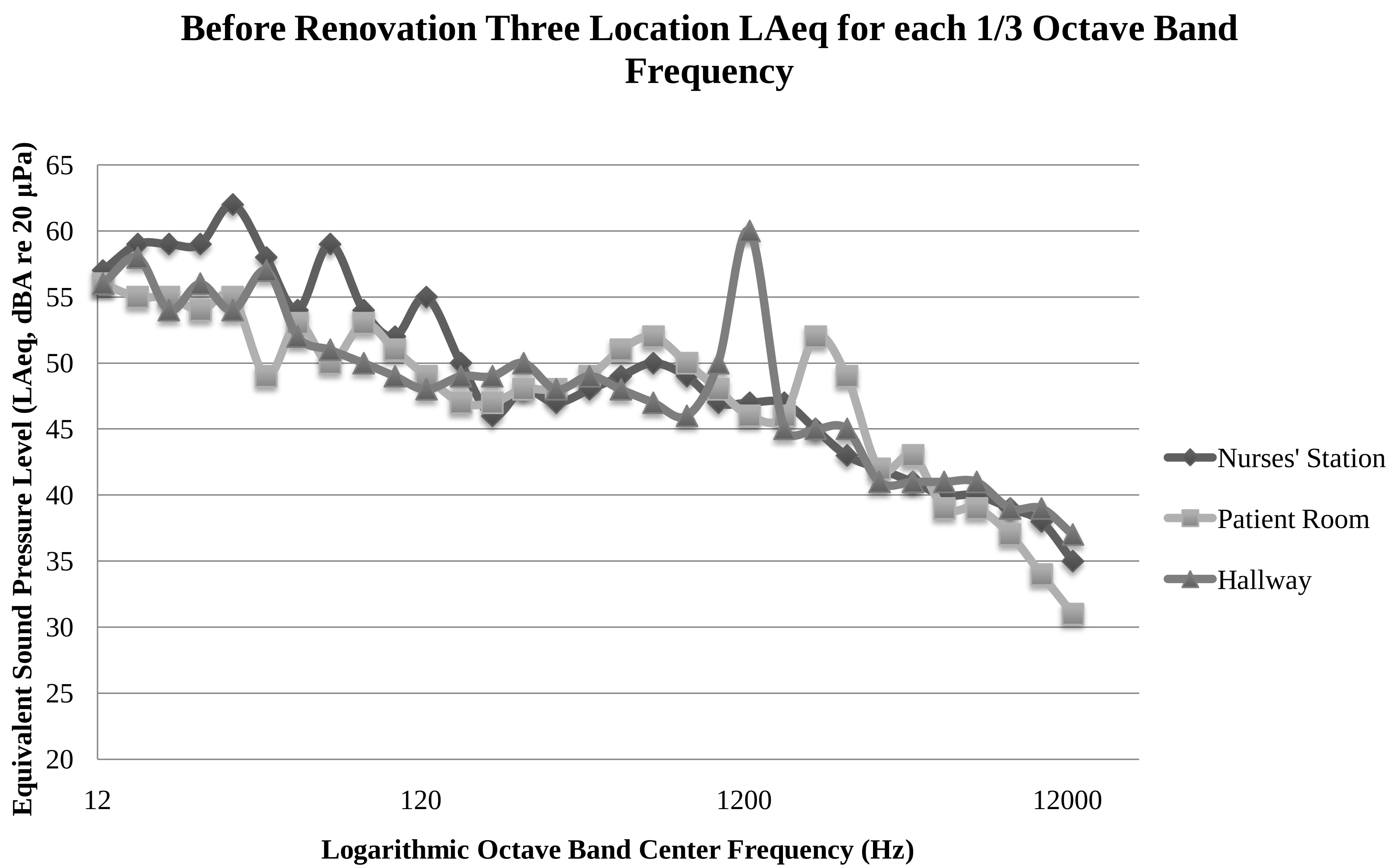


Figure 5.12. Spectral plot for all three locations from the before renovation period.

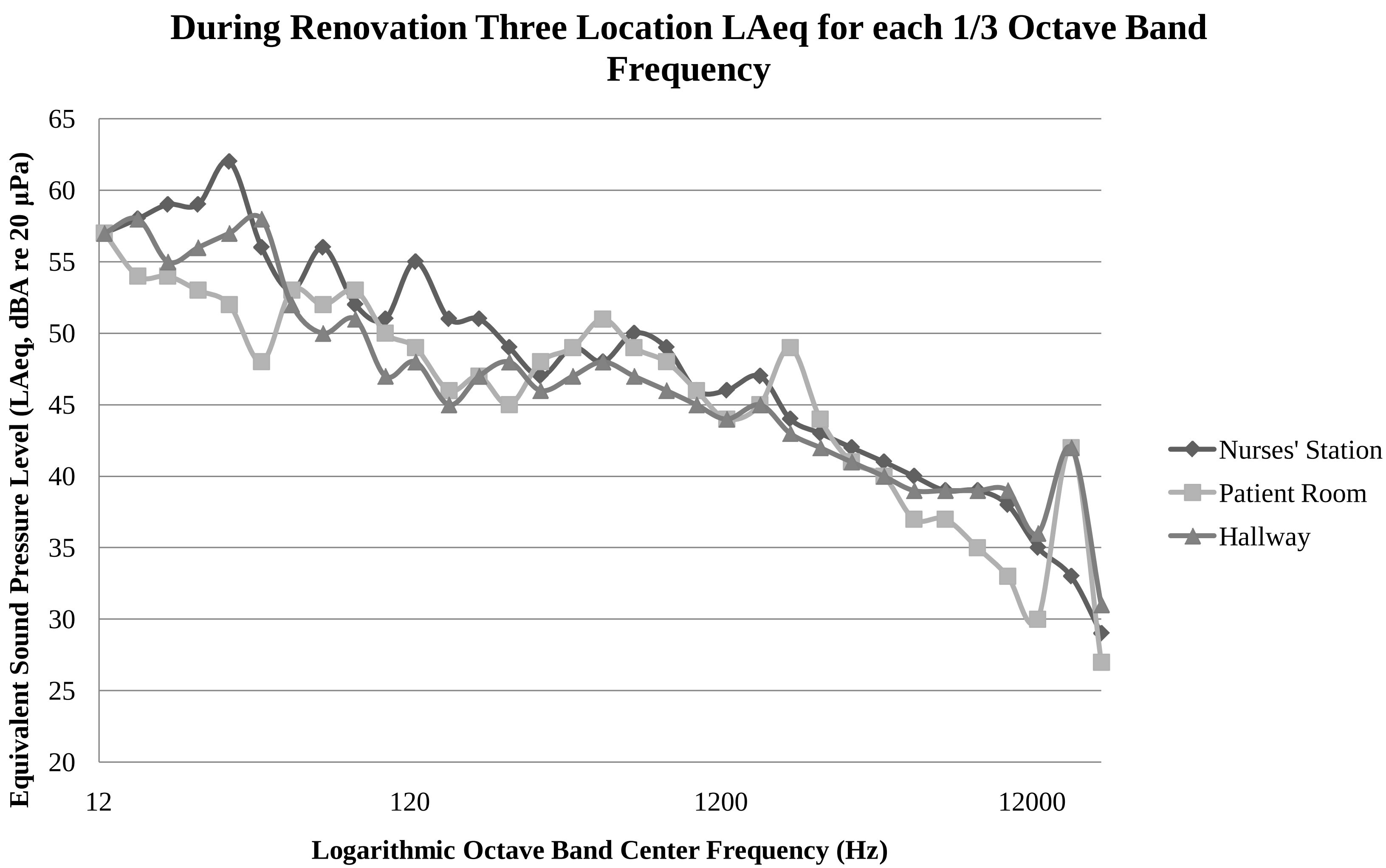


Figure 5.13. Spectral plot for all three locations from the during renovation period.

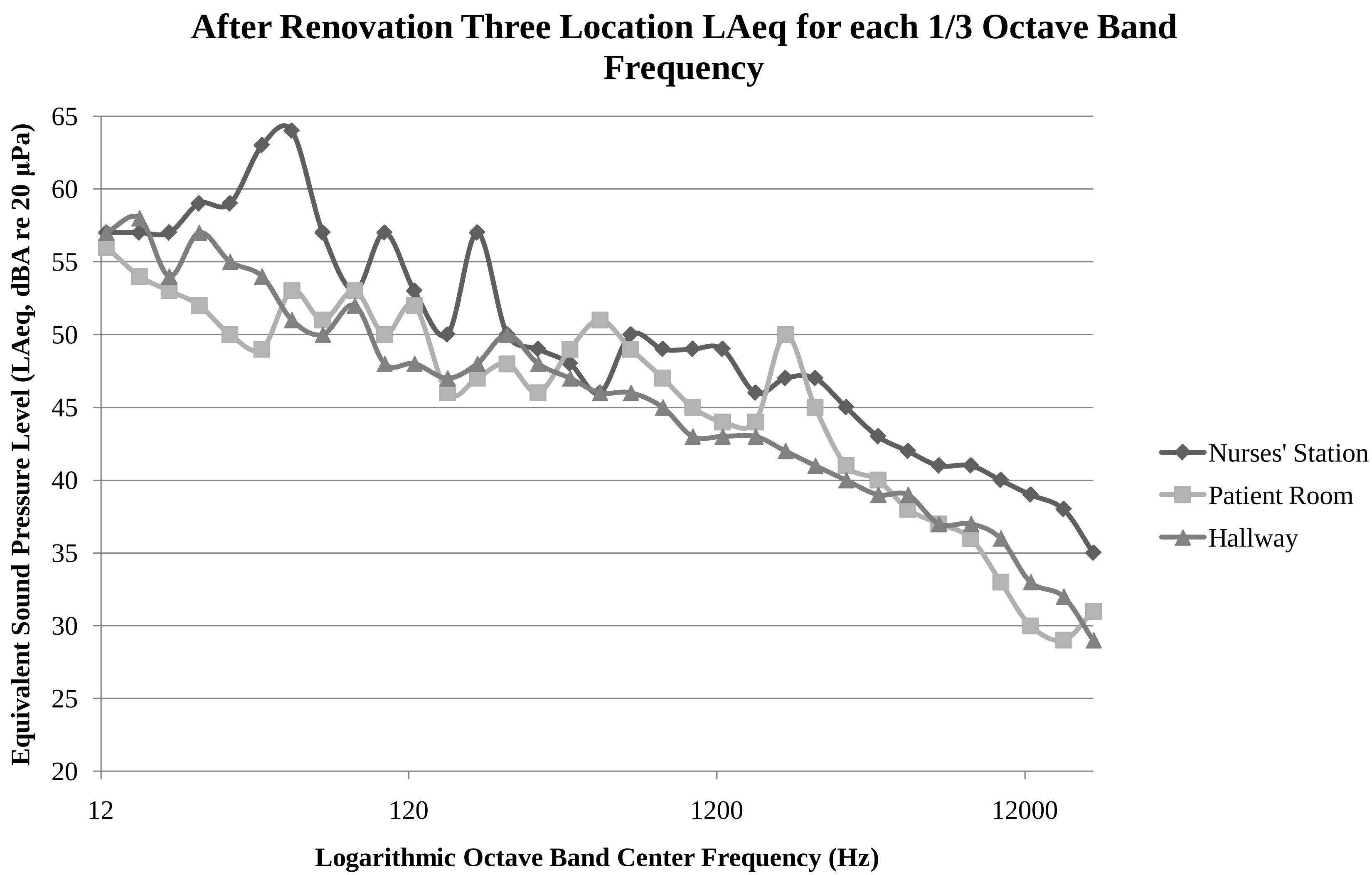
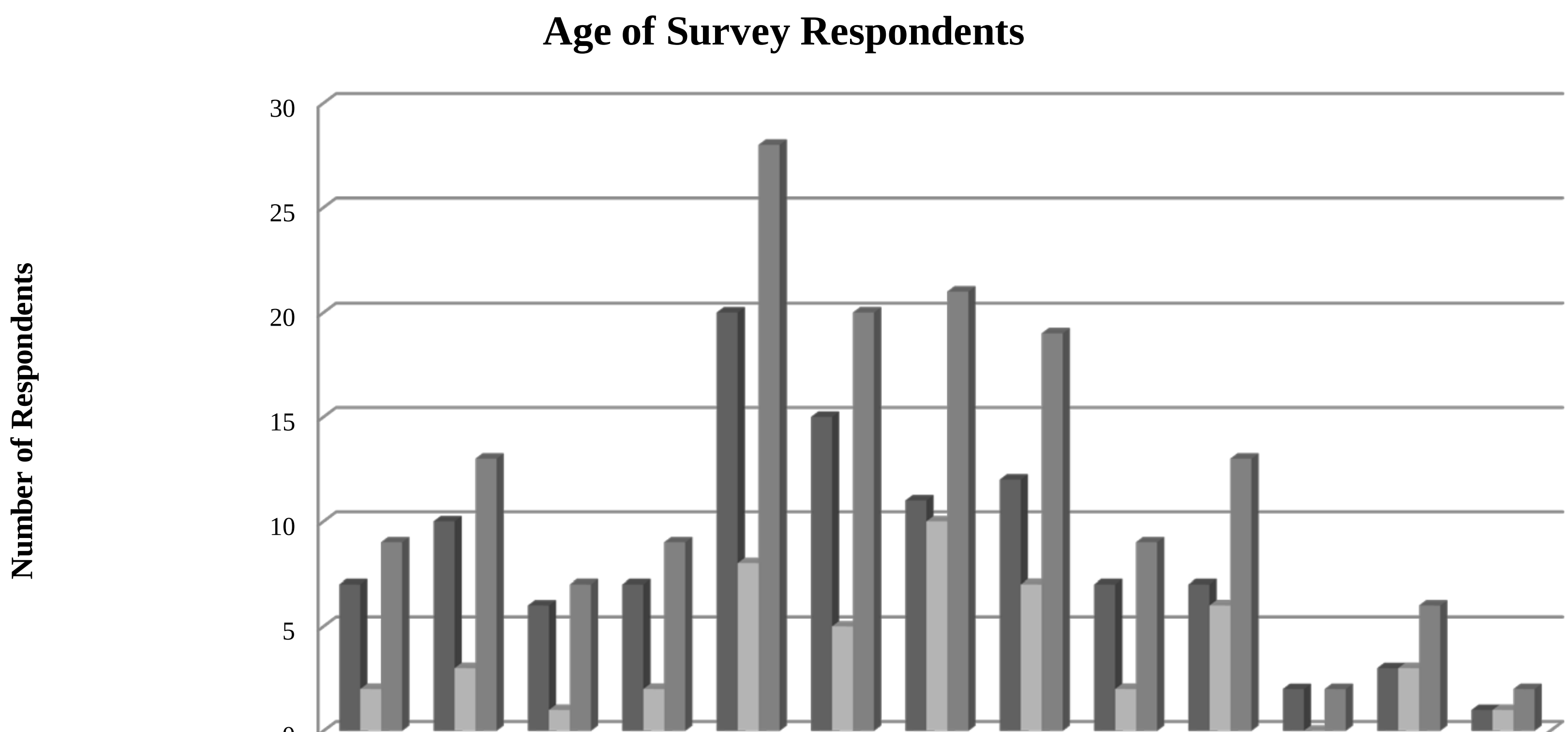


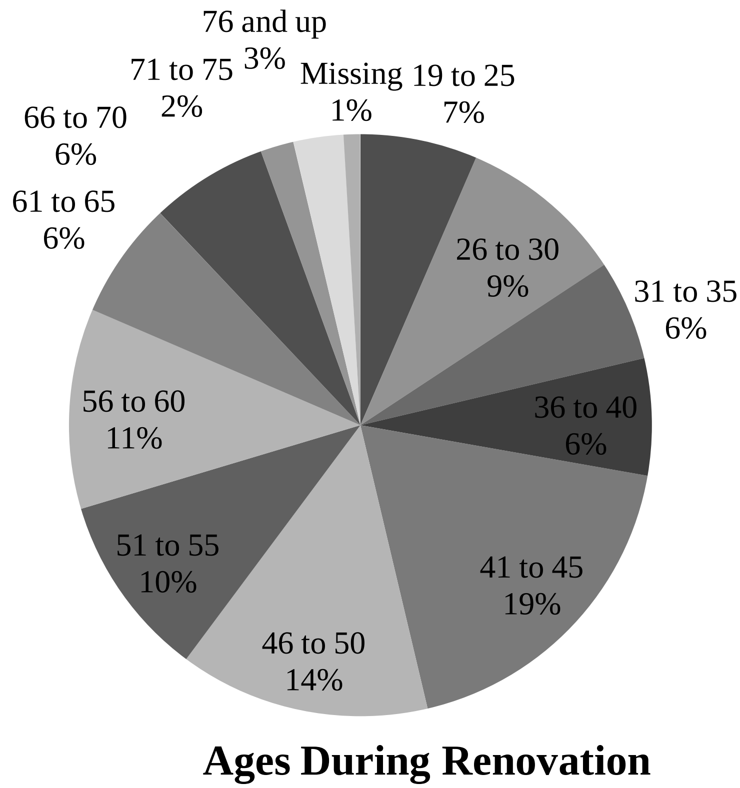
Figure 5.14. Spectral plot for all three locations from the after renovation period.



	19 to 25	26 to 30	31 to 35	36 to 40	41 to 45	46 to 50	51 to 55	56 to 60	61 to 65	66 to 70	71 to 75	76 +	N/A
During Renovation Count	7	10	6	7	20	15	11	12	7	7	2	3	1
After Renovation Count	2	3	1	2	8	5	10	7	2	6	0	3	1
Total Count	9	13	7	9	28	20	21	19	9	13	2	6	2

Age Categories (years)

Figure 5.15. Distribution of age during renovation, after renovation, and total – count.



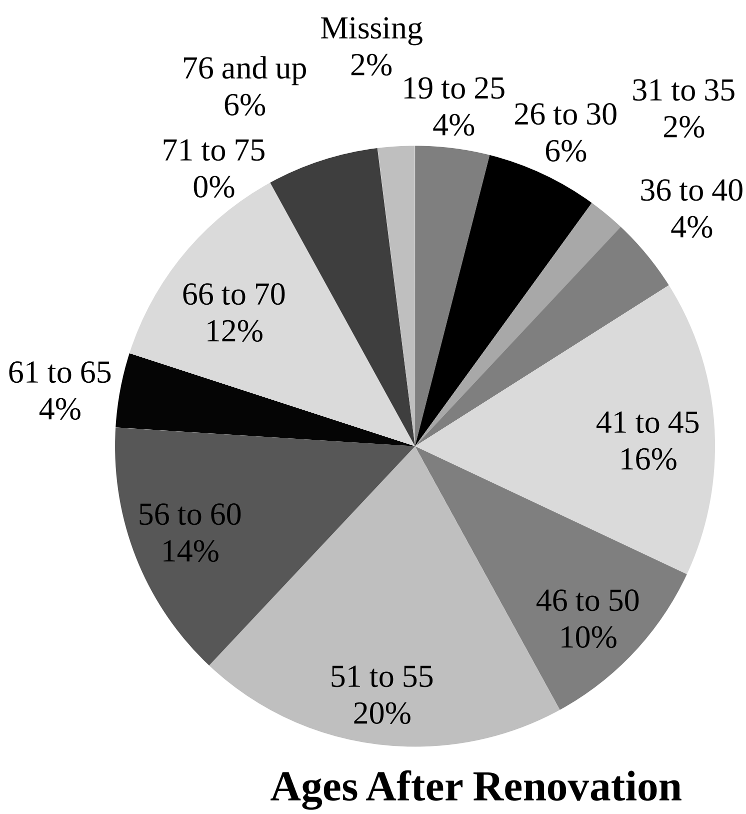


Figure 5.16. Age distribution during renovation and after renovation – percentage.

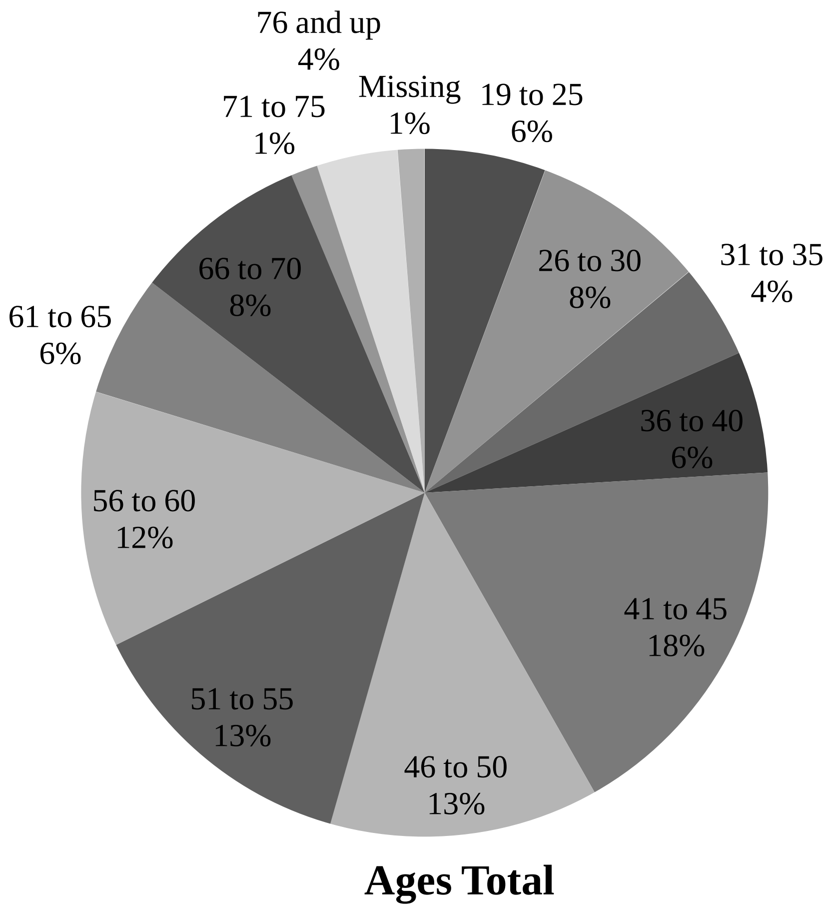


Figure 5.17. Distribution of total age – percentage.

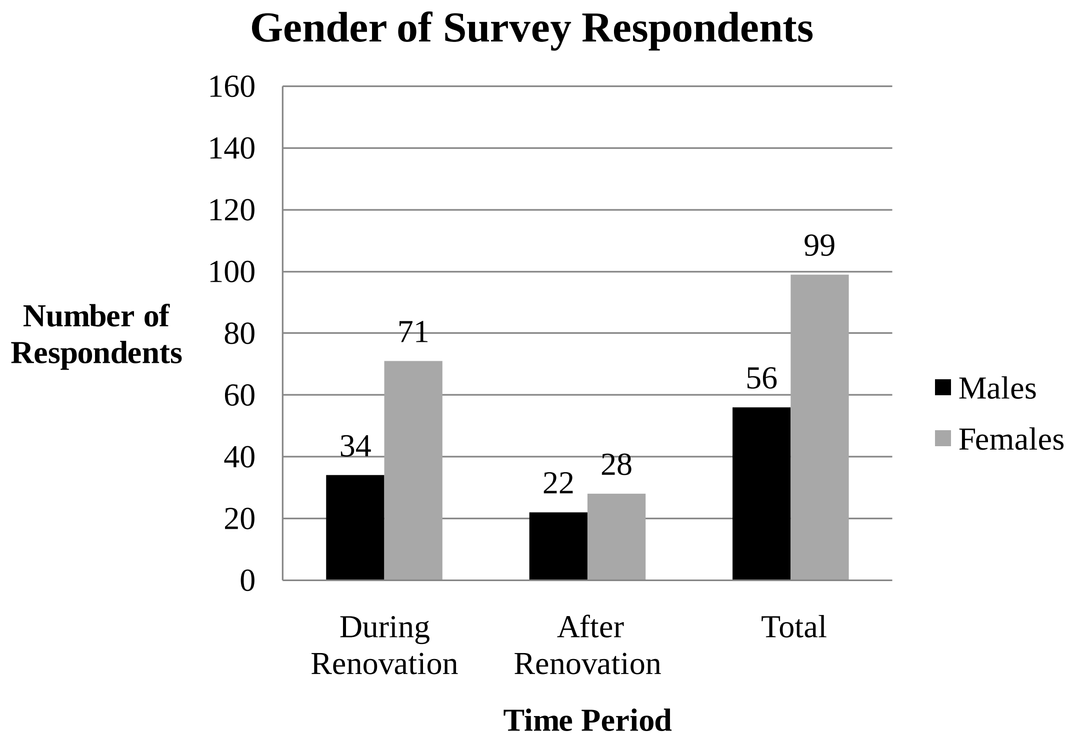


Figure 5.18. Gender distribution: during renovation, after renovation, and total – count.

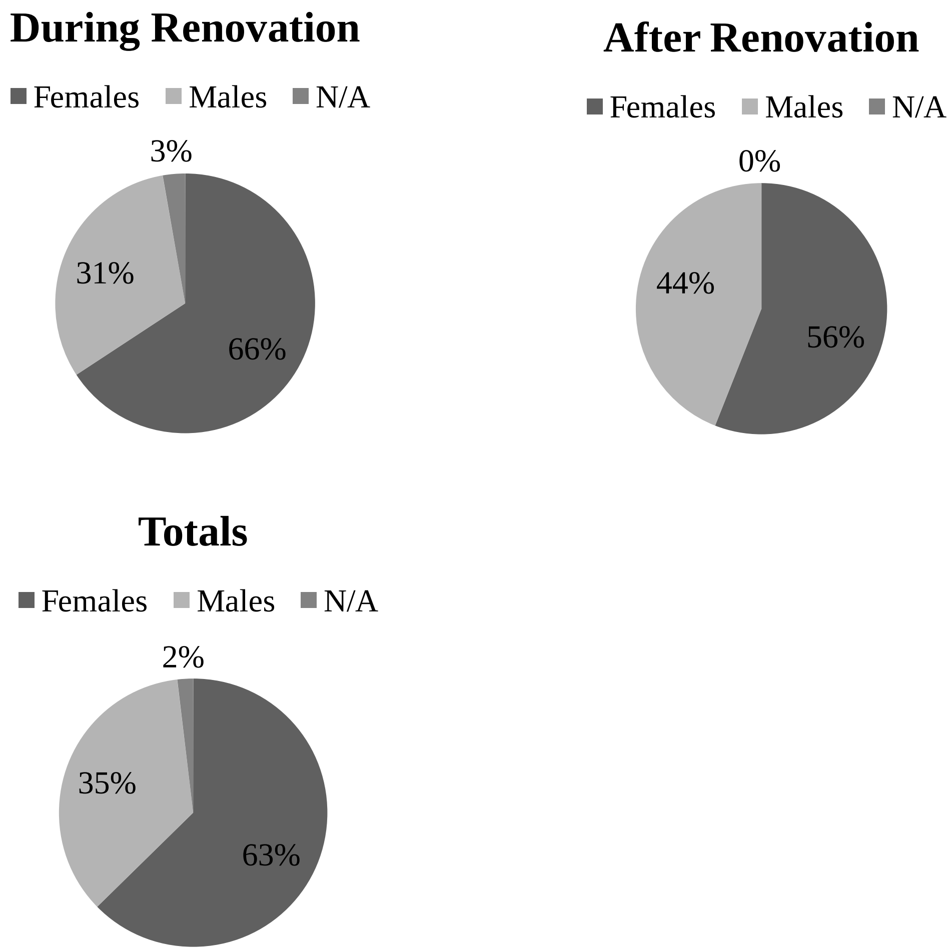
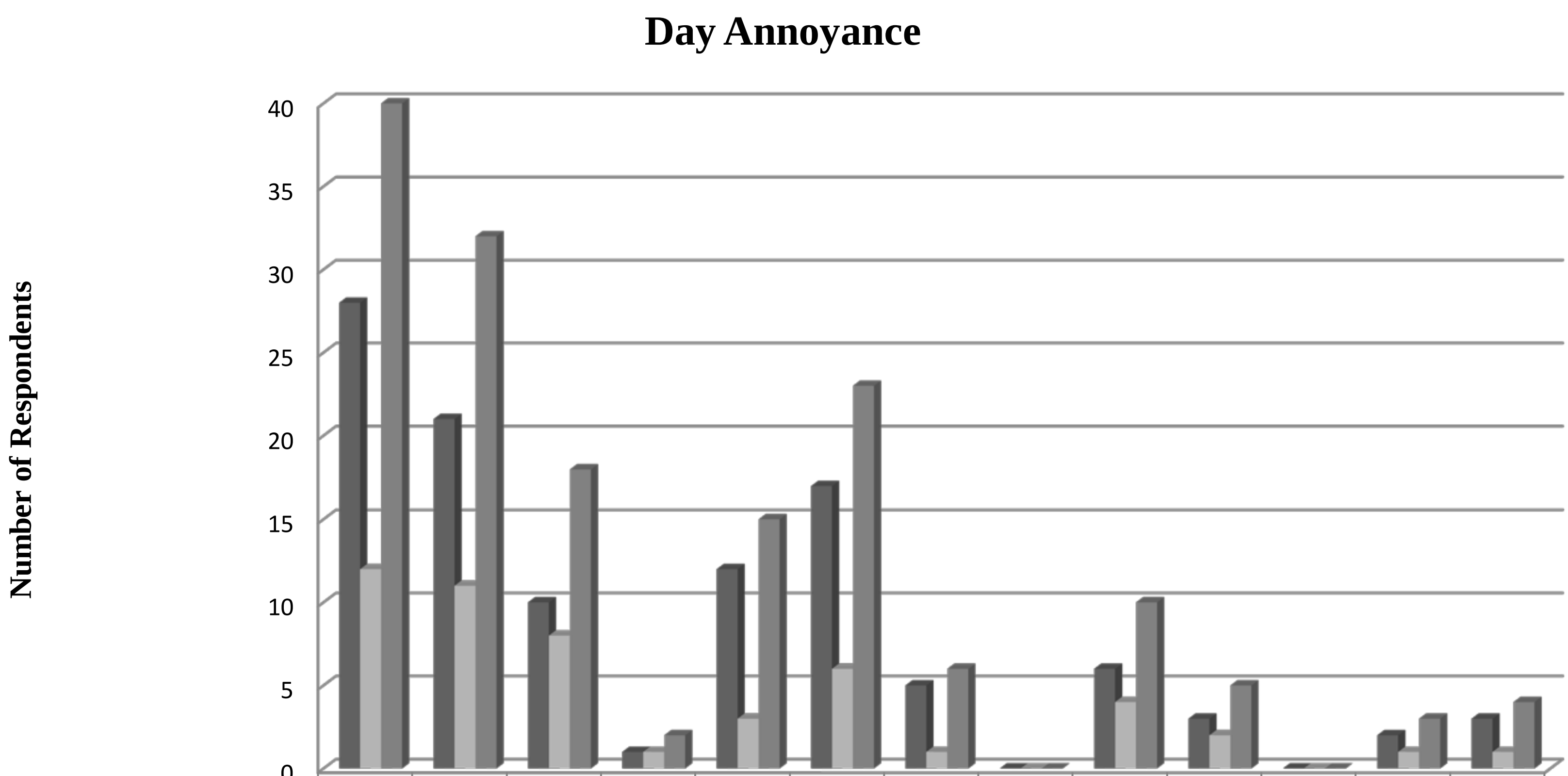


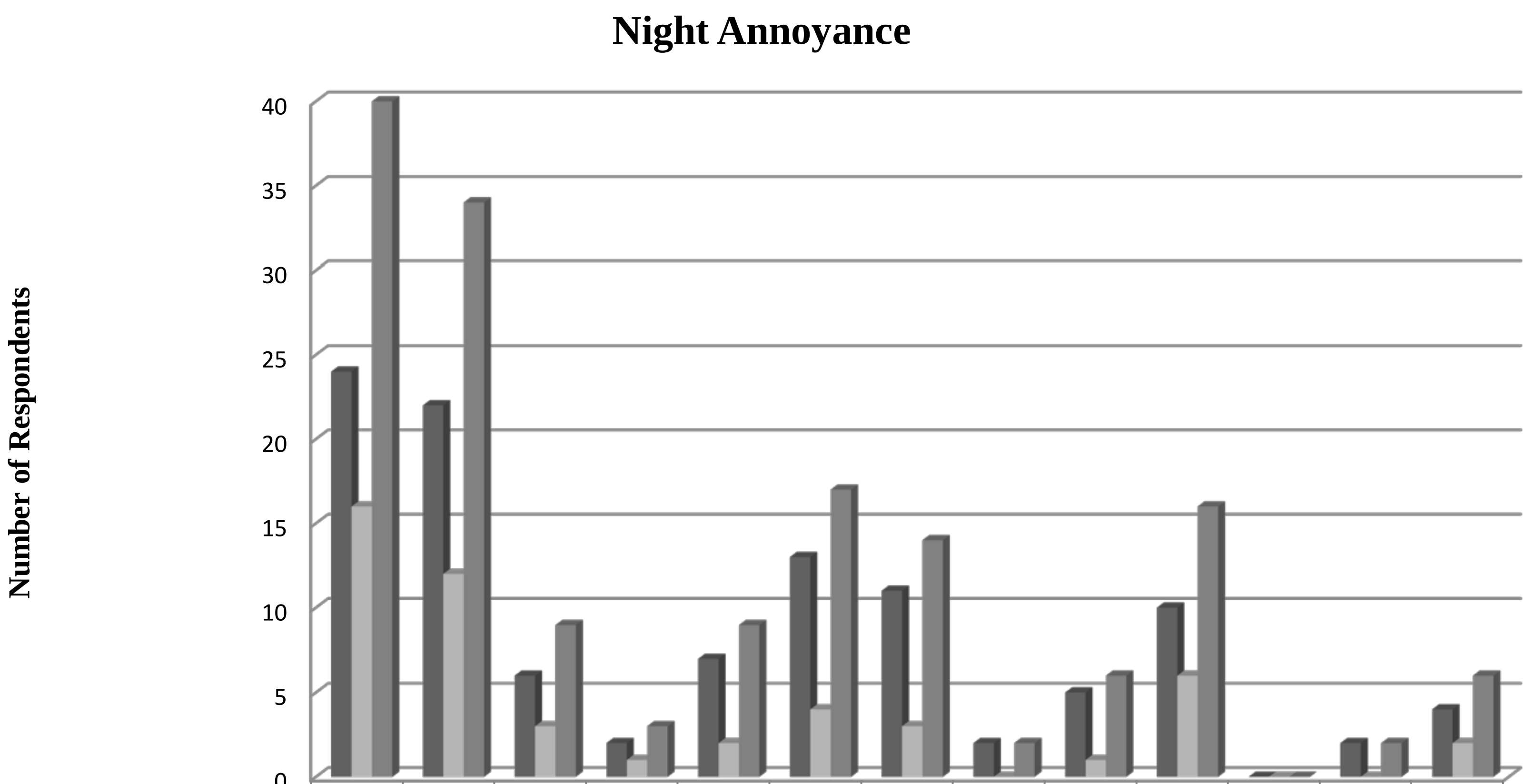
Figure 5.19. Gender distribution: during renovation, after renovation, and total – percentage.



	0	1	2	3	4	5	6	7	8	9	10	11	12
During Renovation Count	28	21	10	1	12	17	5	0	6	3	0	2	3
After Renovation Count	12	11	8	1	3	6	1	0	4	2	0	1	1
Total Count	40	32	18	2	15	23	6	0	10	5	0	3	4

Scale of Annoyance

Figure 5.20. During renovation, after renovation, and total annoyance AM levels – count.



	0	1	2	3	4	5	6	7	8	9	10	11	12
During Renovation Count	24	22	6	2	7	13	11	2	5	10	0	2	4
After Renovation Count	16	12	3	1	2	4	3	0	1	6	0	0	2
Total Count	40	34	9	3	9	17	14	2	6	16	0	2	6

Scale of Annoyance

Figure 5.21. During renovation, after renovation, and total annoyance PM levels – count.

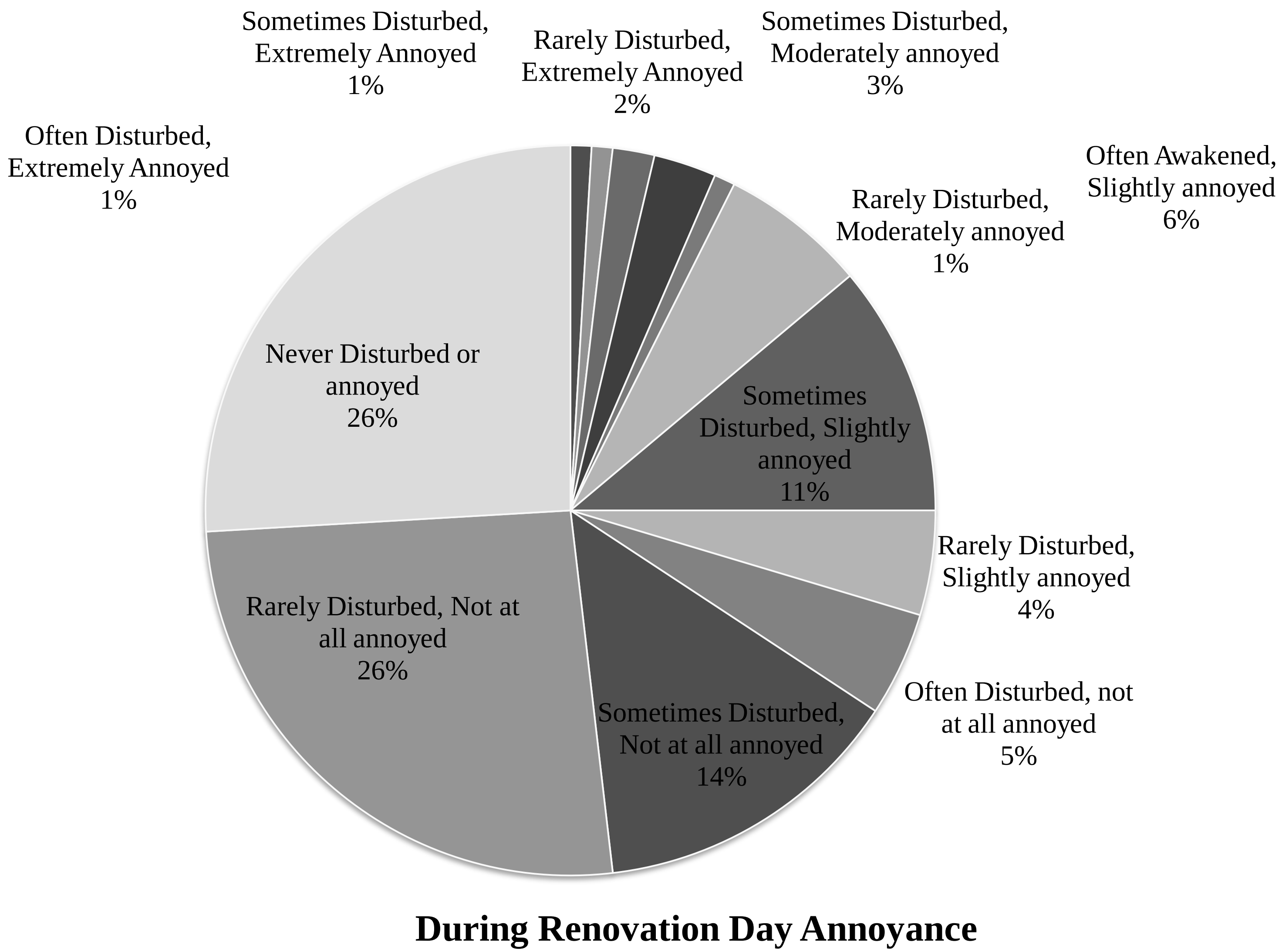


Figure 5.22. During renovation annoyance AM – percentage.

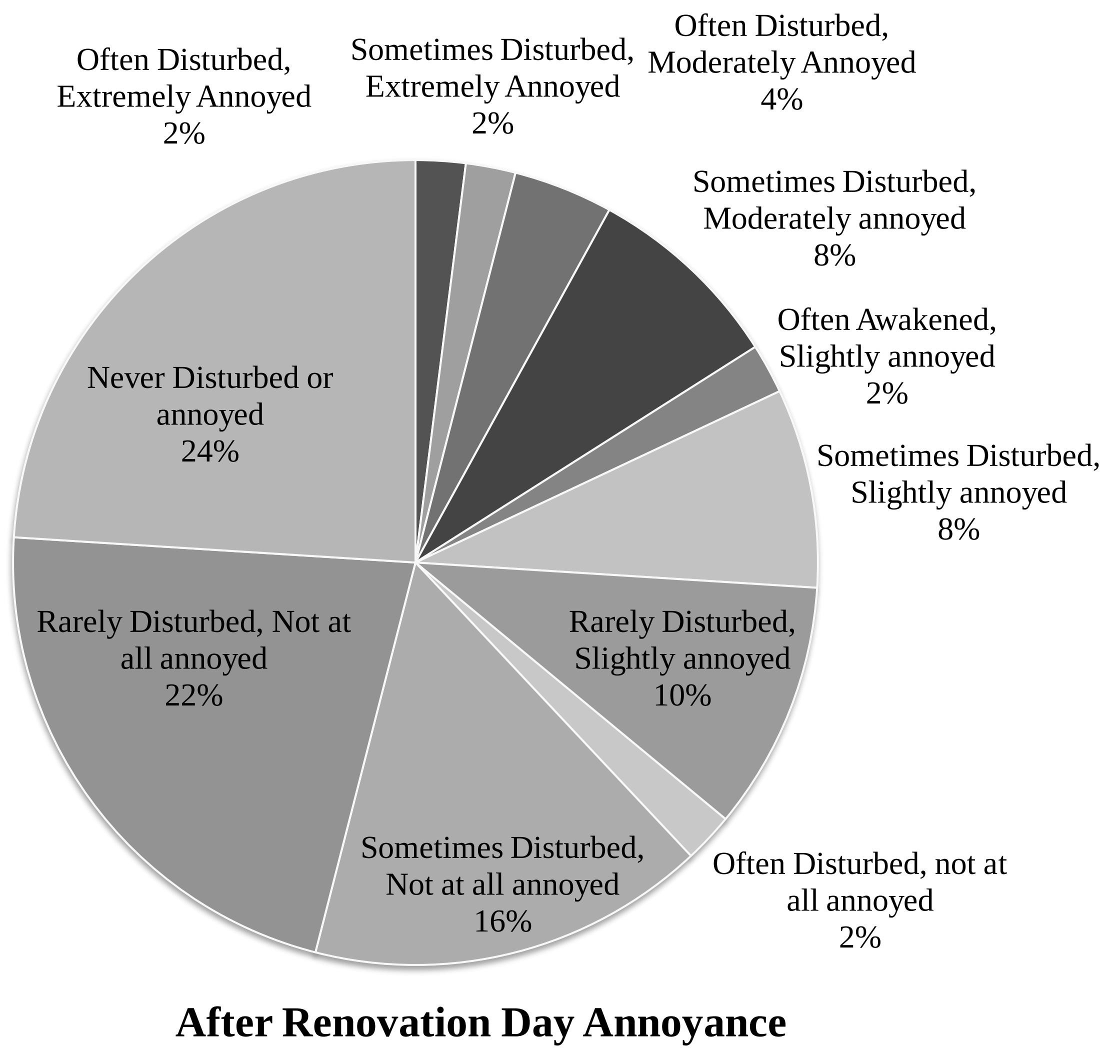


Figure 5.23. After renovation annoyance AM – percentage.

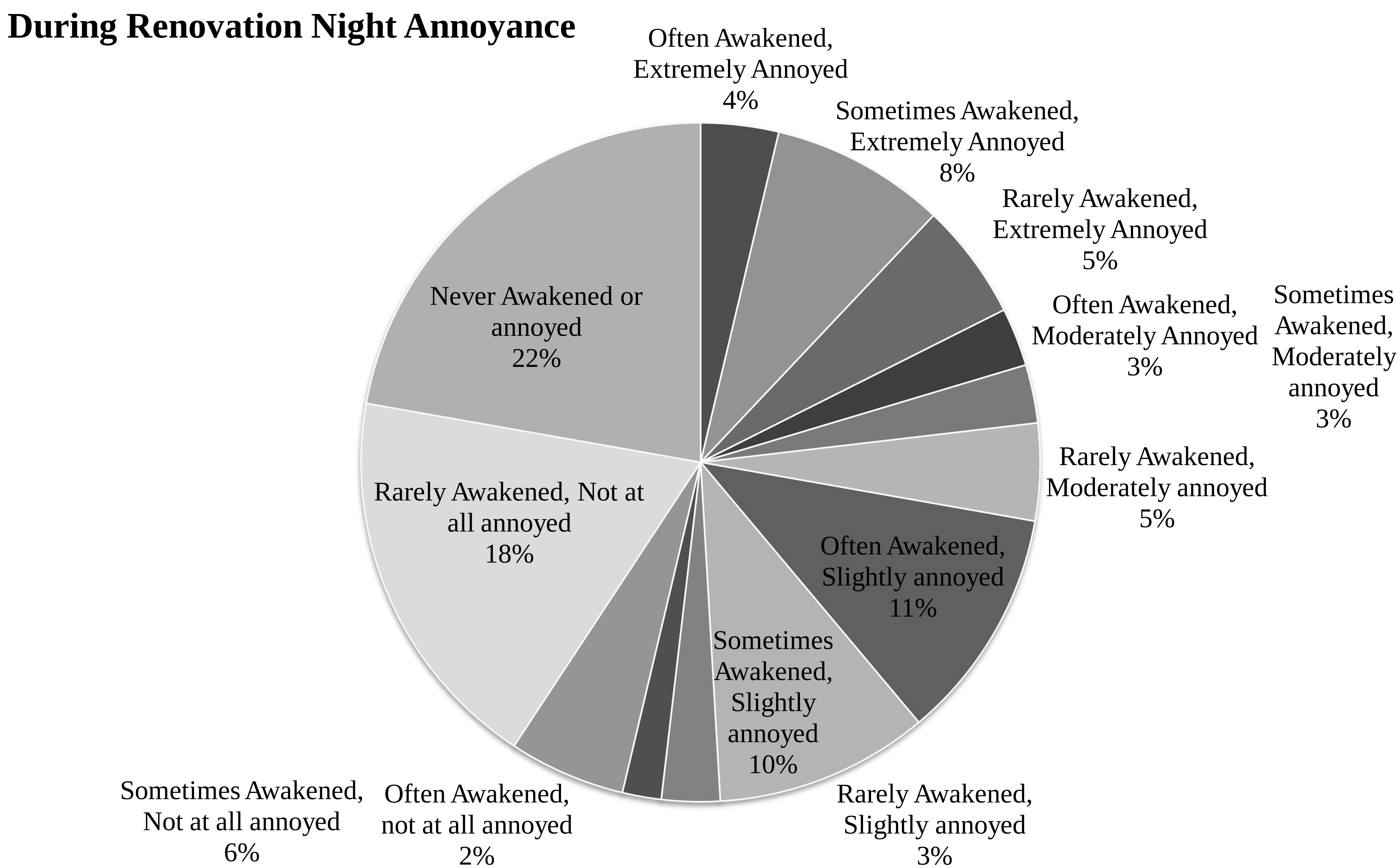


Figure 5.24. During renovation annoyance PM – percentage.

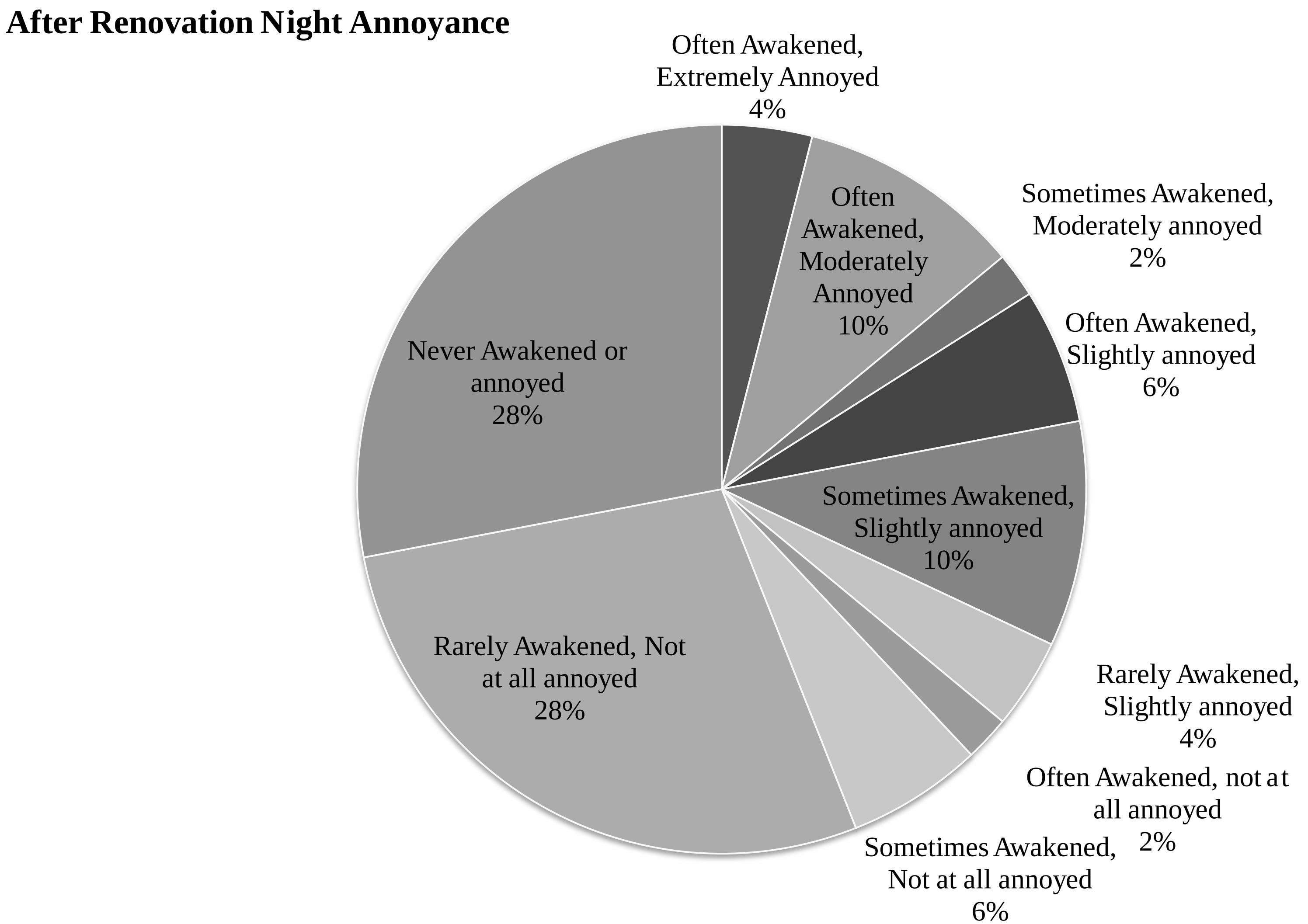
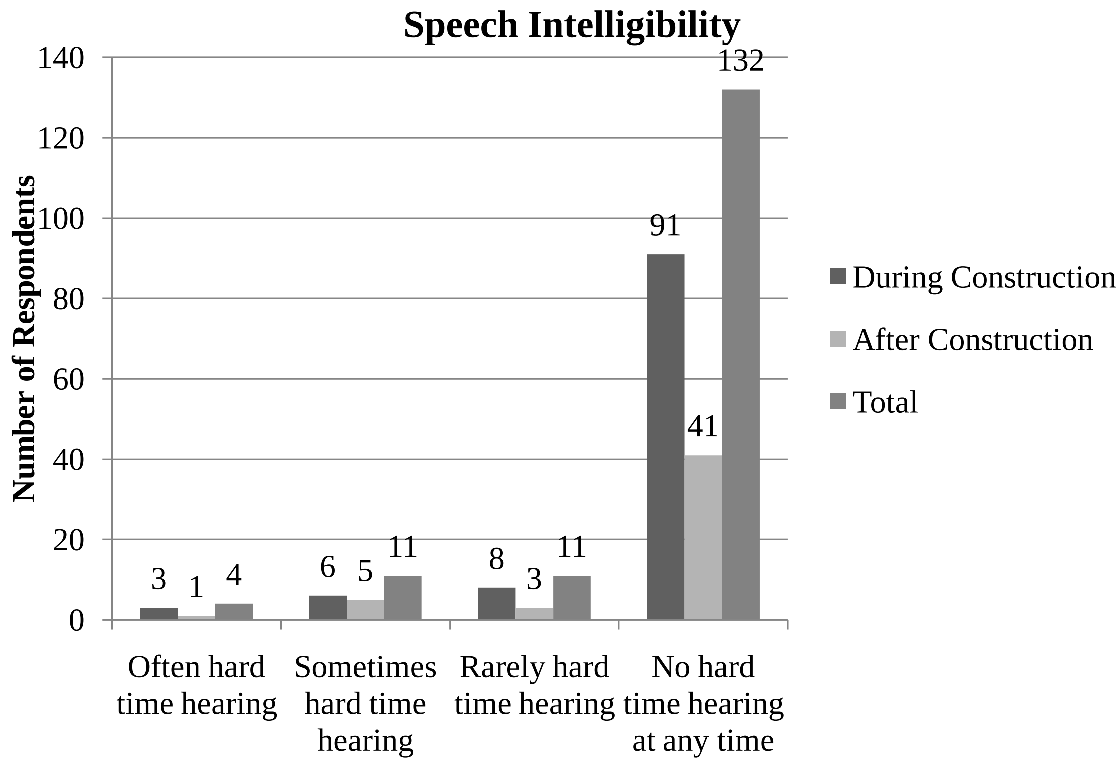


Figure 5.25. After renovation annoyance PM – percentage.



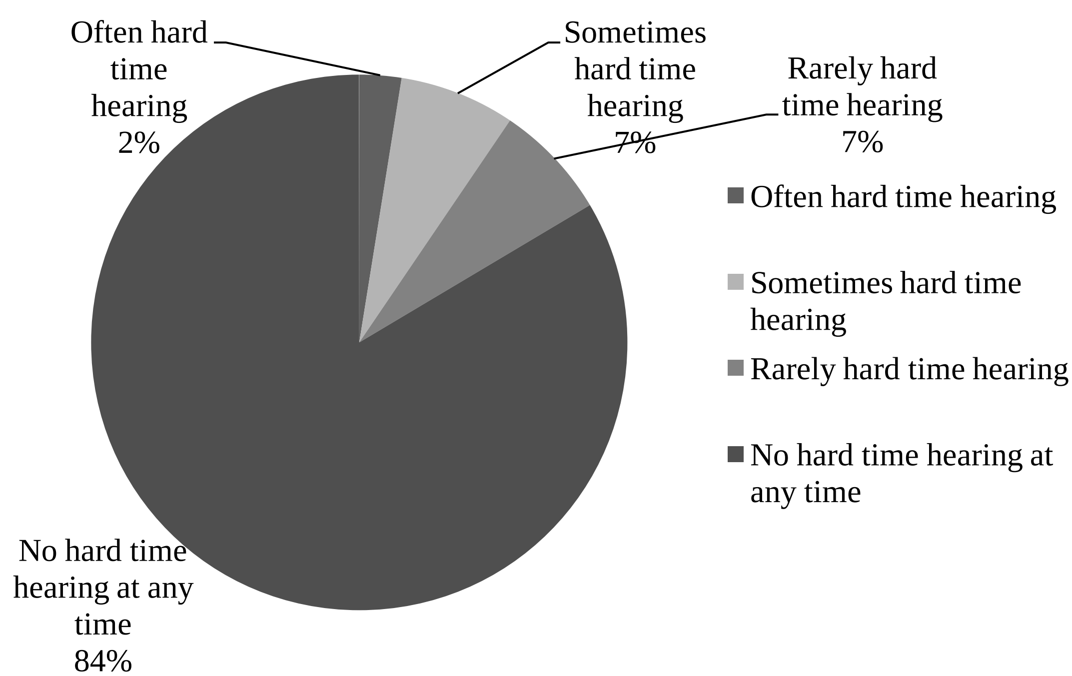
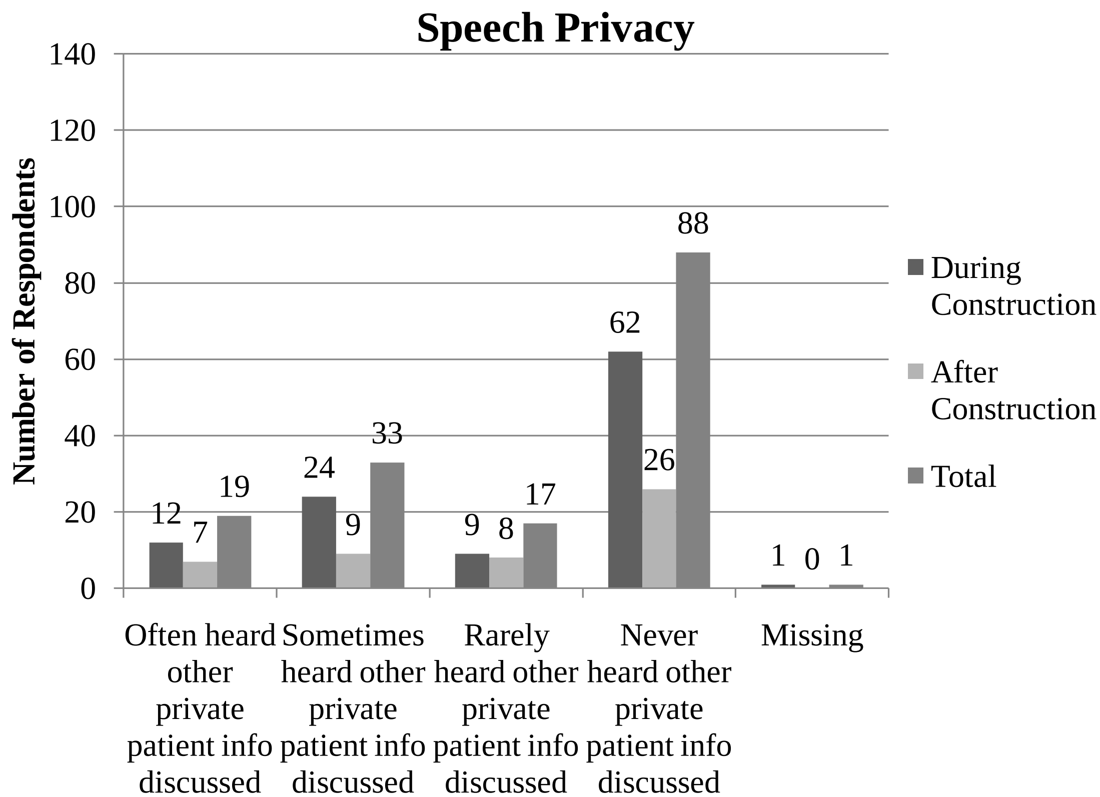


Figure 5.26. Distribution of hard time understanding conversations – (a) total count and (b) percentage.



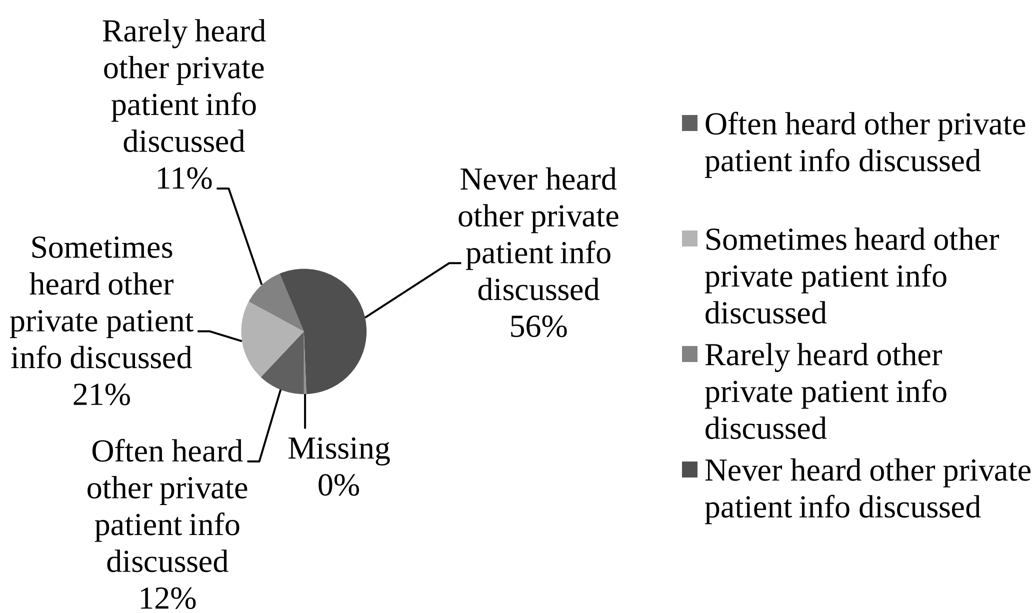


Figure 5.27. Able to hear other patients’ discussions – (a) total count and (b) percentage.

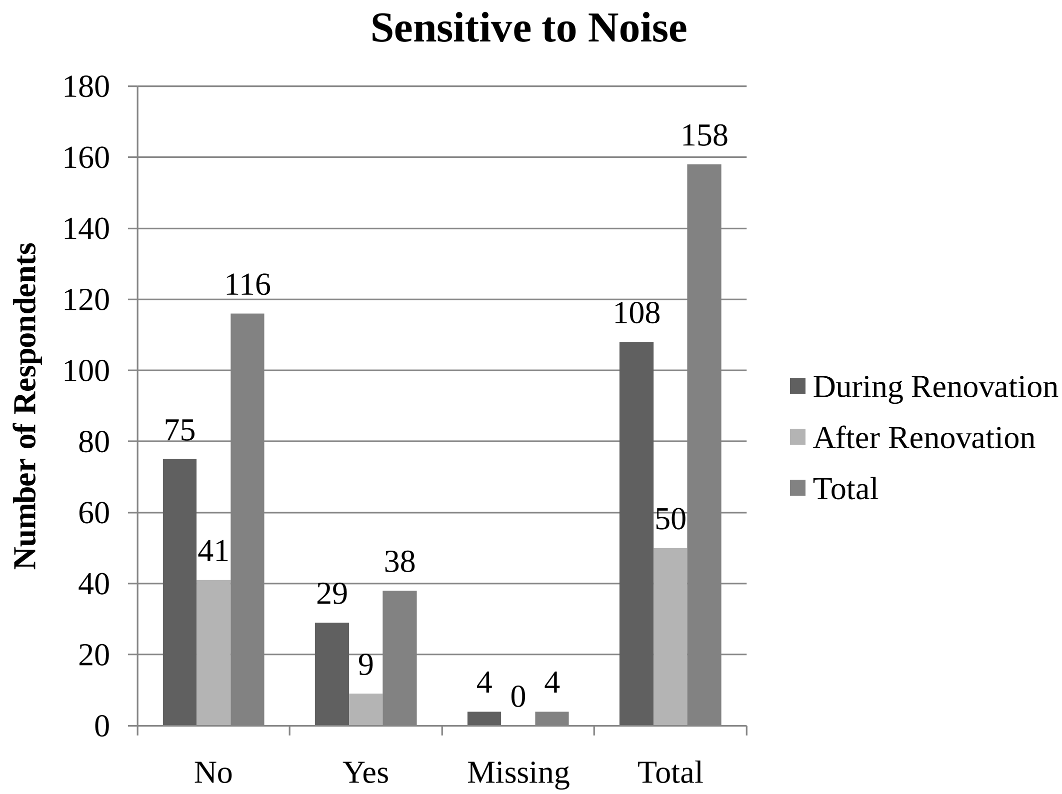


Figure 5.28. Sensitive to Noise: during renovation, after renovation, and total - count.

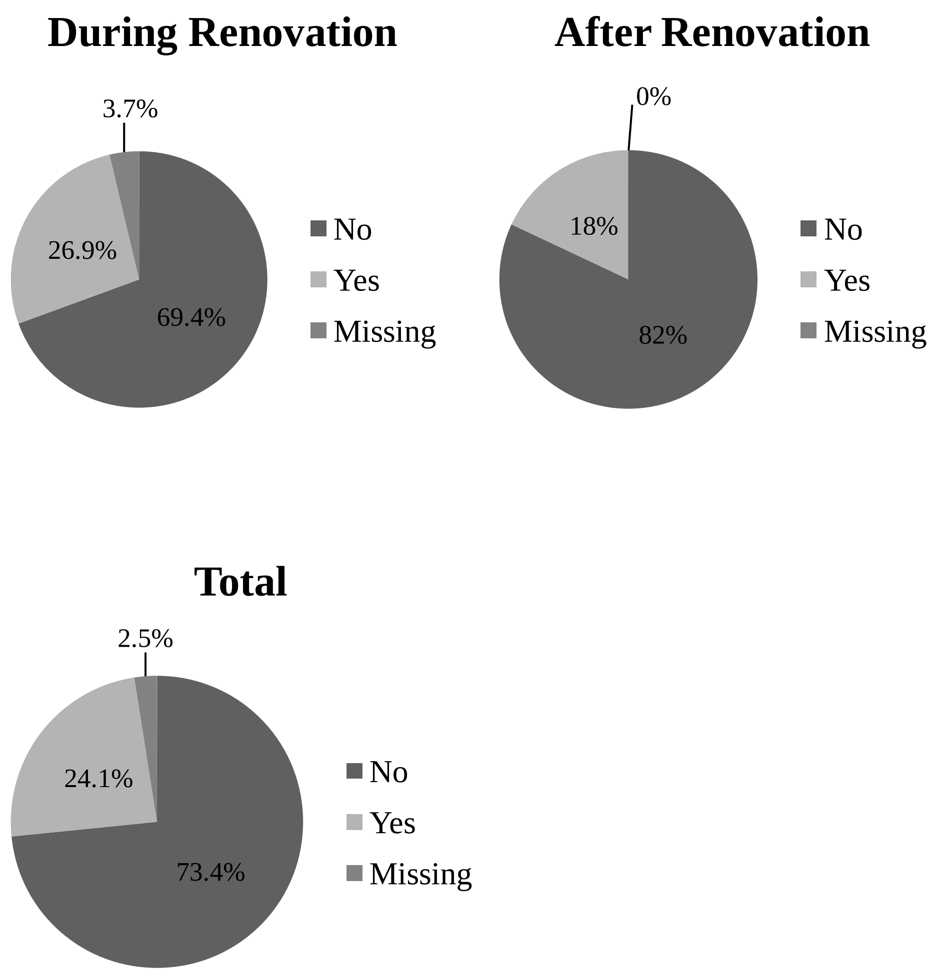


Figure 5.29. Sensitive to Noise distribution: during renovation, after renovation, and total – percentage.

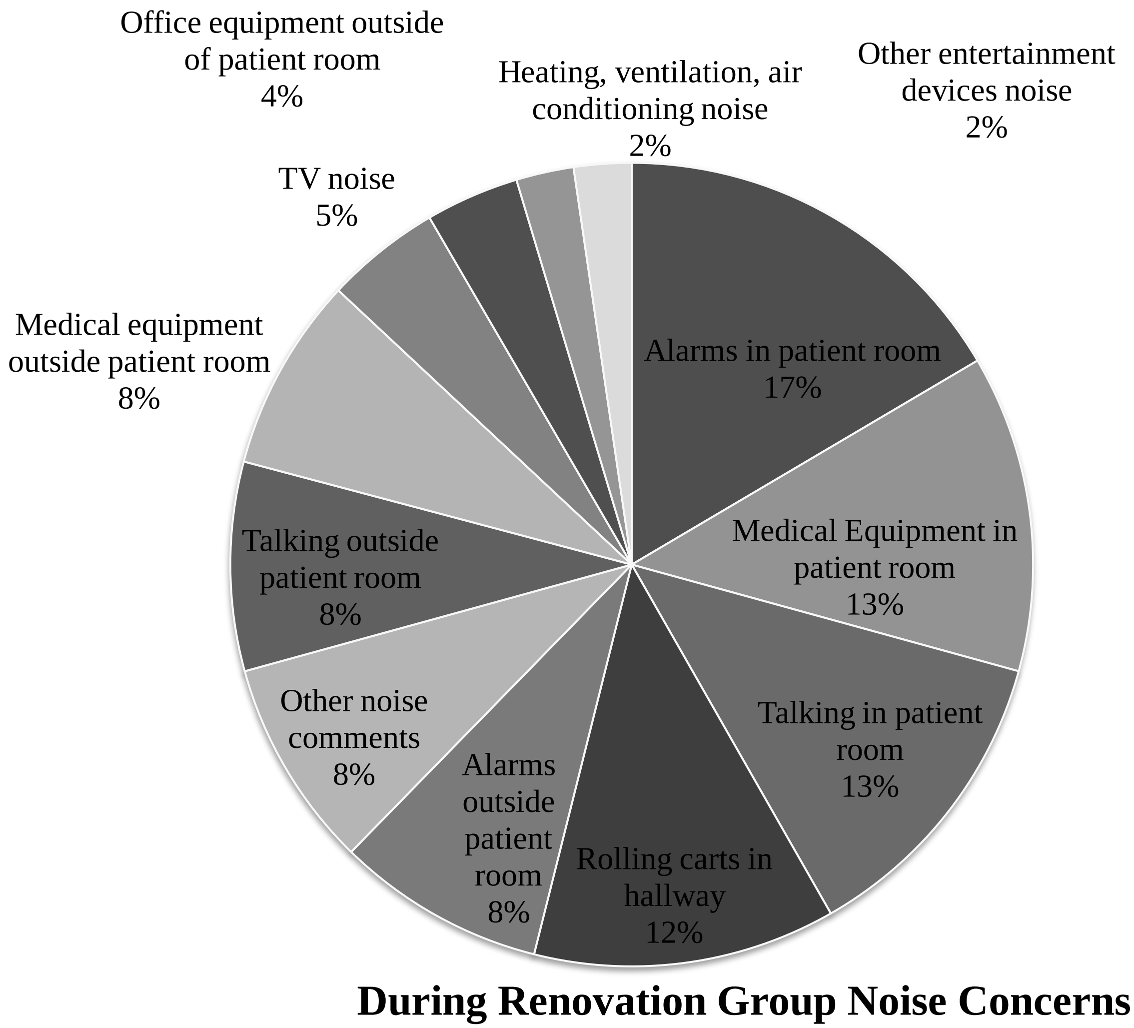


Figure 5.30. During renovation noise sources – percentage.

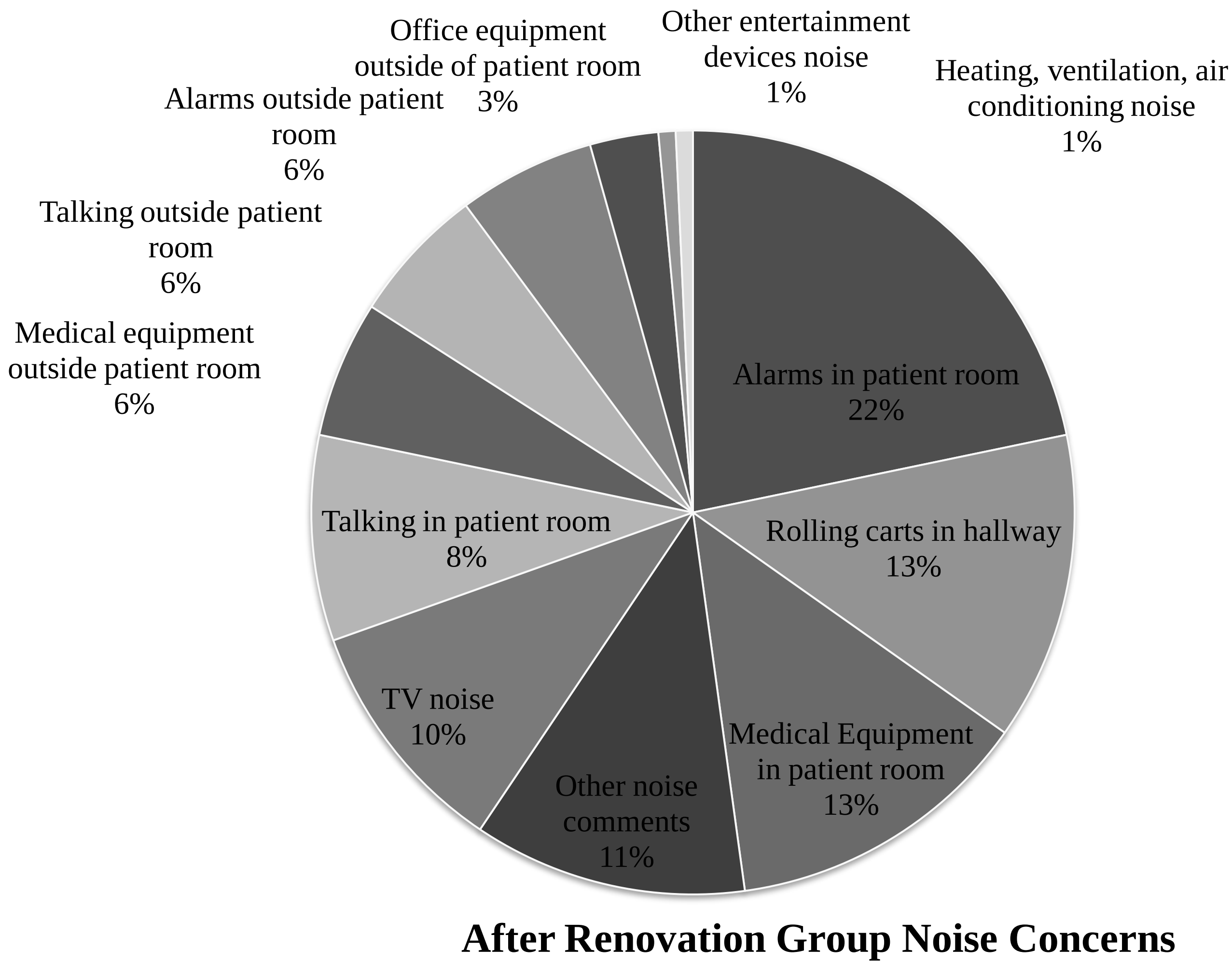


Figure 5.31. After renovation noise sources – percentage.

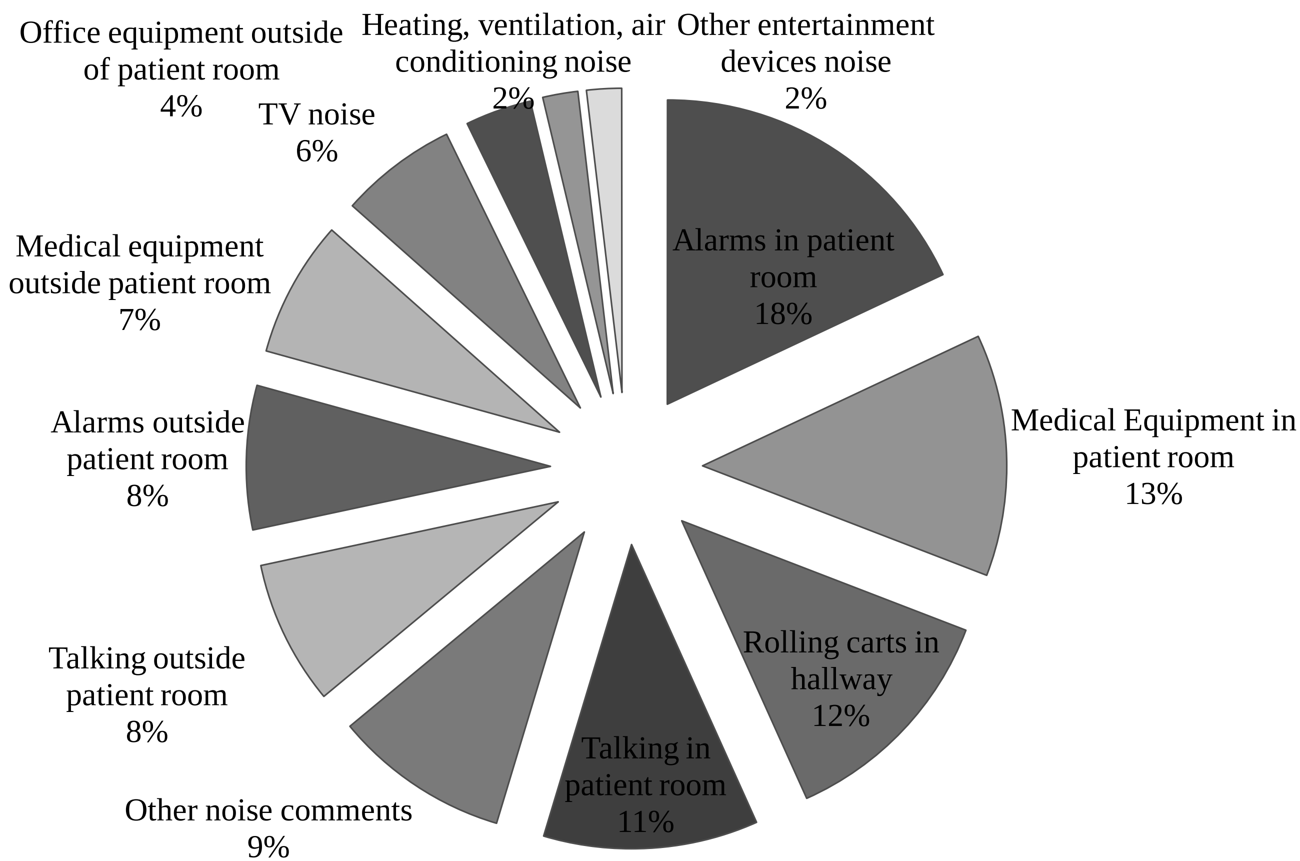


Figure 5.32. Distribution of noise sources – total percentage.

CHAPTER 6: CONCLUSION

The Nebraska Medical Center study presented in this thesis draws upon previous work of others outlined in Chapter 2 and a preliminary study as discussed in Chapter 3. The procedure and analysis was outlined in Chapter 4 with the results being presented in Chapter 5. This study is a cohesive effort to combine both objective and subjective measurements to make conclusive findings and recommendations based upon those outcomes.

6.1 Conclusions and Suggestions

The objectives of the study were to determine if the renovations made to University Tower 6 West at the Nebraska Medical Center improved the acoustics of the space objectively, if patients' perception of hospital noise in that wing was impacted by the improvements, and to make suggestions for further improvements based upon the results of the study. Results from a baseline study that measured sound levels in four different hospital wings with different materials treatments suggested that ambient noise levels could be lowered by adding acoustically absorptive materials, while peak levels could be altered by environmental controls. In University Tower 6 West, the acoustical changes that were made were unfortunately minimal, contrary to what was originally planned by their Facilities office, so one might expect no changes in the ambient or peak levels.

Overall, the sound level meter measurements show only small changes and fairly consistent values between the three time periods: before, during, and after renovations or show a just noticeable difference (3 dBA). The nighttime values are quieter than the daytime ones at all three locations during each time period. The hallway values had the greatest change between the before renovation period and other two renovation time periods with a decrease of 8 dBA, most likely from a piece of medical equipment being left near the sound level meter.

Apparently the changes that have been implemented to date are not enough to make significant decreases in the noise levels, either ambient or peak. All the measurements were over the recommended guidelines set forth by WHO by 20 to 28 dBA. Since many studies have shown the sound levels in hospitals to be above these guidelines, it appears that these current guidelines may be impossible to realize and they should be adjusted accordingly.

The survey on patient perception of hospital noise reveals that a large percentage of respondents did not appear to have a concern about the overall noise levels in this hospital wing, either during the day or night, even though noise has been repeatedly a problem for the Nebraska Medical Center based on their Press Ganey results. Overall, the survey response rate was 158 of 210 or 75%. Results required non-parametric analysis due to non-normal distribution of most of the responses.

As stated in Section 5.2, there was not a statistically significant change in annoyance responses based on the chi-square analysis from during renovation to after renovation, either at night ($p=0.80$) or during the day ($p=0.76$). For the total group: during the night 54% of patients were not annoyed by noise, while 25% were only slightly annoyed; during the day 58% of patients were not annoyed by noise, while 27% were slightly annoyed.

Only 9% of patients indicated having a hard time hearing what was said to them. The surveys showed 33% of patients 'sometimes' or 'often' overheard private discussions of other patients. Several comments were received to remind doctors to use consultation rooms. No relationship was determined between *Gender* or *Age* and the *Annoyance, Hard Time Understanding Spoken Comments, Able to Hear Patient Private Info Being Discussed* or S*ensitivity to Noise* variables. However, a relationship does exist between *Annoyance* and S*ensitivity to Noise*.

The top total five noise sources are: A*larms in Patient Room, Medical Equipment in Patient Room, Rolling Carts in Hallway, Talking in Patient Room,* and *Talking Outside Patient Room.* No major differences between the rankings of sources exist from during renovation time period to the after renovation time period, except for *TV Noise* and *Talking in Patient Room*. *TV Noise* was ranked number 9 of 12 overall but increased as a noise source by 100% in the after renovation surveys (p=0.002); therefore, it is significant. HVAC noise was number 11 of 12 with 2% of responses. Overall after the renovation there was a decrease in actual responses versus expected responses for *Alarms in Patient Room* (-30%, p=0.16), *Talking in Patient Room* (-42%, p=0.02), and *Talking Outside Patient Room* (-28%, p=0.21). Of these, only the decrease in *Talking in Patient Room* is statistically significant.

The renovations in this study unfortunately did not alter patients' perceptions of noise. The biggest concerns for patients are the TV noise and having others overhear their private medical conversations. These concerns stem from having a roommate. Ideas to keep in mind when planning for future improvements include the following: adding soundproofing in the walls of hallways and nurses' station, such as sound reducing wall board, will not help to reduce noise from leading sound sources because most of the sources of noise are located in the patient room. The noises in the patient room stem from the patients or their visitors. These noises are outside of the hospital's control and would involve "policing" the patients and their visitors. Some recommendations are: giving patients private rooms, passing out earphones for the TV or other entertainment devices to patients, handing out earplugs to patients, limiting TV watching hours, installing visual alarms that monitor the speaking noise levels, having doctors use consultation rooms to discuss ailments with patients, and reminding cleaning crew and staff to be quiet when removing supplies from supply room.

6.2 Future Research Work

The study brings up many areas for continued research on the possible impacts of acoustics in healthcare. One would be to do further research in an area of the hospital which will undergo more extensive acoustical renovation. Another would be to conduct a longer study after the renovation is done to determine if staff behavior has changed.

Other ideas for further research would be to simultaneously interview the staff to get their perspective. Another would be to look more rigorously at how noise may impact length of stay or amount of medication or wound healing time on people. Previous research has shown some indication that these could be negatively impacted with greater noise exposure, but it remains unclear whether they are significantly affected by the fluctuating ambient and/or peak levels found in real hospital environments. Furthermore, different noise control techniques could be examined to refine existing suggestions and develop new ones. Another idea would be to look at how patients become conditioned to the noisy environment. Basically, do the patients become used to the noise of the hospital and therefore are less bothered by it the longer they are present?

Suggested modifications to the survey if used in future work are to revise the noise source question by placing a numeric scale of 0 to 5 next to each possible source with directions on choosing the rank value to clarify a patient's perception of that particular source. Another revision for the survey would be to place the numeric scale directly on the questions for question #1, #2, #4, and #5. This would more clearly reflect the patient's choice.

Most patients in this study were not very annoyed with the noise before the renovations occurred, and overall sound levels changed minimally. However, it is clear that noise can be a detrimental component of a healthcare environment. Hospitals seek to provide the best care possible for their patients and a safe working environment for staff. More continued research is recommended to make gains to improve hospital acoustics. Renovation choices need to be carefully thought out before being incorporated because as one can see in this study, sometimes a small change such as changing out the TVs can increase a patient's annoyance with that particular noise source.

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APPENDIX A – SURVEY INFORMED CONSENT

THE NEBRASKA MEDICAL CENTER   UNIVERSITY OF Nebraska Lincoln

Survey on Patient Perception of Hospital Noise (IRB# 086-10-EX)

Patients often complain about the noise experienced during their hospital stays. We are conducting research on patient perception of hospital noise. The purpose of the research is to determine how various factors (such as building materials, light levels, and visual alarms) affect perception of noise in a hospital wing. We are also interested in finding out if this perception correlates with actual measured noise levels.

As a patient who is 19 years of age or older and who has stayed at least one night in the Nebraska Medical Center University Tower 6 West between February and June 2010, we are asking you to complete the attached survey and return it in the envelope provided to the nursing staff before you leave the hospital. We expect that the survey will take only a few minutes to complete. There are no potential risks that you may experience by participating in this research. The anticipated benefits are that the results may improve the comfort of patients during future hospital stays at the Nebraska Medical Center, as well as at other hospitals around the country.

By returning the completed survey, you indicate your willingness to participate in this study. You have the right to withdraw from participating in this research at any time. If you have any questions regarding this study, please feel free to contact one of us listed below. Thank you for your time and consideration!

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VALID UNTIL 2-18-15

APPENDIX B – PATIENT SURVEY

Patient Discharge Survey on Noise During Hospital Stay

Please answer the following questions by marking the appropriate box(es) or filling in the blanks, and return the completed survey in the envelope provided to the nursing staff.
Thank you for your participation!

Gender: Male ☐ Female ☐ Discharge Date: ______________________

Age: 19-25 ☐ 26-30 ☐ 31-35 ☐ 36-40 ☐ 41-45 ☐ 46-50 ☐ 51-55 ☐ 56-60 ☐ 61-65 ☐ 66-70 ☐ 71-75 ☐ 76 and up ☐

Do you (the patient) have any known hearing impairments? Yes ☐ No ☐

1a. How often were you awakened at night by sounds during your hospital stay, other than by a nurse for a required activity?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

1b. How annoyed were you at being awakened?

Did not wake ☐ Not at all ☐ Slightly ☐ Moderately ☐ Extremely ☐

2a. How often was your rest during the day disturbed by sounds during your hospital stay, other than by a nurse for a required activity?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

2b. How annoyed were you at being disturbed?

Did not wake ☐ Not at all ☐ Slightly ☐ Moderately ☐ Extremely ☐

3. Please rank the top 5 sources of noises that disturbed you during your hospital stay, with 1 being the most bothersome.

Medical equipment in patient room ☐ Medical equipment outside of patient room ☐
Alarms in patient room ☐ Alarms outside of patient room ☐
Talking in patient room ☐ Talking outside of patient room ☐
Rolling carts in hallway ☐ Office equipment outside of patient room ☐
TVs ☐ Other entertainment devices ☐ Heating, ventilation, air-conditioning ☐
Other (please describe): ____ ☐

4a. Did you ever have a hard time hearing or understanding the comments from staff because of noise?
Yes ☐ No ☐

4b. If so, how often?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

5a. Were you able to hear other patients, guests or staff discussing private information that did not pertain to you in the areas around you? Yes ☐ No ☐

5b. If so, how often?

Never ☐ Rarely ☐ Sometimes ☐ Often ☐

6. Would you describe yourself as being sensitive to noise? Yes ☐ No ☐

7. Please make any additional comments regarding noise during your hospital stay on the back of this form.

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APPENDIX C-SPSS KEY CODE FOR ANALYSIS

	Male = 1	Female = 2	Category/Score
19-25	M1	F1	1
26-30	M2	F2	2
31-35	M3	F3	3
36-40	M4	F4	4
41-45	M5	F5	5
46-50	M6	F6	6
51-55	M7	F7	7
56-60	M8	F8	8
61-65	M9	F9	9
66-70	M10	F10	10
71-75	M11	F11	11
76 & UP	M12	F12	12
How Often Awakened at Night			
Never	MNN	FNN	1
Did not wake			
Rarely			
Not at all	MNRN	FNRN	2
Slightly	MNRS	FNRS	3
Moderately	MNRM	FNRM	4
Extremely	MNRE	FNRE	5
Sometimes			
Not at all	MNSN	FNSN	6
Slightly	MNSS	FNSS	7
Moderately	MNSM	FNSM	8
Extremely	MNSE	FNSE	9
Often			
Not at all	MNON	FNON	10
Slightly	MNOS	FNOS	11
Moderately	MNOM	FNOM	12
Extremely	MNOE	FNOE	13
How Often Awakened at Day			
Never	MDN	FDN	1
Did not wake			
Rarely			
Not at all	MDRN	FDRN	2
Slightly	MDRS	FDRS	3
Moderately	MDRM	FDRM	4
Extremely	MDRE	FDRE	5
Sometimes			
Not at all	MDSN	FDSN	6

Slightly	MDSS	FDSS	7
Moderately	MDSM	FDSM	8
Extremely	MDSE	FDSE	9
Often			
Not at all	MDON	FDON	10
Slightly	MDOS	FDOS	11
Moderately	MDOM	FDOM	12
Extremely	MDSE	FDSE	13
Sources of Noise			
Medical Equip in Room	MEIR	FEIR	1
Alarms in Room	MAIR	FAIR	2
Talking in Room	MTIR	FTIR	3
Rolling carts in Hallway	MRC	FRC	4
TVs	MT	FT	5
Other Entertainment Devices	MO	FO	6
HVAC	MH	FH	7
Medical Equip outside of Room	MEOR	FEOR	8
Alarms outside of Room	MAOR	FAOR	9
Talking outside of Room	MTOR	FTOR	10
Office Equip outside of Room	MOF	FOF	11
Other	MOTH	FOTH	12
Ever have a hard time hearing staff because of noise			
No	MHN	FHN	1
Yes			
Never	----	----	2
Rarely	MHYR	FHYR	3
Sometimes	MHYS	FHYS	4
Often	MHYO	FHYO	5
Able to hear other patient info in areas around you			
No	MHON	FHON	1
Yes			
Never	----	----	2
Rarely	MHOYR	FHOYR	3
Sometimes	MHOYS	FHOYS	4
Often	MHOYO	FHOYO	5
Sensitive to Noise			
No	MSNN	FSNN	1
Yes	MSNY	FSNY	2