Noise levels in Johns Hopkins Hospital

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This article presents the results of a noise survey at Johns Hopkins Hospital in Baltimore, MD. Results include equivalent sound pressure levels (L_{eq}) as a function of location, frequency, and time of day. At all locations and all times of day, the L_{eq} indicate that a serious problem exists. No location is in compliance with current World Health Organization Guidelines, and a review of objective data indicates that this is true of hospitals throughout the world. Average equivalent sound levels are in the 50–60 dB(A) range for 1 min, $\frac{1}{2}$, and 24 h averaging time periods. The spectra are generally flat over the 63–2000 Hz octave bands, with higher sound levels at lower frequencies, and a gradual roll off above 2000 Hz. Many units exhibit little if any reduction of sound levels in the nighttime. Data gathered at various hospitals over the last 45 years indicate a trend of increasing noise levels during daytime and nighttime hours. The implications of these results are significant for patients, visitors, and hospital staff.
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I. INTRODUCTION

The importance of noise in health care has been recognized for years, as evidenced by a statement in 1859 by Florence Nightingale[1,2]

> "Unnecessary noise, then, is the most cruel absence of care which can be inflicted either on sick or well."

However, little work has been done to characterize and reduce hospital noise even though it routinely ranks among the top complaints of hospital patients, visitors, and staff.[3,4]

There are a small number of hospital noise surveys in the open literature,[4–21] and some studies that specifically consider intensive care units,[14,16,22–35] operating rooms,[36–42] and nurseries.[43–48] A few address tools found in hospitals, particularly incubators and instruments used in orthopedics.[10,49–53] All of these studies are generally conducted by physicians and nurses and reported in the medical literature, which is also replete with editorials and letters railing against noise.[54–58] Taken as a whole, this body of literature suggests that a significant problem exists, and that it is generally getting worse rather than better, even in new construction.

Interestingly, the literature on typical hospital noise levels is generally limited to overall noise levels (either linear or A-weighted). There is little mention of typical spectra and even less discussion of additional measures of the noise such as spectral quality, tonality, and time variance. This makes it quite difficult to discuss the noise in terms of human physiological and psychological response.

There are only a handful of reports dealing with control of hospital noise,[1,43,59] and these are almost entirely limited to administrative control measures such as closing doors and asking staff to speak softly. Such measures have not met with great success in industrial settings where there is, in theory, greater control over personal behavior than exists in hospitals. A notable exception to this is the recent study by Akhtar *et al.*[60] in which noise canceling headphones were given to medical staff and the parents of children in a pediatric intensive care unit (PICU). This study found that subjects generally perceived the headphones to offer an improvement in the environment, but overwhelmingly said they would prefer not wearing them in spite of this improvement.

Noise in hospitals is important for a number of reasons in addition to the obvious issue of annoyance. There is evidence that the high sound levels in the hospital contribute to stress in hospital staff[61] and a suggestion from one study that noise contributes to staff burn-out.[62,63] Further, there is some evidence that noise negatively affects the speed of wound healing. Fife[64] showed that hospital stays for cataract surgery patients increased during the time of higher noise due to construction of a new building. Also, Minckley[65] found that more medications were required for surgical patients in recovery when the sound levels present were high (over 60 dB re 20 μPa). Wysocki,[66] Toivanen *et al.*,[67] and Cohen[68] have all shown delays in wound healing in animals (mice and rats) when noise is present.

There are a few studies of the effects of noise on performance in hospitals, but these present conflicting results. Hawksworth *et al.*[69] looked at the performance of trainee anesthetists on a set of two standard psychomotor tests in the presence of music, white noise, and silence and found no difference in performance. Similarly Moorthy *et al.*[70] studied the ability of surgeons to place three laparoscopic sutures on a suture pad in quiet and noisy conditions using background operating room noise and music. They found no significant differences in performance with and without sound present. Park *et al.*[71] conducted a study of orthopedic surgeons in which they were asked to read x-rays in the presence of controlled levels of noise. It was found that there was no

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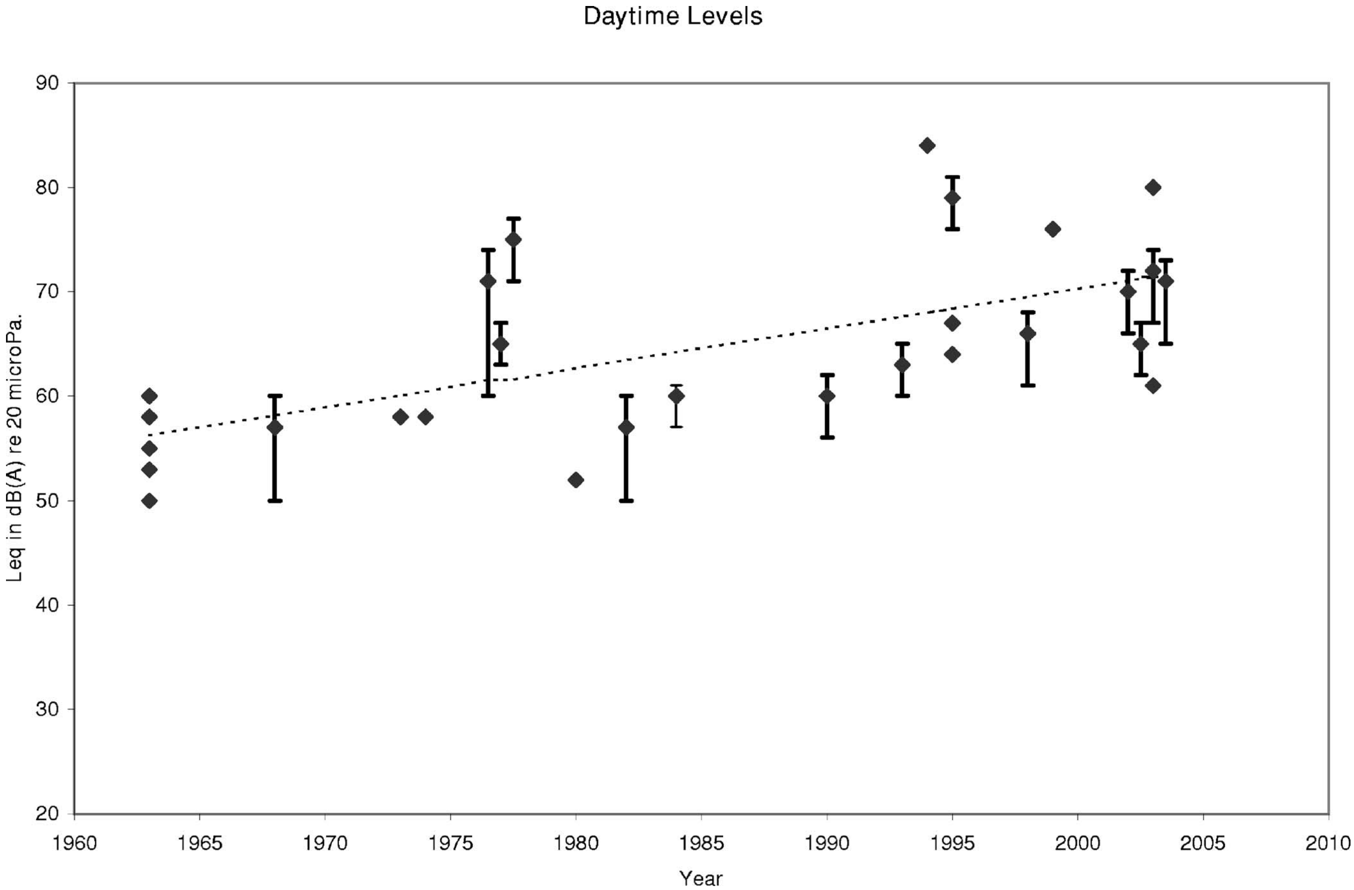

FIG. 1. A-weighted equivalent sound pressure levels measured in hospitals during daytime hours as a function of the year of study publication. Error bars indicate that data were given as a range spanned by the error bar. In these cases, the data point is shown as the logarithmic average of the range extreme values.

significant performance difference between noisy and quiet conditions, but overall residents who preferred quiet did better in quiet environments, and those who stated no preference performed equally as well in both noise and quiet. By contrast, Murthy *et al.*[39] found that mental efficiency and short-term memory declined in the presence of typical operating room noise for anesthetists. Murthy *et al.* also found that speech discrimination declined 23% and speech thresholds increased roughly 25% for the same level of comprehension[72]—a result with important implications for medical safety.

Finally, noise in hospitals could become important if it permits one facility in an area to advertise a better patient environment than other hospitals, i.e., if it offers a competitive advantage.

While the problem of hospital noise has not been adequately addressed, there are established guidelines and standards which deal with hospital noise. The World Health Organization (WHO) included guidelines for hospitals in their *Guidelines for Community Noise* published in 1995.[73] These guidelines recommend an L_{max} of no more than 40 dB(A) (re 20 μPa) at night measured on the fast setting. They also suggest patient room L_{eq} of no more than 35 dB(A) during the day and 30 dB(A) at night. The American National Standards Institute, Inc. (ANSI) also mentions hospital noise but uses different measures for their standard. ANSI S12.2, published in 1995, recommends a maximum RC(N) (neutral spectrum room criterion) value ranging from 25 to 40 depending on the room type, and a maximum NCB (balanced noise criterion) value ranging from from 25 to 40.[74] The Environmental Protection Agency (EPA) document which summarizes the significant community noise studies done in the late 1960s makes its recommendations in terms of the L_{dn} (day-night sound pressure level), which should not exceed 45 dB(A).[75] Of these standards and guidelines, we find the WHO values most frequently cited in the literature and thus we will rely on those in this article. We will show in the following that existing measures of sound pressure levels in hospitals exceed these guidelines significantly, and have for many years.

This article is the first step in a larger project to improve the sound environment in hospitals. It focuses on the existing sound pressure levels in a major US hospital and puts these in the context of sound pressure levels reported at hospitals in the last few decades. The measured data confirm the existence of a serious noise problem.

II. HOSPITAL NOISE LEVELS OVER THE YEARS

Although the literature on hospital noise is thin, some reliable noise measurements have been made at a variety of hospitals throughout the world over the last 40–50 years and published in the open literature. We reviewed these data carefully to enable us to answer the following basic ques-

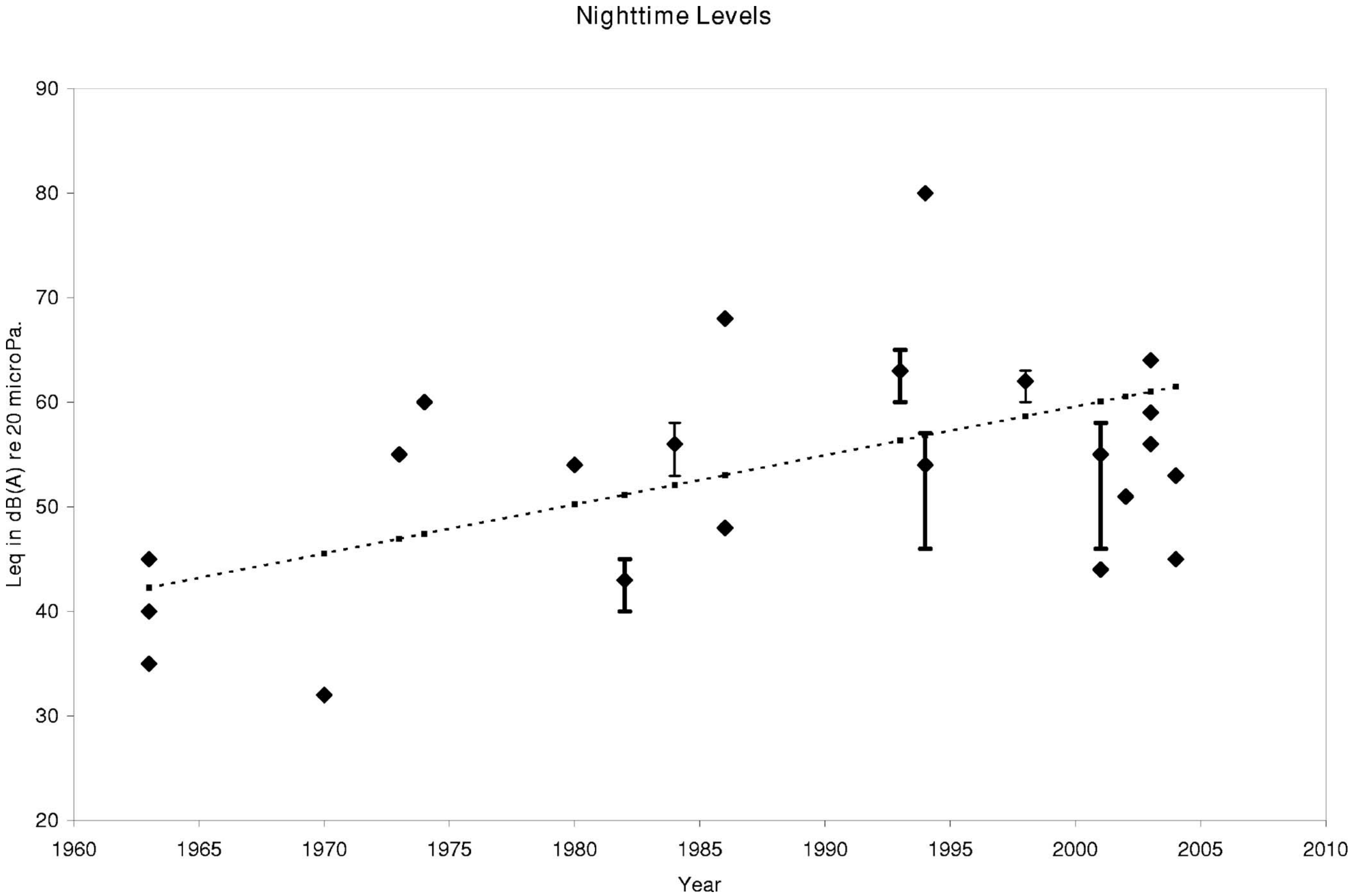

FIG. 2. A-weighted equivalent sound pressure levels measured in hospitals during nighttime hours as a function of the year of study publication.

tions: Is there any indication that hospital noise levels are changing over time? Do hospital noise levels vary dramatically from hospital to hospital? Do hospital noise levels vary significantly with type of unit?

In gathering data to answer these questions, we discovered a problem with the hospital noise literature that had been previously noted by Philbin.[48] The vast majority of the published literature on hospital noise has been written by medical staff with little or no training in acoustics. Unfortunately, there tends to be a consistent error in the presented results, namely that average sound pressure level information is published, but that the average has been computed erroneously by taking the mean of the decibel values read on a meter. The normal presentation gives a mean and a standard deviation (in decibels). To ensure the validity of our analysis, we considered all literature we could find that took correct averages, or presented raw data that we could average, or that presented a standard deviation of 1 dB or less. We also included data that were given as a range, and we show this as a data point at the decibel average of the range end points with error bars showing the span cited. Given the absence of a hospital noise standard, the measurements in the literature also vary from A-weighted L_{eq} to unweighted L_{eq} to L_{peak} or other measures. For consistency, we considered only A-weighted L_{eq} values, as these were most often measured. Even with this restriction, we should note that there is no known uniformity in the averaging time for the L_{eq}; nor is it known whether the sound level meter gathering data in each case were set to slow or fast.

Figures 1 and 2 show the results of our compilation of existing noise studies.[5–8,10–15,18–23,25,31–33,35,37–39,46,48,59,61,65,76–78] In these and all other figures in this article, dB(A) is referenced to 20 μPa and decibel averages refer to logarithmic or energy averages. The A-weighted L_{eq} are graphed as a function of the year of publication of the study. Figure 1 shows results for daytime hours and Fig. 2 for nighttime hours (using the same hourly division as in the L_{dn} when possible). When the data provided did not specify time, they were included in the daytime graph only. The results include hospitals of various types (major research facilities to community hospitals) located throughout the world. They make no distinction based on type of medical unit observed.

Figures 1 and 2 show three items of interest. First, not one published result shows a hospital which complies with the WHO guidelines for noise in hospitals. Most of the data, particularly that which is recent, shows sound levels 20–40 dB(A) higher. This certainly raises the question of what significance the guidelines have.

Second, there is a clear trend for rising hospital noise levels consistently since 1960. A straight line fit to the data (included in the figures) shows an increase, on average, of 0.38 dB per year for daytime levels, and 0.42 dB per year for the nighttime levels. The correlation coefficient for the straight line fit is $r=0.66$ for the daytime levels and $r=0.59$ for the nighttime levels. The (logarithmic) average A-weighted L_{eq} in hospitals have risen from 57 dB(A) in

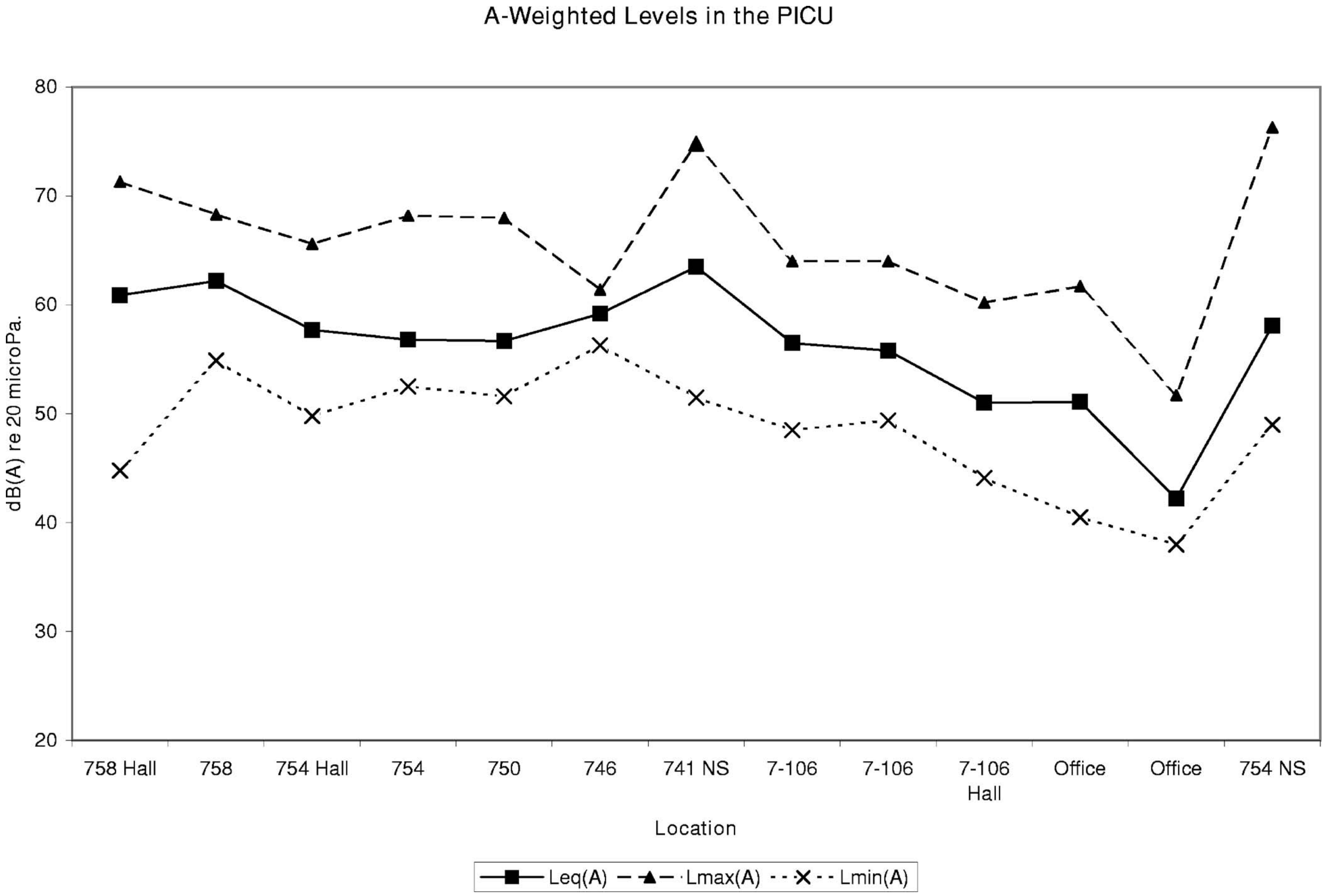

FIG. 3. A-weighted equivalent sound pressure levels measured in various locations in the PICU. Here and subsequently, NS indicates a nursing station.

1960 to 72 dB(A) today during daytime hours, and from 42 dB(A) in 1960 to 60 dB(A) today during nighttime hours.

Third, Figs. 1 and 2 show remarkably little variation given that the results are for widely different sorts of hospitals and medical units. Regardless of the reasons for this relative consistency, it suggests that the problem of hospital noise is universal, and that noise control techniques might also be expected to be applicable broadly. The bulk of the work on hospital noise has centered on intensive care units and operating rooms (with emphasis on orthopedic surgeries). These units do tend to show higher L_{eq} on average than other units included in measurement data, but not dramatically so.

The next sections of this article present new data on noise levels at a particular hospital—Johns Hopkins Hospital in Baltimore, MD. Johns Hopkins Hospital (JHH) is a large research medical facility which services a very broad community. It has been the top ranked hospital in the US (according to US News and World Report) for the last 14 years. As we will show in the following, the noise levels at JHH are completely consistent with the above-presented results.

III. EQUIVALENT A-WEIGHTED SOUND PRESSURE LEVELS IN JOHNS HOPKINS HOSPITAL

Over the last year, we have obtained sound pressure level measurements at five different locations in Johns Hopkins Hospital. These are the Pediatric Intensive Care Unit (PICU), Weinberg 4C, Weinberg 5C, the Children's Medical Services Center 4th floor (CMSC4), and Nelson 7. Weinberg is the oncology center of JHH. Weinberg 5C differs from Weinberg 4C in that Weinberg 5C has no acoustical tile ceiling because it houses immuno-compromised patients and there is concern about the holes in the standard acoustical tiles trapping bacteria. Weinberg is the newest patient care building in the hospital and came on line in 1999. CMSC4 and the PICU are pediatric units, with CMSC4 being a medical/surgical unit and the PICU housing intensive care children (but not neonates). Nelson 7 is an adult medical/surgical unit. Nelson 7, CMSC4, and the PICU are all housed in the older portions of the hospital, which are now roughly 50 years old.

At each unit we used a consistent protocol for measurements. We first measured one-minute L_{eq} at many locations on the unit, always including patient rooms, hallways, and nurses stations. We simultaneously obtained octave-band sound pressure levels at every location. Subsequently, we obtained 24-h measurements at a minimum of three places per unit—a patient room, a nurses station, and an examination room or empty patient room. In every case we requested that patients, staff, and visitors continue with their normal activity. All measurements were obtained with a Larson-Davis system 824. Results were downloaded to a PC for analysis. Measurements in hallways and patient rooms were

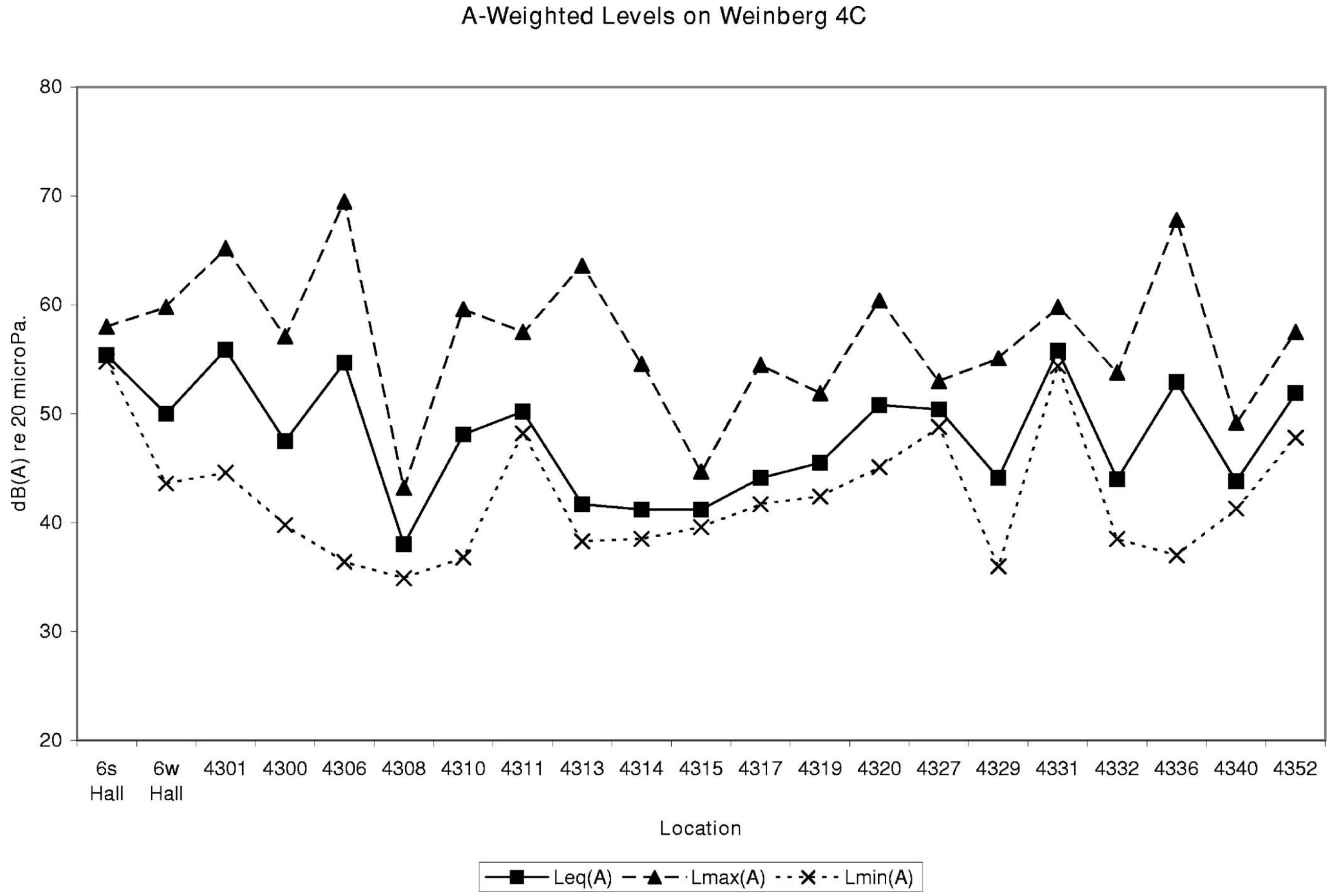

FIG. 4. A-weighted equivalent sound pressure levels measured in various locations in Weinberg 4C.

made near the room center at a height of roughly 4.5 ft. Some of the halls and some of the rooms had acoustical tile ceilings but no other acoustical treatment. Other locations had no acoustical treatment whatsoever. Thus, we found all of the facilities to be quite reverberant.

Figures 3–8 show the 1 min A-weighted L_{eq} as a function of location. In each case, the figure shows the L_{max}, L_{eq}, and L_{min} obtained using the slow averaging setting of the meter. In general, there is more variation between rooms on a unit than between hall measurements. This is almost certainly a reflection of the variations in activity in different patient rooms with higher levels corresponding to rooms with multiple visitors or louder playing of the TV.

Figure 3 shows an almost uniform set of sound levels throughout the PICU, which is somewhat surprising given its L-shaped geometry. The office measurements listed on this figure are two measurements at the office of Nurse Manager Claire Beers. Her office is at the extreme end of the unit. The higher sound level corresponds to the door open, and the lower value to the door closed. All rooms on the unit were occupied. Nurses stations are distributed throughout the larger patient rooms in addition to a main nurses station in the corridor.

Figures 4 and 5 show Weinberg results. From these we see that the new building is not particularly quieter than the older buildings. This is surprising given that noise was an issue considered during Weinberg design and construction. Indeed, the construction design called for NC-35 for the new, unoccupied building. Weinberg 4C is significantly quieter than 5C due to the acoustical tile ceiling there. Further, hospital air flow rates have increased significantly in the last 50 years so the older buildings are now driving more air through air ducts than the system was originally designed to handle, while Weinberg was built to handle the current HVAC standards.

Figure 6 shows the 1 min averaged A-weighted L_{eq} measured in CMSC4. CMSC4 is a particularly interesting location because it serves as a living laboratory for the study of hospitals. One of the corridors in this unit is the traditional straight corridor with small indentation places located along the walls which house computers for staff to enter patient data. These tend to be places where physicians congregate, particularly during rounds. The other corridor is nominally parallel to the conventional one, but has been built intentionally with a curvature to it. This prevents line of sight contact down the entire length of the hallway. On the curved corridor, there are small cubicles oriented at 90° to the corridor axis for staff to enter patient data. CMSC4 also has modified their nurses station so that there is a small reception area at the entry to the unit and a larger work area midway into the unit. This contrasts with the conventional approach of congregating the entire nurses station in a single location (except in intensive care units). Figure 6 shows that there is essentially no acoustical advantage gained by the curved corridor.

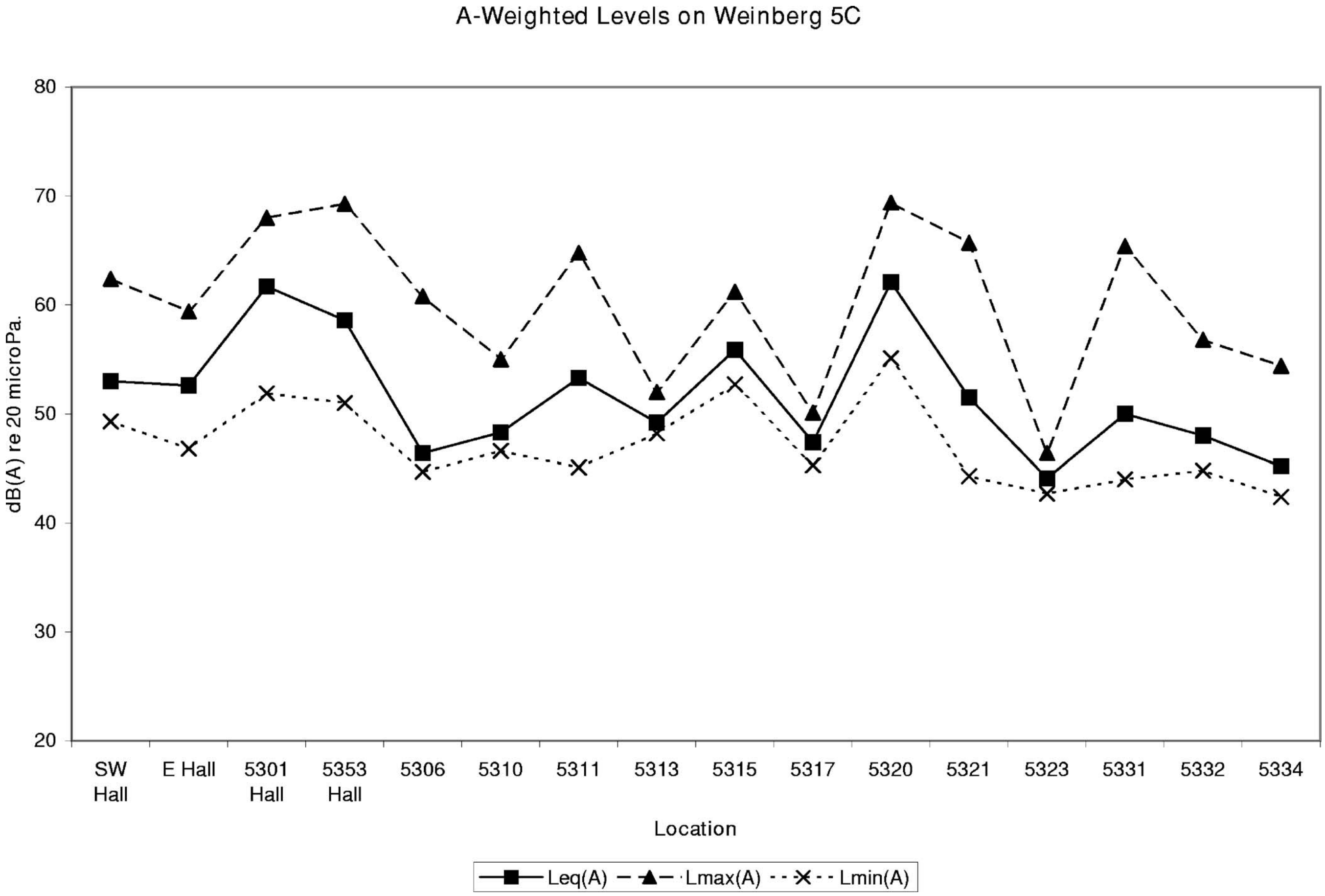

FIG. 5. A-weighted equivalent sound pressure levels measured in various locations in Weinberg 5C.

The results for straight corridor rooms (left half of the figure) are about the same as those for the curved corridor (right half of the figure).

Figures 7 and 8 show the sound levels on Nelson 7. Here we were able to get measurements in rooms with a greater range of uses, and this is reflected in the variability shown in Fig. 7. The rooms with the highest sound levels were a staff conference room and a patient room with loud conversation. The quietest room was an empty equipment room.

Figures 3–8 indicate which measurements were in hallways, which in rooms, and which at nurses stations. By considering the nurses stations separately, one sees a pattern emerge—they are generally noisier than the other areas on the unit by 1–2 dB(A). We can also consider the few rooms that were empty and note that they were generally quieter than the occupied rooms, but not always. In particular, when the empty rooms were near nurses stations, they were noisier rather than quieter than the other rooms on the unit. Finally, we had a single set of measurements with an empty room in which we were able to consider the effect of closing the room door. This yielded a noise reduction of 2.2 dB(A) only. Although we did not measure noise transmission through walls from one patient room to another, we did not hear any such sound transmission at any point during our measurements.

Figure 9 presents the logarithmic average L_{eq}, L_{max}, and L_{min} measured on each of the five units. Also shown in that figure are the WHO guidelines for operational hospital facilities, and representative levels for normal speech and shouting as measured at typical speaker/listener distances. This figure makes three compelling points. First, it is clear that there is little variation in the measured sound levels from among the five units studied at JHH. Average L_{eq} vary from 50 to 60 dB(A). The PICU is the noisiest unit of the five, while CMSC4, Weinberg 4C, and Nelson 7 are very similar in level and are quietest.

The second interesting observation comes from comparing the measured noise levels to WHO guidelines and the typical speech levels (as cited in the WHO report). Clearly, the observed sound levels exceed the WHO guidelines significantly—by at least 20 dB(A) on average levels, and by at least 15 dB(A) on L_{max}. Further, all of the measured logarithmic average sound levels exceed the typical speech level for communication between two people of 45–50 dB(A), suggesting that staff need to raise their voice routinely in order to be heard above the noise. Given the evidence that sound levels in hospitals are rising annually, there is reason to be concerned that it might eventually be difficult to communicate orally even by means of shouting.

Third, the values given in Fig. 9 are a little below those shown in Fig. 1 for 2004, but not dramatically so. They thus complement the pattern shown in Figs. 1 and 2 of a generally rising sound pressure level within hospitals regardless of their type or location.

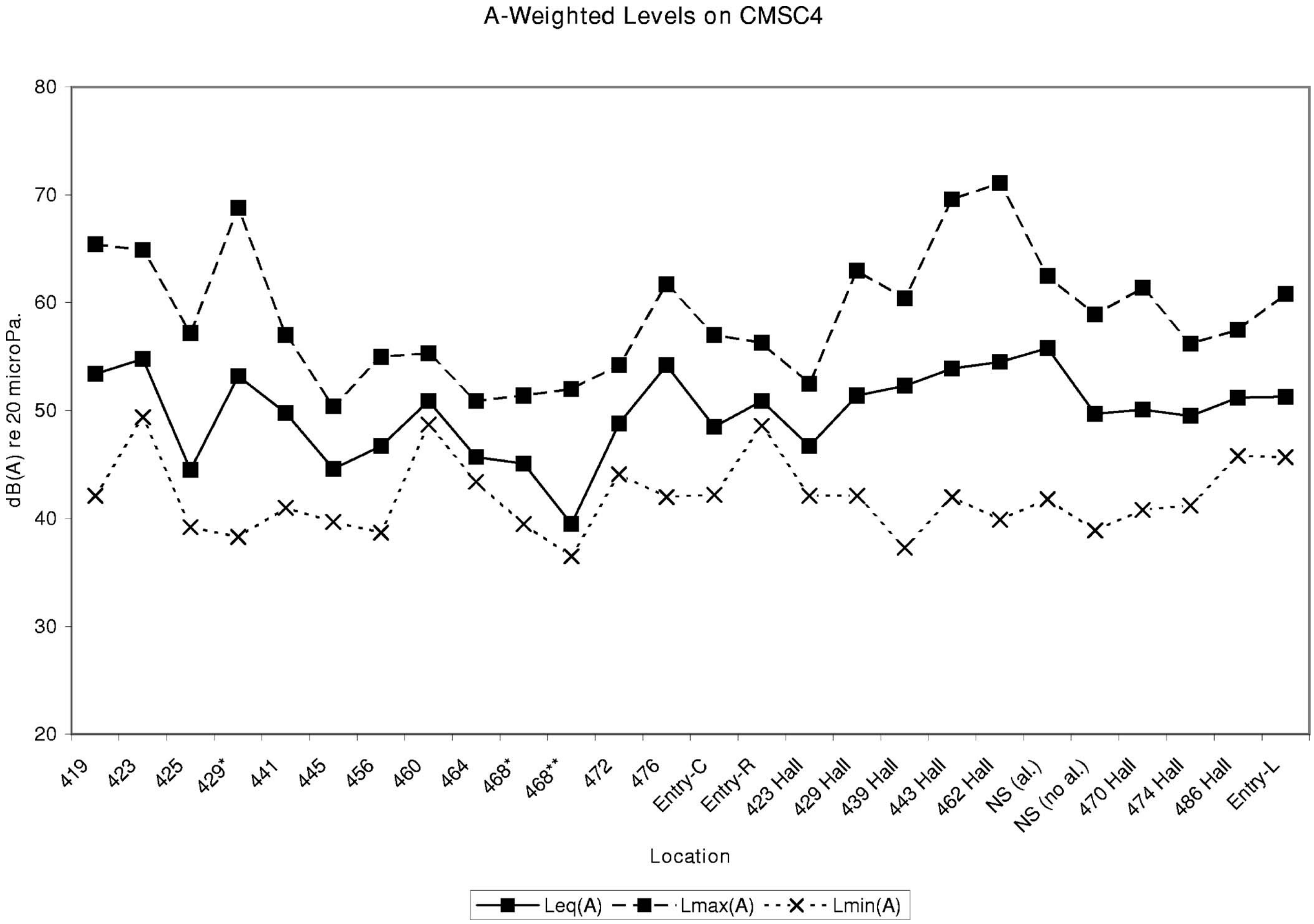

FIG. 6. A-weighted equivalent sound pressure levels measured in various locations in CMSC 4: (*) unoccupied rooms, (**) unoccupied and door closed.

IV. SOUND SPECTRA

Figure 10 shows the sound level in octave bands at the various measurement locations of the PICU. With the exception of the very lowest curve, measured at the Nurse Manager's office, the spectra are very similar in shape. The spectrum is nearly flat between the 63 and 1000 Hz octave bands, rolling off slowly at higher frequencies, and increasing at frequencies below the 63 Hz band. The flat sound spectrum region generally encompasses the speech band and, at the low frequency end, is almost certainly caused by heating, ventilating, and air conditioning noise. Given the constant chatter in hospitals and the mobile sources (doctors and nurses in halls for instance) it is not surprising to find the spectrum shown in Fig. 10.

The octave band levels for the other hospital units measured are quite similar in form to that shown in Fig. 10. What we present in Fig. 11 is the logarithmic average L_{eq} in each unit in each octave band. Note the similarity in shape of the curves, although there is a significant difference in the levels. The largest difference shown in Fig. 11 is 18 dB in the 16 kHz octave band, although the difference is more typically 5–10 dB. In JHH, then, there is significant difference from unit to unit, although the overall form of the spectra is quite similar.

The low frequency noise in the units is commonly found in buildings and likely relates to the air handling system. We obtained a small amount of data using a microphone directly under an air vent and an accelerometer mounted on the wall a short distance away. By considering the correlation between the two signals (with appropriate time delay for travel to the wall from the air vent) it is possible to determine whether the low frequency sound measured in the units is structure-born or airborne. On the basis of our few measurements, which produced generally low correlations, we believe the sound to be airborne.

The high frequency noise roll off in the hospital units we measured is more gradual than one often sees in buildings. We have not yet attempted to determine the source of the high frequency noise, although alarms and mobile medical equipment have been suggested as culprits. We cannot rule out high velocity flow in the air handling system.

V. EQUIVALENT A-WEIGHTED SOUND PRESSURE LEVELS AS A FUNCTION OF TIME OF DAY

In each unit we obtained a minimum of three 24 h measurements of the L_{eq}. When possible, one of these measurements was made at the main nurses station for the unit, one in an occupied patient room, and one in either an unoccupied patient room or an examination room (normally used only in daytime hours). The measurements were made using 30 min time averaging.

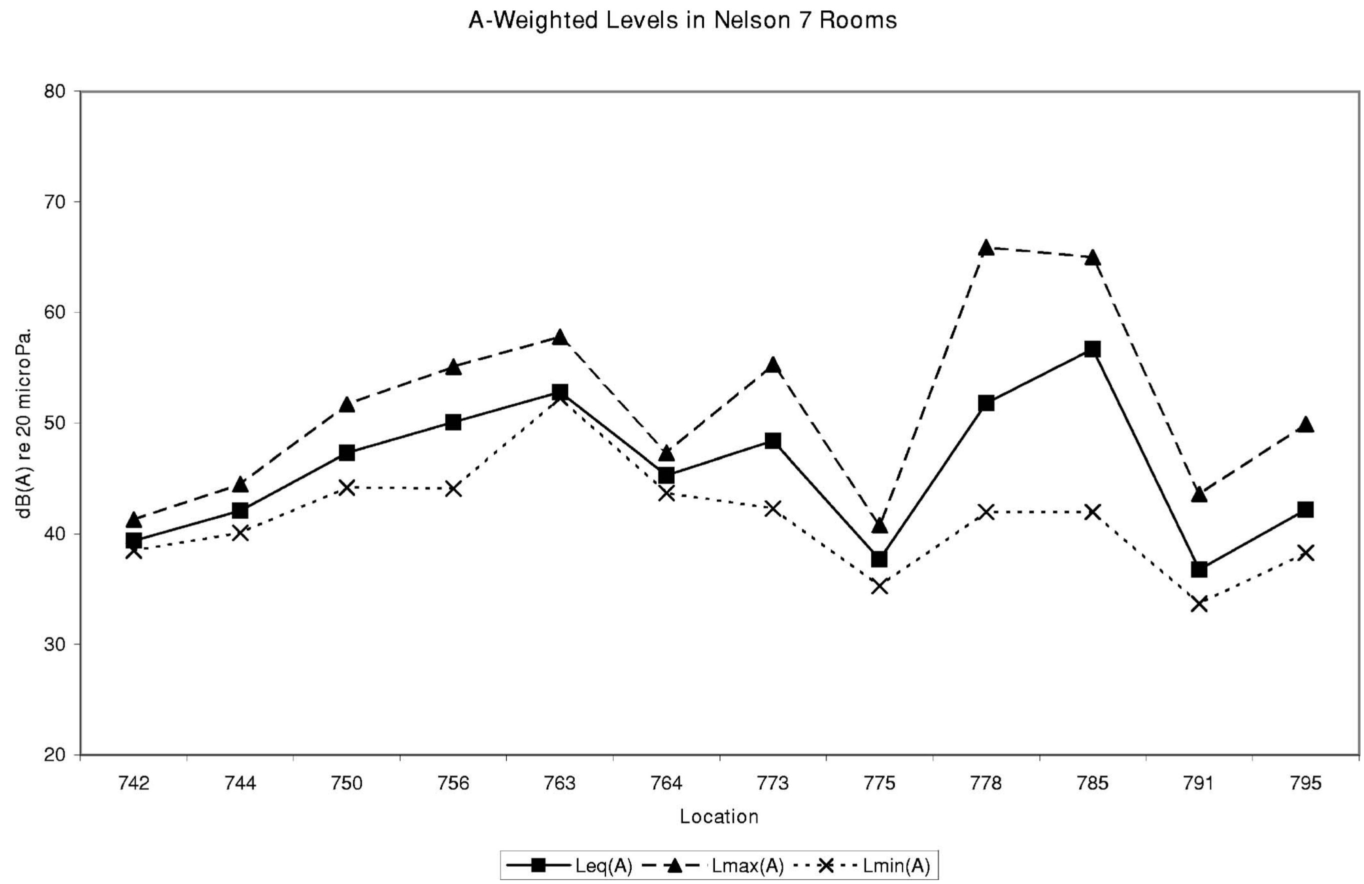

FIG. 7. A-weighted equivalent sound pressure levels measured in various rooms in Nelson 7.

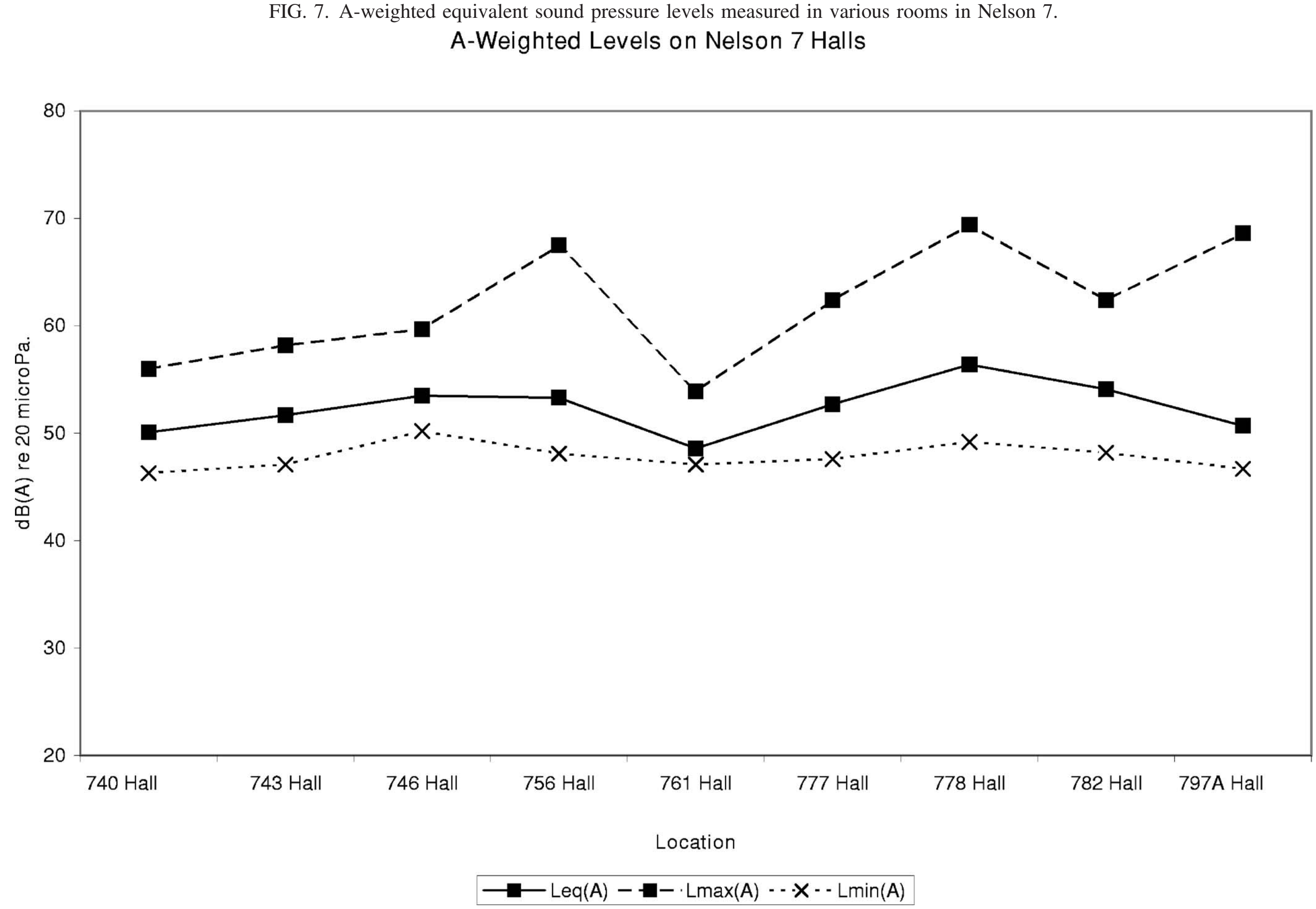

FIG. 8. A-weighted equivalent sound pressure levels measured in various hall locations in Nelson 7.

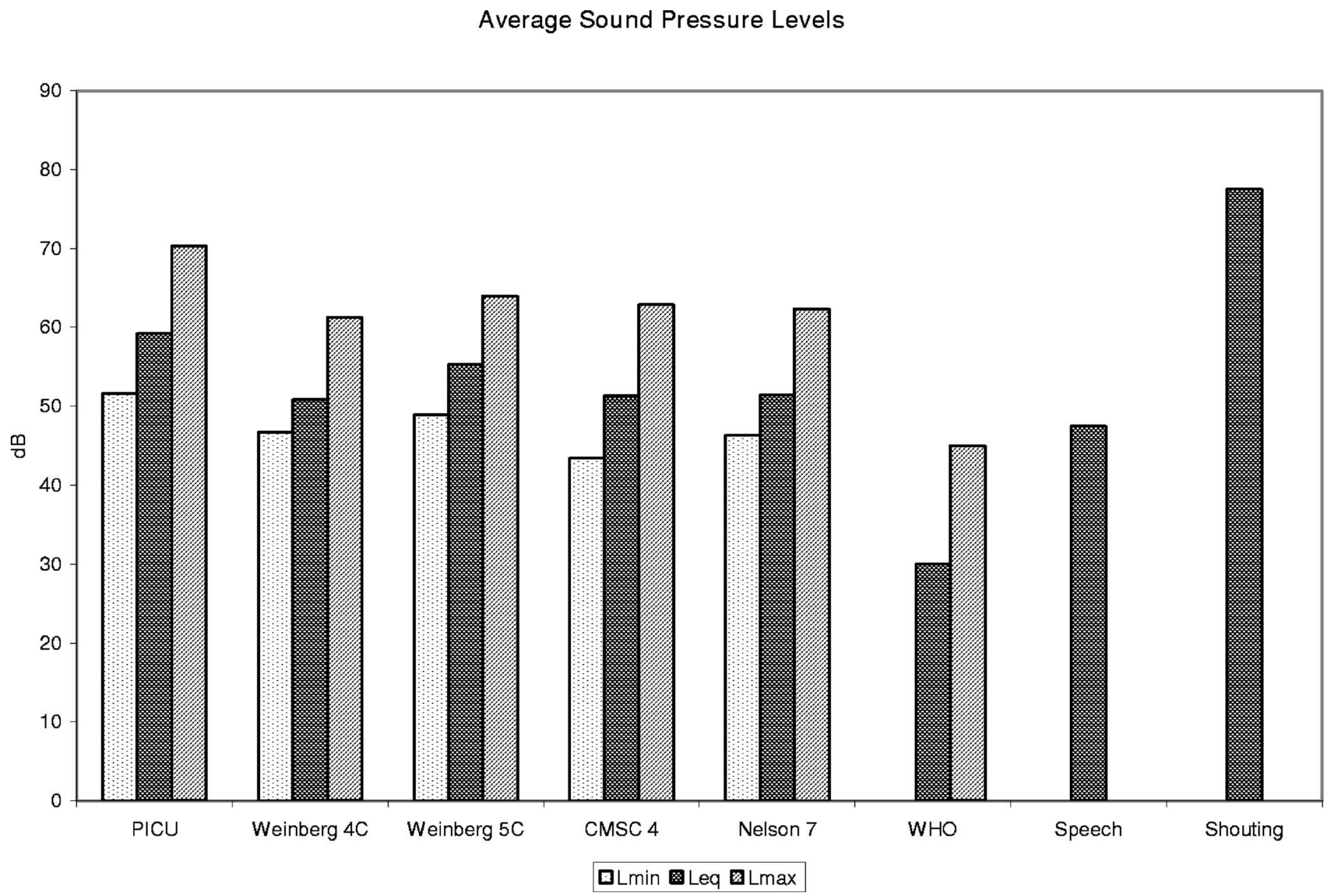

FIG. 9. Logarithmic average A-weighted sound pressure levels measured in JHH compared with WHO guidelines and typical levels for speech.

Figure 12 shows the A-weighted levels in the PICU as a function of time, running from midnight to midnight. Shown for comparison purposes only is the 24 h L_{eq} in the academic campus office of one of the authors. We note that in the PICU it is simply not possible to determine time of day from the sound level present. There is less than a 10 dB variation from the lowest to highest sound pressure level shown in Fig. 12. By contrast, the campus office shows a 15 dB variation and clearly shows when the office was occupied on this particular day.

Because an intensive care unit is for those in need of round-the-clock monitoring, it is not surprising that it is noisy 24 h a day. Indeed, it has been speculated that the incessant noise and constant light make sleep so difficult to achieve for patients in intensive care units that it might explain ICU-psychosis in patients, i.e., the development of psychotic episodes in patients with extended ICU stays.[79]

Figure 13 shows L_{eq} as a function of time in Weinberg 4C. Note that in these data there is a "quiet" period between roughly 11 p.m. and 7 a.m., but it is only about 7–8 dB quieter than the remainder of the day. The measurements in Fig. 13 include three sites near and in the main nurses station, one occupied patient room and one empty patient room. The three nurses station sites are very similar and have higher levels than the patient rooms. The occupied patient room is only slightly different, possessing brief periods of lower levels. The empty patient room is about 10 dB quieter across the board.

Figure 14 shows the L_{eq} results in Weinberg 5C. The results are quite similar to those in Fig. 13. However, the "quiet" period is shorter and more like the noisy period than is the case for Weinberg 4C. Again, the three measurements in and near the nurses station are the most intense. The occupied patient room is quite similar to the nurses station levels. The unoccupied patient room is significantly quieter. In this particular case, the unoccupied patient room was in a corner location and had two sets of doors blocking it from the corridor. The 37 dB level seen in quiet times thus defines the noise floor for this room (the lowest we observed in our measurements). What is also interesting is that hospital activity increased this noise level to about 50 dB (A) even though the room remained empty and both sets of doors were closed. We note that all doors in the hospital have large gaps at the floor so we are not surprised by their lack of acoustic insulation.

Figure 15 shows L_{eq} measurements on CMSC4. Here again the nurses station offered the highest noise levels—in this case significantly above those measured in an occupied patient room and in an examination room. These data show less evidence of a "quiet" time of day than was apparent in Figs. 13 and 14.

Figure 16 shows the L_{eq} results obtained on Nelson 7. Here there is evidence of a quiet period from about midnight until 7 a.m. Again, the nurses station is noisier than the patient room and examination room. The only surprise in this figure is that the examination room, which is rarely used and

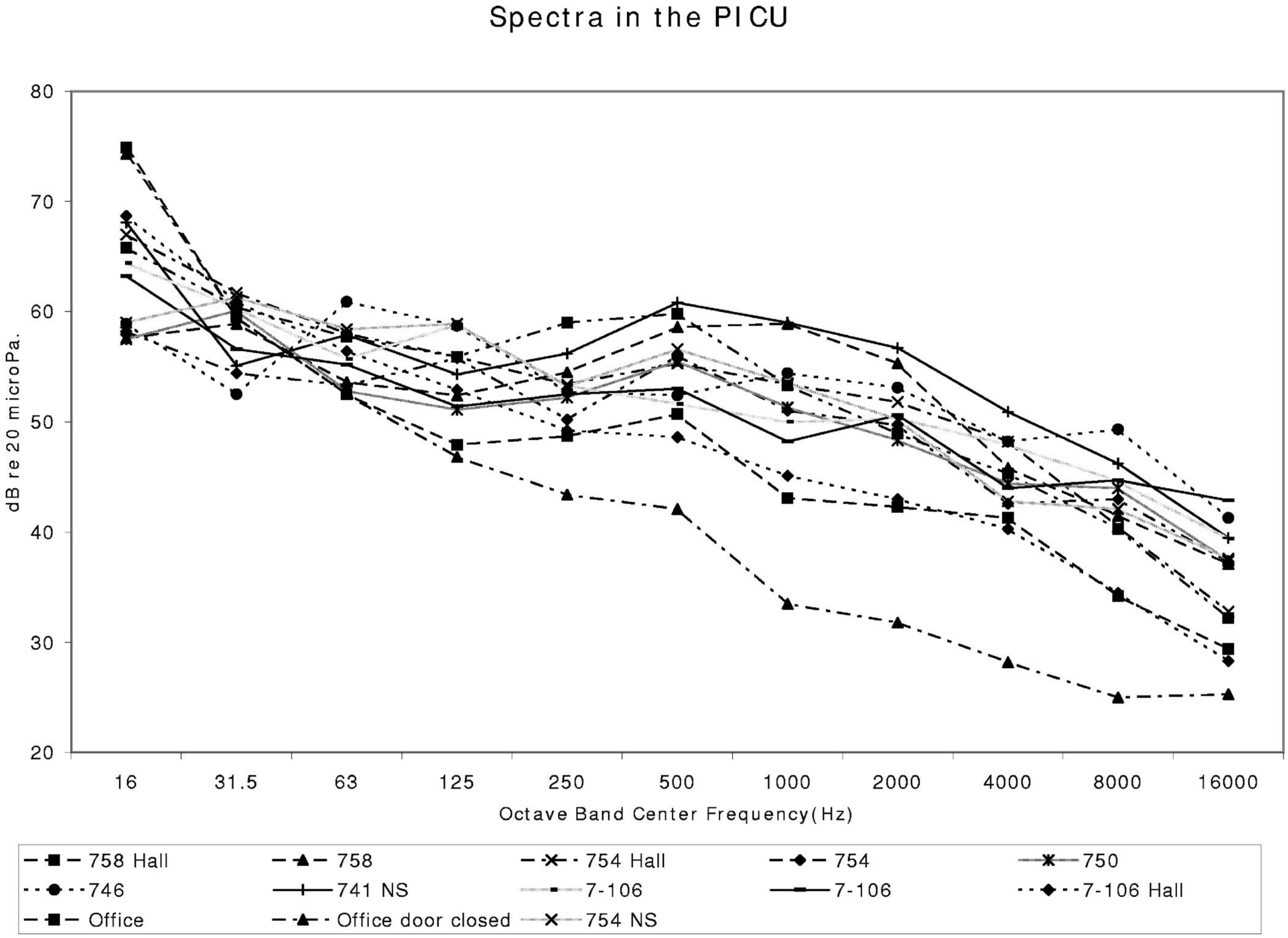

FIG. 10. Octave-band L_{eq}'s measured in various PICU locations.

has two sets of doors separating it from the hallway, exhibits a relatively high noise level. In this case, as for the other empty patient and treatment rooms shown in Figs. 13–15, the noise levels are directly attributable to HVAC noise and show that it is the mechanical systems which are largely responsible for this facility failing to meet the WHO noise guidelines.

Figure 17 summarizes the data shown in 24 h measurements by averaging the levels found in all five units in occupied patient rooms, unoccupied patient rooms or examination rooms, hallways, and nurses stations. The results show that halls tend to be the noisiest areas, with nurses stations and occupied patient rooms being very close to each other and next in line. Empty patient rooms are significantly quieter although they show evidence of noise intrusion during daytime hours (possibly due to the doors being opened for cleaning or other services). Among these divisions of location types, only the empty rooms show significant distinctions in noise as a function of time of day. On average, then, the hospital noise levels which most impact patients, staff, and visitors are at about the same sound level constantly.

VI. THE IMPACT OF PERSONAL PAGING

While the goal of our study is to characterize the current sound pressure levels in Johns Hopkins Hospital, we had a fortuitous opportunity to be involved in the implementation of a noise control measure in the PICU. When we first visited the PICU we noted their dependence on overhead paging. During these visits the overhead speakers throughout the unit would be active at least once every 5 min, typically for no more than 30 s per page. We investigated opportunities to replace overhead paging of everyone in the PICU with personal, hands-free call units which broadcast only to the individual desired to be reached. At the time, we found only one commercial manufacturer of such devices—Vocera, Inc. of San Jose, CA.

The idea of a personal, hands-free telecommunicator is to provide a lightweight, convenient microphone and loudspeaker or earphone to each staff member. These are typically linked via the existing telephone infrastructure or through a computer server and use wireless technology. Instead of a page, a call is instigated to an individual's personal communicator. The net effect is that an overhead page heard by everyone can be converted to a broadcast to a single individual.

During our noise characterization study, the PICU opted to run a trial of the Vocera, Inc. noise badges. Subsequently they purchased the devices and have been very successful in using them routinely. Today, overhead pages in the PICU

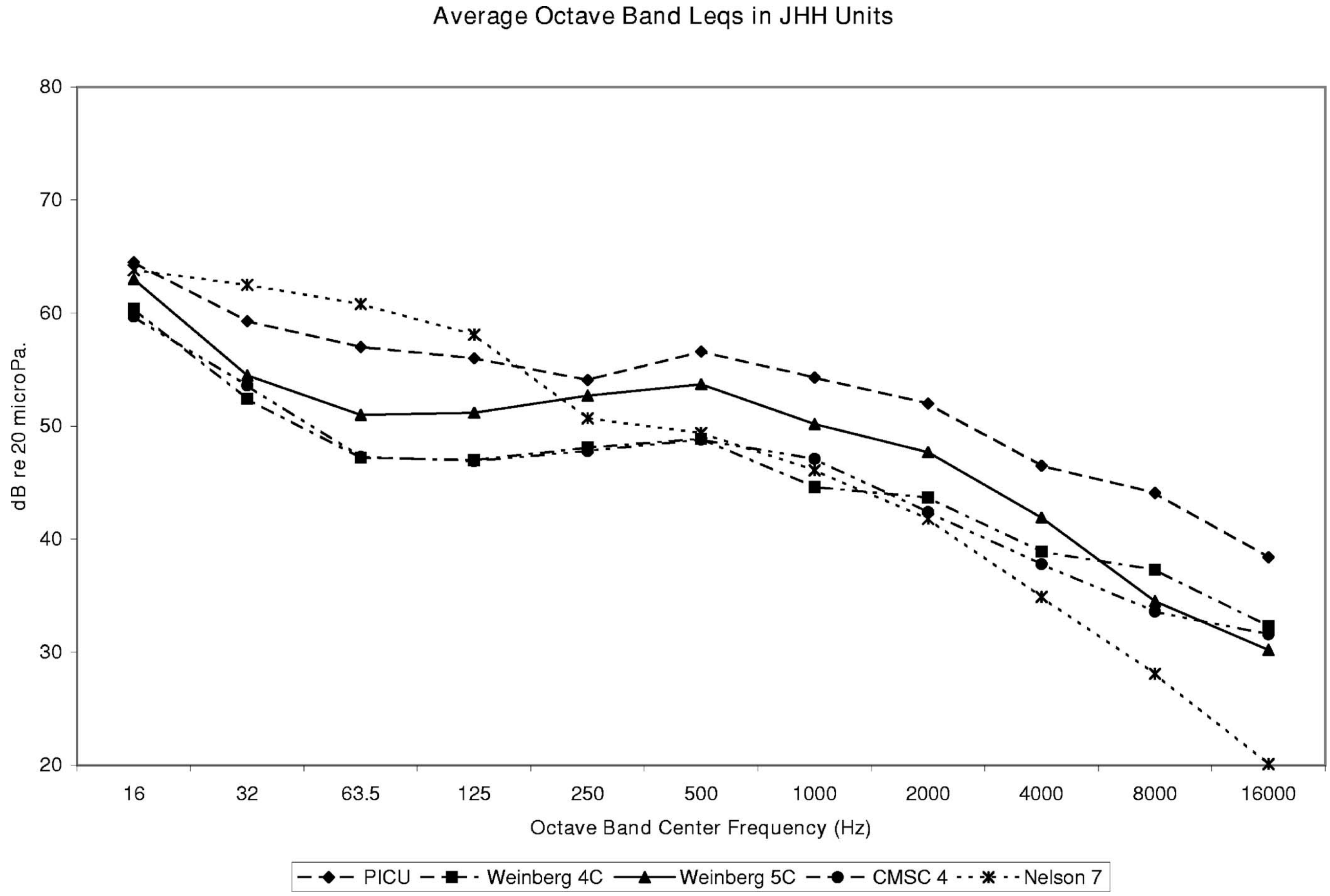

FIG. 11. Logarithmic average spectra measured on the five monitored units.

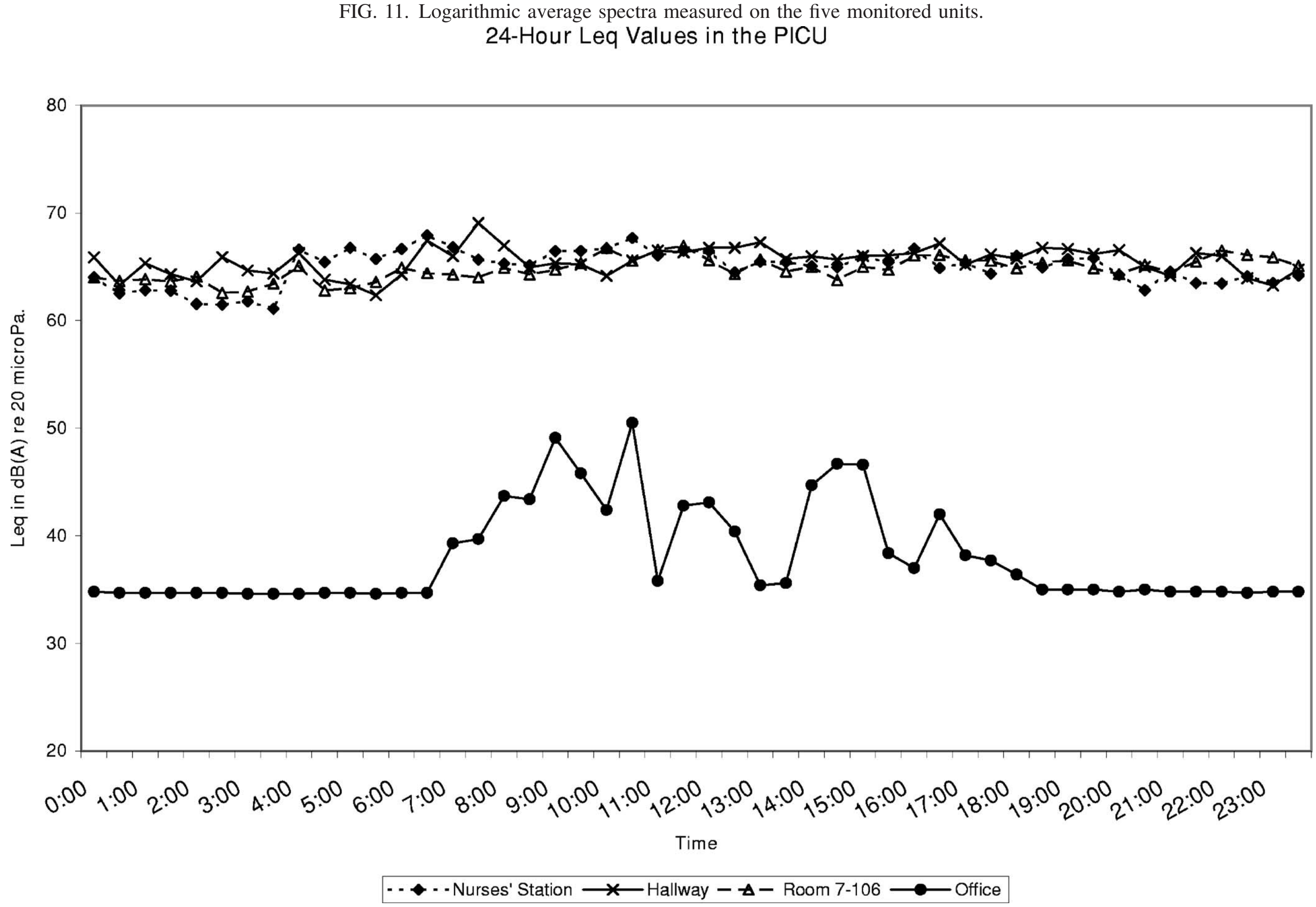

FIG. 12. L_{eq} vs time in the PICU.

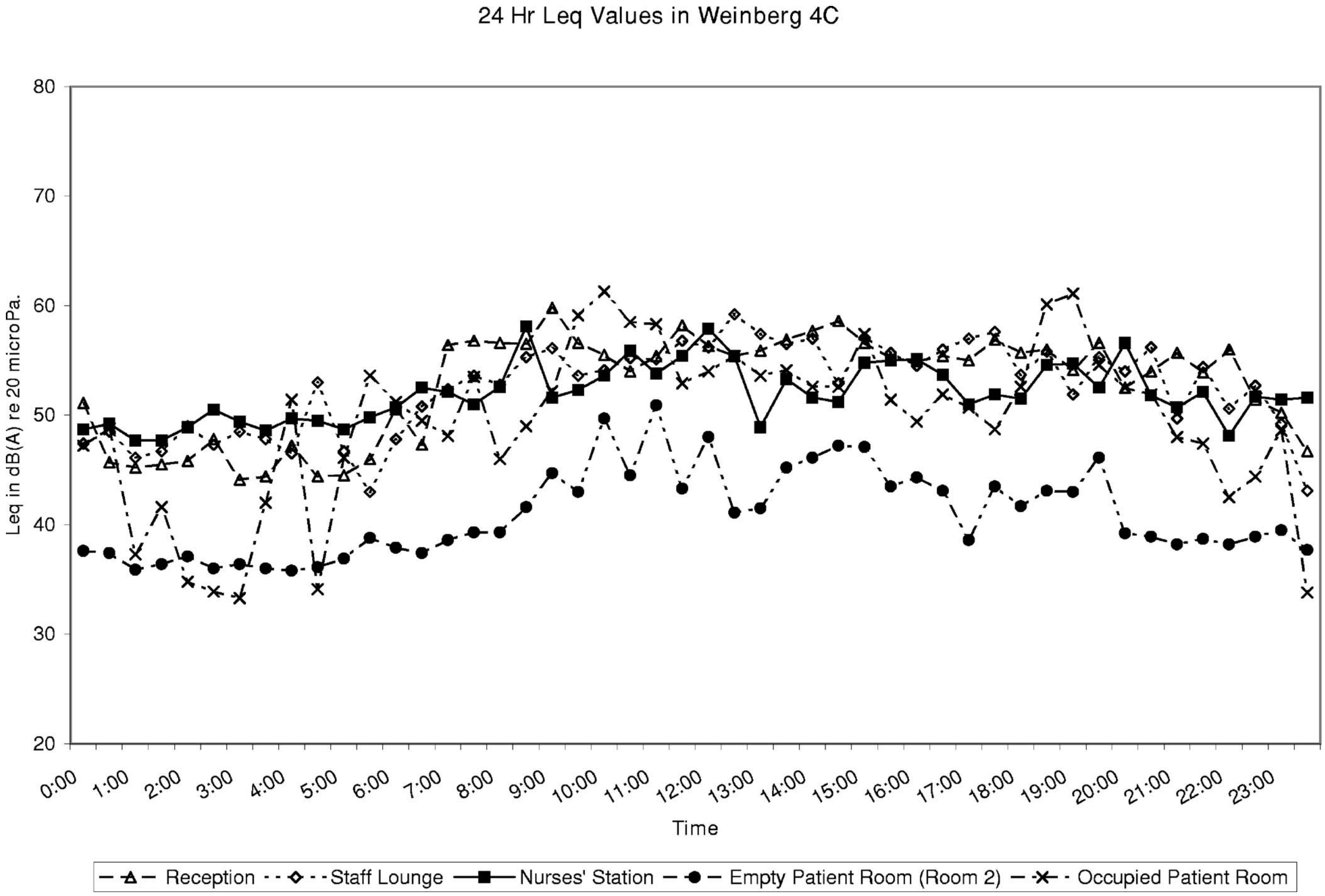

FIG. 13. L_{eq} vs time on Weinberg 4C.

have been reduced to roughly one or two per hour, generally for people on the unit temporarily (for a consult, for instance).

We assessed the difference between the overhead paging system and the personal communication system. Measurements were made during a scripted broadcast from the speakers and a badge at a distance of 3 ft (roughly the minimum distance to the ear from an overhead speaker) and 6 in (roughly the distance to the ears from a personal communicator badge). Results showed a 5.4 dB reduction of sound from the overhead at a distance of 3 ft to the badge at a distance of 6 in.. Of course, the reduction would be even greater comparing the badge at a distance of 3 ft to the overhead at 3 ft (a useful measure for privacy considerations). However, even these numbers are misleading, because the greatest gain is in the reduction of the population insonified using personal communicators compared to overhead paging.

Although personal communicators show significant promise in reducing noise from overhead paging, it should be noted that the speakers on these units are quite small in order to prevent them from being large and heavy. Thus, the quality of the sound produced is not as good as that generally available in overhead paging systems. Sound quality seems to be the single biggest compromise needed in conversion from an overhead to a personal communication unit. However, the advantages of efficiency, hands-free communication to prevent contamination, and noise reduction are seen by the PICU staff as far outweighing the quality reduction.

We also note that although we studied only the single commercial device available at the time, there are new entries into the market for personal, hands-free paging systems. We are actively interacting with a second project involving Avaya at Johns Hopkins Hospital for CMSC4.

VII. DISCUSSION

The above-presented results certainly demonstrate a noise problem in Johns Hopkins Hospital and suggest that this problem probably exists at virtually all other modern hospitals as well. The sound pressure levels are sufficiently high to interfere with sleep, to potentially affect speech intelligibility unless voices are raised, and to create a general din that is annoying to many. In addition to these direct effects of noise, there linger serious questions which have not been answered adequately by research studies, namely, whether elevated noise levels contribute to medical errors.

A related issue of great importance is the impact of noise on communication and the potential of safety hazards arising from an inability to be understood correctly. We have not found studies which directly relate to hospitals and medical errors, but we can offer some speculations. Normal hearing individuals are well adapted to detecting speech signals imbedded in noise, as is evidenced by their ability to correctly interpret speech even when the signal to noise ratio is as low as −6 dB. However, the same statement cannot be made for people with significant hearing impairments. Nor does it ap-

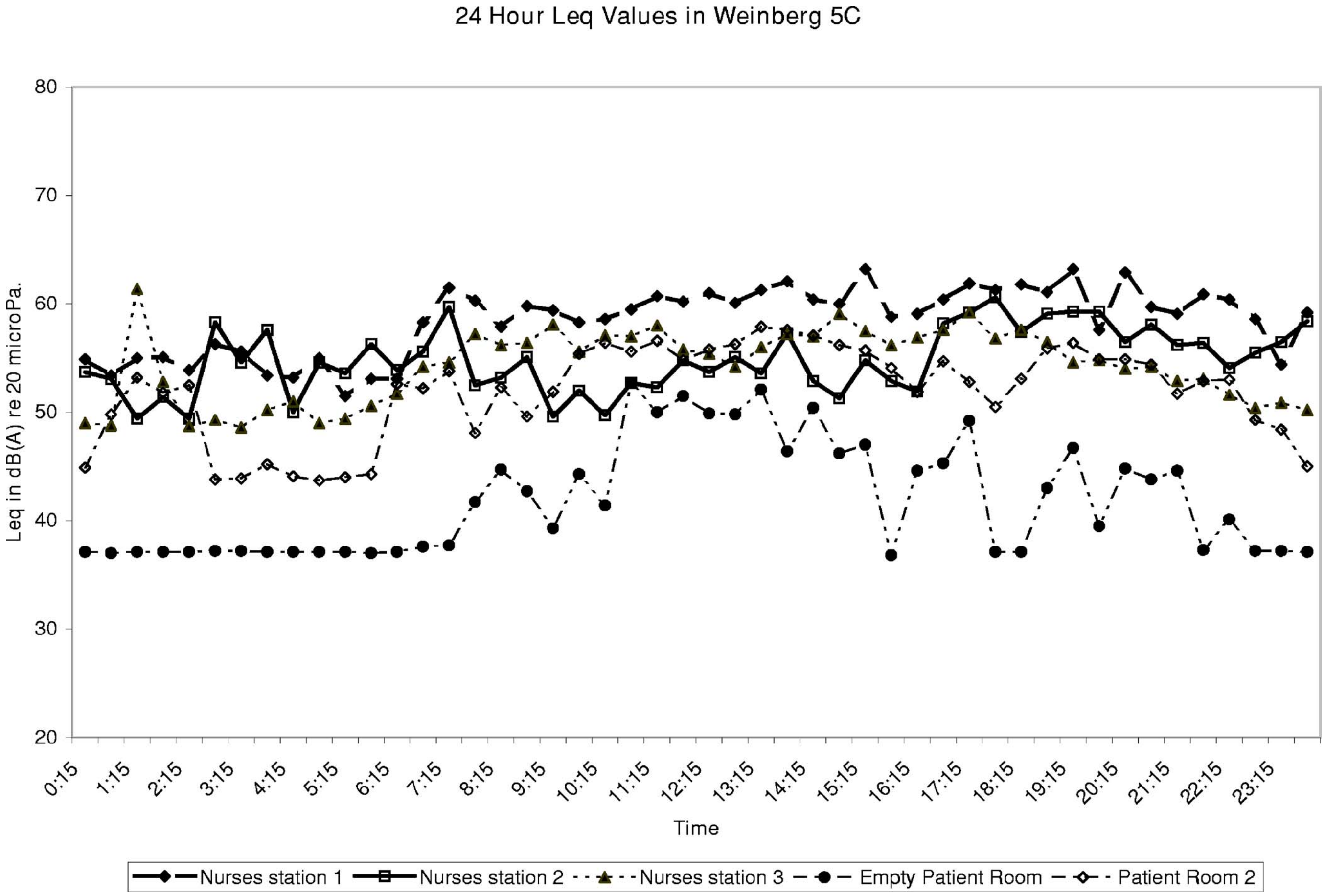

FIG. 14. L_{eq} vs time on Weinberg 5C.

ply to automated speech recognition systems, where one normally needs a signal to noise ratio of at least +15 dB in order to ensure correct interpretation of the signal. This distinction between human ears and automated speech recognizers is very important for the hospital setting, as there is a great desire to automate many hospital operations and this requires use of speech recognition. The move toward a digital hospital includes functions from automated transcription of doctors' notes spoken into recorders to automated dispensing of pharmaceuticals, and errors due to a poor acoustic environment simply cannot be tolerated. Further, when correct speech interpretation is critical, as is often the case in hospital situations, then a +15 dB signal to noise ratio requirement is appropriate. Thus, the high noise levels currently in place pose a real impediment to moving forward with plans for a digital hospital and with improved communication in general.

The study reported here simply documents the situation currently in place in a single hospital. What remains to be done is to study and demonstrate means of improving the noise environment in hospitals. There are several avenues for investigation along these lines, some of which we are pursuing.

First, although we have measured the noise in significant parts of JHH, there are many areas we have not yet studied. We will continue our work by measuring the noise environment in some of these areas as well. Of particular interest are the operating rooms and the emergency treatment facilities. Our study of operating room noise is just beginning. We have been invited to monitor the noise in every operating room for at least one 24 h period, and to correlate noise levels with the types of surgeries being performed. This will permit us to identify which surgical procedures are noisy and which are relatively quiet. This is particularly important when one considers that a prior study of orthopedic surgeons indicated that over half showed significant noise-induced hearing loss, presumably from exposure to bone drills and saws.[50,53]

Second, it is important to not only characterize the existing environment, but to understand why it is so noisy. To this end, we note that hospitals are notoriously lacking in the materials that one normally associates with acoustical absorption. This is largely the result of concerns about infection control, wear, and cost. However, there are materials available which meet hospital standards in these areas as well as in related areas such as flammability and smoke production. We are thus involved in a program to produce a series of prototype sound absorbing panels for ceilings and walls which meet hospital standards. We will demonstrate their impact by installing them in Weinberg 5C while carefully monitoring before and after ambient noise levels and reverberation times.

Third, communication in noise is an issue of increasing importance in hospitals as they move to smaller operating arenas and greater automation. We have embarked on a collaboration with medical personnel at JHH to consider technological solutions to communication problems which per-

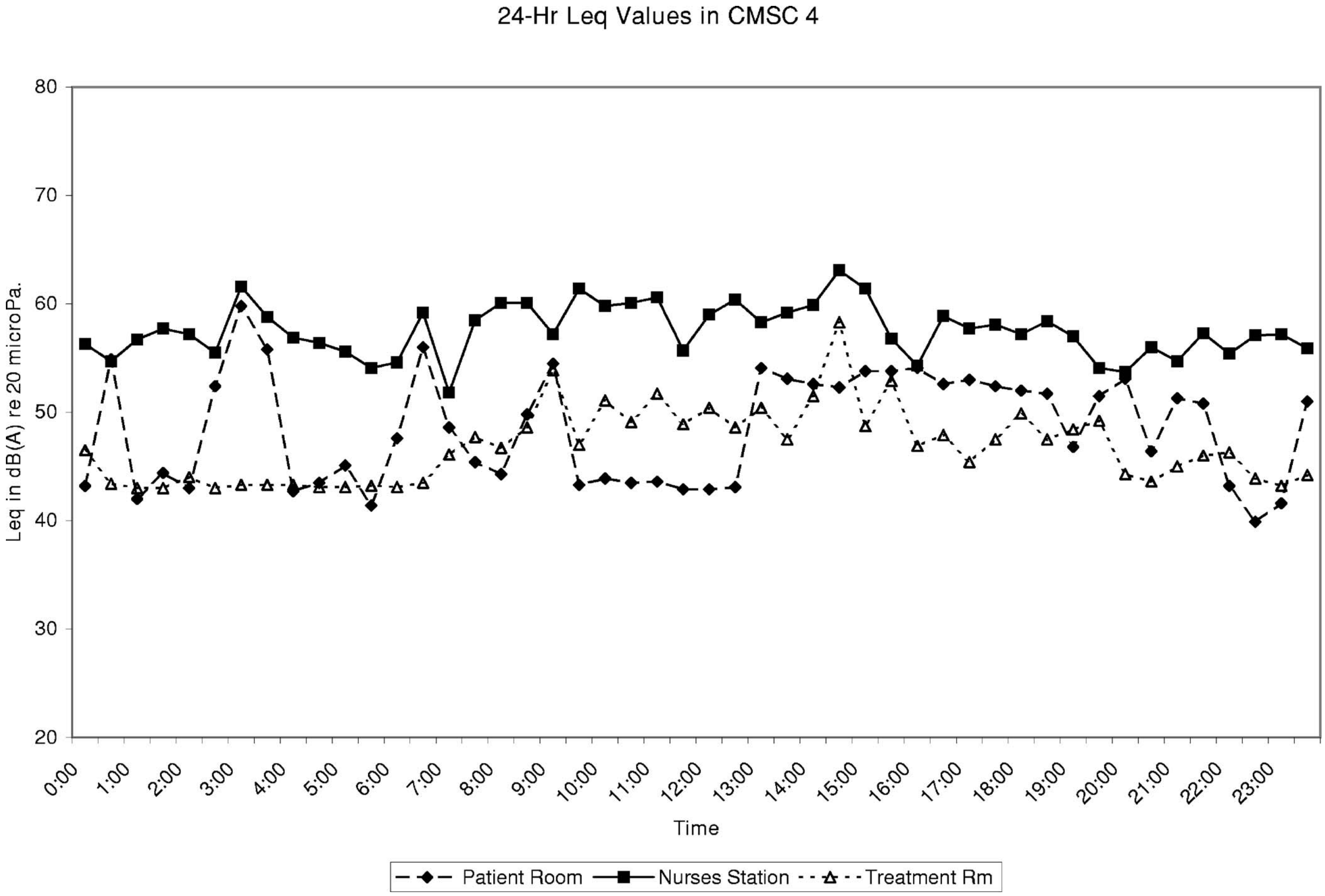

FIG. 15. L_{eq} vs time on CMSC 4.

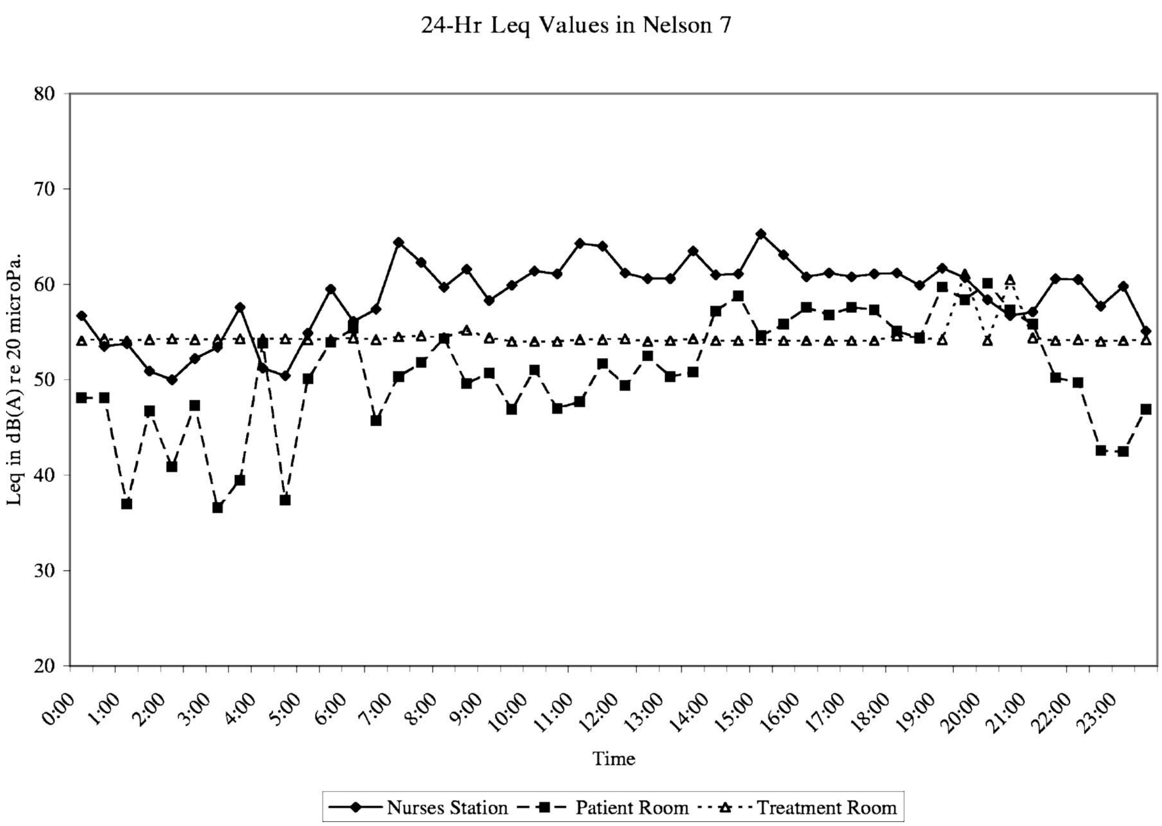

FIG. 16. L_{eq} vs time on Nelson 7.

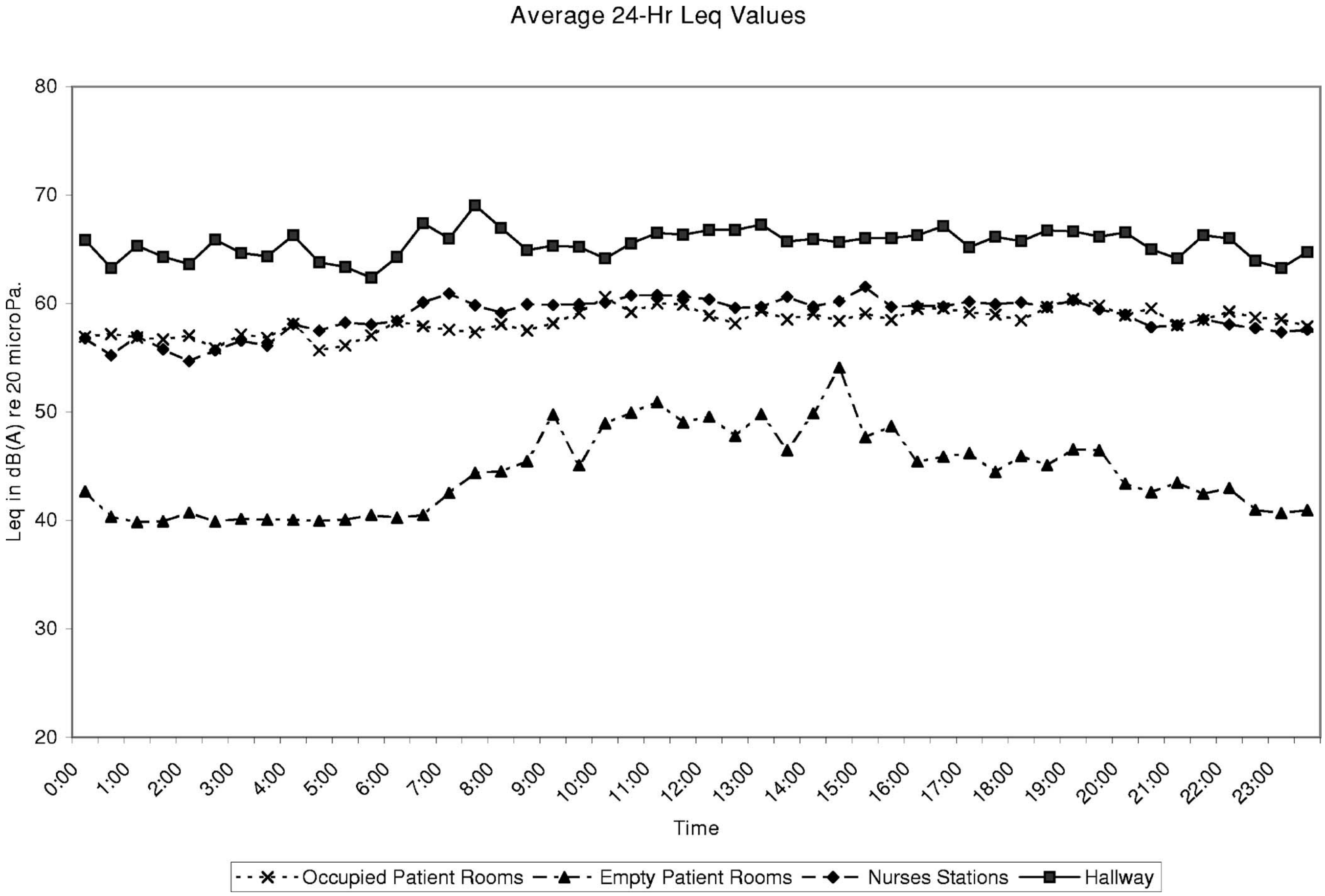

FIG. 17. Logarithmic average L_{eq} values vs time for halls, nurses stations, and occupied and empty patient rooms.

mit improved speech recognition. In particular, the advantage of stereophonic sound reception has not been exploited in hospital environments using sound systems so we are working to demonstrate such systems and incorporate their advantages.

Fourth, the literature shows that the overwhelming majority of audible alarms in hospitals result in no action being taken.[77,80–82] These alarms are, not surprisingly, a major source of irritation to patients and visitors. A ripe avenue for research is thus the effective use of audible alarms in hospitals, with the aim to preserve patient safety while reducing alarm noise.

Finally, although the current focus is on the major noise sources such as HVAC systems, overhead paging and speech, if we are successful in reducing the general din in hospital units it is likely that the noise of particular instruments or service objects (such as the meal tray carts) will become more identifiable and important as contributors to the noise. Here there will be a great opportunity for the design of quiet hospital items which could be tested and marketed on the basis of their ability to perform well while producing less noise.

Overall, most people will spend some time in a hospital and many will spend a large amount of time in them. The problem of hospital noise is clearly under-studied and not well understood. Our goal is to alter this landscape in meaningful ways.

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