M. D. ANDERSON
NOISE, VIBRATION, AND ULTRASOUND DESIGN GUIDE

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RECORD OF CHANGES

A

A triangle next to a paragraph is used to denote revisions. The details of the revisions are summarized in this table.

Edition	Date	Description
Rev. A	15 July 2010	Initial publication

EXECUTIVE SUMMARY

The purpose of this document is to provide guidance and information on design principles to reduce the impact of noise and vibration in Small Animal Vivaria. Existing and proposed criteria are set forth for noise, vibration, and ultrasound. These criteria were determined to take into account the high frequency sensitivity of rodent hearing. Equipment selection and requirements from the vendors are outlined, with equipment specific level-limits provided. This can serve as a purchasing standard for any new equipment. In addition, a brief discussion is given of appropriate mitigation techniques during planning, construction, and after a problem is detected. Lastly, a guide on commissioning noise measurements in vivaria and a discussion of employee best practices are included.

INTRODUCTION

This Design Guide was created to provide guidance on noise, vibration, and ultrasound (NVU) to those involved in facility design of new facilities or the upgrading of existing facilities related to rodent vivaria.

The scope of this guide is to aid personnel in facilities planning and veterinary management in understanding the complicated problems of noise, vibration, and ultrasound in rodent vivaria. The guide assumes that a location has already been chosen for the building, so it doesn't include external sources like parking garages and mass transit. The primary focus, instead, is on equipment selection and floor plan design.

Section 2 of this report presents descriptions and definitions of sound, ultrasound, and vibration.

Section 3 provides an overview of the hearing of humans and rodents and suggests proposed specific criteria limiting noise and ultrasound in vivaria.

Section 4 presents current M. D. Anderson Guidelines for noise, vibration, and ultrasound limits in vivaria.

Section 5 presents common noise, vibration, and ultrasound sources found in typical vivaria.

Section 6 presents mitigation techniques that can be employed if an acoustical problem is perceived during design or after construction is completed.

Section 7 discusses commissioning measurements and their importance.

Section 8 summarizes employee best practices.

Section 9 presents our conclusions.

Section 10 provides an annotated bibliography of the literature review performed.

DESCRIPTION OF SOUND

Sound

"Sound is a (fluctuating) disturbance that propagates through an elastic material at a speed characteristic of that medium" (Franken 1971).

Important terms

Decibels: The decibel scale is a logarithmic scale which relates a measured quantity to a reference. For sound pressure, the reference pressure (p_{ref}) is 20 µPa (micro-Pascals), the threshold of human hearing. For sound power, the reference is 10^{-12} Watts (W). In discussing the magnitude of sound, the sound pressure level or sound power level, in dB, is the most often used term.

A-weighting: A filter which weighs the sound power or pressure levels at different frequencies based on the sensitivity of the human ear. The A-weighted sound level, often expressed dBA, is the sum of the octave band levels with the frequency weighting applied.

C-weighting: A filter which weighs the sound power or pressure levels at different frequencies with a relatively flat response, but a decreased response at the ends of the human hearing range, to de-emphasize noises outside the range of human hearing. The C-weighted sound level, expressed dBC, is the sum of the octave band levels with the frequency weighting applied.

Sound Pressure (p_{rms}): The RMS (root-mean-square) value of the instantaneous variation about ambient pressure caused by sound waves. Sound pressure is measured in Pascals (Pa).

Sound Pressure Level: Sound pressure level, abbreviated L_p or SPL, is calculated by $20\log_{10}\left(\frac{p}{p_{ref}}\right)$ and is measured in units of dB. Sound pressure level is dependent on the sound source and the environment in which it is measured.

Sound Power Level: Sound power level, abbreviated L_W or SWL, is calculated by $10\log_{10}\left(\frac{W}{W_{ref}}\right)$ and is measured in units of dB. Sound power level is dependent only on the source, not on the environment.

Frequency: The frequency of sound is the rate at which the molecules fluctuate in the elastic medium and is measured in cycles per second or Hertz (Hz). This is perceived by humans as the pitch or tone of a sound. In addition, a doubling of frequency is the same as an octave difference in music.

Frequency Bands: In order to study sounds consisting of a wide range of frequencies, frequencies are grouped into bands with proportional bandwidths. Frequency bands are identified by their center frequency. The two commonly used filters for frequency analysis are octave-bands, in which the ratio between upper and lower frequencies is 2, and the one-third-octave-bands, in which the ratio between upper and lower frequencies is $2^{1/3}$. Typical octave-bands are: 31.5, 63, 125, 250, 500, 1000, 2000, 4000, and 8000.

Sound Level Meter: The equipment used for measuring sound pressure levels; these meters usually consist of a microphone or other transducer, a frequency band analyzer, and data display/storage.

Sound Transmission Class: STC is a single-number rating used to compare the transmission loss of different materials.

Noise Reduction Coefficient: NRC is an average of the sound absorption coefficient across the 250, 500, 1000, and 2000 Hz octave bands. It is often used as a specification.

Transmission Loss: The transmission loss is the logarithm of the ratio between the incident and transmitted sound power through a barrier.

Ultrasound

Ultrasound is sound that is above the human hearing threshold. For the purposes of this guide, we will consider ultrasound as any sound above the 20 kHz, one-third octave frequency bands. Ultrasound in buildings is not a widely studied field and methods for measurement and reporting these ultrasound levels have not been standardized. Many of the terms associated with sound are appropriate to carry over to ultrasound.

Vibration

Important Terms

Velocity Level: This level relates the velocity of a surface to a reference velocity with the equation $20\log_{10}\left(\frac{v_{surface}}{v_{ref}}\right)$. The reference velocity used by the Federal Transit Authority is 1 micro-inch per second (Hanson 2005). In this report, acceleration level is used instead of velocity level.

Acceleration Level: AL, relates the acceleration of a surface to a reference acceleration, $20\log_{10}\left(\frac{a_{surface}}{a_{ref}}\right)$ and the reference acceleration is usually either 1 g (9.8 m/s/s) or 1 µg. Because of the variation in reference level, the unit for acceleration level is written “dB re a_{ref},” i.e., “dB re 1 g” or “dB re 1 µg.”

Simple Acoustical Calculations

This section describes simplified calculations that can be performed to calculate the sound level in a room, given its size, the equipment inside it, and any noise treatments that might exist.

Adding Levels

Due to the logarithmic nature of sound or vibration levels, they cannot be added linearly. Depending on the difference between the two levels to be combined, a single number can be added to the larger of the two levels to get the combined level. Table 1 below shows this guide.

Table 1. Guide to Decibel Addition

If the difference between levels is…	0-1	2-3	4-9	10 or higher
Add this to the larger of the two levels	3	2	1	0

For example, if you want to find the total level with 2 pieces of equipment next to each other, one with a sound level of 84 and one with a sound level of 80, you would add 1 to 84 to get a total sound level of 85. The guide is accurate to within about 0.5 dB.
The mathematical formula for combining sound pressure level or sound power levels in decibels is:

$$L_{p,tot} = 10\log_{10}\left(10^{\frac{L_{P1}}{10}} + 10^{\frac{L_{P2}}{10}} + 10^{\frac{L_{P3}}{10}} + \dots\right)$$

Calculating Sound Power from Sound Pressure

The sound power level of a source can be calculated from the sound pressure level measured in a free field (without any reflecting surfaces) by the following equation:

$$L_w = L_p + 10\log_{10}(Area)$$

Where: L_p is the sound pressure level, dB
L_W is the sound power, dB
Area over which the sound pressure level is measured, m^2

For example, if the source is on the ground and radiates over a hemisphere, then the area is 2π times the square of the radius. For a radius of 1.26 m, the difference between the L_p and L_w is 10 dB.

Calculating Room Sound Pressure

The sound pressure in a room depends on the strength and number of sources in a room, as well as the size and architectural features of the room. For a single source, the sound pressure level at a distance r from the source would be:

$$L_p = L_w + 10\log_{10}\left(\frac{1}{4\pi r^2} + \frac{4}{S\alpha + 4mV}\right) + 10\ dB$$

Where: L_p is the sound pressure level
L_W is the source sound power
r is the distance from measurement position to source, ft
S is the surface area of the room, ft^2
α is the average sound absorption coefficient of the room

m is the sound absorption coefficient of air
V is the volume of the room, ft^3

The sound pressure level would be calculated for all of the sources and then combined using the equation in Section 2.4.1

Because animal holding rooms are relatively small and have multiple sources of the same strength, the calculation can be simplified to the equation:

$$L_p = L_w + 10\log_{10}\left(\frac{4}{S\alpha}\right) + 10\ dB$$

Where: L_p is the sound pressure level in the middle of the room, dB
L_w is the total sound power of all sources, dB
S is the surface area of the room, ft^2
α is the average absorption coefficient of the room

These quantities are frequency dependent and this calculation would need to be performed for each octave-band frequency. The following table shows the values of m and α for different frequencies in a typical vivarium.

Table 2. Values for m and α for Different Frequencies

	Octave Band Frequency, Hz							
Parameter	63	125	250	500	1000	2000	4000	8000
m	1.00E-04	2.00E-04	4.00E-04	8.00E-04	1.60E-03	3.40E-03	8.60E-03	1.56E-02
α	0.06	0.13	0.05	0.05	0.05	0.07	0.07	0.03

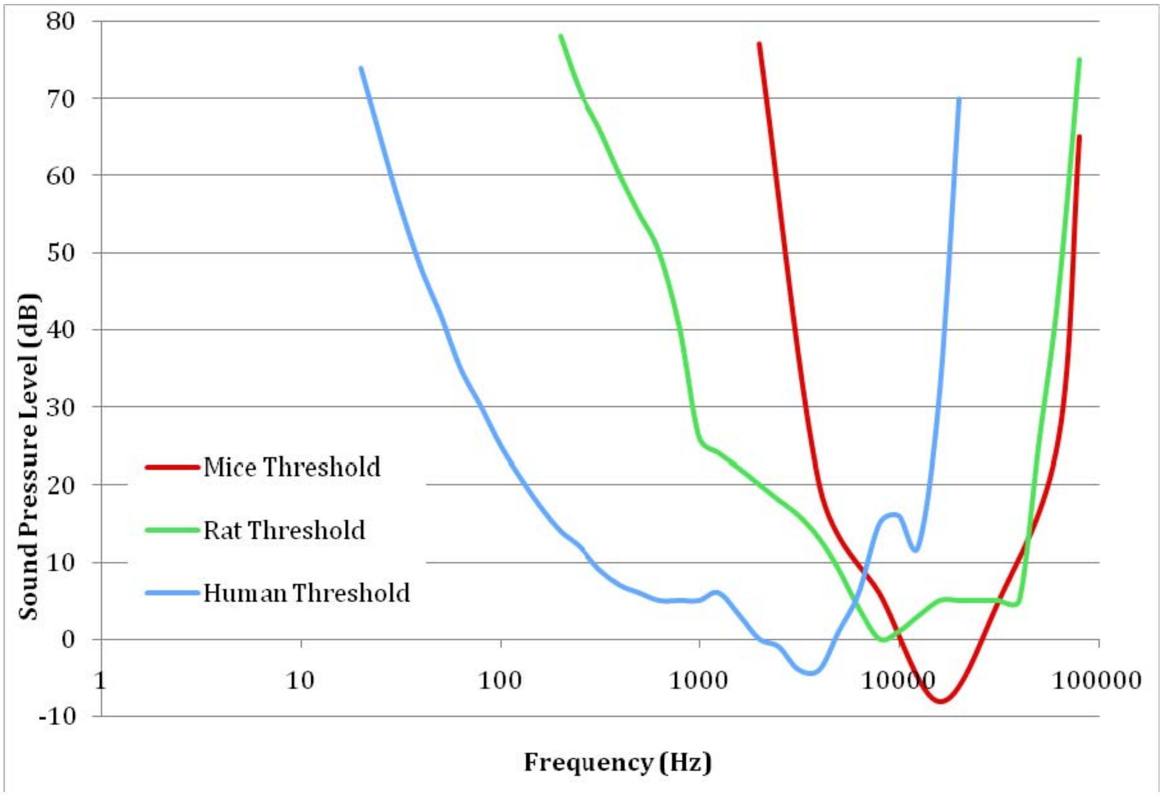
This method of using a lumped source model differs from the actual sound pressure by less than 2 dB for most situations and by less than 7 dB when the calculation location is very close to a source. It can be used as a way to approximate the sound level in an animal holding room.

HEARING AND CRITERIA

Hearing Thresholds

Humans, mice, and rats will be in vivaria; thus, it is appropriate to consider the hearing thresholds of each as shown in Figure 1.

Figure 1. Hearing Thresholds of Humans, Mice, and Rats



Kelly and Masterson developed the audiogram for rats (Kelly 1977) and Ralls developed the audiogram for mice (Ralls 1967). It is interesting to note that there is some similarity in the shape of the threshold of hearing as a function of frequency.

Human Criteria

Three different noise criteria are most often used to limit noise exposure of humans:

- The A-weighted sound level, dBA
- The Noise Criteria Curves, often called NC curves
- The Room Criteria Curves, denoted RC curves

Although the A-weighted level can be useful, it is inadequate to describe the character of a sound, which is very important in determining the potential for annoyance of sounds.

For this reason, the Noise Criteria curves and the Room Criteria curves are utilized. These curves give sound level limits in octave bands of frequency from 31.5 Hz to 8 kHz. Different sound curves are recommended for different activities. Both sets of curves take into account the spectral information in different ways. Room criteria has two distinct steps, the first is to determine the mid-frequency average level. The second step is to determine the perceived balance between high and low frequency content of the spectra. This is done by ascribing one of three qualifiers to the sound: neutral, hissy, or rumbly. A neutral sound is one in which no particular frequency range is dominant to the listener. A hissy signal indicates that the high frequencies dominate the noise and a rumbly signal indicates that the low frequencies dominate the noise.

The Noise Criteria curves are shown in Figure 2. The A-weighted sound level is also shown for the NC curves. Noise Criteria curves have a gentle slope from low frequency to high frequency and are similar to the threshold of hearing. Researchers over the past 50 years have measured the sound levels in thousands of rooms and developed recommended ranges of noise levels for different activities. Where speech or music listening are important, lower levels of NC curves are recommended.

Figure 2. Human Noise Criteria Curves

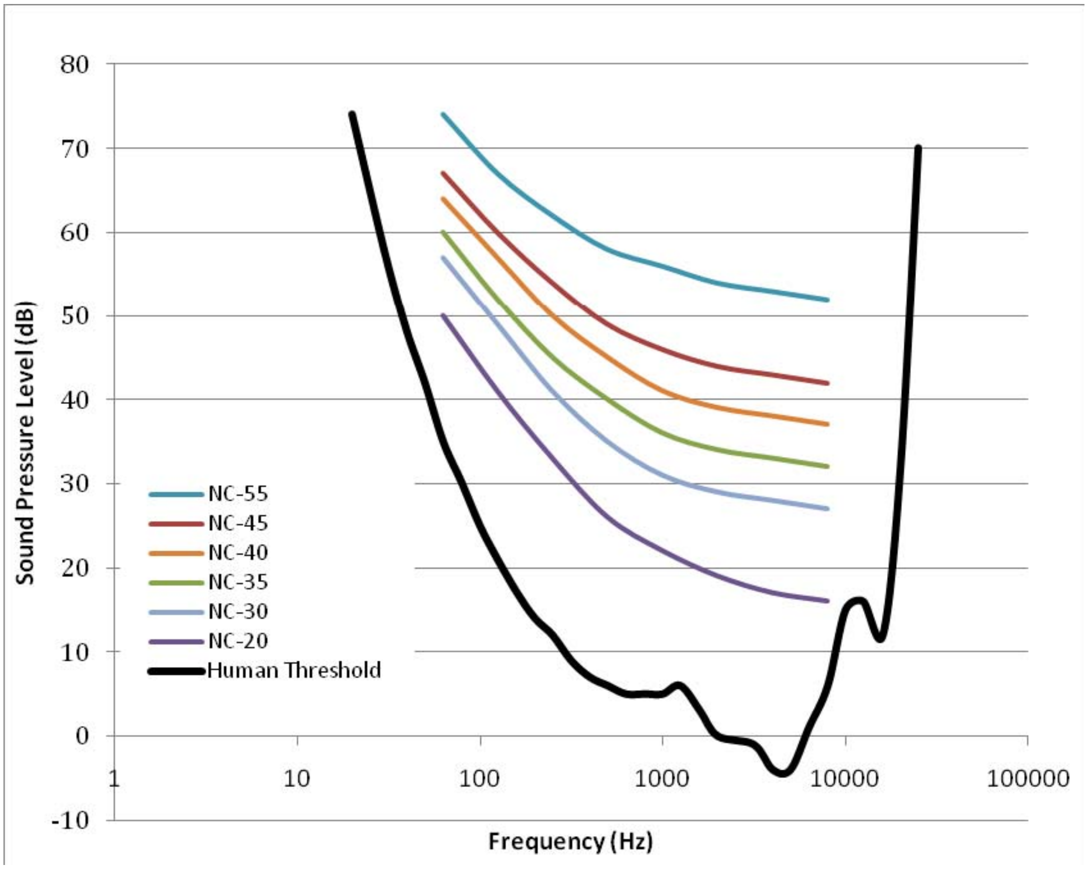
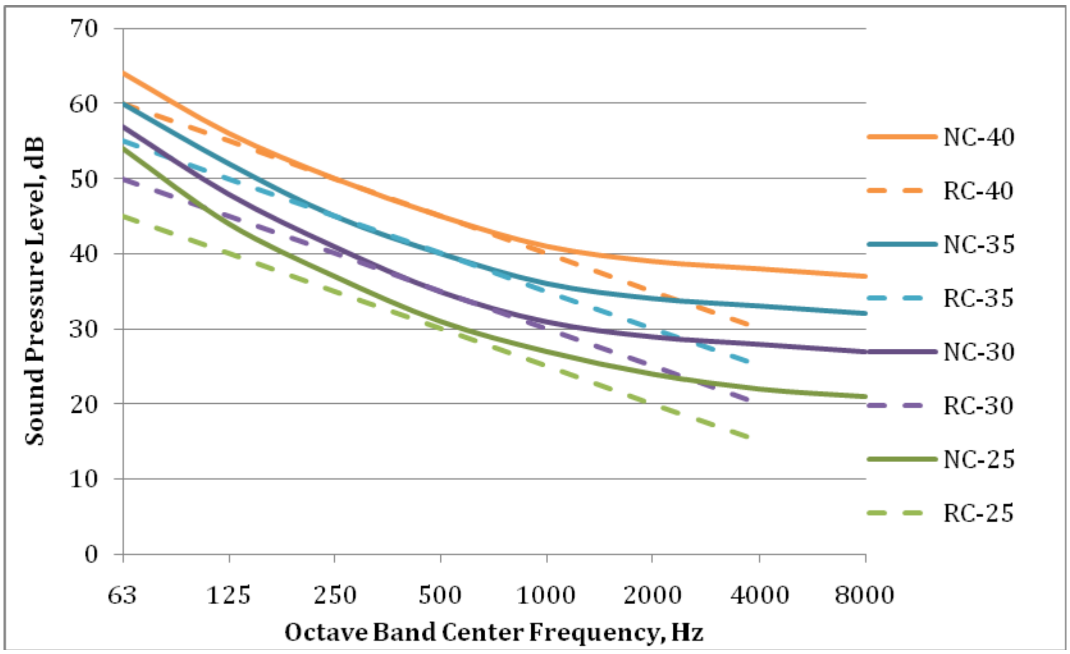


Figure 3 presents a comparison of RC curves with NC curves.

Figure 3. Comparison of RC with NC



Because the NC curves are widely used in current design recommendations, they will be used in this guide. Since frequency dependence is a significant concern in animal spaces, the A-weighted levels will not be used as the design criteria, but are included for reference.

Figure 4 shows the various NC curves for human occupied spaces.

Figure 4. NC Curves for Human Occupied Spaces

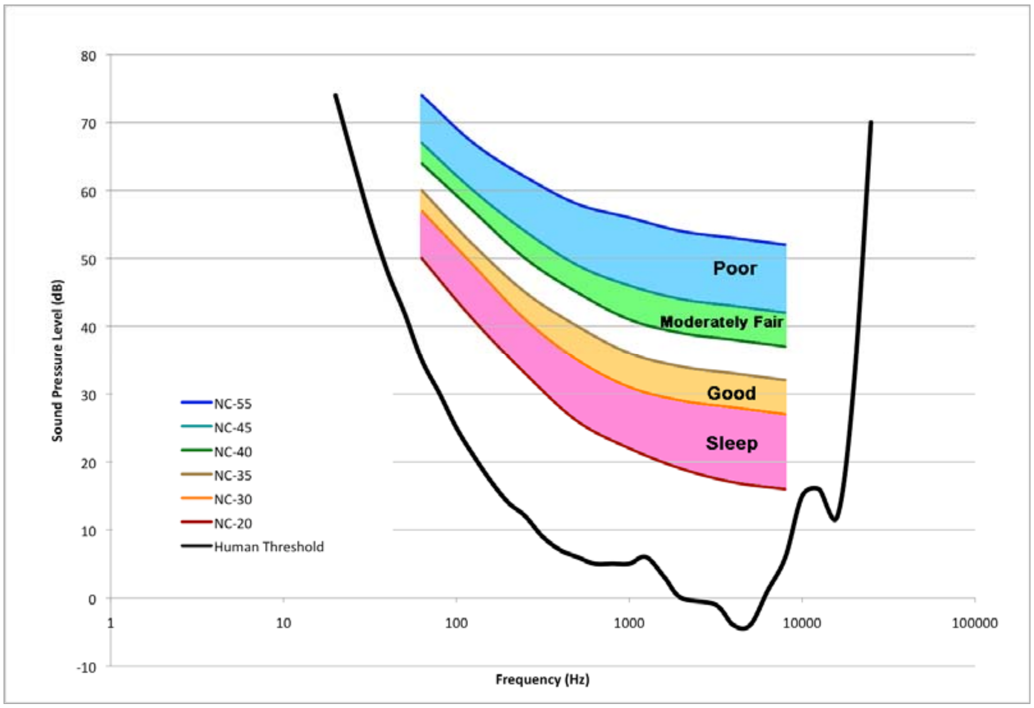


Table 3 presents the range of recommended NC curves for specific types of rooms (Egan 1972).

Table 3. Recommended Noise Criteria for Rooms

Location	NC Curves	Approximate Equivalent Sound Level, dBA
For excellent listening conditions – concert halls, recording studios	NC-15 – NC-20	25-30
For sleeping, resting, relaxing	NC-20 – NC-30	30-40
For good listening conditions – private offices, conference rooms	NC-30 – NC-35	40-45
For fair listening conditions – reception areas, restaurants, retail shops	NC-35 – NC-40	45-50
For moderately fair listening conditions – lobbies, corridors, laboratories	NC-40 – NC-45	50-55
For poor listening conditions – kitchens, industrial shops, garages	NC-45 – NC-55	55-65

In addition, ASHRAE recommends the following noise criteria for acceptable HVAC noise levels in unoccupied rooms in hospitals and clinics (ASHRAE 1991).

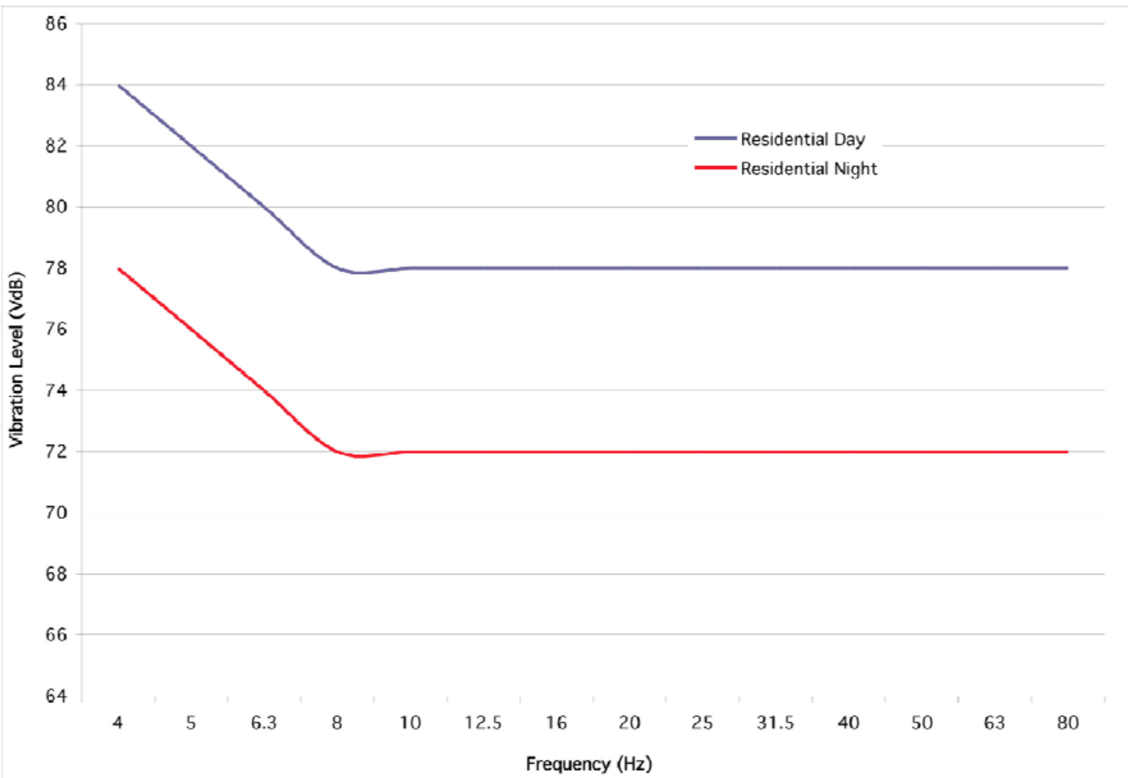
Table 4. Criteria for HVAC Noise Levels in Unoccupied Rooms

Occupancy	NC Curve Recommendation
Private Rooms	NC-25 – NC-35
Wards	NC-30 – NC-35
Operating Rooms	NC-25 – NC-30
Laboratories	NC-35 – NC-40
Corridors	NC-30 – NC-35
Public Areas	NC-35 – NC-45

Human Vibration Criteria

FTA has published vibration criteria. Figure 5 shows the proposed vibration criteria for residences for humans. As additional research for acceptable levels of vibration for rodents are performed, the criteria can be updated to include this information.

Figure 5. FTA Vibration Criteria



Rodent Criteria

The criteria for animal care facilities describe the regulation of as many external factors as possible. These factors include: airflow, bedding, food, water, population size, light, and noise. Although noise is mentioned in each of the current criteria as a concern, there is very little on noise level limits. Four main documents are cited as current criteria:

- The test procedure by the animal protection center for biomedical research of the Faculty of Medicine (TIZ-BIFO),

- The Code of Practice for the Housing and Care of Animals used in Scientific Procedures,

- The Guide to the Care and Use of Experimental Animals, and

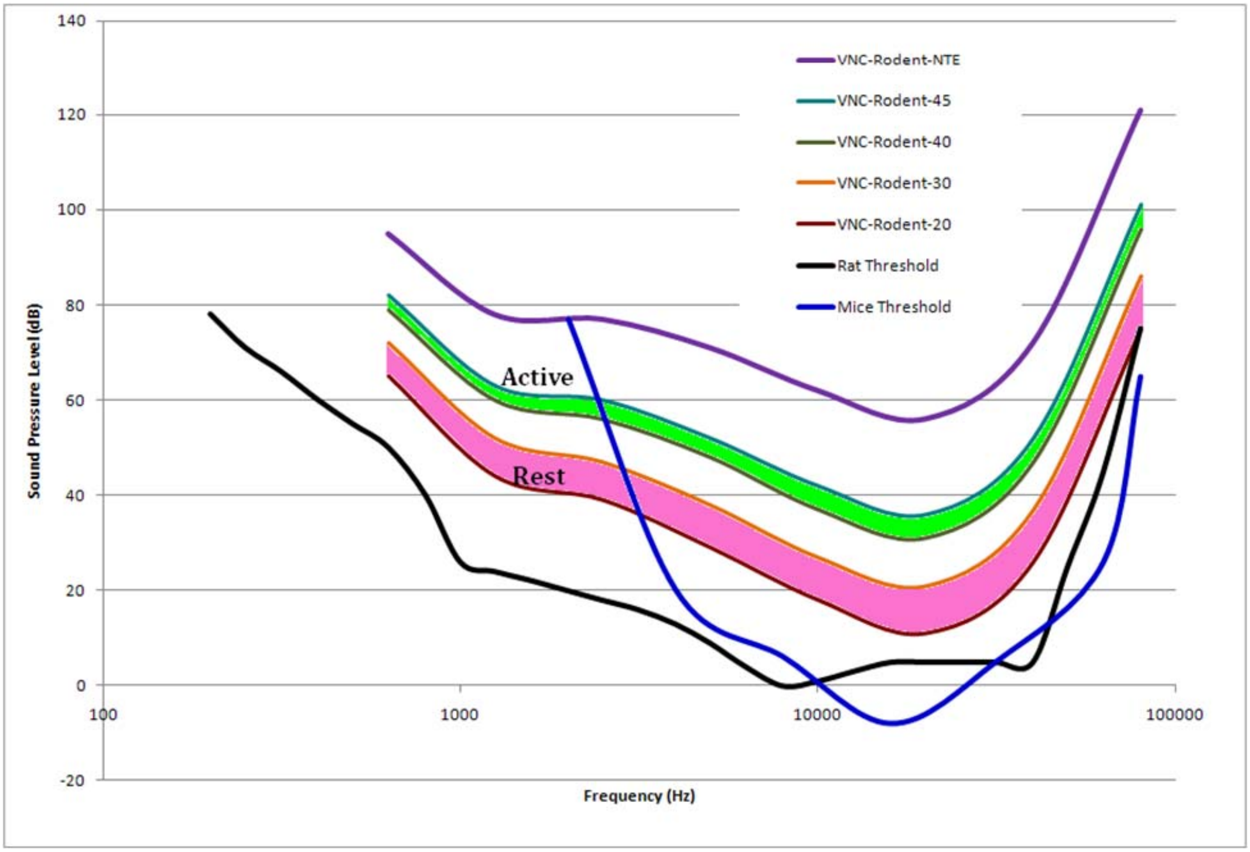
- The National Institute of Health (NIH) Biomedical and Animal Research Facilities Design Policies and Guidelines.

All of these documents mention noise and/or vibration at least once and identify it as a concern. TIZ-BIFO does not identify any absolute sound pressure levels. The Code of Practice for the Housing and Care of Animals Used in Scientific Procedures suggests that empty rooms should be kept below 50 dBA and below an RC 45 curve. It also suggests that the spectrum be free of tonal content. The Guide to the Care and Use of Experimental Animals states that adverse effects have been seen in rats at sound levels as low as 83 dB. NIH does not specify any absolute levels for noise or vibration.

In a previous study conducted by CSTI acoustics for M. D. Anderson Cancer Center, preliminary criteria were suggested. This was done in an attempt to fill the gaps in the current criteria by specifying sound pressure level limits as well as identifying all of the important frequency bands.

The rodent criteria, which combines the hearing sensitivities of mice and rats, is shown in Figure 6.

Figure 6. Vivarium Noise Criteria for Rodents



CURRENT M. D. ANDERSON BUILDING GUIDELINES

Sound

M. D. Anderson has provided two sound criteria documents that are relevant to the design of small animal facilities. The first is Element D2002 Sound Criteria. This is particularly related to the HVAC design and implementation. The RC Mark II room criteria method is employed in the 500, 1000, and 2000 Hz octave bands. Table 5 gives the requirements for various spaces prior to any equipment or furnishings installed in the room.

Special note should be given to the fact that these are all neutral spectra. In addition, the requirement for animal holding rooms of RC 35-45 should be noted.

Table 5. M. D. Anderson Sound Criteria for HVAC Systems

Application	Room Criteria(N)
Private Offices	25-35
Open-Plan Offices	30-40
Office Corridors and Lobbies	40-45
Conference Rooms	25-35
Teleconferencing Rooms	25
Training Rooms	25-35
Large Meeting/Banquet Rooms with Amplified Speech	30-40
Libraries	30-40
Dining Rooms and Serveries	35-45
Inpatient Rooms	25-35
Shared Patient Rooms	30-40
Exam Rooms	35-40
Procedure/Treatment Rooms	35-40
Operating Rooms	25-35
Patient Corridors and Public Spaces	30-40
Shared Work Rooms	30-40
Normally Unoccupied Support Rooms	40-45
Laboratories	45-55
Laboratories with Extensive Speech and Telephone Conversation	40-50
Animal Holding Rooms	35-45

The document also specifies that the services of an acoustical consultant must be employed to verify that these requirements are met. If the requirements are not met, then noise control treatments must be identified.

The second document of interest is the UT M.D. Anderson Design Standards – Small Animal (Rodent) Vivarium (ARSAC 2007). No specific sound level limits are identified. However, guidelines on surface finishes, which affect the acoustic properties of the room, are mentioned. These architectural standards are presented below in Table 6.

Table 6. M. D. Anderson Architectural Standards – Small Animal (Rodent) Vivarium

Architectural Element	Applicable Standard
Corridors	Size: 8 ft wide (minimum)
Doors	Size: 4 ft x 7 ft (minimum) STC 45 or greater
Floors	Material: Resinous epoxy
Walls	Material: Cement fiber wallboard or concrete masonry Units
Ceilings	Material: Cement fiber wallboard suspended ceilings undesirable
Room Ratio	1 procedure room to 1260 cages

Ultrasound

Currently M. D. Anderson states in the UT M. D. Anderson Design Standards – Small Animal (Rodent) Vivarium document that ultrasonic motion detectors should not be used for lighting controls and security.

Vibration

The UT M. D. Anderson Design Standards – Small Animal (Rodent) Vivarium document describes the following design requirements to mitigate the vibration:

- The structural system should have relatively short column spacing and be relatively stiff.
- Framed floors, corridors, and animal facility spaces should not be combined in the same structural bay.
- Animal facility spaces should be located away from sources of vibration such as cage washers.
- Animal facilities should be located on grade-supported slabs.
- Vibration isolators should be installed appropriately on equipment that may be a source of vibration.

All of these actions will reduce vibration levels within the animal housing rooms.

SOURCES

Common Sources

Equipment inside Animal Holding or Procedure Rooms

By performing a study of product literature, typical levels for equipment in vivaria were found. This vendor data, while not all from the brands currently in use at M. D. Anderson, is representative of vivaria equipment. These levels, both A-weighted and in octave bands, are presented below in Table 7 for equipment which can be found in the animal holding or procedure rooms. The cells highlighted in peach are estimated.

Table 7. Typical Equipment Sound Pressure Levels

Equipment	Details	Octave Band Center Frequency, Hz														A-weighted, dBA
		16	32	63	125	250	500	1k	2k	4k	8k	16k	32k	63k	125k	
Biosafety Cabinet	Limits without Alarm	17	23	40	48	54	59	59	58	54	40	21	10	30	50	64
	Limits with Alarm	17	25	41	50	55	60	60	60	68	51	24	10	30	50	71
Fume Hood	Assumed same as Biosafety Cabinet	17	23	40	48	54	59	59	58	54	40	21	10	30	50	64
Individually Vented Cages	Measured data			47	46	38	50	37	26	20	16	16	10	30	50	49
Bedding Dispenser	Assumed Spectrum			66	65	64	66	68	70	67	64	61	10	30	50	75
Rodent Treadmills	Estimated for motor and pulley system															50
Bottle Filler	Keep faucet out of line-of-sight with rodent cages															
Automated Watering System	Flushing for maintenance. Perform during the “night” portion of a light cycle.															
Lights, fluorescent lights	‘A’ ballast															20-24
Computers and Monitors	CD-ROM operation Regular operation CRT monitors emit high frequency sounds. LCD monitors are extremely quiet.															43 <32

Equipment External to Animal Holding or Procedure Rooms

Often, the equipment that is external to the animal room is noisy. For these reasons, it is best if this equipment is isolated from the animal holding rooms into another room, such as a storage closet, an office space, or a corridor. Table 8 below presents the vendor data and estimated spectrum for some of this equipment. The cells highlighted in peach are estimated.

Table 8. External Equipment

Equipment	Details	Octave Band Center Frequency, Hz														A-weighted, dBA
		16	32	63	125	250	500	1k	2k	4k	8k	16k	32k	63k	125k	
Cabinet Cage Washer	Assumed Spectrum			77	73	70	67	61	53	48	45	39	10	30	50	68
Rack Washer	Assumed Spectrum			77	73	70	67	61	53	48	45	39	10	30	50	68
Tunnel Cage Washer	Assumed Spectrum			82	79	75	72	66	58	53	50	44	10	30	50	68
Freezer	Assumed Spectrum			53	55	58	60	58	55	51	47	45	10	30	50	62
HVAC System	from ASHRAE			60	52	45	40	36	24	33	32					49

Ultrasonic Cleaning Equipment

Ultrasound cleaning equipment should only be utilized in areas away from the animal housing rooms. This requires that the equipment be housed in a separate corridor, separated by at least one wall. In addition, there will be no connection between the animal housing corridor and the cleaning room. This prevents direct line-of-sight between the equipment and the animals during the opening and closing of doors.

HVAC Systems

In addition to the fan and airflow noise created by HVAC systems, oil canning of the ductwork can create loud impulsive noises. To reduce the probability that oil canning occurs in ducts, either a stiffer, thicker gage metal can be used, or the ducts should be made circular.

Elevators

Elevators and mechanical equipment rooms, for the operation of the elevators, should be positioned far from the animal housing areas. Sound and vibration mitigation techniques should be employed.

Mechanical Building Equipment

All animal housing facilities should be far enough away from mechanical building equipment in order for them to be isolated from any residual vibration.

Motion Detectors

Ultrasound motion sensors should not be used in the animal housing facilities where animals could be exposed to the ultrasound noise. This includes using the device in the room or in the corridors adjacent to the animal housing facilities. If the animal housing facilities require ultrasound motion sensors, they must operate above 200 kHz. This will ensure that the ultrasonic noise is significantly above the hearing range of the animals.

Imaging Equipment

Imaging equipment should have vibration isolation where appropriate. All imaging suites should be far enough away from the animal housing facilities that the sound and vibration will be negligible.

Requirements from Vendor during Design

1.1.1 Sound

The vendor should provide measured levels based on ANSI S12.3-1985 (R 2006) American National Standard Statistical Methods for Determining and Verifying Stated Noise Emission Values of Machinery and Equipment.

One-third-octave-band or octave-band data should be made available by the vendor.

1.1.2 Vibration

Vendors should provide the vibration levels of all equipment with moving parts. If the vibration levels exceed 72 VdB on the ground surrounding the equipment, then the vendor should provide information on appropriate vibration isolators compatible with their equipment.

1.1.3 Ultrasound

If any equipment produces ultrasound noise above 10 dB in any of the octave bands between 16 kHz and 100 kHz, then the ultrasound levels must be reported. If the levels are below 10 dB, then this should be noted and the specific levels do not need to be reported.

Any other equipment specifically claiming use in the ultrasound range, the vendor should provide the frequency range in which the equipment operates. If the frequency range is above 200 kHz, the equipment can be used in the room; however, if it falls below 200 kHz then the equipment should not be used in the room or the adjoining hallways.

MITIGATION TECHNIQUES

General mitigation techniques that will reduce sound, vibration, and ultrasound can be employed. Because the majority of noise in the animal housing facilities is due to human activity, these general mitigation techniques attempt to reduce the impulsive noise generated by door slamming and cage moving. Quiet door closures should be used. This can include either a controlled door closure device that slows the door as it is automatically shut or a sealing ring that reduces the hard contact of the door to the door jam. There are several varieties of commercially available quiet door closure devices.

Sound

Due to the need for sanitation, animal housing rooms are often completely acoustically hard. This will raise the overall sound level in the room, which can be mitigated by adding sound absorption into the room. There are several different types of sound absorbing materials that can be sanitized. Sanitary sound absorbing panels provided by SoundSeal can be mounted overhead. These are designed as hanging baffles and would be attached to the ceiling. They could also be hung on the walls, but the effectiveness of the absorption would be reduced slightly. The baffles can be purchased as two types: Type A - 2'x4'x1.5" thick and Type B - 2'x4'x2" thick. The sound absorption of these baffles is shown in Table 9.

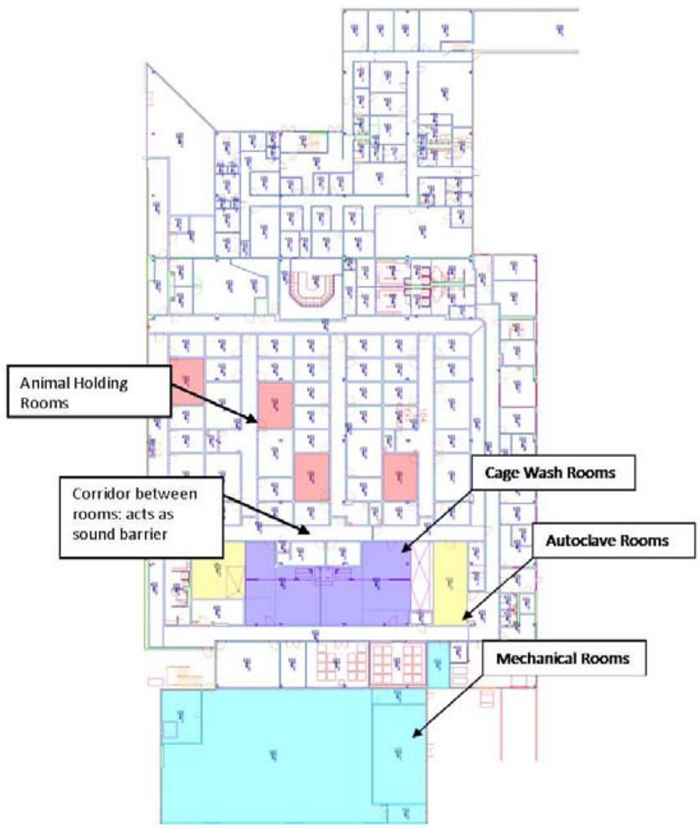
Table 9. Sound Absorption Coefficients for SoundSeal's Sanitary Sound Absorption Baffles – Sabines Per Baffle

Sanitary Baffle	**One-Third Octave Band Center Frequency, Hz**						NRC
	125	250	500	1000	2000	4000	
Type "A"	1.15	5.26	8.0	10.9	9.34	5.5	8.4
Type "B"	1.00	8.9	14.65	15.72	12.68	4.93	12.8

An additional type of sound absorbing material is micro-perforated panels. These have been employed in hospitals as hygienic acoustic ceilings. They are easily cleaned and are available in aluminum, steel, and stainless steel. These panels have the advantage of having good absorption in the higher frequencies, where the rodents are more sensitive. They need to be mounted an appropriate distance from a wall in order to be effective. A dropped acoustic ceiling would be a good implementation for this treatment.

Figure 7 presents a layout of one of the areas in M. D. Anderson's South Campus Vivarium. This is an excellent example of how to reduce impact of noise by the proper arrangement of individual components of the facility. Notice how the mechanical equipment rooms, the autoclave rooms, and cage wash rooms are all away from the animal holding rooms.

Figure 7. The South Campus Vivarium Layout



1.1 Vibration

When vibration needs to be mitigated above and beyond the initial stiffening of the structure, it should be done by adding vibration isolators. The vendors should be consulted on the type of vibration isolators that will be appropriate for their equipment due to the highly variable frequency, level, and functions of each of the pieces of equipment.

Ultrasound

Ultrasound can be mitigated using absorption or even just a thin barrier. Due to the high frequencies, a relatively thin piece of material can attenuate ultrasound significantly.

A curtain type mitigation technique can be used when a piece of equipment is producing ultrasound and must be kept in the animal housing room. A material like mass loaded vinyl can be hung like a curtain. This can then be pulled shut to create a barrier between the animals and the machinery.

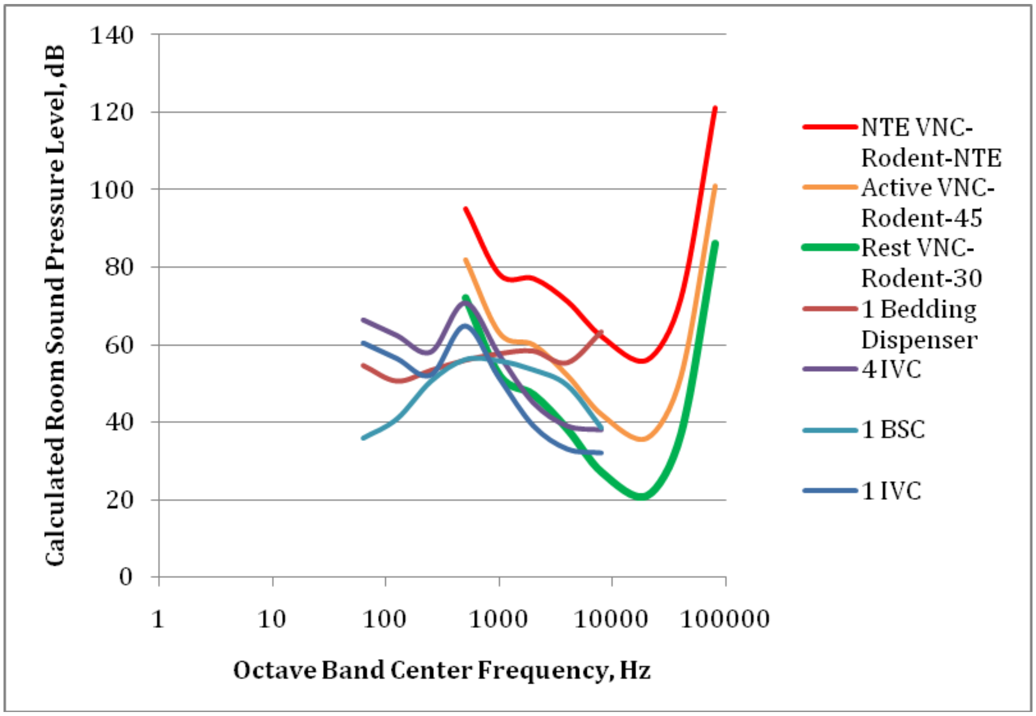
Absorbing material for sound may provide some reduction in the ultrasound range; however, the data for ultrasound frequencies is not well studied. Particularly, in the lower ultrasound frequency bands, 25 kHz to 50 kHz, typical sound absorption materials may be helpful. If an ultrasound problem is present in the room, it is recommended that additional testing be done to ensure the sound absorbing characteristics of any material used.

COMPARISON OF MEASUREMENTS WITH CRITERIA

Using the data for a biosafety cabinet, some individually vented cages, and a bedding dispenser, we have calculated the sound level in a typical room. Figure 8 presents this calculation and compares it with the Rodent Criteria. Curves of sound pressure are shown for:

- 1 Bedding Dispenser
- 1 Biosafety Cabinet
- 1 Individually Ventilated Cage Rack
- 4 Individually Ventilated Cage Racks

Figure 8. Comparison of Equipment Noise with Criteria



In our previous study, we measured the sound and ultrasound levels in the BSRB; some of this data is presented in Figures 9 and 10. Figure 9 presents daytime measurements plotted against the rest criteria and Figure 10 presents nighttime measurements plotted against the active criteria.

Figure 9. Daytime Sound and Ultrasound Levels with Rest Criteria

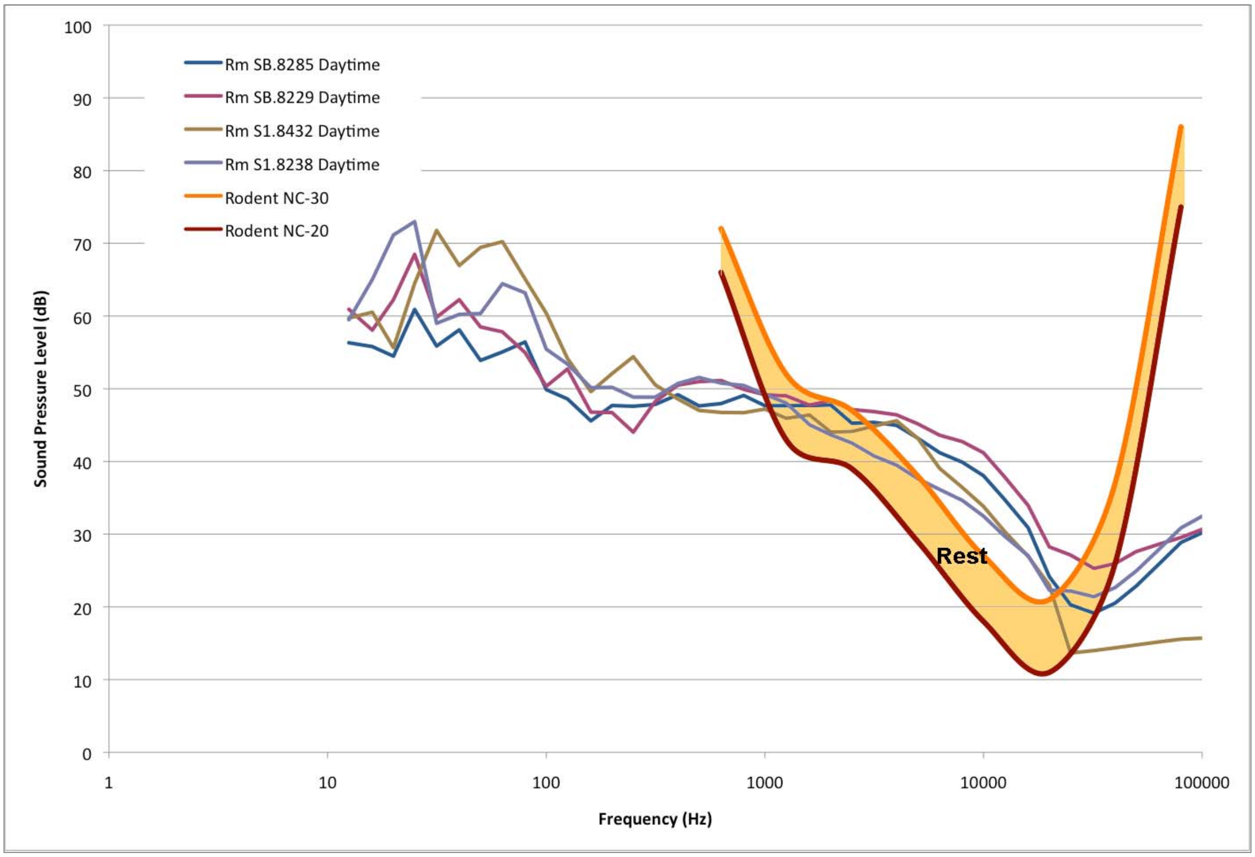
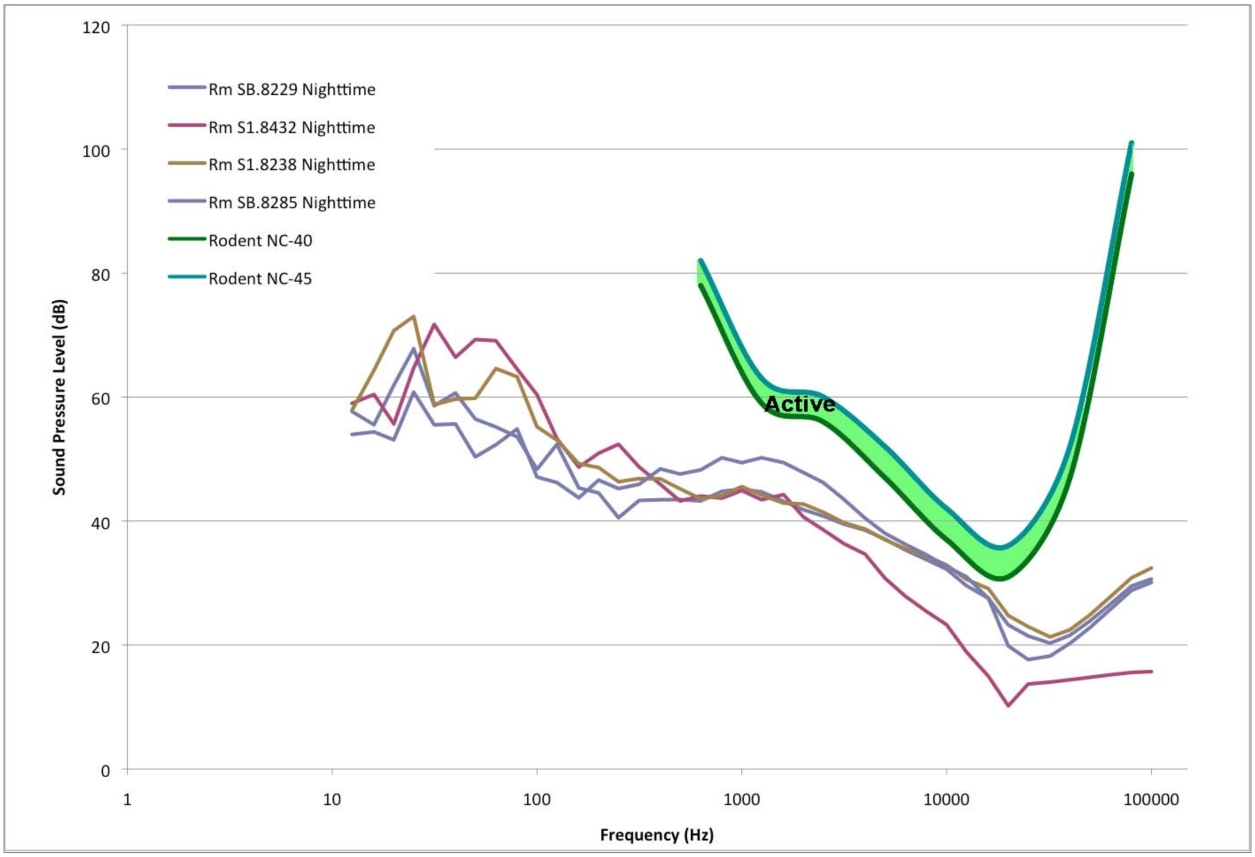


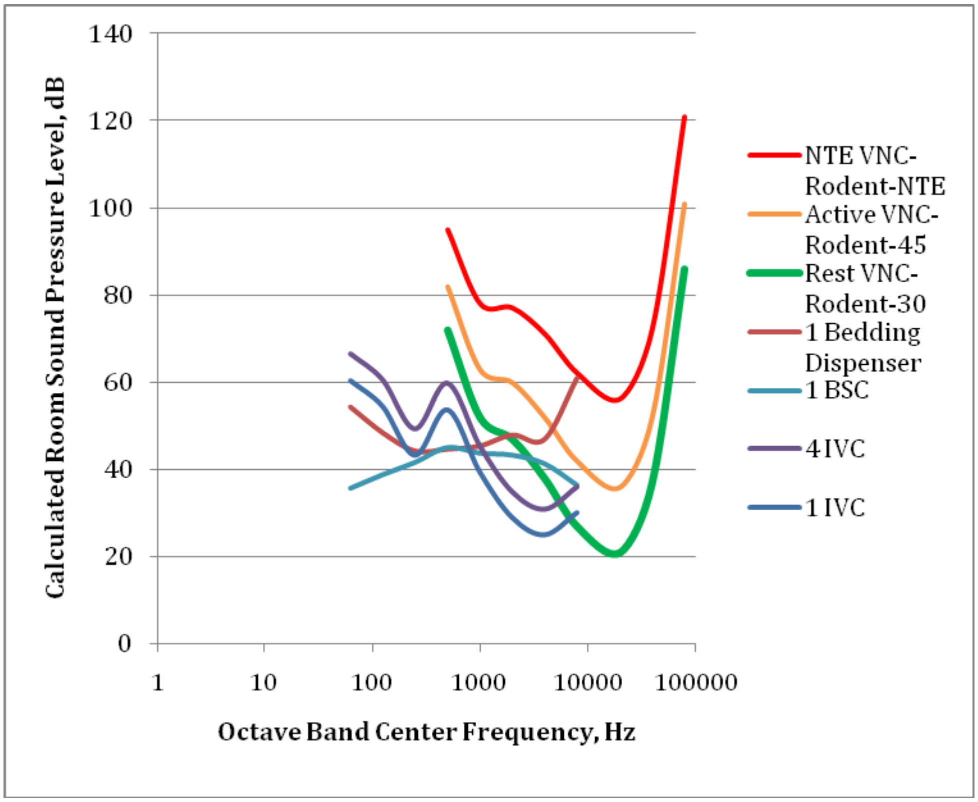
Figure 10. Nighttime Sound and Ultrasound Levels with Active Criteria



These measurements are consistent with our calculations for sound in animal holding rooms.

Figure 11 illustrates the benefit of adding 100 sq ft of sound absorption (the Type "A" baffle from Table 9) to the room. The sound levels have decreased several dB as a result of this treatment. In general, sound absorption will be of benefit to most of M. D. Anderson's animal holding and procedure rooms.

Figure 11. Comparison of Equipment Noise with Criteria – with Absorption



COMMISSIONING MEASUREMENTS ON SOUND AND VIBRATION

All commissioning measurements should be taken once all equipment has been installed. This includes all operating equipment in the animal housing rooms such as biosafety cabinets, individually ventilated cages, and other husbandry equipment. Two measurement conditions shall be taken:

- Normal Operating Conditions: this shall include all equipment that runs more than 12 hours per day.
- Worst Case Operating Conditions: this scenario includes all equipment in the room.

Several locations in the vivarium shall be measured. The sound levels in at least two animal rooms shall be measured:

- One that is closest to any external loud equipment such as imaging suites, cage washers, or mechanical rooms.
- Another that is the farthest away from these external sources.

The sound inside the animal rooms shall be measured with the door opened and closed.

One corridor directly adjacent to animal housing facilities should be measured. One corridor that has high traffic such as elevators, carts, or a loading dock shall also be measured. If offices or human working areas are present in the building, at least one space shall be measured.

Any rooms that directly house animals shall meet the rodent criteria set forth above in Section 3.3. All other areas shall meet human criteria standards outlined in Section 3.2.

Sound

Sound measurements during the commissioning process should be taken both during daytime and nighttime hours. The A-weighted equivalent sound level shall be measured for at least one hour during each time period. One-third-octave-band samples must be taken during the day and at night. They should include at least 16 Hz to 16 kHz. These should be taken at least 6 points around the room, which must include, but are not limited to:

- Inside the door
- At the back of the room
- Near the ceiling
- In the center of the room

Vibration

Vibration measurements should be made on the ceiling, the floor, and each of the walls. A floor measurement should be taken for at least one hour during the day and night. The vibration shall be measured in one-third-octave-bands of frequency for at least 30 seconds.

Ultrasound

Ultrasound measurements during the commissioning process should be taken both during daytime and nighttime hours. Ultrasound measurements should be taken from 20 kHz to 100 kHz in one-third-octave-bands of frequency. Ultrasound measurements shall be taken for at least an hour during both the daytime and the nighttime hours. Sample ultrasound measurements should be taken in approximately the same location as the sound level measurements.

EMPLOYEE BEST PRACTICES

Many technical papers point out that the greatest cause of noise disturbances in vivaria is human activity created by the employees when performing their tasks. Some of their tasks are inherently noisy; others can be performed in a quieter manner. For example, the following produce ultrasounds:

- Dropping a cage onto a countertop
- Slamming a door
- Placing laptops or other portable electronics near rodent cages

All of these activities can be avoided by trained employees.

If a warning light were to come on whenever the noise level exceeded a set value, then it is possible this reminder would influence employees to work more quietly.

This suggests the possibility that training on reducing noise should be presented to employees who handle animals.

CONCLUSIONS

This design guide has presented criteria for the noise, vibration, and ultrasound in Small Animal Vivaria, typical values for specific equipment which are in line with the current equipment in MDA buildings, and suggested mitigation techniques when criteria are not met. It has also provided information on commissioning measurements and employee best practices.

While there will always be a tradeoff between purchasing quiet equipment, applying mitigation techniques, or exceeding limits, it is hoped that this design guide has provided the reader with the proper information to make an informed decision which best fits the needs of the current project.

As more research facilities become interested in ultrasound measurements, we anticipate that additional work will be performed to:

- Determine the sound and ultrasound levels for all equipment used in vavaria
- Determine the relative benefits of ultrasound mitigation treatments
- Develop efficient, relatively inexpensive, sound absorptive treatments for vavaria

ANNOTATED BIBLIOGRAPHY

ARSAC ed. (2007). University of Texas M.D. Anderson Cancer Center Design Standards: Small Animal (Rodent) Vivarium.

The design standards for small animal vivaria which discusses many of the architectural and systems standards for building new vivaria. While a chapter on noise and vibration is included, it does not set specific limits.

ASHRAE, ed. (1991). Heating, Ventilating, and Air-Conditioning Applications: Inch-Pound Edition. Atlanta, GA, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

One volume of four in the ASHRAE Handbook, it discusses the applications for HVAC engineering. Included are the guidelines on laboratories, environmental control for animals and plants, and sound and vibration control.

Bailey, K. J., D. B. Stephens, et al. (1986). "Observations on the effects of vibration and noise on plasma ACTH and zinc levels, pregnancy and respiration rate in the guineapig." Laboratory Animals **20**: 101-108.

This paper discusses the affect of vibration and noise on pregnant guinea pigs using a device which simulates transportation of the cages. The study also looked at the increase in respiration during typical cage transportation.

Beranek, L. (1971) *Noise and Vibration Control.* McGraw-Hill

This is a comprehensive text on Noise and Vibration Control. It offers insight into the mechanisms behind sound and vibration and offers significant detail into how to mitigate noise and vibration problems.

Bjork, E., T. Nevalainen, et al. (2000). "R-weighting provides better estimation for rat hearing sensitivity." Laboratory Animals **34**: 136-144.

This paper recommends the use of a species-specific weighting system after comparing the levels of a white noise signal calculated with different weighting systems.

Clough, G. (1982). "Environmental Effects on Animals Used in Biomedical Research." Biological Review **57**: 487-523.

A discussion on the environmental factors upon which the reliability of biomedical research depends, reviewing specifically the effects of temperature, relative humidity, air movement, air quality, light, and sound.

Clough, G. and J. A. L. Fasham (1975). "A 'Silent' Fire Alarm." Laboratory Animals **9**: 193-196.

A fire alarm which is annoying to humans, but is out of the hearing sensitivity of rodents is discussed in this paper, from the conception of the device to the testing and results. The importance of such a device is that it will not startle the test animals and produce adverse effects on the test results.

Clough, G., J. Wallace, et al. (1994). "A positive, individually ventilated caging system: a local barrier system to protect both animals and personnel." Laboratory Animals **29**: 139-151.

This paper discusses the advantages of individually ventilated caging systems in vivaria to protect the rodents and the personnel in the space. However, the relevance to these studies is that it provides octave-band sound levels and their relation to Code of Practice requirements.

Council, N. r., Ed. (1996). Guide for the Care and Use of Laboratory Animals. Washington, D.C., National Academy Press.

From the Institute of Laboratory Animal Resources, the guide promotes humane care of animals and describes, among other things, the facilities and environment in which the animals should be housed. While noise is mentioned and some recommendations are made, strict limits are not provided.

Egan, M. D. (1972). Concepts in Architectural Acoustics. New York, McGraw-Hill Book Company.

A simple and practical summary of architectural acoustics which focuses on room acoustics, sound isolation, sound reinforcing systems, and mechanical system noise control. It also includes a very helpful chapter on basic acoustic theory.

Faith, D. R. and S. Miller (2007). "The Need for Sound and Vibration Standards in US Research Animal Rooms." ALN Magazine.

This article stresses the need for standards for vibration and sound in vivaria, due to a shift in the animal models from larger animals to rodents and the increasing use of ultrasound. It also discusses the potential sources in vivaria and the negative impact of sound and vibration.

Franken, P. (1971). Chapter 1 in Beranek's Noise and Vibration Control.

Gamble, M. R. (1982). "Sound and its Significance for Laboratory Animals." Biological Reviews **57**(3): 395-421.

This paper reviews other scientific literature to determine the hearing abilities of laboratory animals, the sounds produced by them and the effects of sound on them.

Hanson, C. E. (2005). "Federal Transit Administration's Noise and Vibration Guidance Manual - Updated after 10 Years of Experience." Proceedings of Noise-con 2005.

A document which reviews the changes made to the FTA's noise and vibration criteria for new transit projects. It provides criteria for vibration in buildings depending on their sensitivity.

Jankovich, J. P. (1972). "The Effects of Mechanical Vibration on Bone Development in the Rat." J. Biomechanics **5**: 241-250.

This paper studies the effects of vibration on the bone development in the rat. The rats were exposed to 20 and 25 Hz vibration at peak vibration of 1g. Several characteristics of the bone were examined including: porosity, rigidity, microhardness, and elasticity. It was found that the vibrated bones became more rigid, developed a higher Modulus of elasticity, and microhardness than those of non-vibrated bones.

Kelly, J. B. and B. Masterton (1977). "Auditory Sensitivity of the Albino Rat." Journal of Comparitive and Physiological Psychology **91**(4): 930-936.

This paper presents the auditory sensitivity of a specific strain of the albino rat, using pure tones and the conditioned suppression technique. It also compares this audiogram with different tests of the albino rat as well as other rodents.

Kryter, K. D. (1972). "Non-Auditory Effects of Environmental Noise." Environmental Noise: 389-398.

A discussion is presented of research information and ideas on the effects of noise on human beings aside from auditory aspects. Limitations on present knowledge are indicated and needed research is described.

Moiseev, N. Ashrae Recommended Vibration Criteria.

A presentation given to the ASHRAE Technical committee 2.6 on Sound and Vibration Control. The talk summarizes the suggested vibration criteria.

Montenegro, M. A., H. Palomino, et al. (1995). "The Influence of Earthquake-induced Stress on Human Facial Clefting and its Simulation in Mice." Archives Oral Biology **40**: 33-37.

After observing an increase in the percentage of facial clefts after a Chilean earthquake, researchers decided to emulate the stress of an eathquake on mothers by using two different strands of mice and exposing them to similar vibrations. This paper demonstrates another, albeit unusual, adverse effect of vibration.

Office, H. (1989). Code of Practice for the Housing and Care of Animals Used in Scientific Procedures.

This U.K. government document provides guidelines for the ethical and scientifically responsible care and housing of laboratory animals.

Pfaff, J. (1974). "Noise as an Environmental Problem in the Animal House." Laboratory Animals **8**: 347-354.

This 1974 literature review of standards and requirements for noise in animal housing discusses the inadequacies of then-current standards and the harmful effects of noise on laboratory animals. It also recommends playing white noise in the background to avoid a startle response.

Pfaff, J. and M. Stecker (1976). "Loudness Level and Frequency Content of Noise in the Animal House." Laboratory Animals **10**: 111-117.

After making and presenting measurements of sound from technical devices, work in the animal rooms, and the animals; this paper then describes the usefulness of masking to block these noises.

Poole, T. (1997). "Happy Animals Make Good Science." Laboratory Animals **31**: 116-124.

This paper looks at the growing body of evidence which shows that physical environmental factors, which influence the animals' psychology also affect the immune system. Therefore, keeping animals happy is both good ethics and good research practice.

Ralls, K. (1967). "Auditory Sensitivity in Mice: Peromyscus and Mus Musculus." Animal Behavior **15**: 123-128.

The hearing sensitivities of Peromyscus and Mus Musculus mice were measured. This was done measuring the potentials across electrodes implanted in the mouse ear. Threshold of hearing curves are given.

Sales, G. D., K. J. Wilson, et al. (1988). "Environmental Ultrasound in Laboratories and Animal Houses: A possible Cause for Concern in the Welfare and Use of Laboratory Animals." Laboratory Animals **22**: 369-375.

A study of sources of ultrasound in vivaria; this paper provides levels and major peak frequencies of common laboratory devices. It also recommends performing further research into the effect of ultrasound on lab animals and formulating guidelines for acceptable levels.

Scheer, M., C. Heinekamp, et al. "Performance Evaluation of IVC Systems - Part 1: Test Instructions." TIZ-BIFO.

This technical document from the animal protection center for biomedical research for the Faculty of Medicine, a working group out of the Ludwig-Maximilian-University of Munich, highlights test procedures which should be standardized for individually ventilated cage systems.

Included in these test procedure outlines are how to measure noise and structure-borne noise, but no standardized limits are offered.

Suckow, M. A., S. H. Weisbroth, et al., Eds. (2006). The Laboratory Rat. Amsterdam, Elsevier.

The second edition of the premier source of information on laboratory rats. Information on noise, vibration, and hearing in rats features in the chapters on morphophysiology, reproduction and breeding, housing and the environment, and occupational health and safety.

UTMDACC, Ed. (2007). "Master Construction Specifications". Owner's Design Guidelines.

The overall design standard for M.D. Anderson buildings, this guide gives requirements for nearly all aspects on construction. The only section which mentions noise is under the HVAC systems, in the Sound Attenuators sub section.

Williams, W. O. (2004). "Ultrasonic Sound Measurement as an Indicator of Pain and Distress in Laboratory Rodents." Animal Welfare Enhancement Awards.

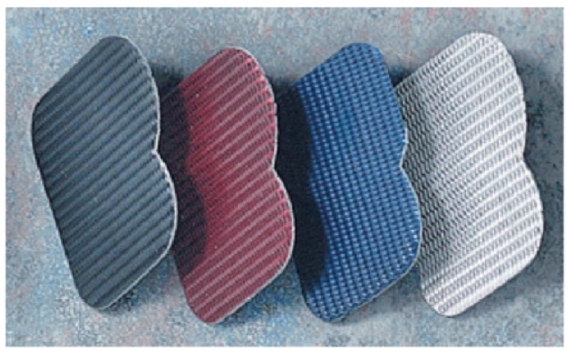
This paper presents research on ultrasonic vocalizations of mice when exposed to a painful procedure. It notes that ultrasonic vocalizations accompanied audible vocalizations when the mice experienced pain.

Wiseman, L. and J. L. Cezeaux (2002). "Experimental Procedure to Test the Effects of Vibration on Vascular Permeability in Rats." IEEE: 99-100.

Rats were exposed to a vertical vibration of 50 m/s^2 rms at 125 Hz. The animals are then injected with dye through the caudal vein. After allowing the dye to circulate for 20 minutes, the amount of dye present in areas close to the vibration and in the liver were examined.

APPENDIX A

Airborne Sound Absorption



ACUSTIMET

Areas of application

Industry
Workshop machines, fans, mills, printers, materialhandling machines, ovens, particle separators, power equipment, generators, engines, compressors, hydraulic equipment, food processing machines.

Transportation and vehicles
Engine compartment in boats and vehicles, scooters, off road vehicles, gardening tools, combustion mufflers.

Hospital and kitchen
Dish and washingmachines, vacuum cleaners, ovens, airconditioners, mobile walls, hygienic acoustic ceilings.

Architecture
Elevators and engine rooms, ventilation installations, ceilings.

How to apply

Cut and form to desired shape. Mount at an appropriate distance from back wall. Seal all edges.

Product characteristics

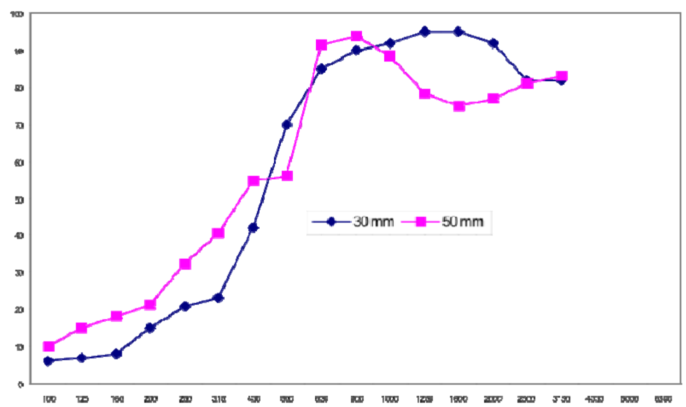
Acustimet is an all-metal soundabsorbing element without any fibers. Metal quality and thickness can be choosen according to requirements.

Advantages

- Non combustible
- Does not attract fluids or dirt
- Easily cleaned
- Withstand high temperatures
- Does not age
- Resistant to chemicals
- Fibre free
- Good sound absorption
- Mechanically rigid and tough
- Aesthetic appearance
- Resistant to wear
- No static electricity
- Easy to form

SONTECH NOISE CONTROL

Absorption Coefficient % (ISO 10534)



Frequency, Hz, Third Octave Bands

Technical data

Sound absorption	See diagram
Temperature resistance	Depending on metal
Flammability	Non combustible
Metal	Aluminium, steel, stainless steel
Colour	On demand
Thickness	1,2,3 mm, Other on demand. Stainless 0,5 mm.
Weight	Depending on Metal
Formability	As metal sheet
Sheet size	600x1200 and 1000x2000 mm

Advice

Forming and location of the material has importance to achieve maximum damping results.

SONTECH has a long experience of many practical sound damping projects. This experience i a valuable addition to the laboratory data shown in this document.

SONTECH can help you with advice and sound measurements as well as manufacturing a complete material kit

Designation system

Acustimet	AM
Thickness mm	0,5 , 1
Metal	AL, Fe, SS
Example of ordering code.	AM1AL2

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