The Acoustic Environment of Hospital Nurseries

Facility and Operations Planning for Quiet Hospital Nurseries

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This article discusses architectural design and construction and recommends criteria for achieving quiet nursery environments. Designs for new construction or facility renovation should incorporate vibration and noise control methods appropriate to the occupants and activities of the proposed space. Noise and vibration are environmental factors within a hospital nursery that can affect infant health and development, staff and parent communications, operational efficiencies, and the fatigue/comfort level of all occupants. Facility noise and vibration levels set a threshold that will be increased by operational noise. It is important, therefore, that hospital administrators, clinicians, and facility managers assure that architects, engineers, and builders use appropriate acoustical design criteria, methods, and materials to control noise and vibration.
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INTRODUCTION: THE PROCESS OF CREATING A HOSPITAL NURSERY

Understanding Expectations

The processes of hospital design and construction are as unfamiliar to clinicians as the processes of caring for babies and families are to those who design and build nurseries. Many clinicians begin a construction project by assuming that the architects and engineers know what the clinical work requires and end by complaining that these professionals did not do their jobs properly. In fact, most architects and engineers do what they are asked to do (or what they have been asked to do many times in the past) and assume that they will be informed about the needs of the clinical program.

In architecture and construction, as elsewhere in life, timing is everything, including money. Architectural and engineering planning for a new hospital typically begins 3 to 5 years before construction. Financial planning may begin well before that. If clinicians get on board the process too late or get on and off at irregular intervals, they will have a reduced influence on the way the building functions after it is built. However, nonphysician clinicians and families often enter the planning and design process after it is long underway only to discover that incorporating particular features would require costly changes in plans that were made far upstream.

Project Resources

The Institute for Family-Centered Care offers several publications that can guide an integrated, collaborative process through successive phases of planning, design, and construction.[1–3] A consensus document titled ''Recommended Standards for Newborn ICU Design'' describes minimum requirements for a facility that supports staff, infants, and families.[4,5] A research-based recommendation for permissible noise criteria (NC) in the occupied facility is founded on the work of the Sound Study Group of the Physical and Developmental Environment of the High-Risk Infant.[6]

As clinicians and parents have little experience with the wide variety of possible nursery designs, interdisciplinary field trips (including the architect and engineers) to well-designed nurseries may prove a good use of time and money. Conversely, all designers from the various disciplines should receive an orientation and demonstration of caregiving and space use in or near working nurseries early in the design process to assure that they understand the ultimate impacts of their design decisions on the environment of the nursery. At least one detail-oriented clinical person who can be relieved of clinical responsibilities from time to time should stay closely connected with a project from beginning to end. That person can ensure that concepts as well as details important to the clinical program are not lost in the crush of information that transforms over time from concepts to drawings and material specifications to lists of items for bid to construction to the finished space.

The Design Process

Successful planning begins with a statement of philosophy or concept. If developmentally supportive, family-centered care is to be a guiding principle or goal, and a quiet nursery one of the objectives, these must be articulated with the architects before spaces are blocked out and budget dollars allocated. A professional acoustical engineer should be involved in this phase if a quiet nursery is an objective.

During the planning phase, the amount of space allocated for various functions is determined, building spaces are laid out, and criteria are set down. All of these will govern the remainder of the process. During this phase, architects, planners, and design engineers turn goals and objectives into drawings and criteria. Interior designers are responsible for developing options for surface finishes and furnishings. Their work typically starts after the architectural

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drawings are complete. Specialized engineers turn criteria into detailed drawings and specifications for mechanical, electrical, and other building systems. Engineering quiet nurseries is a fairly new concept and clinicians can support engineers by consulting with them at regular intervals.

Construction companies bid on the project based on architectural drawings, engineering and design specifications, and recent historical costs for similar facilities. Once the project "has gone out for bids," it is very costly to make changes in the design. During construction, a team from the hospital visits the site at specific intervals to check progress against project designs and specifications. Nonphysician clinicians are typically not included in the visiting team. However, the designated, followthrough clinician can often spot variations from the plan (e.g., the stray sink, the unwanted overhead speaker, the missing special utilities or finishes unique to the nursery) which, although minor in the great scheme of things, can be important to the clinical program.

After the building is constructed, a validation process, sometimes called the test and balance phase or commissioning, brings the space into conformity with design specifications. Confirmation of sound and other specialized criteria may not be included in the process unless specifically required. Particular problems (e.g., unexpected noise from the plumbing, louder-than-specified background sound levels) should be identified, solutions should be investigated, and corrective measures should be taken before the owner accepts the building and clinicians move into the space.

TERMINOLOGY

The needs and desires of future building occupants must be expressed to architects and engineers in terms and criteria that will survive the torturous design and construction process. In the hope of assisting clinicians, the following terms are defined in conceptually, although not technically, accurate language. Technically precise definitions can be found in official documents and professional textbooks.[7–10] Lay definitions of terms not covered here can be found in the articles by Gray[11] and Gray and Philbin.[12] All decibel measurements given in this article use the A-weighted scale.

Allowable Sound Level Criteria: NC, Room Criteria (RC)

Sound levels can be measured over the entire audible spectrum of frequencies. For some specific purposes (e.g., spaces in which verbal communication is important), the spectrum can be divided into smaller frequency spans, such as octaves, or specific narrow bandwidths. Background noise within a room is often measured in octave bands for comparison with a family of smooth, balanced spectrum curves called NC or RC. These single number criteria systems are used for design and validation of building spaces because they define allowable sound levels in each audible octave band. Such criteria systems are more descriptive than a single number overall level such as dB or dB(A) which does not carry enough information about levels at various frequencies to distinguish between a pure tone, a balanced spectrum, or sound dominated by lower or higher frequencies. Each system is designed to represent sound levels relative to human hearing characteristics, which are less sensitive at low and very high frequencies.

Background or Facility Noise

Background noise refers to the continuous ambient sound in a space due to the mechanical and electrical systems of the facility or building itself. Background noise is produced by sources outside the building and by the building's own heating, ventilation, and air conditioning systems, pneumatic tube systems, elevators, plumbing, automatic doors, etc. Because occupant-generated noise will add to the "noise floor" or background noise of the building, allowable background level criteria should be set low enough to prevent annoyance, reduced speech intelligibility, sleep disturbance, or other disturbances after the building is occupied.

Facility Versus Operational Noise

Exterior sources (e.g., street traffic and outdoor building mechanical equipment) and interior sources (e.g., air conditioning and exhaust systems) generate facility noise. It exists in the empty building as it is constructed. The people and equipment that occupy the building generate operational noise.

Operational Noise

A general rule of thumb states that occupants and their equipment will add about 10 dB to the background noise. However, this generalization does not apply to all room uses. For example, two or three people in an office environment with 45 to 55 dB(A) background would add about 10 dB(A), but the same group of people in a quiet conference room with 35 to 45 dB(A) background might add 20 dB(A). A very large group of people might add 40 dB(A). In intensive care nurseries, the hard surfaces, close spacing of multiple patient beds, and large amounts of staff and equipment typically cause occupied room noise to be 20 dB(A) or more above background noise with brief sounds well above that.

Reflective and Absorptive Surfaces: Noise Reduction Coefficient (NRC)

Within any enclosed space, sound levels are affected by reflections of sound waves from surfaces. When the surfaces of a space are predominantly hard, sound pressure builds up in the space, increasing the original level with reverberation. Conversely, when the surfaces of a space are acoustically absorptive, reflected energy is reduced and sound pressure buildup is less. Acoustically absorptive materials are rated by NRC, an average of absorption coefficients in the middle range of the audible spectrum of sound frequencies. Although an oversimplification, the NRC rating of a material can be thought of as the percentage of the sound energy absorbed. If the NRC is 0.65, about 65% of the sound energy is absorbed and about 35% of it is reflected back into the room.

Sound Attenuation by a Barrier: Noise Reduction (NR), Sound Transmission Class (STC)

Sound can be transmitted between spaces via either air-borne or structure-borne paths or both. The attenuation of sound pressure by the barrier may be rated in three ways: (1) by NR units — a measure of both wall performance and room acoustics; (2) by the simple A-weighted difference between sound levels on either side of the wall — a measurement affected by acoustical conditions in the receiving room; or (3) by the STC — a complex rating that essentially removes room conditions from the performance of the wall. STC is a single number laboratory rating of sound reduction through a barrier between the frequencies of 125 and 4000 Hz. In situ measurements can be made outside of a laboratory, but should be referred to as field STC. Lower-frequency noise, commonly due to mechanical sources, is not included in STC but can be described by NR — the overall or linear decibel difference in sound levels on either side of a noise barrier. The NR and STC ratings for sound transmission should not be confused with or substituted for the NRC rating for sound energy absorbed in reflection.

Sound Transmission Loss (TL)

The sound reduction as sound passes through a material is the TL, measured in dB or dB(A).

Source–Path–Receiver Model

Acoustical analyses are generally based on the loudness of a noise source, the ambient noise or an allowable criterion for noise at the receiver, and the amount of NR on the path between them. For example, the background sound level in a room is 35 dB(A) and a noise source in an adjacent room is 75 dB(A). The path from the 75 dB(A) source to the 35 dB(A) receiver room determines how audible or annoying the noise intrusion is. The noise source will be inaudible or just noticeable in the receiver room if the TL through a wall between them is 40 dB(A) or more ($75-40=35$), but it would be increasingly more intrusive as the wall TL decreases from 40.

Vibration

Vibration is perceptible to humans at a certain magnitude or level and can cause annoyance or discomfort. Larger magnitudes of vibration may cause rattling of lightweight building elements, superficial cracking in partitions, or even structural damage. Very small magnitudes of vibration not perceptible to humans may disturb high magnification optical microscopes or very sensitive electronic instruments.

NEW FACILITY DESIGN: FROM THE OUTSIDE IN

Exterior Environmental Noise

Intrusive noise and vibration within the nursery can originate outdoors from both mobile and stationary sources. Mobile sources usually involve transportation (e.g., buses, trucks, garbage collection, motorcycles, vehicle sirens, cars, aircraft flyover, and trains). Stationary sources include mechanical equipment (e.g., engine generators, cooling towers and air-cooled chillers, roof-mounted air handlers and exhaust fans), helicopter operations, and construction. This variety of sound sources produces both ground-borne and structure-borne vibration and a full spectral range of noise. While traffic and mechanical sources tend to be continuous, some sources (e.g., busses, trucks, motorcycles) produce transient noise with instantaneous or rapid volume increase. Some sounds can be more annoying due to tonality, such as the low-frequency pulsation of helicopter blade slap, rumble of large diameter, slow rotation cooling tower fans, or whine of screw compressor chillers.

The location and orientation of the nursery should be considered in relationship to the type, direction, and distance from exterior noise sources. Low-frequency sounds have very long wavelengths and can refract or bend around sound barriers. If the sound source is nearby, increasing the distance from the source by moving the nursery a couple of structural bays (horizontally or vertically) may be effective. If the sound source is more than 100 ft distant, however, minor relocation will not significantly reduce the noise at the nursery. To the extent possible, therefore, the nursery should be placed where it cannot "see" any disturbing sound source. Many sound sources, however, surround or engulf the building.

Planners and engineers can influence the selection of exterior sound sources associated with the hospital building by requesting radiated sound level data from the manufacturers of mechanical equipment to be compared with building NC. Selections should not be limited to equipment with "closest to requested" maximum sound levels. Instead, manufacturers or engineers should be required to design additional noise attenuation and/or vibration isolation to reduce radiated noise levels to the desired criteria limits. The long-term benefits of increased quiet to patients, families, and staff can easily outweigh the increased space and installation costs required to meet specific criteria.

Sound Isolation: Exterior Walls

Noise intrusion from outdoor or environmental noise sources can cause disturbance or distraction in the nursery, including speech interference, interruption of diagnosis or monitoring processes, and sleep interruption. For such a variety of sound sources, the building envelope must attenuate sound transmission in all parts of the audible spectrum.

External, ground-borne, and structure-borne vibration can transmit through the building structure to occupied spaces and reradiate as sound from large lightweight surface areas such as ceilings and partitions. The amount of sound (especially low-frequency sound) or vibration attenuated by an exterior wall is related to the mass and stiffness of the wall. Sound can also enter the building via air-borne transmission. Exhaust and fresh air ducts to the roof and openings in the walls serve as secondary sources of noise intrusion by transmitting noise into ceiling plenums (i.e., the space between the ceiling and deck above). Large wall penetrations for exhausts, fresh air inlets, or through-the-wall air conditioning units should be avoided not just in the critical spaces but in nearby rooms as well. More noise usually enters through windows than through other structures because windows are lower mass or acoustically weaker than exterior walls and because windows are coupled to the exterior skin.

Setting criteria for sound TLs through the building envelope may be the most effective means of reducing environmental noise intrusion. An evaluation of environmental noise sources can identify not only the potential sources of disturbance noise, but also its sound spectrum and level. Engineers can then specify STC ratings for design criteria and building materials to achieve minimum sound TL in the octave band where noise source peaks. For high-frequency NR through windows (e.g., noise from sirens and vehicle tires), laminated glass and double-glazed windows with large air gaps >2 in. (50 mm) are recommended. Low-frequency sound and pulsation from mechanical equipment, helicopters, and transportation sources require more substantial building elements, such as higher mass walls (e.g., masonry) and window glazing designed and rated for sound TL. However, if the skin of the building is lightweight curtain wall construction, the inside finish layer should have multiple layers of gypsum board. Since outside sound levels can vary significantly, a single generic radiated NC (at the source) cannot be made. Generally, if exterior sound levels at the building wall can be limited to 60 to 65 dB(A), interior sound levels will be acceptable for average sensitivity occupancies.

Structural Vibration Control

Structural vibration is largely an engineering, as opposed to an architectural, design issue. Vibration problems can be anticipated in the planning stage and highlighted in the development of design parameters. Hospital personnel can refer planners and designers to the American Society of Heating, Refrigerating, and Air Conditioning Engineers[13] vibration criteria and identify optical or other equipment that could be affected by building vibration, or equipment that might put vibration or impact energy into the building structure.

Roof structures are often lighter and more susceptible to vibration than floors. The potential structure-borne transmission of roof vibration may affect decisions about the use or location of rooftop mechanical equipment, especially if laboratories or spaces housing sensitive equipment or occupants might be located on the top floor of the facility. Transmission of vibration from the roof must be addressed with particular care if a helicopter landing area is planned for the roof.

Building Systems Noise and Vibration Control

Like structural vibration, noise and vibration control from building electrical and mechanical systems are largely engineering issues. Hospital staff and planners should specify appropriate design criteria and insist on complete engineering analyses, not just rule-of-thumb estimates, to assure that criteria are met. Installations of mechanical (including plumbing) and electrical equipment along with connected piping, conduits, and ducts should be specified with appropriate vibration isolation, not just within mechanical spaces, but where vibrating elements pass through or near sound-sensitive rooms. Guidelines and reference texts for controlling heating, ventilating, and air conditioning noise include those by the American Society of Heating, Refrigerating, and Air Conditioning Engineers,[13] Schaffer,[14] and Ebbing and Blazier.[15]

Building Layout

Operational noise. The source–path–receiver method of evaluating noise can be used to protect the sensitive infant receiver from operational noise. Operational noise sources tend to be located in places where staff gather to work or to socialize (e.g., sinks, desks, entryways, telephones, computers, storage areas, break rooms, and infant bed spaces). Two examples illustrate the use of the model to plan for the quiet operation of nurseries.

Example 1: bulk storage location. Bulk storage areas for medication and supplies used at the bedside become noise sources while they are being stocked and while items are being removed. By tradition, nurses have wanted bulk storage to be as near the infant bed as possible to reduce walking distance. In most nurseries, therefore, bulk storage and infant beds are in the same open space with a few beds located quite near the supply area. Supply carts — additional sources of noise — typically pass the beds going to the storage area and nurses pass by them going between the storage area and the bedside at which they are working. The noise produced at the source (i.e., the storage area and the walkway to it) has an unhindered path (the open room) to the receivers (the individual infants). Yet most nurseries also provide for 24 hours of storage at the bedside itself so that once daily restocking of bedside storage should be an option. By locating bulk storage in a closed room, with direct access from the corridor only, the path between the noise source and the receiver is blocked by barrier walls and doors.

Example 2: work areas for nurses, clerks, and physicians. Office work areas within the nursery contribute to disturbance levels at the bedside from telephone, fax, voice communications, and office equipment. By tradition, office functions of clerical staff and physicians take place in the same area as office functions of the caregiving nurse. Because the nurse needs to be near the bedside, this community work area also tends to be near the bedside and is usually cramped. Nurses, clerks, and physicians have come to accept working conditions which lack even minimal office amenities for proper body mechanics (e.g., knee space under the work surface, chairs of correct height, unobstructed work surfaces), privacy for telephone and other voice communications, and space for organized storage of office supplies. (One of the authors has a collection of slides showing physicians and nurses writing chart notes while sitting on various objects and using laundry hampers as work surfaces. These slides get laughs of recognition everywhere.) The noise generated in these crowded work areas nearly always has an unobstructed path to the infant/parent receiver.

By separating the office work functions of the different groups, the facility can provide appropriate workspace for staff and appropriate quiet at the bedside. Nurses' office work has been greatly reduced in recent years and is now done during brief time periods between clinical tasks. An appropriate space at the bedside, therefore, may consist of a small surface at standing height with additional space for a computer monitor and silent keyboard (but no printer or permanently mounted phone). As the path between this workstation and the infant receiver is short and unhindered, the nurse is responsible for limiting the noise at the source. Clerical staff can work in a separate area near the entrance where they can also serve as greeters. There will likely be multiple barriers between this source and the receiver. Physicians can be drawn away from the bedside by separate work areas nearby that provide appropriate seating, large work surfaces, ample computer and telephone access, office supplies, speech privacy, and options for bringing in food and beverages. Thus, moving the noise sources of most of the office work away from the open nursery not only reduces noise at the bedside and improves working conditions for staff, but also improves the privacy of the bedside as infant and family space.

Compatible adjacencies. Hospital personnel and architects should consider both the functional relationships and acoustical compatibilities between spaces. Some incompatibilities are obvious. For example, rooms with high noise levels (e.g., staff locker rooms and break rooms) should not be adjacent to quiet rooms (e.g., nursery rooms or staff sleep rooms). Mechanical and electrical equipment rooms should be remotely located from sound-sensitive spaces. The most common incompatibility in hospital nurseries is the juxtaposition of adult work spaces and infant sleep spaces. Compatibility considerations should involve vertical as well as horizontal room relationships. If an incompatibility cannot be avoided appropriate attenuation measures need to be incorporated in the design.

It is axiomatic that rooms with no occupants or activity (e.g., long-term equipment storage) will not contribute intrusive noise to adjacent spaces, but rooms with moderate activity and normal conversational speech should not disturb adjacent spaces either. Using the source–path–receiver model, conversational speech in an administrative area (the sound source) might be 60 to 65 dB(A), whereas the continuous background level in the nursery (the sound receiver) may be 40 to 45 dB(A). If these two spaces are adjacent and separated by a barrier wall, noise intrusion to the nursery space is likely to be minimal. Alternately, a toilet block, mechanical equipment room, or even a large conference space might have source sound levels of 75 to 85 dB(A) and be very audible in an adjacent quiet room. Sound barrier partitions can be designed to overcome the noise difference, but at greater cost and complexity. Therefore, the least costly and most effective noise control is intelligent planning.

Traffic control. Commonly used travel paths are, themselves, sources of noise in hospital nurseries. Humans, like deer, locate and artfully adhere to the most direct route to a destination. Unlike deer, however, humans talk while they walk and carry noisy objects with them. Clinicians and architects need to review initial blueprints to locate travel paths inadvertently introduced in the layout of spaces (e.g., a short cut to the staff bathroom past a group of infant beds). Common destinations for travel paths include entryways, sinks, printers, refrigerators, bathrooms, and break rooms. The review of blueprints should also look for "cut through" opportunities to or from destinations unrelated to the nursery.

Sound Isolation

Interior walls or partitions. Sound transmission through partitions between rooms can permit intrusive disturbances from adjacent rooms and also compromise speech privacy. Sound paths include the partition itself, the ceiling plenum, doors, windows, and partition penetrations. Mid- and high-frequency sound transmission can be controlled with drywall construction, although multiple gypsum board layers may be required to achieve sufficient attenuation. Mechanical and machinery noise containment in equipment rooms is best achieved with masonry construction, although de-coupled, double-stud drywall with multiple layers of gypsum board on each side of the wall may be adequate. The use of sound attenuation blankets within the stud cavities of drywall construction is beneficial for 3 to 5 dB reduction of reverberant buildup within cavities but should be considered an enhancement, not a primary noise control solution. Special care should be exercised during design specification and construction to assure that all penetrations of the sound wall above and below the ceiling elevation are sealed airtight with caulking.

Doors and windows are often the weaker components of partitions. Open doors or windows will attenuate mid-frequency sound no more than 7 to 10 dB. A closed door, without sound seals, can provide 20 to 24 dB of NR. Single pane plate or tempered glass 1/8 to 1/4 in. thick (3 to 7 mm) will also provide sound TL up to 23 or 24 dB. There is also sound-rated glazing available with a range of STC values. Where attenuation is required for speech privacy or to prevent noise intrusion, up to 30 dB of attenuation can be achieved with laminated glass 1/4 in. or greater thickness, or doors with acoustic head, jamb, and threshold seals, such as closed cell sponge elastomer or tube-type gaskets. Felt or brush-type head and jamb door gaskets, which are designed for smoke or air infiltration, do not attenuate sound. A two-door vestibule configuration, sometimes referred to as a "sound lock," can be planned with acoustical seals on entering and exit doors. Where space or other constraints do not permit a vestibule, special sound-rated frame and door assemblies can be used in lieu of building standard doors to achieve more than 30 dB of sound separation.

Sound isolation within an enclosed space is very difficult, unless some kind of physical barrier can be inserted. For example, in many traditional nursery layouts, an adult workspace is in the same room as the baby beds, separated only by a 3 to 4 ft (1 to 1.35 m) or half-height partition. Such a partition provides no acoustical separation. If the partition were extended to 6 ft (2 m) or up to the ceiling, disturbances from speech and business machines would be significantly reduced, even if the partition does not create another room by extending wall to wall. Visual contact is easily maintained if the partition is glass or if it is typical drywall construction with a window. Keep in mind, however, that windows reflect, rather than absorb, sound within each space.

Floor/ceiling assemblies. Most normal vertical adjacencies, (e.g., an office or laboratory above patient rooms) are adequately separated by concrete floor slabs with suspended acoustical ceilings. Where a loud source room is above or below a very quiet sound receiver room (e.g., a conference room with A/V systems or mechanical equipment rooms vertically adjacent to an infant bedroom), more noise control is often necessary. Depending on the source and receiver conditions, solutions may vary from a high TL ceiling, to suspension of a sound barrier between structural slab and ceiling, to a "floating floor" separated from the structural slab by isolators.[16]

Room Acoustics: Reverberation and surface finishes

Planning for room acoustics involves controlling sound generated within a space. Room shape, volume, and surface finishes all influence the behavior of sound within an enclosed space.

Hard surfaces such as drywall, masonry, doors, glass, and casework or cabinetry reflect sound and thereby contribute to reverberation. The shape of the surface (e.g., curved, flat, articulated, etc.) may affect the direction or concentration of reflected energy, but not whether the energy rebounds. Convex surfaces (rounded like the outside of a ball) cause diverging reflections or spreading out of the energy to other parts of the space. Concave surfaces (rounded like the inside of a bowl) converge or focus reflected sound toward its origin. Right-angle or 90° corners also reflect sound back to its origin. Acute or obtuse corner angles direct reflections to places other than their origins.

Because sound waves follow principles of wave mechanics, sound both reflects and refracts as it strikes a surface. Some energy transmits or refracts into any surface, such as a wall, ceiling, or window, but the amount of energy that is refracted is very small compared to the energy that reflects back into the space.

Within the nursery and its associated spaces, certain acoustically reflective architectural features (e.g., doors, exterior windows, cabinetry) set the choice of surface finish. Other surfaces, however, such as those on partitions, walls, floors, and ceilings can be acoustically absorptive. To prevent standing wave patterns and flutter echoes, at least one of two parallel opposing surfaces should not be reflective. Therefore, the preferred locations for acoustical absorption are the surfaces opposite window, door, cabinet, hard partition, or floor surfaces. For control of random incidence reflections or reverberant buildup, any acoustical absorption is beneficial, although 25% to 40% of surface area in small- to medium-size rooms may be required to achieve significant mitigation. To control direct reflections on first or second bounce, absorptive surface areas can be placed on both vertical and horizontal surfaces.

Acoustically absorptive finishes such as acoustical ceilings and other porous, low-density materials trap sound energy and convert it to heat. Most materials are partially absorptive, reflecting a portion of the energy and absorbing the rest. Concrete, gypsum board, glass, and similar materials have NRCs ranging from 0.01 to 0.05. Acoustical ceilings have NRCs ranging from 0.6 to 0.99.

As a minimum, ceilings should be rated NRC>0.65, although a NRC between 0.80 and 1.00 is preferable in the infant bed area. Fabric or vinyl-wrapped acoustical wall panels, rated NRC>0.80, can be mounted or hung on walls. Window curtains can be absorptive if they have many deep folds and are made of thick, fuzzy fibers. However, tight-weave synthetics such as nylon and fiberglass are acoustically transparent unless bunched up in corners when full open. Infant bedding and incubator covers can be acoustically absorptive but, because of their location and small surface area, have little effect on reverberant buildup.

By their nature, acoustically absorptive surfaces are not sound barriers. They are considered acoustically transparent. Therefore, some sound energy incident on absorptive surfaces will reflect off the hard wall or ceiling surface behind it, although this effect decreases substantially with distance between the absorptive surface and reflective surface. If, e.g., carpet is thin and is backed up by hard floor, it is not considered absorptive although it will have noise control properties to the extent that it absorbs impact energy and thereby reduces the sound of footfall, equipment, dropped objects, etc. (Note that carpet in nurseries needs to meet specific infection control criteria.)

EXISTING FACILITY MODIFICATION AND RENOVATION

Planning and designing for renovation of existing facilities are fundamentally the same as planning for proposed new facilities except that a myriad of existing conditions places constraints on potential design choices. A successful NR program for an existing nursery begins with a baseline assessment of existing facility and operations conditions that create the noisy environment. The baseline assessment should include continuous dosimetry measurements, information gained from nursery personnel and building engineers, background sound measurements, and an on-site inspection of existing conditions. In addition to changes in the building, a successful noise abatement program will include opportunities for staff education and behavior change.

Following the assessment, an interdisciplinary team of clinicians, managers, and a space planner working with an acoustical consultant can determine alternative uses for the existing spaces. In many older nurseries, there may be more potential space and therefore more options available than staff realize. However, the best result may mean configuring the space in an unfamiliar way. For example, to achieve the objectives of reduced noise, increased space for infant beds, a parent break room, and functional space for staff office work, the familiar large nursery may be divided into two or more smaller nurseries separated by rooms with other functions. Old patterns of voice communication across the open nursery may then need to be augmented with alternative communications systems such as personal telephones.

High background sound levels can often be reduced in modification or renovation projects. Fans in heating and air conditioning systems and large machines generate low-frequency noise. Mid-frequency noise (speech frequencies) is generated by velocity and fitting turbulence in ducts. Supply air diffusers and exhaust or return air registers may cause high-frequency noise. Rather than asking for adjustment, balancing, or superficial tinkering with the air conditioning and ventilation systems, hospital staff should request investigation and evaluation of noise problems by mechanical engineers and acoustical consultants, with the intent of identifying fundamental sources of noise. Then equipment, layout, components, or aerodynamic conditions that cause objectionable noise can be corrected.

CONCLUSION

It is important to note that creating a quiet, calm environment involves changing the culture of the traditional nursery as well as changing its physical characteristics. Changing the culture is a long-term, complex, and socially difficult process that may involve losing opportunities for exuberant camaraderie, discharging tension, and ad libitum talking. Alternative social opportunities, as well as new expectations for appropriate nursery behavior, need to be developed during the change process. A hospital can create a new facility or successfully renovate an old one and still have a noisy nursery if the noise culture remains unchanged.

Conversely, a reverberant, open nursery with high background sound levels can be nearly impossible to keep in a quiet state. Even the most aware, calm staff are eventually discouraged from trying to maintain quiet if the conditions of the building dictate that the smallest human- and machine-generated noise travels past bed spaces unhindered.

Comprehensive planning and designing for quiet, nonreverberant facilities, with careful consideration of infant needs as well as staff and family activities, can result in functionally better and more comfortable nurseries. Parents, as well as clinicians who will work in the space, should participate throughout the planning and design process, including frequent communication and interaction with design professionals, to assure implementation and validation of operational parameters and relevant design criteria.

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APPENDIX: RECOMMENDED ACOUSTICAL CRITERIA

Recommended Sound Isolation/Acoustical Privacy Criteria

The criteria below are for sound TL or attenuation through horizontal barriers (e.g., walls, doors, windows) and vertical barriers (e.g., between floors). (These criteria are based on the professional experience of the author (JBE).) The STC rating spans speech frequencies and is relevant for separation of spaces with conversational and other occupant-generated noise. NR, which covers a wider frequency span, is more relevant for mechanical noise dominated by low frequencies.

Recommended criteria for sound TL between adjacent spaces.

Adjacent spaces	*STC*	*NR*
Corridor/nursery	STC 45	–
Nursery/nursery	STC 40	–
Reception/nursery	STC 55	–
Staff support/nursery	STC 50	–
Parent–infant room/nursery	STC 55	–
Family support/nursery	STC 50	
Administrative space/nursery	STC 45	–
Nonrelated space/nursery	STC 50	–
Mechanical space/nursery	–	60–65
Electrical space/nursery	–	50–55

Recommended Background NC

The RC below define the spectrum and level of sound, shown with approximate equivalent A-weighted overall sound levels. Additional information on building NC is provided by the American Society of Heating, Refrigerating, and Air Conditioning Engineers.[17]

Recommended allowable continuous background sound levels from building systems.

Room	*Minimum*	*Maximum*	*Approximate equivalent dB(A)*	
			Minimum	*Maximum*
Nursery	RC 25	RC 35	37	47
Isolation/NICU	RC 30	RC 35	42	47
Nurses' station	RC 30	RC 40	42	52
Private office	RC 30	RC 35	42	47
Open office	RC 35	RC 40	47	52
Reception/waiting	RC 35	RC 40	47	52
Parent–infant room	RC 35	RC 40	47	52
Corridor	RC 40	RC 45	52	57

Recommended Allowable Structural Vibration

Isolators for vibrating machinery or equipment mountings should be sized for spring resonant frequency not greater than one fifth of the source disturbing frequency. In other words, if the disturbance is 29 Hz (1750 rpm/

60 sec/min), the isolator resonant frequency should be less than 6 Hz (29/5 = 5.8 Hz). Criteria for building vibration measured in the structure of the building are available from the American Society of Heating, Refrigerating, and Air Conditioning Engineers.[13]

Reverbration Criteria

An appropriate design criterion for nurseries and related spaces is theoretical reverberation not greater than 0.75 seconds. In order to control focusing or convergence of sound, reflection, and flutter echo, the design should provide acoustical diffusion and/or acoustically absorptive finishes on three mutually perpendicular (horizontal and vertical) surfaces (e.g., two adjacent walls + ceiling).

Occupant-Produced Noise

Occupant NC are fundamentally different from building or facility criteria. Architects and engineers cannot control the behavior of occupants or limit the noise they may choose to generate. Therefore, occupant criteria should not be part of architectural and engineering planning and design criteria but should be incorporated into quality assurance programs of hospital management.[6] Occupant criteria could, however, be incorporated as a design parameter through the use of a matching architectural requirement, e.g., wall and ceiling absorption criteria (to prevent buildup of occupant noise) or STC and NR criteria (to prevent transmission of occupant noise between rooms).

Occupant NC recommended by Philbin et al. [6] are intended to limit infant sleep disruption and improve speech intelligibility for infants and adults. "Recommended Permissible Noise Criteria for Occupied, Newly Constructed or Renovated Hospital Nurseries: Patient bed areas and the spaces opening onto them shall be designed to produce minimal ambient background noise and to contain and absorb much of the transient noise which arises within the nursery. Overall, continuous sound in any occupied bed space or patient care area shall not exceed: (a) an hourly L_{eq} of 50 dB and (b) an hourly L_{10} of 55 dB, both A-weighted, slow response. The 1-second duration L_{max} shall not exceed 70 dB, A-weighted, slow response".[6]

References

1. Hall J. Designing for Family-Centered Care (Videotape). Bethesda, MD: Institute for Family-Centered Care; 1995. 34 minutes.
2. Devine-Webster P, Johnson BH. Collaborative Design Planning. Bethesda, MD: Institute for Family-Centered Care; 1999. p. 114.
3. Hall JH. Related settings: a family-centered approach to neonatal and pediatric intensive care unit design. J Health Des 1994;6:127–132.
4. Committee to Establish Recommended Standards for Newborn ICU Design, Robert D. White, Chair. Recommended standards for newborn ICU design. J Perinatol 1999:19;S1–S12.
5. White RD. Enhanced neonatal intensive care design: a physiological approach. J Perinatol 1996;16:381–384.
6. Philbin MK, Robertson A, Hall J. Recommended permissible noise criteria for occupied, newly constructed or renovated hospital nurseries. J Perinatol 1999: 19;559–563.
7. American National Standards Institute. ANSI S1.1. New York, NY: American National Standards Institute, Inc.; 1992. (Note: There are no page numbers in this publication. The standard number, S1.1, serves that function.)
8. American Society for Testing and Materials. ASTM C-634-94. Vol. 4.06. Annual Book of Standards. Philadelphia, PA: American Society for Testing and Materials; 1994. (Note: The C-634 standard is published as a pamphlet or within the annual book of standards. It should be listed as C-634, like a chapter number.)
9. Beranek LL. Acoustics. New York, NY: American Institute of Physics; 1986. pp. 8–15.
10. Cavanaugh WJ, Wilkes JA. Glossary. Architectural Acoustics Principles and Practice. New York, NY: John Wiley and Sons, Inc.; 1999. pp. 318–326.
11. Gray L. Properties of sound. J Perinatol 2000;20:S6–S11.
12. Gray L, Philbin MK. Measuring sound in hospital nurseries. J Perinatol 2000;20:S100–S104.
13. American Society of Heating, Refrigerating, and Air Conditioning Engineers. Chapter 46: Sound and Vibration Control. In: ASHRAE Handbook of HVAC Applications. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers; 1999. pp. 46.37–46.38.
14. Schaffer ME. A Practical Guide to Noise and Vibration Control for HVAC Systems. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.; 1991. p. 177.
15. Ebbing C, Blazier W, editors. Application of Manufacturers' Sound Data. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.; 1998. p. 225.
16. Meta M, Johnson J, Rocafort J. Structure-borne sound insulation (impact isolation). Architectural Acoustics: Principles and Design. Upper Saddle River, NJ: Prentice-Hall; Simon and Schuster; 1999. pp. 147–153.
17. American Society of Heating, Refrigerating, and Air Conditioning Engineers. Chapter 46: Sound and Vibration Control. In: ASHRAE Handbook of HVAC Applications. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers; 1995. pp. 46.22–46.25.