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Case study: Teaching hospital design with FGI acoustical criteria

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Criteria and guidelines in the Facility Guidelines Institute "Guidelines for Design and Construction of Hospitals and Outpatient Facilities," are adopted as code in many states of the United States and in other countries. In other states, including the location of the project in this paper, the criteria serve as a design standard implemented at the discretion of the owner or architect. Determination of compliance with criteria requires theoretical calculation in design phase or performance validation testing after construction. This acoustician was retained to document design conformance with the criteria by calculation, review and analyses of architectural and engineering designs for an eight-story teaching hospital. This study discusses the required acoustical criteria and allowable limits for indoor mechanical equipment noise and environmental noise exposure Calculation procedures, analyses, and on-site measurements undertaken to document conformance are presented with results. Commentary is offered about design alternatives that aided or inhibited success of conformance with criteria.

1 INTRODUCTION

The Dell Seton Medical Center at The University of Texas (DSMC-UT) was created as a private teaching and regional hospital in conjunction with University of Texas Dell Medical School, a new institution established by the state government and public university system. The facility will be a multistory patient tower on a pedestal containing admitting, management/administration offices, emergency and trauma, imaging, surgery kitchen/dining, back-of-house, docks and other services surrounded by noisy urban environment.

HKS Architects and their engineers and consultants were commissioned to design the hospital with a mandate to achieve sustainability certification under the U.S Green Building Council's "Leadership in Energy & Environmental Design" (LEED) rating system. The project is designed to conform with LEED BD+C Healthcare, which incorporates criteria from FGI Guidelines for Design and Construction of Health Care Facilities, 2010 Edition [1] and ASHRAE HVAC Systems Manual [2].

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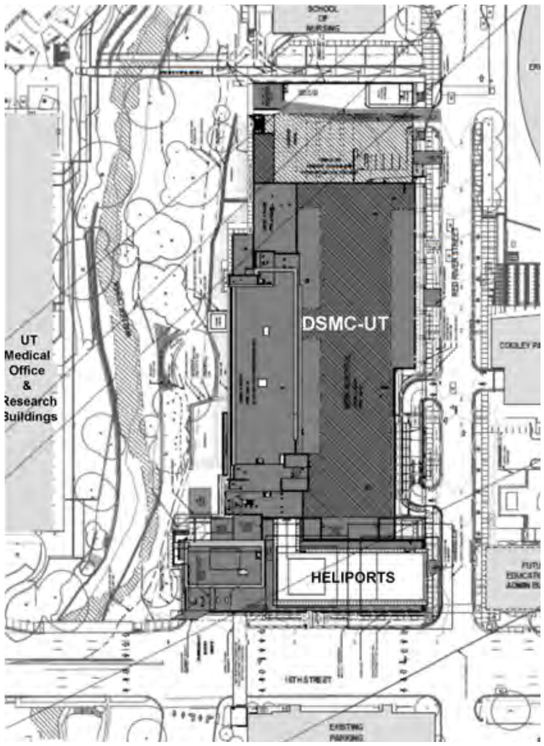
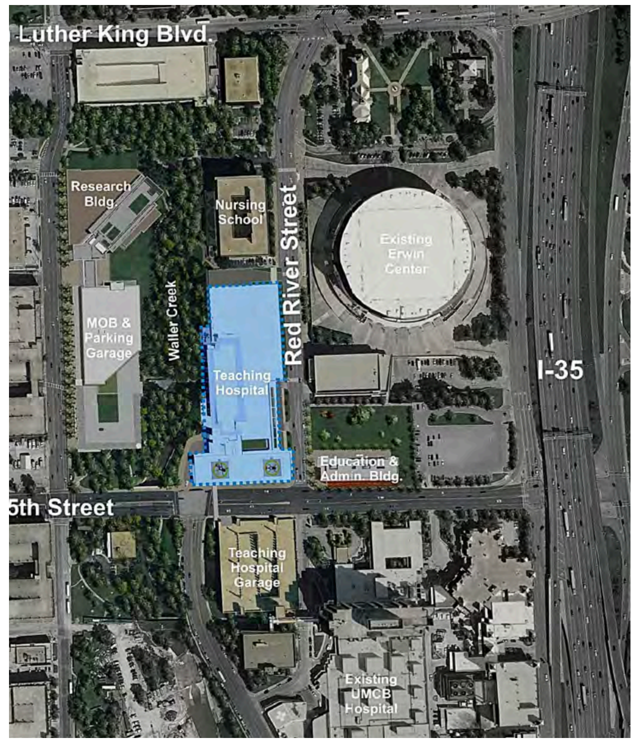
As Acoustical Consultant to the architects, the authors' scope of services included establishment of Acoustical Criteria, review and evaluation of architect's and engineers' (A/E) design documents, and development of recommendations to be implemented in A/E documents, which were designed to achieve the above criteria. With owner's and architect's concurrence, FGI 2014 acoustical amendments were also considered. The consultant recommended acoustical design criteria, based upon FGI, ASHRAE and successful experience in previous projects.





Figs. 1, 2 : Dell Seton University Medical Center at The University of Texas - Site and Vicinity

2 Criteria overview

The architect's programming for the hospital incorporated FGI 2010 in the overall project Basis of Design (BoD). The acoustical consultant recommended comprehensive acoustical design criteria as BoD, based on ASHRAE 2010, FGI 2010 with consideration of 2014 amendments, and successful experience in previous projects. Conformance to privacy mandates in the 1996 Health Insurance Portability and Accountability Act (HIPAA) are also required, but anticipated to be achievable when FGI privacy criteria are satisfied in design.

FGI presents six acoustical criteria sets with one set of vibration criteria (applicable 2010 and 2014 tables, see Tables 1 and 2)[3,4]. Architectural design parameters include interior room finishes (noise reduction coefficients, NRC) and sound isolation between rooms, vertically and horizontally (composite sound transmission class, STCc). Within certain enclosed rooms and open-plan spaces, speech privacy is controlled by a designer's choice of descriptors (AI, PI, STI or SII). Noise criteria are established for permissible sound spectrum levels for various room uses in Room Criteria (RC, preferred), Noise Criteria (NC) and/or A-weighted overall (dBA). Noise control criteria also include environmental or outdoor noise intrusions with regard to sound transmission loss via building shell, STCc (2010) or OITCc (2014), based on acceptable interior levels resulting from exterior noise intrusions. FGI also describes communications devices (alarms, call and paging) levels and comments on locations.

FGI Floor Vibration Criteria due to footfall impact are recommended as general proxy for a wide range of vibration disturbances (structural vibration was neither included in the consultant's scope of services nor in this case study, but is mentioned here in relation to acoustical criteria).

LEED Healthcare has 2 potential acoustical points [5], both of which reference FGI 2010 acoustical criteria tables (re: Tables 1 and 2):

Option 1: Speech Privacy, Sound Isolation, and Background Noise (1 point); FGI 2010 Tables 1.2-3 Minimum Sound Isolation, 1.2-4 Speech Privacy and 1.2-2 Min.-Max. Noise

Option 2: Acoustical Finishes and Site Exterior Noise (1 point, after Option 1 satisfied); FGI 2010 Tables 1.2-1 Sound Absorption Coefficients and A1.2-a Exterior Noise Classification.

The 2014 edition, which was also considered for this project, amended some of the criteria and changed acoustical criteria category table numbers. Notable amendments included change from STC to OITC for building shell, substituting SPC for STI privacy/intelligibility rating and added patient area floor vibration between procedure and administration floor permitted levels.

Tables 1, 2 – FGI Acoustical Criteria Categories, 2010 and 2014, respectively (changes in blue).

FGI Guide	Acoustical Criteria Categories, 2010
Exterior Noise Table A1.2-a	Exterior shell STC 35-50 based on exterior site noise exposure category, outdoor day-night average level (Ldn)
Acoustical Finishes Table 1.2-1	Design Room noise reduction coefficient (NRC) based on room/function type
Room Noise Table 1.2-2	Permissible continuous building systems background noise criteria (RC, NC, dBA)
Sound Isolation Table 1.2-3	Permissible room-to-room composite sound transmission class rating (STCc)
Speech Privacy Table 1.2-4	Closed Plan and Open Plan: separate ratings for normal, confidential and secure (AI, PI, STI or SII)
Alarm, Call & Paging Table 2.1-4	Locations and Criteria for audibility, intelligibility and minimal annoyance and masking
Floor Vibration Table 1.2-5	Patient, Operating, Procedure rooms: ISO Operating Theatre (4000 µ-in/sec) Administrative and public circulation: ISO Daytime (8000 µ-in/sec)

FGI Guide	Acoustical Criteria Categories, 2014
Exterior Noise Table 1.2-3	Exterior shell OITC 35-50 based on exterior site noise exposure category, outdoor day-night average level (Ldn)
Acoustical Finishes Table 1.2-4	Design Room noise reduction coefficient (NRC) based on room/function type
Room Noise Table 1.2-5	Permissible continuous building systems background noise criteria (RC, NC, dBA)
Sound Isolation Table 1.2-6	Permissible room-to-room composite sound transmission class rating (STCc)
Speech Privacy Table 1.2-7	Closed Plan and Open Plan: separate ratings for normal, confidential and secure (AI, PI, SPC or SII)
Alarm, Call & Paging Table 2.1-4	Locations and Criteria for audibility, intelligibility and minimal annoyance and masking
Floor Vibration Table 1.2-8	Patient, Operating, Procedure rooms: ISO Operating Theatre (4000 µ-in/sec) Administrative and public circulation: (8000 µ-in/sec) Patient (6000 µ-in/sec)

2.1 Room Absorption

Room-average sound absorption criteria, using noise reduction coefficient (NRC), varies by occupancy or room function. The average NRC is determined by summation of surface areas multiplied by their individual coefficients and divided by summation of areas. Transitory or non-occupied spaces, such as atrium require only a small amount of absorption. Areas where speech privacy is necessary, such as admissions, procedure or physician/consultation, require more absorption. Unique or special function areas listed in FGI, such as imaging board, conference, training or auditorium, were evaluated in more detail to determine appropriate absorption in conjunction with reflection and noise control measures.

Table 3 - Design Room (Average) Sound Absorption Coefficients (NRC)

Medium Live	Atrium, Entry Lobby	NRC 0.10
Average	Patient, Treatment Rooms, Corridor, Physician Office, Medication	NRC 0.15
Medium Dry	Waiting Area, Admitting, Other 'Privacy' Areas	NRC 0.25

FGI 2014 adds "medication safety zones" and "operating rooms" to spaces above

2.3 Sound Isolation

Sound isolation criteria were applied for FGI-listed and other occupied space demising partitions and floor-ceiling assembly designs. Isolation is the summation of noise reductions from source to receiver plus receiver location background sound. As first priority, space planning avoided non-compatible space adjacencies, vertically and laterally. Composite transmission loss values were used where partitions incorporated doors, windows, penetrations, etc. Minimal interior continuous background sound levels were assumed to be at least 30 dBA. Where partition designs do not extend above ceiling the partition STCc was recommended to be complemented by ceiling attenuation class (CAC) 35-40 for sound containment and privacy. Demising assemblies of FGI-listed spaces were allowed to be de-rated 3-5 STC points, if electronic sound masking of at least 48 dBA is used in adjacent non-sensitive areas.

Demising Assembly STCc =============== Source Room => .... Receiver Room v	Consultation Room	Exam/Physician Room (no masking)	Exam/Physician Room (with masking)	NICU / NICU Room	Patient Room, (same floor)	Patient Room, (floor-to-floor)	Procedure / Treatment Room	Public Space	MRI Room	Toilet Room	Corridor	Corridor w/ entrance	Break Room / Lounge	Service Area	Mech/Elec Equip Room
Consultation Room	50	50	40	50	50	50	50	50	60	50	35	35	50	50	60
Exam/Physician Room (no masking)	50	50	40	50	50	50	50	50	60	50	35	35	50	50	60
NICU / NICU Room	50	50	40	50	50	50	50	50	60	50	50	35	55	50	60
Patient Room	50	50	40	50	45	50	50	50	60	50	50	35	55	60	65
Procedure / Treatment Room	50	50	40	50	50	50	50	50	50	50	35	35	50	50	60
Public Space	50	50	40	50	50	50	50	50	50	45	35	35	50	50	60

Note: Black STCc values are from FGI 2010, Table 1.2-3. Blue STCc values are JEAcoustics recommendations, adapted from Table 1.2-3

Fig. 3 : Demising Assemblies Selection Matrix – minimum sound isolation performances between enclosed rooms FGI Criteria in Black, other non-FGI-listed spaces are in blue.

2.4 Acoustical privacy

FGI 2010 permits a choice of four different descriptors of speech privacy for enclosed rooms, AI, PI, STI and SII. FGI 2014 (blue) introduces SPC in lieu of STI, but retains the other three ratings. Privacy, defined as speech intelligible to casual listeners, or a small percentage of speech syllables can be understood is categorized from "normal" to "secure." Guidance is provided for confidential speech privacy in enclosed rooms with sum of composite demising assembly STC plus A-weighted background noise in receiving room not less than 75 dB. The Guidelines note that speech privacy cannot be fully achieved in open areas, but provides a "normal" recommendation rating. Proper space planning, partitions or barriers, room finishes and/or effective use of sound masking may be employed to achieve speech privacy.

Table 4 - Speech Privacy Goals (FGI 2010 black, 2014 blue)

Enclosed Rooms Goal	AI	PI	SII	STI	SPC
Normal	≤0.15	≥85%	≤0.20	≤0.19	65-70
Confidential	≤0.05	≥95%	≤0.10	≤0.12	71-79
Secure		Special consideration required			≥80
Open Plan Goal	AI	PI	SII	STI	SPC
Marginal	0.21-0.40	60-79%	0.26-0.45		55-64
Normal	≤0.20	≥80%	≤0.25	≤0.23	65-70
Confidential		Special consideration required			55-64

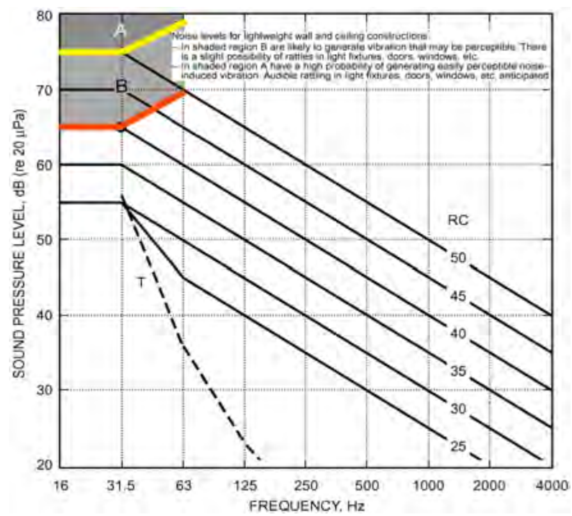
Public Law 104-191, The Health Insurance Portability and Accountability Act (HIPAA), Title I protects insurance coverage for workers that change or lose their jobs. Title II requires establishment of standards for electronic transactions and identifiers for health providers, insurance plans and employers, and created standards for health data security and privacy. [6, 7]

2.5 Continuous Background Noise in Interior Spaces (RC, NC, dBA)

FGI considered ANSI and ASHRAE recommended noise levels in determination of 2010 Guidelines, which includes minimum and maximum levels. 2014 changes criteria to maximum levels only and introduces “medication station,” “NICU sleep areas” and “NICU staff and family areas.” The intent of noise criteria is to achieve comfortable, non-annoying background sound levels with smooth spectra that do not interfere with speech or normal activities, and that neither induce vibration nor interfere with noise and vibration sensitive lab or diagnostic instruments. FGI references room criteria (RC), noise criteria (NC) and A-weighted sound (dBA). The consultant recommends the RC system, which produces a more neutral spectrum and incorporates two lower octaves than other criteria, where acoustically induced vibration occurs.

Table 5 - Minimum – Maximum Design Criteria for Continuous Interior Background Noise [8]

Room Type	RC(N) / NC	dBA
Patient Room	30-40	35-45
Medication Station	45	50
Multiple Occupant Care	35-45	40-50
Corridors / Public Spaces	35-45	40-50
Physician Office, Exam	30-40	35-45
Conference Rooms	25-35	30-40
Teleconference	25 (max)	30
NICU (2010)	25-35	30-40
NICU sleep areas	30	35
NICU staff and family	35	40
Operating Rooms	35-45/50	40-50/55
Testing/Research Lab	45-55	50-60
Group Teaching Lab	35-45	40-50
Auditorium, Large Lecture	25-30	30-35



2.6 Building Vibration Based on Structural Floor Response to Footfall Impact

Building vibration criteria are recommended for structural design, including vertical motion related to building systems equipment, user-installed equipment, occupant activities etc. or exterior sources entering the structure through the foundation. There are horizontal vibration criteria for sensitive lab and diagnostic instruments, such as microscopes and imaging systems. Structural design vibration criteria are in 1/3 octave bandwidths over a limited 1 Hz–100 Hz frequency span. Manufacturers’ vibration sensitive instruments and equipment vibration tolerance criteria are often in narrow bandwidths over various frequency spans, indicating resonances and sensitivities to discrete frequencies of apparatus disturbance. FGI 2010 recommends 4000 µ-in/sec velocity (peak), or 4k mips, for operating, treatment, lab and patient rooms, and 8k mips (peak) or for administrative areas and public circulation. 2014 relaxes patient rooms and other patient areas from 4k mips to 6k mips (peak).

3 Environmental Noise

Determine outdoor noise intrusions into interior spaces with regard to acceptable ambient and transient noise levels and determine facility noise emissions to the community with respect to local code and ordinance permitted limits. Design and recommend noise attenuation, damping and/or sound isolation measures that achieve the project Basis of Design Noise Criteria and regulatory noise limits, based on acceptability criteria in LEED "Site Exterior Noise" requirement, i.e. 2010 FGI, Table A1.2-a1, Categorization of Health Care Facility Sites by Exterior Ambient Sound, with consideration for changes in the FGI 2014 edition, Table 1.2-3, and introduction of exterior shell composite OITC ratings [9] (OITCc).

Fig. 4 – Architect's perspective rendition of completed hospital, view from Red River St (east).

3.1 Existing noise environment

Overnight airborne environmental noise monitoring was conducted during 2014 at two locations within 500 m (1,640') of the proposed project. Each of the monitoring surveys lasted about 24-hours and were carried out at different times of the year, so the combined results were considered representative of the environment, with noise from roadway and highway buses, trucks, autos, motorcycles and ambulances, plus flyovers of airplanes and medevac helicopters serving other nearby existing hospitals.

Environmental sound monitoring at nearby locations demonstrates that the building is subject to frequent and periodic noise disturbances from emergency vehicle sirens and citywide medical helicopter overflights, in addition to roadway traffic noise. These transient noise events are anticipated to increase when the proposed DSMC-UT is occupied and operational. The loud transient exposure is similar in level and frequency distribution on all sides of the building.

Frequent transient interior intrusions exceeding continuous background sound level are recommended by the consultant to be limited to 5 dBA, i.e. 42-45 and 47-50 dBA, respectively for sensitive and typical FGI-listed spaces. Given neighborhood helicopter overflights commonly exceeding 70-75 dBA at this location (including the west facades of Area 1 and 3), glazing should have +/-30 dBA of noise reduction with strong low-frequency resistance to achieve indoor transient noise disturbance goals. This suggests, at minimum, glazing with > 22 dB sound transmission loss (TL) in 125 Hz octave (not the same as STC rating) for tower patient rooms, office and even more for sensitive spaces, such as for Education or Executive Conference or near imaging, microscopy, etc.

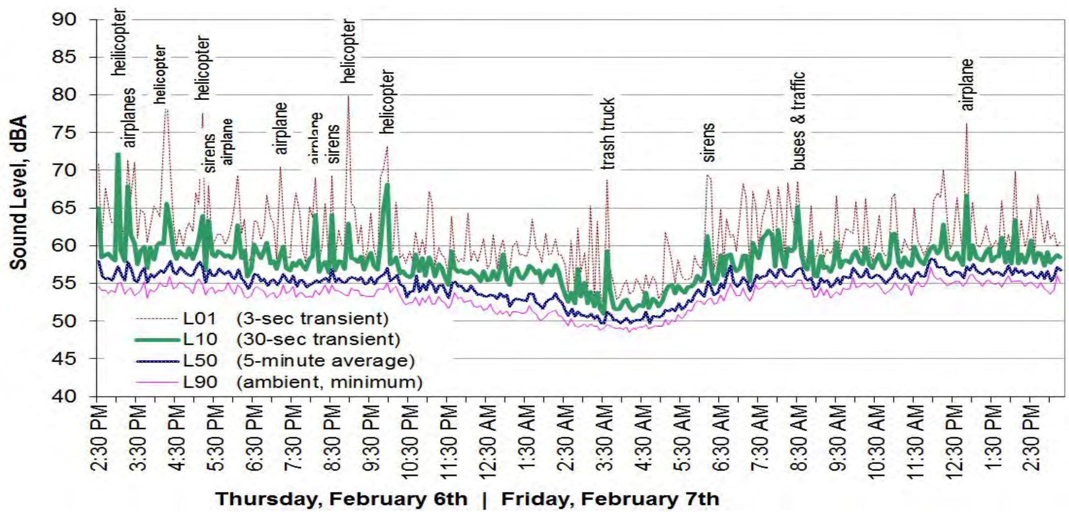


Fig. 5 – Environmental sound monitoring results[10] (existing noise), LA(n)

3.2 Future noise environment

Heliport take-off and landing operations [11]: The proposed flight path layout shown in Fig. 1, and assumed AW139s helicopter equipment to be used, provided by heliport planners, was incorporated into SoundPLAN® 3-D environmental noise modeling. The program produced color-coded noise contours indicating maximum noise with various representative helicopter flight paths and take-off landing events. That other helicopters may be used in the future was recognized. For comparison with FGI average hourly nominal maximum (L01) sound criteria [12], maximum sound power spectra for helicopter take-off and landing were determined, based on field noise measurements, and were applied to the noise model as line sources to determine maximum transient airborne noise conditions for various representative flight paths.

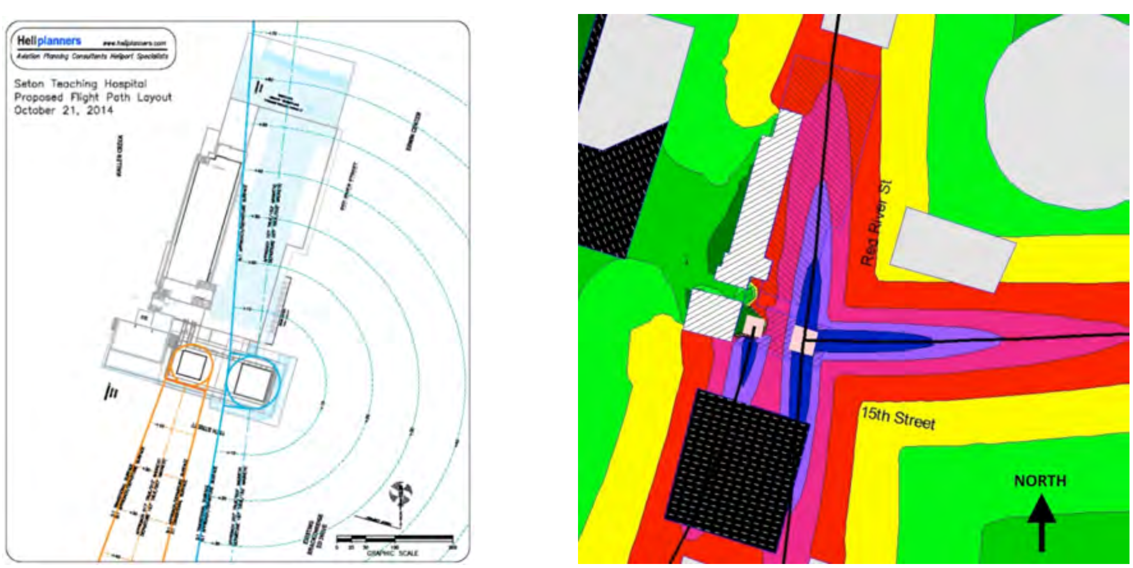


Fig. 6 – Flight path layout provided by heliport planners (left). Modeled flight paths (right).

Modeling determined general conformance to the environmental noise criteria; estimated average hourly nominal maximum (L01) sound < 75 dBA at most facades, with the following exceptions: South Tower patient rooms on Levels 2–5, the chapel, conference room, offices on Level 1 of South Tower, conference and office spaces in the North Tower. Summarized results and exterior noise exposure categories are in Table 1.

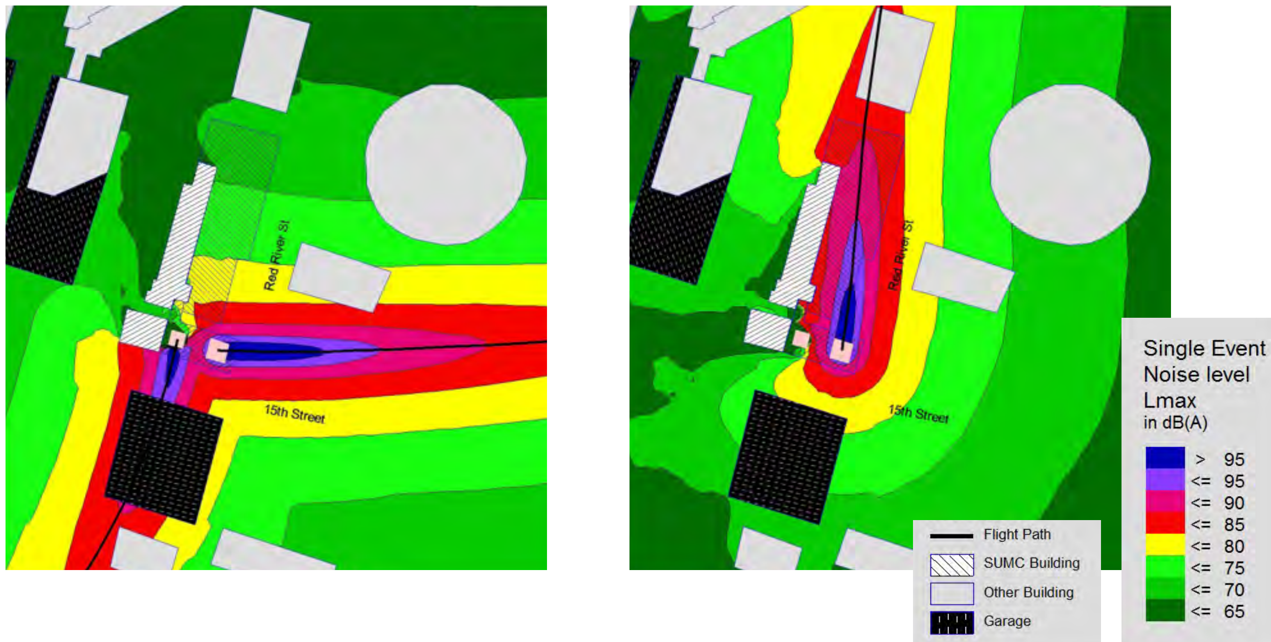


Fig. 7 – Heliport events (Lmax) received at Level 7: east & south paths (left); north path (right).

Table 6 – Heliport Noise Exposure Results Indicating FGI 2010 Noise Categories [13]

South Tower					**Predicted Lmax (dBA)**	
Floor	**Interior Uses**	**Exterior Site Noise Exposure Category**	**Avg Ldn**	**Average Maximum (L_{01})**	**South and East Flight Paths**	**North Flight Paths**
6-7	Heliports	D-extreme	100	95	100	100
5	12 Bed Unit, Conf	**C-significant**	**74**	**85**	90	90
4	Future	**C-significant**	**69**	**80**	84	85
3	I.M.C., Conf	**B-moderate**	**66**	**77**	82	85
2	I.C.U.	**B-moderate**	**65**	**76**	81	84
1	Chapel, Conf, Offices	**B-moderate**	64*	**76**	80	83

North Tower					**Predicted Lmax (dBA)**	
Floor	**Interior Uses**	**Site Noise Exposure Category**	**Avg Ldn**	**Average Maximum (L_{01})**	**South and East Flight Paths**	**North Flight Paths**
7	Conf, Break	**B-moderate**	64*	77	80	86
6	Office	**B-moderate**	64*	75	78	84
5	Lobby	A-minimal	64*	74	77	83
4	Lobby	A-minimal	64*	74	77	83
3	MECH	A-minimal	64*	74	78	83
2	Lounges	A-minimal	64*	74	78	82
1	Lobby	A-minimal	64*	74	78	81

* Average environmental noise exposure at the site would not be less than Ldn 64 resulting from off-site traffic, highway, aircraft and other ambient noise conditions.

Spaces highlighted did not meet the FGI criteria due to exterior noise exposure from helicopter take-off and landing operations at both heliports. Compared to other parts of exterior wall assemblies, windows are acoustically weakest elements. Therefore, implementation of high STC glazing for patient rooms subject to greatest exposure (South Tower Levels 4 and 5) and somewhat lower STC for rooms with moderate exposure (lower floors of the South Tower and portions of the North Tower) should be implemented to meet the FGI criteria.

The recommendations may be implemented with a graduated A-B-C category vs TL system. For all glazing, including system A (above) for minimal noise exposure category A, the consultant recommended insulating glazing fixtures that have inner and outer panes of different thickness, if possible. For example, with a 9 mm (3/8") inner pane along with a 5 mm (3/16") outer pane; or a 5 mm (3/16") inner pane along with a 6 mm (1/4") outer pane. Unbalanced fixtures mismatch glass pane resonances, improving sound isolation performance. [14]

System B is recommended for facades with moderate exposure.

System C, window+frame or curtain wall should be used on the façades with significant exposure in order to achieve FGI criteria for allowable environmental noise received in the indoor spaces.

Table 7 – Façade and Glazing Exposure and Noise Reduction Guide

Category / System:	**A**	**B**	**C**
Outdoor-Indoor Transmission Class (OITC) not less than:	24	26	28
Minimum Sound Transmission Class (STC) not less than:	28	32	35

Specifications with minimum requirements to achieve FGI criteria were recommended. Fixtures with performance values slightly less than (1 or 2 points below) recommended minima were permitted for less sensitive areas and where FGI criteria do not need to be achieved.

If glazing exceeding these specifications by 1 to 3 points can fit the budget, the consultant recommends implementing higher performance where possible to achieve greater isolation and better indoor sound quality for patient rooms and conference rooms.

Specified performance should be based on laboratory test results for assembled curtain/storefront or window fixture (glazing-and-frame assembly) per ASTM Standard E 90 (STC) and ASTM E 1332 (OITC). [15]

In addition, laboratory-tested performance for windows should achieve minimum TL values >30 dB between 1000 Hz and 2000 Hz to ensure proper high-frequency siren, car horn or alarm sound isolation, plus minimum values >22 dB between 100 Hz and 250 Hz to ensure proper low-frequency sound isolation.

Penetrations through exterior assembly, such as plumbing (hose bibbs), electrical (conduit for exterior lights), ductwork, window flanges, etc. are recommended to be caulked and sealed, particularly at the South Tower roof and at facades on both towers at occupied spaces nearest the two heliports. The consultant recommends Acoustical Sealant, a permanently resilient caulk, non-brittle fire caulk, or permanently resilient gasket material.

The consultant reviewed mechanical plans to identify fresh air inlets, exhaust and ventilation ductwork, or other potential short outdoor-indoor paths that could allow intrusion of outdoor sound into sensitive indoor spaces.

Additional ductwork enclosure or attenuation is recommended for South Tower’s Isolation Exhaust Fan, which is open to exterior at the fan discharge. Depending on discharge duct stack height, location, and whether that duct opening has a direct line of sight to the heliports and flight paths, attenuation is recommended in the exhaust duct such as additional bend(s), shielding, or sound attenuator, to reduce helicopter sound transmission indoors to isolation patient rooms via exhaust ductwork.

For other rooftop mechanical equipment, the consultant recommends 18-gauge sheet metal for rooftop supply and return ducts on tower rooftops connecting to risers in the building.

Tower roofs should have insulation and waterproofing membrane with enough mass to reduce the transmission of noise through the roof/ceiling assembly. Similarly roof deck sound transmission loss is recommended to reduce intrusion of low frequency airborne sound and impulse from helicopter blade slap during take-off, landing and north approach operations.

In conjunction with roof measures, the consultant recommends a mass layer > 10 kg/m^2 (2 psf) between roofing membrane and insulation, such as mass-loaded vinyl, or possibly an additional layer of gypsum board below the roof deck suspended on resilient channels.

Sound barrier lagging is recommended for roof drains and other piping penetrations of roof deck, unless enclosed in shafts, to contain excess low frequency or blade slap pulsation radiation within ceiling plenum.

4 Architectural Acoustics

4.1 Sound Isolation/sound privacy

Establish demising assembly sound transmission losses necessary to acoustically separate adjacent rooms based on probable source room sound levels and ambient or background levels in receiving rooms. "Demising assemblies" may refer to partitions and/or floor-ceilings. In open-plan spaces, coordinate sound isolation barriers with room acoustics surface finishes. Design and recommend solutions or implement prescriptive demising partition STC ratings that achieve the project Basis of Design Acoustical Criteria and LEED "Speech Privacy and Sound" requirement [16], i.e. 2010 FGI, Table 1.2-3, Design Criteria for Minimum Sound Isolation Performance between Enclosed rooms and Table 1.2-4, Speech Privacy for Enclosed Room and Open-Plan Spaces. FGI-listed spaces refer to patient room, procedure, office and conference rooms. The goal of sound isolation criteria is to provide minimally acceptable speech privacy and freedom from intrusive noise.

DSMC-UT Conditions: Open spaces such as a waiting area, corridor, etc. have relatively poorer speech privacy than enclosed spaces such as physician's office, patient room, etc. Information discussed should match room's operational or management function. Use architectural layout and design perspective. Room/open space designs should consider audible transfer of private information.

Determine FGI-listed room demising assemblies' sound transmission losses, STC/STCc. Review and adjust all selections of demising assembly selections and designs to meet criteria. Where very loud sources or very sensitive receiver spaces are vertically adjacent (*i*) install decoupled top slab on resilient floor underlayment over structural slab or (*ii*) construct a resiliently suspended sound barrier below structural deck and above architectural. Provide partition decoupling to reduce structure borne vibration in framing and resultant surface radiated sound in sensitive rooms.

Decrease room-to-room transmission of airborne sound with additional partition mass layer, such as additional drywall layers on framed partitions. Reduce radiated impact and vibration noise by decoupling drywall surfaces from partition framing with resilient drywall mounting. Outlets and other partition penetrations between the two adjacent rooms should to be staggered (not back to back) and caulked around perimeter to reduce flanking. Also attenuate crosstalk between adjacent rooms via HVAC duct and return transfer penetrations that reduce speech privacy.

Reduce room to corridor noise with acoustical seals on doorframe heads, jambs and bottoms or thresholds. Relocate return air registers from above door toward rear or center of room, whichever is farther from other R/A registers or receivers. Where feasible, plan or relocate entry doors on secondary corridor. Utilize vestibule entries where sensitive rooms are situated on busy corridors or lobbies separate from the main corridor, lobby, etc. Restrict access to noise sensitive spaces such as patient rooms.

4.2 Architectural Room Acoustics/ Sound Absorption

Decide appropriate room surface finishes to improve speech intelligibility or good communications using acoustically absorptive, diffusive and reflective materials to control reverberation and reflection patterns. Design and recommend solutions that achieve the project Basis of Design Acoustical Criteria and LEED "Acoustical Finishes" requirement [17], i.e. 2010 FGI, Table 1.2-1, Design Room Sound Absorption Coefficients.

DSMC-UT design review and evaluation indicated most FGI-listed spaces conformed, with certain exceptions: operating room, multi-bed patient room and waiting room. Improve speech and listening conditions within rooms by modifying configuration, shape or furnishing layout to reduce distance between sound source (person speaking) and receiver (person/people listening). Place similar function spaces adjacent to or above each other to decrease noise disturbance between rooms with differing uses, such as patient above patient, exam next to exam. A lab microscopy room with a multi-headed microscope adjacent to the generator room presented special problems. Noise and vibrations from the generator propagate via structure-borne and air-borne pathways to occupied spaces. The first solution is to reallocate the lab space away from the generator room for a less noise sensitive critical function area. If the lab must stay, assure the microscope room's demising partitions and floor is decoupled from the generator room to reduce the image resolution issues from the noise and vibrations.

Determine reverberation times for sensitive spaces. Recommend proportions of absorptive, reflective and diffusive room finishes (material type, thickness, characteristics, amount and/or locations) necessary to achieve criteria. Increase the acoustically absorptive proportion of the total ceiling area or increase the ceiling tiles' NRC-rating. Absorption surfaces may be placed in three dimensions, horizontal (ceiling) plus vertical north-south and east-west walls. Consider specifying "composite ceiling tiles" that have high mass layers adhered to low-mass high-absorption tiles for combination of absorption plus barrier characteristics. Similar results can be achieved by laying gypsum board tiles over acoustical tiles.

Design default to absorption on adjacent perpendicular walls in lieu of opposite parallel walls. Add acoustically absorptive wall finishes to increase room absorption and control reflections control especially in sensitive spaces, such as video or teleconferencing, recording/editing, etc. Good mid-to high-frequency absorption is possible with materials ≤ 1" thick. Good low-frequency absorption may require ≥ 2" thickness. Carpet adds minimally to room absorption, but is a good noise reduction material to minimize footfall, impacts and scraping or moving noises.

Special Condition Design Challenge: operating room has an NRC = 0.10 including air. FGI 2010 does not include a specific value for the operating room. However, covering non-HVAC/lighting part of ceiling with medically appropriate (sanitary cleanable and impervious barrier enclosed) acoustically absorptive material where drywall ceiling is indicated will increase the absorption in the room. Products generally have fiber or open-cell foam covered or enclosed within high-strength membrane, such as vinyl, Tyvek, Mylar, etc. The protective membrane is transparent to mid to lower frequencies and does not reduce absorption. Higher frequency absorption is reduced somewhat by membrane coverings over absorptive fill, but not completely.

5 Indoor Mechanical Equipment and Environmental Noise

Determine building systems' generated noise and natural system attenuation for result comparison versus permissible sound spectra. Design and recommend noise attenuation, damping, sound isolation and vibration control measures that achieve the project Basis of Design Noise Criteria and LEED "Background Noise" requirement, [18] i.e. 2010 FGI, Table 1.2-2, Minimum-Maximum Design Criteria for Noise in representative interior rooms and spaces and ASHRAE HVAC Systems Handbook, 2011, Chapter 48, Sound and Vibration Control, Table 1.

Noise produced by building systems equipment, such as mechanical/HVAC, electrical, plumbing (MEP) and elevator systems, contributes to the continuous ambient noise in spaces. Transient events outside or inside the building, including occupant speech and activity, user-installed equipment and/or intermittent building system cycles contribute to variability of noise. Intermittent-building systems operations also contribute to variability of noise.

Quiet ambient noise levels improve speech perception and allow for a large dynamic range for sound, making the nuances of speech more audible and understandable. Limiting MEP systems noise permits occupants to experience reasonable levels of speech intelligibility without unnecessarily raised voices. Balanced (neutral) spectrum building systems noise without tones or temporal variations promotes concentration, without annoyance or distraction.

Neutralize tonal noise spectra of MEP and HVAC sources. Provide a balanced (neutral) spectrum of noise without tones or temporal variations to help occupants maintain reasonable levels of concentration, without annoyance or distraction due to the MEP systems. Maintain a minimum continuous ambient noise levels with HVAC and MEP in conformance with permissible criteria, to reduce variability of cyclical and transient noise distractions.

5.1 Central Plant, Engine-Generator and Exterior Building Systems Equipment

Generator Equipment Room: Engine exhaust and radiated noise spectra were evaluated to determine noise containment and attenuation requirements [19]. The pre-selected reactive muffler conforms to criteria for engine exhaust noise, but otherwise would have been prescriptively specified ~45 dBA attenuation with body diameter and length $\geq$ 3x and 10x inlet pipe diameter, respectively. OITC $\geq$ 65 demising partition required at occupied space adjacency and OITC > 55 required for exterior walls. Inlet and radiator discharge wall openings required deep acoustic louvers or sound attenuator banks inside architectural louvers, with attention to static pressure limitations of radiator fan. A contingent recommendation permitted small reduction of acoustic louver or attenuator insertion losses if 2"-4" acoustically absorptive surface finishes are placed on $\geq$ 30% of generator room surface area.

Vibration isolation was required for the engine generator rail base (essentially constant weight load, because day fuel tank is remote from engine base). Vibration isolation hangers were recommended for engine exhaust muffler and pipe.

5.2 Interior Building Systems/Mechanical Noise

Permissible continuous background noise criteria include FGI-listed spaces. Patient rooms, medical on-call sleep rooms and conference rooms with AV require the strictest quiet conditions to avoid sleep or speech interference, in the sense that neither excess level nor frequent transients care tolerable.

The Interior buildings systems design evaluation for noise indicated air handler unit (AHUs) and mechanical equipment rooms (MER) noise exceed criteria. AHUs and distribution ducts require expansion chamber plenum or attenuator insertions within or near MERs. Dynamic insertion losses (DIL) were scheduled for each AHU system, based on FGI-listed spaces. Patient isolation room and medical on-call sleep room exhaust fans need special consideration due to the sanitary-sterile isolation requirements and sensitive nature of these spaces.

Air terminal devices radiate sound from plenum inlet and casing. Locate air terminal devices above areas with a noise criteria RC-40 or greater, such as corridors, open-office and other less sensitive spaces. Discharge noise is emitted from diffusers or grilles into occupied areas. Noises generated at the terminal are attenuated locally and in the discharge duct. At the AHU inlet or discharge expansion-chamber plenum losses provide attenuation.

Noise from Air Handler Unit (AHU) fans transmit downstream via attached supply and upstream via return or exhaust ductwork. Along the path, breakout noise radiates from duct wall surfaces. Radiated and duct borne noise attenuation methods focus on altering aspects of the ductwork in order to reduce noise transmission.

Duct geometry, internal fittings and flow velocity contribute turbulence-generated sound. Recommend low aspect ratio ductwork and aerodynamically efficient fittings to reduce turbulence noise generation. Adjust duct airflow velocities because high flow rates may generate additional noise. Externally, heavier sheet metal gage, duct lagging and/or acoustical enclosures provide containment. Within ducts, attenuators, and/or absorptive liner thickness provide attenuation. Where duct attenuators are recommended, locate with appropriate size transitions in ductwork close to the air handler or in ceiling plenum above corridors or utility spaces near mechanical room for lower frequency AHU noise.

Insulated flexible duct is recommended for the last 1m-2m (3'-6') of duct following volume dampers and before grille or register termination. Duct lagging or acoustical enclosure is recommended where trunk duct breakout radiation may exceed occupied space noise criteria and/or where branch duct penetrations and routing through sound sensitive room may permit break-in-breakout distraction or privacy compromise. Coordinate architectural and mechanical noise control measures by increasing the transmission loss of the ceiling tile with CAC $\geq$ 40 and NRC $\geq$ 0.65 in non-sensitive rooms and corridors.

An exhaust systems strategy is to reduce the noise. Place attenuation in the ductwork. Install expansion chamber muffler or plenum in areas where contaminants or corrosives will not allow acoustically absorptive materials within the duct for labs or isolation patient rooms. Reselect a quieter fan by the needed attenuation amount or a less tonal fan. Place a noise barrier at the ceiling level.

Kitchen exhaust will require special consideration to reduce unwanted noise. Due to fire and safety code, kitchen exhaust cannot have silencers making it difficult to eliminate unwanted sound. Quietest fan selection that meets other aerodynamic parameters is recommended with specification of acoustically absorptive surfaces in or near kitchen, where allowable.

5.3 Building Equipment Vibration Isolation

Specify building systems equipment vibration according to ASHRAE Applications Manual [20], 2011, Selection Guide for Vibration Isolation, Table 47 and related notes. Provide flexible couplings for chilled and hot water pipe connections to coils, power and cable conduit connections duct connections and condensate drain pipes. Pipes connected to AHUs and/or pumps in MERs should have vibration isolators in stanchion or hanger supports, if structure is immediately above or below sensitive occupied spaces. Install static deflection internal fan-motor vibration isolators or springs isolators where required. Provide pad or machine mounts under AHU casing / mounting points or under housekeeping pad to reduce aerodynamically and sound-induced vibration in casing from transmitting to building.

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7 REFERENCES

1 Guidelines for Design and Construction of Health Care Facilities – FGI 2010 Edition, ASHE (American Society for Healthcare Engineering of the American Hospital Association, Chicago, (2010)

2 ASHRAE Handbook of HVAC Applications. "Sound and Vibration Control," Chap. 48. Pg.48.2, American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc., Atlanta (2011).

3 *Ibid. FGI, 2010*

4 Guidelines for Design and Construction of Health Care Facilities – FGI 2014 Edition, ASHE (American Society for Healthcare Engineering of the American Hospital Association, Chicago, (2014)

5 *LEED BD+C Healthcare:* U.S. Green Building Council, Washington, DC (2009)

6 U.S. Public Law 104-91

7 http://aspe.hhs.gov/admnsimp/pl104191.htm

8 *Ibid, ASHRAE, Fig. 31, p. 47.32.*

9 Standard Classification for Determination of Outdoor-Indoor Transmission Class, ASTM E1332-90 (1998), American Society for Testing and Materials, West Conshohocken, PA. (1990)

10 C.N. Himmel, "UT-Dell Medical School, Phases B, C, Environmental Noise Monitoring Results," (Unpublished report), JEAcoustics, (Feb, 2014).

11 C.N. Himmel, "DSMCUT Environmental Noise," (Unpublished report), JEAcoustics, (Jan, 2015).

12 *Ibid.* FGI 2010, 2014

13 *Ibid* DSMCUT Environmental

14 Quirt, J.D. Sound transmission through windows; II. Double and triple glazing. Journal of the Acoustical Society of America, Vol. 74, p. 534-542. (1983).

15 *Ibid. Quirt*

16 J.B. Evans and C.H. Wiese, "DSMCUT Architectural Acoustics," (Unpublished report), JEAcoustics, (Jan, 2015).

17 *Ibid.* Architectural Acoustics

18 J.B. Evans and C.H. Wiese, "Final DSMCUT Mechanical Noise" (Unpublished report), JEAcoustics, (Jan, 2015).

19 J.B. Evans and C.H. Wiese, "DSMCUT Engine-Generator Noise & Vibration," (Unpublished report). JEAcoustics, (Jan, 2015).

20 *Ibid.* ASHRAE