Western Washington University
Design Guide
Acoustical Standards

WESTERN WASHINGTON UNIVERSITY

BELLINGHAM, WASHINGTON

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WWU Design Guide

PART 1 INTRODUCTION

1.1 Contents

Good room acoustics are essential to facilitate communication between instructor and student in every learning environment. This guideline will assist in defining what constitutes "good acoustics". Architectural systems to ensure sound quality of instructional spaces, noise and vibration control of mechanical systems and environmental noise control issues are included in this guideline.

1.2 Purpose

This manual is intended for use by design professionals to facilitate the design and construction of facilities on the Western Washington University campus with good sound quality. The purpose of classroom acoustic standards is to ensure that all students in a classroom will be able to intelligibly hear and understand all program audio and spoken word throughout a class session of up to three hours. Faculty members will be able to lecture comfortably in a natural voice for up to three hours and will be able to intelligibly understand all student responses.

This guideline is not intended as a replacement for the services of a professional acoustical consultant, but only as a tool in defining the elements required to create desirable listening conditions in every classroom. Attention to detail is crucial to creating effective learning environments. This guideline will provide information on good design practices, installation methods, and procedures to demonstrate compliance.

It is acknowledged that all information contained herein will not be universally applicable to every project. The guideline must be correctly applied to each project. This manual is also not intended as a replacement of codes, or other design standards.

PART 2 NOMENCLATURE

2.1 Decibel, dB

The most common measure of sound level is expressed in decibels. The auditory response to sound is a complex process, which occurs over a wide range of frequencies and intensities. Decibel levels, or "dB", are a form of shorthand that compresses this broad range of intensities into a convenient numerical scale.

The decibel scale is logarithmic, and as such, a doubling or halving of energy causes the sound level to change by 3 dB; it does not double or halve the sound level as might be expected. The minimum sound level variation perceptible to a human observer is generally around 3 dB. A 5 dB change is clearly perceptible, and an 8 to 10 dB change is associated with a perceived doubling or halving of loudness.

2.2 A-weighted Decibel, dBA

The human ear has a unique response to sound pressure. It is less sensitive to those sounds falling outside the speech frequency range. Sound level meters and monitors utilize a filtering system to approximate human perception of sound. Measurements made utilizing this filtering system are referred to as "A weighted" and are called "dBA".

2.3 Impact Insulation Class (IIC)

Impact Isolation Class (IIC) is a single number descriptor indicating overall isolation from impact sources, such as footfalls of human activity overhead.

2.4 Equivalent Sound Level, L_{eq}

Equivalent Sound Level, L_{eq} is the A-weighted level of a constant sound having the same energy content as the actual time-varying level during a specified interval. The L_{eq} is used to characterize complex, fluctuating sound levels with a single number. Typical intervals for L_{eq} are hourly, daily and annually.

2.5 Day-Night Sound Level, L_{dn}

Day-Night Sound Level, L_{dn} is the L_{eq} measured over a 24 hour interval, with sound levels occurring between 10:00 PM and 7:00 AM penalized by 10 dBA to reflect greater potential for disturbance. The nighttime penalty is imposed where sleep interference is a consideration. The L_{dn} has been found to have a close correlation with community response to noise.

2.6 Noise Criteria (NC)

Noise Criteria (NC) is the prevalent method for defining maximum permissible mechanical background noise levels. NC is a single descriptor derived by comparing octave band sound pressure levels with a prescribed set of curves. The shape of the curve compensates for sensitivities of human hearing and allows higher levels of energy at the low frequencies.

2.7 Noise Reduction Coefficient (NRC)

Noise Reduction Coefficient (NRC) is the average rate absorption of a material at 250, 500, 1000, 2000 Hz, reported to nearest 0.05.

2.8 Reverberation Time (T60)

Reverberation Time (T60) determines how rapidly sound decays in a room. Reverberation time is dependent on the physical volume and surface materials of a room. The reverberation time measurement determines, in seconds, the time required for the root mean square sound pressure to decrease by 60 dB after the source has been stopped.

2.9 Signal-to-Noise Ratio (S/N)

In classroom design, the Signal to Noise Ratio (S/N) is a simple comparison of the voice level of the instructor to the background noise level in the room, both in dBA. The difference between these levels is useful for estimating intelligibility of speech. The larger the S/N, the greater the speech intelligibility.

2.10 Sound Transmission Class (STC)

Sound Transmission Class (STC) is a single number descriptor indicating overall effective Transmission Loss (TL) characteristics of building elements at speech frequencies (125 Hz - 4 kHz).

2.11 Sound Power Level (PWL)

The term sound power is the amount of energy per second generated by a source, measured in watts. Sound power is independent of distance, path or influence from any nearby surfaces.

2.12 Sound Pressure Level (SPL)

Sound pressure level correlates with what is heard by the human ear. SPL is defined as the squared ratio of the sound pressure with reference to 20 μPa. Sound pressure is affected by distance, path, barriers, directivity, etc.

2.13 Vibration Level

Vibration is an oscillatory motion, which can be measured in a variety of ways: displacement, velocity or acceleration. The displacement is a measure of the distance that a point moves away from its resting position. The velocity represents the instantaneous speed of the movement and acceleration is the rate of change of the speed.

PART 3 ENVIRONMENTAL NOISE

3.1 Regulatory Criteria

A. City of Bellingham Municipal Code (BMC) Chapter 10.24.120
The 2001 *Western Washington University Institutional Master Plan (IMP)* was developed by Western Washington University and the City of Bellingham and was adopted by the City as an amendment to the 1998 *Western Washington University Neighborhood Plan* to ensure that the Campus “evolves in a planned and coordinated manner”. The *IMP* further imposes conditions of WAC 173-60 on development on Campus.

The City of Bellingham Municipal Code (BMC) Chapter 10.24.120 restricts sounds characterized as “public nuisance” and limits construction activity to between the hours of 7:00 AM and 10:00 PM.

B. State of Washington WAC 173-60

1. Exterior Mechanical Equipment
Chapter 173.60 of the WAC proscribes the maximum permissible noise levels transmitted between adjacent, non-related properties. These levels are outlined below.

	Receiving Property EDNA		
Noise Source EDNA	Class A	Class B	Class C
Class A	*55 dBA*	*57 dBA*	*60 dBA*
Class B	*57 dBA*	*60 dBA*	*65 dBA*
Class C	*60 dBA*	*65 dBA*	*70 dBA*

Environmental Designation for Noise Abatement (EDNA) Zones are defined in WAC 173-60-030 as follows:

Class A EDNA – Lands where human beings reside and sleep, including “Recreational and entertainment, (e.g., camps, parks, camping facilities and resorts)”
Class B EDNA – Commercial Zones
Class C EDNA – Industrial Zones

The City of Bellingham Planning Department considers the perimeter of the institutionally zoned Campus areas as Residential for compliance with noise restrictions.

WAC 173-60 imposes a nighttime penalty of 10 dB between the hours of 10:00 PM and 7:00 AM (10:00 PM and 9:00 AM on holidays and weekends), thereby reducing the maximum allowable level at adjacent Residential property lines to 45 dBA. For sound levels of a short duration, this ordinance is also modified to increase the limits as specified below:

Exceedance	Maximum Hourly Limit
5 dB	15 minutes, or
10 dB	5 minutes, or
15 dB	1.5 minutes.

3.2 Supplementary Criteria

A. WWU Intercampus Criteria

1. WWU also imposes a maximum limitation on intercampus noise levels. Sound from exterior mechanical equipment shall not exceed 60dBA at any point 30 feet from the building which it serves.

B. Construction Noise

2. Airborne

No quantitative limits are imposed by either State or Local Codes on construction or maintenance activity. The following additional criteria shall be considered a requirement of any construction project on the WWU campus, to ensure that construction activity on Campus is not overly disruptive to either neighboring properties or adjacent Campus buildings. The location of the measurement shall be considered at the real property of another individual or at a distance of fifty feet (50’) from the equipment, whichever is greater. These levels shall not be exceeded between the hours of 7:00 AM and 10:00 PM on weekdays and between the hours of 9:00 AM and 10:00 PM on weekends.

The maximum permissible sound levels from construction activity shall increase above limits delineated in WAC 173-60 by not more than the following:

a. 25 dBA for equipment on a construction site, including but not limited to crawlers, tractors, dozers, rotary drills and augers, loaders, power shovels, cranes, derricks, graders, off-highway trucks, ditchers, trenchers, compactors, compressors and pneumatically powered equipment. This would include also processes such as demolition debris collection and removal.

b. 20 dBA for portable powered equipment used in temporary locations in support of construction activities or used in the maintenance of public facilities, including but not limited to chainsaws, log chippers, lawn and garden maintenance equipment, and powered hand tools.

c. 15 dBA for powered equipment used in temporary or periodic maintenance or repair of the grounds, including but not limited to lawnmowers, powered handtools, snow-removal equipment and composters.

Sound created by impact-type construction equipment may exceed the maximum permissible sound levels noted above in any one-hour period between 8:00 AM. and 5:00 PM on weekdays and 9:00 AM and 5:00 PM on weekends, but shall in no event exceed the following:

1. L_{eq} 90 dBA continuously;
2. L_{eq} 93 dBA for thirty minutes;
3. L_{eq} 96 dBA for fifteen minutes;
4. L_{eq} 99 dBA for seven and one-half minutes

The standard of measurement shall be a one hour L_{eq}. L_{eq} may be measured for times not less than 1 minute to project an hourly L_{eq}.

Construction activity that exceeds the maximum permissible sound level of 57 dBA, when measured from the interior of an occupied classroom or office space in a Campus building is prohibited between the hours of 8:00 AM and 5:00 PM. Interior sound levels shall be measured after every reasonable effort, including but not limited to closing windows and doors, is taken to reduce the impact of the exterior construction noise.

3. Vibration

Vibration from construction activity is also a source of human annoyance and can cause potential disruption to processes where a high sensitivity to vibration exists, such as vibration-sensitive research instrumentation. The following criteria are required to minimize the interference from vibration during construction.

Land Use Category	Ground Borne Vibration Impact Levels (VdB re 1 micro/inches/sec)
Category I: Buildings where low ambient vibration is essential for interior operations[1]	65 VdB
Category II: Residences and buildings where people normally sleep.	72 VdB
Category III: Institutional land uses with primarily daytime use.	75 VdB

[1]Vibration sensitive research will require detailed evaluation to define the acceptable vibration levels

4. General Mitigation Techniques
   The Contractor should consider the following mitigation techniques in staging projects on WWU Campus:
   - Temporary walls or berms created from excavated materials are effective at reducing sound levels. The most effective location of a barrier for noise mitigation is typically near the noisy piece of equipment. However, on a site with multiple mobile and fixed sources of noise, it is often more effective to locate barriers along the property lines to shield the neighboring properties.
   - Carefully route construction vehicles to minimize activity near noise and vibration sensitive receivers, where possible.
   - Position noisy equipment away from noise sensitive receivers, where possible.
   - Combine noisy operation into one time period, rather than spreading throughout the day. Total noise levels will increase only slightly with several simultaneous operations.
   - Avoid noisy activities during nighttime hours.
   - Phase vibration-generating activities to occur in different time periods. Unlike airborne sounds, vibration levels can be significantly less when vibration sources operate independently.
   - Limit demolition and excavation activity to daytime hours.
   - Provide a noise education program for operators of excavation equipment and spoil haul trucks. Operator attitude can have a more pronounced affect on vehicle noise emission than nearly any other variable. Discourage use of wide open throttle or compression release (Jake) brakes, which rarely provide real additional acceleration or braking, especially at low speed. Provide incentives for individuals regularly operating their

vehicles in a quiet manner. Repeat education sessions frequently.

- Electrically driven equipment is preferable to pneumatically driven equipment where noise is a consideration.
- Verify and insure that equipment mufflers and noise shrouds are intact and operational.
- Shut off equipment that is not in use.
- Consider alternative methods of construction such as drilled piles or use of vibratory pile driver rather than impact pile driving.
- Where possible, select demolition methods which do not involve impact processes.

3.3 Site Noise Conditions 2001/2002

A Site Noise study was completed in and around campus between January 23, 2002 and June 24, 2002. The intent of the study was to establish pre-construction average noise conditions in 2002. The sites included in the study ranged from Residential (Single Occupancy) and Residential (Multiple Occupancy) to Institutional zones. Average noise levels at this site are dominated by traffic from nearby Interstate-5, distant construction, and distant trains. The Campus area itself is active with frequent student traffic activity.

Twenty four-hour average sound levels were documented for each measurement location. The table below presents the sound pressure levels measured at the various locations.

Measured Sound Pressure Levels

Site	**Site Location**	**District**	**Dates**	**24 hour L_{eq}**	**L_{dn}**
1	Bennett Street	16 (Institutional)	6.21-6.24	49.4	54.4
2	20th St. Private Residence	12 (Institutional)	1.10-1.14	49.0	57.2
3	Ridgeway Gamma	10 (Institutional)	1.10-1.14	47.0	54.0
4	Practice Field	14 (Institutional)	2.13-2.15	60.5	63.3
5	Science Quad	11 (Institutional)	2.14-2.16	53.8	60.4
6	Red Square	7 (Institutional)	6.21-6.24	52.4	58.2
7	Nash Hall	3 (Institutional)	2.14-2.17	49.8	54.2
8	Alumni House	2 (Residential Multi)	6.14-6.17	49.8	53.8

The noise conditions for Western Washington University are consistent with a Suburban environment along the perimeter of Campus and with an Urban environment in the more active public areas, such as the Sports fields and Red

Square, according to definitions published by the US Environmental Protection Agency.

3.4 Verification of Compliance

A. Types of Measurements and Test Equipment

Verification of compliance with the above standards may be required during any construction project on campus. Personnel administering any sound and vibration testing shall have a minimum of 2 years experience conducting this type of testing.

Airborne sound levels shall be measured in root means square (rms) re: 20μPa with a sound level meter complying with the following minimum standards:

- Type I or Type II meter per American National Standards Institute (ANSI) 1.4 or IEC 60651.
- internal octave band filters.
- range 30 dB to 120 dB
- setting options of linear, A or C weighting
- setting options of fast, slow or impulse
- averaging capabilities of not less that 1 minute

Ground borne vibration levels shall be verified during the construction process where the construction site is near sensitive adjacencies. Vibration measurements documenting construction activity shall be unfiltered, root mean square (rms) in units of velocity, VdB re:1μin/sec at the building face or in units of acceleration, re: 1 μg at the site of the sensitive instrumentation. The spectrum analyzer used in the measurements shall comply with the following minimum criteria:

- transducer with a rated frequency response down to 8 Hz. at not more than 3dB outside linear output
- analyzer frequency range 0 Hz to 200 Hz.
- adequate sensitivity to measure energy in either μg or μin/sec
- Fast Fourier Transforms (FFT) mode
- resolution of not less than 1 Hz.
- Hanning window

For documenting human perception, the vibration measurements shall be made on structure bearing soil directly outside of the sensitive building. In cases where vibration sensitive lab equipment may be affected by the construction activity, the measurements shall be made at the location of the sensitive equipment.

All meters shall be calibrated in the field immediately before and after measurements. Equipment shall have been factory calibrated within 1 year of the measurement. This includes the meter, microphones and transducers.

PART 4 ARCHITECTURAL SYSTEMS

4.1 General Criteria

A. Sound Isolation

1. General

Audibility of intruding sound is dependent on the amount of acoustic isolation provided by the construction separating the two adjacent spaces and by the amount of background sound in the receiving space. Sound is transmitted from one space to another through walls, floor, ceilings assemblies and glazing. Sounds transmitted from adjacent spaces can disrupt the learning process as effectively as sounds generated within the classroom, especially during quiet activities such as test taking. With the prevalence of media intensive classrooms and elevated levels of program sound, isolation between classrooms is becoming even more crucial to preserving the learning environment.

a. Adjacencies

The most cost effective approach to achieving good sound isolation for learning spaces is accomplished in the planning stage. During the design process, identify areas with noisier activities:

- mechanical rooms (equipment locations)
- gymnasiums
- music rooms
- industrial design shops
- etc

Optimize the location of the sensitive learning spaces away from noisy spaces and activities. Corridors, storage and other less noisy spaces can help buffer the sound intrusion. Preventive design can often eliminate the need for added construction to ensure adequate acoustical separation for the classroom.

b. Structural Systems

The structural components selected must be able to meet STC criteria listed herein. However, the STC rating does not sufficiently address low frequency transmission. If the source of the sound contains a significant low frequency component (mechanical equipment, music, etc), consider using concrete or filled masonry.

There are many publications that delineate acoustical performance ratings for various partition configurations. Many promote the use of resilient channels to achieve the desired rating. Resilient channels will **not** be accepted for wall construction on this campus. Recently a new resilient clip product has been introduced to the market. The product, PAC International RSIC, has some advantages compared to traditional resilient channels with respect to its installation procedure. PAC International RSIC is acceptable for both wall and ceiling installation.

Typically, the weakest point in the acoustical isolation will occur at the interface between the ceiling plane and the wall. Partitions should extend to the structure if at all possible. Caution must also be used to prevent further breach of the barrier through conduit and ductwork penetrations, recesses in the wall (speakers, clock, etc.), relights, etc.

The following notes should be included directly on the drawings.

- All gypsum board used in sound retardant partitions must be type X.
- Stagger joints on all multiple layers of gypsum board.
- Attach multiple layers of gypsum board with nails or screws, do not use adhesive.
- Caulk along both sides of the perimeter with a non-hardening silicone mastic.
- Avoid back-to-back outlets. Caulk all openings in electrical boxes.
- Where a double row of studs is used, make no connections between rows.
- Where a sound retardant partition abuts perpendicularly to a continuous gypsum board partition, interrupt the gypsum board at the point of intersection and caulk the joint liberally. Do not continue the gypsum board behind the intersecting stud.
- All openings around pipe penetrations shall be sealed with a non-hardening silicone mastic.

Operable partitions can provide flexibility for room configuration but a sacrifice in acoustical integrity of the wall will occur. A typical high quality, STC 50, partition will provide only moderate sound isolation between the spaces. If amplified sound will be utilized on either side of the partition, an operable partition will provide inadequate isolation.

c. Background Sound Levels

The perception of the intrusion of the sound is directly related to the amount of background sound present in the room receiving the intruding sound. People in rooms with higher background sound levels, typically produced by the HVAC system, are less able to hear intruding sounds. Conversely, people in rooms that are quieter can hear intruding sounds more easily.

Classrooms shall be designed with background sound levels not exceeding those listed below (Section 5.1c, NC Criteria). However, it is becoming more prevalent with the emphasis on sustainable design practices, that ventilation is depending less on mechanical systems and more on passive means. In areas where the background sound is significantly below the typical levels, an increase in the STC rating may be required to preserve the acoustical privacy for the space.

d. Enhanced Media Classrooms

The sound levels associated with enhanced program material are typically significantly above an unamplified human voice. Consideration should be given to both current and future uses of the subject spaces. If enhanced media or distance learning may be a future use of any space, providing the increased level of sound isolation in the original design will prevent costly modifications later.

2. Airborne Sound
   a. STC Matrix

STC Ratings

Receiving Space	*Classrm*	*Commons /Toilet*	*Circulation*	*Music Room*	*Office/ Conf*	*Exterior*	*Mechanical /Gym/Pool*
Classrm	50	53	45	60	45	50	60
Corridor	45	45	45	60	45	45	55
Music Room	60	60	60	60	60	45	60
Office or Conference	45	45	45	60	45	45	60

Source: ANSI S12.60-2002

3. Impact Sound
   a. IIC

In multi-story facilities the transmission of impact sound from the space above to the learning space below is also contributory to the over all background level. The minimum IIC ratings are given in the Table below:

IIC Ratings

Receiving Space	***Classrm***	***Commons /Toilet***	***Circulation***	***Music Room***	***Office /Conf***	***Mechanical /Gym/Pool***
General Classrm	50	60	50	60	50	60
Tiered Lecture Classrm	60	60	55	60	60	65
Music Room	60	60	60	65	60	65
Office or Conference	50	50	50	60	50	60

Source: ANSI S12.60-2002

In addition to IIC, which is a measure only of the high frequency footfall sounds, consideration must be given to the structural response of the floor system. A flexible structure with a low natural frequency will transmit low frequency sound induced by the movement of the structure. The construction of upper floors is critical to the amount of sound isolation achievable. One of the most crucial elements of the design is the structural stiffness of the floor. The upper floors should be designed to have a natural frequency of not less than 10 Hz.

B. Vibration Control

1. General

The response to this vibration by humans, buildings and equipment is more accurately described using either velocity or acceleration. Standards for equipment sensitivity studies are typically defined in terms of velocity, so for the proposes of this study, velocity levels are reported.

a. ISO 2631-2

Shown below are acceptable vibration levels for various types of equipment. These criterion were developed by ISO and ANSI.

Vibration Criteria

Facility Equipment or Use	***Vibration in Velocity, micro inches/sec. ****	***Structural Design Factor Kips/inch-sec.***
Workshops	32000	200
Offices	16000	400
Residences	8000	800

* maximum level from 8hz to 100 hz.

2. Laboratories with Sensitive Equipment

a. ISO 2631-2

Facility Equipment or Use	***Vibration in Velocity, micro inches/sec. ****	***Structural Design Factor Kips/inch-sec.***
Microscopes to 100X	4000	1600
Bench microscopes to 400X Class A	2000	6000
Micro surgery, microscope above 400X Class B	1000	12000
Electron Microscope up to 30,000X, Microtomes, MRI, Micro electronics manufacture, Class C	500	24000
Electron Microscope Mass spectrometers, Cell implant equipment Class D	250	48000
Unisolated Laser and Optical Research systems, Microelectronics manufacturing Class E	130	96000

* maximum level from 8hz to 100 hz.

This criteria applies to the frequency range from 8Hz to 80 Hz. for equipment without internal isolation, as sensitivities below 8 Hz are not as great. For equipment with internal isolation, the criterion is applied from 1 Hz to 80 Hz. Above

80 hz. isolation base or isolation tables may be used to augment isolation of equipment.

4.2 Maximum Permissible Interior Noise Levels

A. ANSI S12.60-2002

Learning Space	***Maximum one-hour A-weighted steady background noise level, dBA***	***Maximum Reverberation Time in seconds for sound pressures in the midband frequencies of 500, 1000, 2000 Hz.***
Classroom < 10,000 ft^3	35	0.6
Classroom >10,000 ft^3 and <20,000 ft^3	35	0.7
Classroom >20,000 ft^3	40	Varies with use

Source: ANSI S12.60-2002

B. WISHA

The risk of hearing loss has been related to the total energy of the noise exposure. The State of Washington, under the Washington Industrial Safety and Health Act (WISHA), and the Department of Labor and Industries have developed noise exposure limits to protect the welfare of those working in a noisy environment. The limits are based on the intensity of the noise level and the amount of exposure time. WISHA regulations are based on a 5 dB exchange rate, where a 5 dB increase in noise level is assumed equivalent to a doubling of the exposure time. This 5 dB exchange rate is based on intermittent, rather than continuous, noise exposure.

The following table outlines permissible exposure limits for areas of high noise levels, such as shops, music rooms, or labs.

Noise Level, dBA	***Exposure Time, Hours***
85	16
90	8
95	4
100	2
105	1
110	½
115	¼

Source: Washington State Department of Labor and Industries.

In addition to the above, hearing protectors must be worn:

- By anyone who is exposed to an 8-hour time-weighted average of 85 dBA or greater; or
- By anyone who is exposed to noise above 115 dBA; or

- By anyone who is exposed to any impulsive or impact noise measured at or above 140 dB peak using an impulse sound level meter set to either the linear or C-scale.

4.3 Room Finishes

A. General Classrooms

1. ANSI S12.60-2002

Excessive background noise levels or high levels of reverberation in a classroom will interfere with speech intelligibility, resulting in reduced understanding and diminished learning. Studies have determined that a signal-to-noise ratio of less than +10 dBA will result in significantly diminished speech intelligibility for students with average hearing. Students with some degree of hearing impairment require not less than +15 dBA S/N.

Ideally, classrooms should have reverberation times in the range of 0.6 to 0.7 seconds. Achieving this will require the addition of absorptive surfaces to the room. The most effective surface to treat will be the ceiling as this plane is exposed to the entire room. The treatment selected for the ceiling should have a minimum NRC 0.65.

Adding carpeting to a classroom floor will not significantly reduce reverberation time, especially at low frequencies, but carpeting will reduce noise resulting from students sliding their chairs or desks on the floor. Carpeting will also be beneficial to reducing impact sounds below for upper level classrooms.

Wall treatment is desirable to minimize reflections from wall surfaces which may be perceived as echoes. The addition of wall treatment becomes more important as the size of the room enlarges. For rooms with dimensions beyond 30 feet, wall treatment should be included along two adjacent walls in a band between 3 feet from the floor and door height. The material selected should have a minimum NRC 0.80. Finishes should be selected that are able to withstand the abuse of classroom use.

B. Tiered Lecture

A lecture-style classroom will benefit from leaving the front portion of the ceiling hard to provide some natural reinforcement for the voice of the instructor. An angled panel may enhance the reflected energy and redirect it into the audience. The remainder of the ceiling should be absorptive, minimum NRC 0.65.

Reflections off of the rear wall have the potential to be perceived as an echo at the instructor's position. This can be very distracting to the lecturer. Treating the rear wall and the rear side walls with an absorptive or diffusive panel will minimize this effect.

C. Computer Labs

Computer labs are inherently noisy rooms with the cooling fans on numerous computers. These rooms typically do not make good lecture rooms because of the noise level.

The ceilings in Computer labs should be absorptive, minimum NRC 0.65.

D. Science Labs

Science labs are typically equipped with fume hoods, which operate continuously. A well designed fume hood will produce noise levels in the high 50's to low 60's dBA. This is substantially above the 35 to 40 dBA required for good intelligibility of the spoken word. These rooms also are not conducive to lecture classroom environments. If possible, the function of lab and lecture should be separated.

The ceiling surface in Labs should be absorptive. A material glued to the underside of exposed deck is acceptable in these rooms. The material selected should have a minimum NRC 0.65.

E. Study/Library

In high ceiling Library areas used for quiet study or reading, ceiling surfaces may remain hard. Enclosed study rooms should have absorptive ceilings, minimum NRC 0.65.

Wall treatment is not necessary in stacks, as the books will provide adequate diffusion. In other spaces, place wall treatment on two adjacent walls between 3 feet from the floor and door height.

F. Commons/Student Lounge

Ceiling surfaces in these areas must be absorptive for general noise control.

Wall treatment is desirable, if space allows.

G. Circulation

Ceiling absorption is desirable.

H. Administration
Absorptive treatment must be included along ceiling surfaces.

<u>PART 5</u> MECHANICAL SYSTEMS

5.1 General Criteria

A. WWU Mechanical Standards Rev 7
The designer shall become familiar with the entire Mechanical Standards document. Elements of the document that pertain to the noise and vibration control of the system are extracted and presented here for convenience. It is not the intent of this document to minimize the importance of all information contained therein.

Following are requirements of the Mechanical Standards that relate to acoustics:
Section 15050 D. Sound and Vibration Control

1. Sound and vibration control shall be designed in accordance with the latest edition of the applicable ASHRAE Handbook. Maximum acceptable noise levels shall be those set forth in the aforementioned handbook.
2. Vibrating machinery shall be isolated from both the structure and connecting piping and ductwork. Flexible connectors on piping shall be metal braided rather than rubber.

Section 15080 Mechanical Insulation
A. General:

7. Ductliner for acoustical insulation in heating, ventilating and air-conditioning applications shall be limited in application per Project Managers approval. Duct liner shall be only used near air handlers and mechanical rooms where access is readily available and listed hatches are installed. Duct liner coatings shall be fiber free in airstream, if possible, with EPA approved biocide is acceptable upon approval of University Engineering Staff. Knauf Ductliner “M” or approved alternate.

Section 15090 Balancing
A. General:

4. Vibration readings of all equipment over 5 hp is mandatory. Sound readings shall be repeatable and locatable and taken at 10% of room locations and as directed by the University Engineering Staff.

B. Sustainable Design

Sustainable design often uses passive approaches to provide ventilation, which create potential paths for sound to transfer between spaces. Care should be exercised to fully evaluate all potential flanking paths for sound transmission. Common points of acoustic leakage are listed below:

- underfloor heating systems are typically inherently quiet, but the open plenum under the floor may compromise sound isolation between acoustically sensitive rooms.
- open window ventilation will create an acoustic connection between rooms when both windows are open.
- open windows are also a point of infiltration for external noise sources, ie: leaf blower, lawnmower, traffic, crowds of students, etc.
- transfer grilles into an open high-bay corridor are also leakage paths for sound from public spaces to classroom and from classroom to classroom.
- Air is often exhausted from a central high point in an open atrium-frequently the roof fan is a source of noise in the common space.

C. Noise Criteria (NC)

Space	**NC**	**dBA**
General Circulation Areas, Lavatories	45	50
Gym	40	45
Classrooms	30-35	35-40
General Offices	35	40
Conference Rooms, Private Offices, Commons	30	35
Music Rooms	25	30

D. Vibration Control

Many buildings on the WWU campus contain vibration-sensitive equipment and research projects. Vibration criteria, acceptable to the program for which the building is being designed, shall be established early in the technical program. A schedule shall be included in the design documents listing the vibration isolation requirements for equipment, piping and ductwork. While each situation must be evaluated and designed in response to the unique requirements and characteristic of each building, the following general criteria is offered:

- for rotating equipment on grade provide spring-type or rubber-in-shear vibration isolators.
- for rotating equipment in areas not on grade furnish spring-type vibration isolators and inertia bases.

- for inertia base installations, the base shall be equal in weight to all equipment installed on it. Vibration isolators shall be designed that support the equipment, including the inertia base.
- Springs designed with integral seismic restraint features are preferred.

Careful coordination with the Structural Engineer is also essential to ensure that the structure supporting the Mechanical equipment does not have a natural frequency close to those at the operating points of the equipment.

5.2 HVAC Selection

All mechanical systems shall be designed to meet the instructional NC ratings listed in Section 5.1 above.

A. Air Moving Equipment

The most efficient and cost effective solution for noise control issues is to reduce noise at the source, ie the fans. This is most feasible at the design stage. Noise levels of fans are more influenced by pressure than by volume. Designing the system for minimum airflow restriction will reduce noise. Conversely, systems with high static pressures will have an increase in noise level. The operating point of a fan also has a strong influence on noise level. Fans should be selected to operate as closely as possible to their rated peak efficiency.

Most manufacturers can provide published Sound Power Level data on equipment operating under various conditions. Equipment should be selected for low sound level ratings. The manufacturer’s Sound Power data for the basis of design shall be listed in the schedule on the contract documents to ensure that bidders comply with the design intent.

B. AHU

Noise generated by air handling units varies greatly with fan type and size. Plug fan configurations generally produce less low frequency noise than typical fan configurations, because the fan is enclosed in a plenum which can be lined with duct liner. Lined plenums are quite effective for attenuating low frequency noise. Fans should be either internally isolated or the air handling unit itself should be spring isolated at the base. Base mounted units must have seismically rated springs as seismic struts will short-circuit the isolation.

All ductwork connections to the air handling units shall be made of neoprene with reinforced canvas flexible connections.

C. Terminal Units
Avoid locating fan powered terminal boxes, unit ventilators, fan coil units and ductless split systems within classrooms wherever possible. These units contain fans and sometimes compressors that are notoriously loud and difficult to treat due to their position in the classroom.

VAV air terminal box fans must be selected for operation at speed ranges that don't create excess noise or motor problems. Internally isolate the fans in air terminal boxes. Line the air terminal boxes with at least 1 inch of fiberglass batt insulation. Provide a lined boot with at least one 90-degree elbow on the inlets of any box. Connect fan powered air terminal boxes to the ductwork via flex connections. Connect air terminal boxes to structure with via vibration isolators.

Sound power level rating for both discharge and radiated noise levels must be included in the contract documents. Specifying by NC rating alone is not sufficient.

D. Exhaust Fans
Exhaust fans are often overlooked as sources of noise, vibration and sound transfer. Duct velocities need to be controlled in these systems as well. See Section 5.9 below.

Rooftop installation will be required to meet all local and WWU noise criteria.

E. Fume Hoods
Controlling noise levels from Fume Hood operation will be imperative to creating good spaces for research. Systems should be designed to have noise levels not exceeding 62 dBA. Measurements should be taken 1 foot from the fume hood with the sash fully open using not less than a type 2 sound level meter per ANSI SI.4-1971 and an octave band filter for 31.5 to 4000 Hz.

Noise control measures that have been successfully applied to fume hood design include:

- Use backward inclined or forward curved rather than radial blade fans where possible.
- Select fans for operating at low tip speed and maximum efficiency.

Identify labs with sensitive research instrumentation. Additional vibration control measures may be needed in these spaces.

Lab spaces containing fume hoods will be inherently noisier spaces, even when the above specification is met. It should be noted that these spaces will never be optimal spaces for lecture. Where possible, separate the lab and lecture functions. In cases where laboratories must also function as lecture rooms, amplification will be essential for lecturers to maintain a sufficient signal to noise ratio (S/N) to have good intelligibility at every student position.

5.3 Boilers

Boilers are typically provided with a fan assisted venting system. These fans can produce a tonal effect in the stacks if the operating conditions coincide with resonances in the piping. Careful analysis of this effect is required for all boiler installations.

5.4 Pumps

Base-mounted pumps are preferred over in-line pumps. Locate on concrete inertial bases on seismic type steel spring isolators.

Isolate all pump pipe connections with twin-sphere neoprene flexible connections. Electrical connections should be made through a generous length of flex conduit.

5.5 Cooling Towers

Any cooling towers will be required to comply with maximum permissible exterior sound levels, as outlined in Section 3.1. Attention shall also be given to the WWU criteria of 60 dBA within 30 feet of the Building containing the noise source, as outlined in Section 3.2.

5.6 Chillers

Chillers have several components, which generate sound. The primary sources are the compressors and the drive systems that run the compressors. Typically chillers are a significant noise source and require additional sound isolation to protect adjacent space from excessive sound exposure levels.

Rotary screw chillers should be located on grade, as the vibration levels associated with this type of equipment are significant. If it is not possible to locate on grade, it is likely air springs will be required to provide sufficient isolation. Vibration isolation is critical for chillers. Ensure that not only the chiller, but all associated piping and electrical conduit is also resiliently isolated from the structure.

5.7 Emergency Generators

Sound levels associated with the operation of emergency generators should be designed to comply with local noise codes and WWU criteria during times of testing. Operation in an actually emergency will be exempt from regulation.

Caution should be used in design to locate generators away from critical listening spaces.

5.8 Mechanical Equipment

A. Location
Select location for mechanical equipment, VAV boxes, and fan-coil units, etc. away from critical listening spaces such as classrooms, if possible. Positioning units above/adjacent to less acoustically critical spaces such as corridors, toilet rooms or storage areas will provide a buffer to the more critical spaces.

B. Installation

1. General
Installation is critical to minimizing the transfer of sound and vibration from the mechanical systems. Ensure that vibration isolation system is not breached with seismic restraints.

2. Underfloor systems
The open plenum typically associated with underfloor systems can provide paths for sound transfer. Ensure that diffusers are not located closer than 10 feet to any common wall. In areas where additional sound privacy is required, or an operable partition may have been included, a barrier will be required in the plenum directly under the partitions. Air transfer will need to be accomplished with a lined transfer grille with 2 90-degree elbows. Careful coordination will be required with the Architect.

3. Equipment above Ceilings
Avoid placing any mechanical equipment inside classrooms wherever possible. In situations where it is essential to locate equipment above the ceiling of an occupied room, careful analysis of the radiated noise levels expected from the equipment will be required. Special ceiling components, i.e. composite tiles or gypsum ceilings, may be required to maintain specified background sound levels.

4. Exterior Locations
   Any exterior piece of mechanical equipment will be required to comply with local noise codes, as previously outlined in Section 3.1. In addition, those buildings within the core of the WWU campus will have noise restrictions imposed by the University between classroom or administration buildings. Noise from any exterior piece of mechanical equipment shall not exceed 60 dBA within 30 feet of the building.

5.9 Ductwork

Design duct layouts to be simple and, to the extent possible, to have straight and uniform airflow. Size ducts adequately to maintain velocities outlined below. Sound traps, if required, should be located in a section of duct where a uniform velocity profile across the duct prevails. The air velocity at the face of the trap should not exceed 1000 fpm.

Round ductwork is better resistant to duct breakout noise than rectangular. In areas where ductwork must be exposed, spiral wound ductwork is preferred. Rectangular ductwork is more efficient at reducing noise levels within the duct. All ductwork should be galvanized steel throughout, no exceptions. Fiberglass ductboard does not provide sufficient attenuation for sound transmission through the duct walls to contain fan noise.

To minimize generated duct noise, locate volume dampers at least two duct diameters from a fitting and as far away as possible from the outlet or inlet.

Ductwork within mechanical rooms should be suspended on combination spring and neoprene hangers with 1-inch static deflection.

A. Use of Ductliner
   WWU Mechanical Standards Rev 7, Section 15080 7 limits the application of ductlining in WWU facilities. See Section 5.1 above.

B. Design velocities
   To prevent noise from being regenerated at fittings or by airflow induced vibration, air velocities in ductwork should not exceed the following values.

Duct	**Velocity, fpm**
Main Trunks	1500-1800
Branches	900-1200
Connection to Diffuser or Grille	400- 600

Lining the ductwork is not a substitute to reduce noise regenerated by airflow and vibration. Lining the ductwork would attenuate discharge fan noise passing through the diffusers but would not effectively reduce noise.

5.10 Grilles, Registers and Diffusers

Grilles, registers and diffusers should be selected 8 NC points below the room criterion to allow for generous room absorption effects usually applied to catalogue ratings. Transfer grilles located in acoustically private rooms, such as offices, will short circuit the attenuation provided by the structure. Transfer grilles in these locations should include internal acoustical lining for their entire length. The use of transfer grilles shall be limited to acoustically non-sensitive spaces. Return grilles opening into a return plenum shall be fitted with a lined boot.

Dampers should preferably be located at least five feet upstream of diffusers and be followed by lined ductwork, or a plenum, to absorb aerodynamic noise.

5.11 Piping and Plumbing

Use cast iron DW&V piping throughout. Water passing through rain water leaders may be audible in spaces directly below. Rain water leaders over spaces with NC 35 or less need to be wrapped in insulation and surrounded by a loaded noise barrier material.

Piping within 25 feet of pumps should be suspended on a combination of springs and neoprene hangers. Saddle type hangers, with insulation shields, should provide sufficient isolation downstream from this point.

5.12 Testing and Balancing

Verification of compliance with the above standards will be required during any construction project on campus. Testing shall not commence until it is certified that the system has been balanced. Systems shall be tested in full operation. No mechanical systems should be permitted to be installed that compromise the NC ratings.

Personnel administering any sound and vibration testing shall have a minimum of 2 years experience conducting this type of testing.

Airborne sound levels shall be measured in root means square (rms) re: 20μPa with a sound level meter complying with the following minimum standards:

- Type I or Type II meter per American National Standards Institute (ANSI) 1.4 or IEC 60651.
- internal octave band filters.
- range 30 dB to 120 dB
- setting options of linear, A or C weighting
- setting options of fast, slow or impulse
- averaging capabilities of not less that 1 minute

Reported data shall also include the NC calculation based upon the measured octave band data.

All meters shall be calibrated in the field immediately before and after measurements. Equipment shall have been factory calibrated within 1 year of the measurement. This includes the meter, microphones and transducers.

PART 6 A/V SYSTEMS

6.1 General

Sound systems will be needed for reinforcement of the voices of teachers and presenters, as well as for audio reproduction of recorded material. Classrooms, computer labs, and other instructional spaces need to be designed for effective audio systems. The acoustics, as described above, is an important element of this. In addition, the design of the audio electronics and transducers must be chosen to provide appropriate performance in concert with the acoustic design. It is not sufficient to simply hear well. The class or audience must also be able to understand speech, to intelligibly discern the spoken voice from a program source, or a person using a microphone.

Classes are generally unattended by A/V technicians, so once the systems are set up, they should be able to operate as automatically as practical, and be usable by non-technical persons.

The systems are expected to be high quality with good performance, although they are not expected to be exotic or esoteric. The general intent is that they be suitable for speech, and light to moderate music with good fidelity, but are not intended for “rock and roll” or to reproduce thundering levels of bass.

6.2 Sound Reinforcement

Sound reinforcement provides amplification of the teacher via microphones. It should be provided in all lecture halls, and should also be considered for classrooms which are:

- Larger then 1200 square feet
- Equipped with more than 75 seats
- Exhibit elevated noise levels (e.g., are equipped with many computers with standard cooling fans)
- In labs, where requested by the instructor or department

Where suitable, a single-point loudspeaker cluster is preferred. However, typical classrooms do not lend themselves to this approach, as the ceilings are low and the layout places the instructor close to the front wall. Therefore, the loudspeaker system for sound reinforcement should be an overhead-distributed type, unless:

- The loudspeaker can be located at least 20 feet above the floor of the instructor area
- Coverage from the single cluster will be even within a tolerance of plus or minus 3 dB.

6.3 Program Audio

The audio system should provide for reproduction of the audio of various media sources, such as computer programs, videotapes and DVDs, and audio recordings. Where stereo reproduction is not required, and sound reinforcement is being provided, the program audio can be routed to the overhead loudspeakers. Otherwise, a pair of wall-mounted loudspeakers, one on each side of the projection screen, is usually employed. The design should verify that coverage, front to back, is adequate (within plus or minus 4 dB) for the location chosen; if the split pair cannot provide sufficient coverage then the overhead speakers should be used, or supplemental stereo pairs provided.

Where both overhead speakers (for speech reinforcement) and wall speakers (stereo pair for program) are provided, the system will need to route the signals appropriately. Several manufacturers make small, remotely controlled mixers having both stereo and monophonic outputs which form an economical solution.

6.4 Assistive Listening Systems

ADAAG, which is the Federal design guide for the ADA laws, generally requires that permanently-installed sound systems include assistive listening systems

(ALS). WWU policy is to provide permanently installed ALS in rooms having more than 50 seats.

ALS should be selected and designed to be compatible with existing ALS systems at WWU, and to adhere to its standards for ALS:

- [[WWU input needed:]]
- Dual (or single?) channel infrared, compatible with Sennheisser XXX series
- Wireless radio-based ??

ALS should be fed by both the speech reinforcement and program audio sources.

Where not permanently installed, provisions shall be made for the use of portable assistive listening systems in smaller instructional spaces.

PART 7 A/V TESTING

7.1 General

For proper operation, audio systems must be properly adjusted and tested upon completion of the installation. Although specific tests and adjustments will be a function of the particular design, the following provides general guidance of WWU's expectations.

In general, preliminary tests and adjustments should be performed by the Contractor upon completion of installation. Testing and adjustment should be performed by qualified technicians with prior knowledge of the particular items of equipment, and general knowledge of video and audio systems alignment and trouble shooting, and knowledge of the specific systems and installations of this project.

Then the A/V Consultant should verify the results, by spot-checking and review of the Contractor's test reports. When discrepancies are found, it may be necessary for tests to be repeated in the presence of the Consultant.

In all cases, WWU should be informed of tests and measurements with sufficient notice so that WWU personnel can observe the testing, if they desire.

7.2 Types of Measurements

A. General

- Test each and every device, input and output, in all routing combinations.

- Verify that the system is completely free from hum, noise, parasitic oscillation, and RFI.
- Measure and record impedance of each speaker load at the main junction box or rack cabinet, and total load on each amplifier. At a minimum, make measurements at 100, 1000, and 10,000 Hertz. If required, make corrections as required so that the load impedance of each amp is equal to or greater than rated load impedance.
- Acoustical tests should be performed with the measuring microphone at the seated ear height of the audience, within designated seating areas.
- All interior finishes and furnishings shall be in place during measurements.

B. Signal to Noise, and Gain Balance

- Low frequency sweep tests on speakers, to verify lack of buzz and rattles in speakers or mounting apparatus. Tests should be at relatively high power, but should not exceed 25% of maximum amplifier power, or 50% of rated continuous power handling of loudspeakers.
- Gains should be balanced so that all components except power amplifiers reach rated nominal output and onset of clipping at the same signal level (as system input). Then the power amplifier gains should be set so that power amplifiers just begin to clip at the onset of clipping of the upstream device, plus 0 or minus 2 decibels.
- Measure the overall end-to-end signal to noise ratio (from mic input to power amp output), to verify that the result is at least that of the worst component of the signal chain, plus or minus 5 decibels.

C. Maximum Output Level

- Measure the maximum sound pressure level of pink noise at onset of amplifier clipping. Make measurement using both A-weighted and unweighted (flat) settings of the Sound Level Meter (SLM).

D. Set Final Operating Levels

- Re-adjust gains if required for proper operation of each system and component, and to optimize normal operating and listening levels. Measure and record any such re-adjustments; also record the reason adjustment was deemed necessary. Assume a voice level of 70 dB-SPL at 4 feet from the talker's mouth.

E. Coverage

- Measure the A-weighed sound levels at each student seat, using pink noise as source. Record the average, high, and low, and verify that the variation does not exceed the design parameters.

F. Frequency Response
- Measure overall frequency response of complete signal path.
- Measure acoustic frequency response at three locations in each listening area.
- Adjust equalizers to optimize the specified frequency responses. Adjust notch filters (if any) to minimize "ringing" with open microphones; make adjustments with microphones in their normal operating positions. Care should be taken not to over-equalize; too little is generally better than slightly too much.

7.3 Measurement Equipment

The following list of equipment is given as a general guideline for what is needed to perform the above tests, and to comply with WWU expectations.

- Dual-trace, triggered oscilloscope with calibrated settings, and minimum bandwidth of 100 megahertz.
- Sine wave oscillator with balanced output and distortion below 0.1%
- AC voltmeter with balanced input, 100 millivolt full-scale sensitivity and 50 to 10,000 Hertz frequency response
- Distortion Analyzer, equivalent to Leader
- Sound Level Meter, Type 1 or Type 2, equivalent to Ivie IE-30, Goldline SPL120, Larson-Davis, Bruel and Kjaer.
- One-third octave real-time spectrum analyzer, or FFT analyzer, and calibrated microphone, equivalent to Ivie IE-30, SMAART with PC and calibrated microphone, or Goldline TEF.
- Pink Noise generator, equivalent to Ivie IE-20, White, Hewlett-Packard or Goldline.