ALL PRODUCTS

SOUND

HVAC AIR DISTRIBUTION SYSTEMS AND SOUND LEVELS

APPLICATION AND DESIGN GUIDELINES

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SOUND APPLICATION AND DESIGN OVERVIEW

The purpose of this document is to provide basic application and design guideline information on sound as it applies to mechanical equipment and common building HVAC air distribution systems. This document will cover both mechanical and architectural aspects of a project and will help determine how a properly designed system can help prevent noise problems in a building.

The information contained within this document applies to mechanical equipment that has been installed in typical applications such as office buildings or retail establishments and even addresses more sound sensitive facilities such as schools and movie theaters. It is important to note that this document does not provide a complete design solution for sound critical spaces such as performing arts theaters or similar type applications. Designing HVAC air distribution systems for these applications typically requires the assistance of an acoustical consultant or mechanical engineer with critical sound application project experience.

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COMMON ABBREVIATIONS AND TERMS

Abbreviation	Definition
dB	Decibel (numerical expression denoting the relative loudness of a sound)
Lw	Sound Power Levels
Lp	Sound Pressure Level
dB(A)	A-Weighted Sound Level
NC-XX	NC Criteria
RC-XX(X)	RC Criteria
PSIL	Preferred Speech Interference Level
STC	Sound Transmission Class

Term	Definition
Source	Equipment or object that actually creates the sound
Path	Equipment or object that delivers the sound to the space
Receiver	Person or object that hears / receives the sound

MECHANICAL EQUIPMENT SOUND LEVEL MEASUREMENT

The Sound Power Level and Sound Pressure Level define two different ways to measure the sound from a piece of mechanical equipment. Each measurement provides useful information that will indicate mechanical equipment sound levels either at the equipment or as measured from a distance.

Sound Power Level, L_w

Sound Power Level (L_w), expressed in decibels (dB), describes the acoustical power that radiates directly from a piece of mechanical equipment. For example, this rating will measure the actual sound coming from a packaged rooftop unit's discharge or return opening. This is a common measurement that most manufacturers typically list in their production information.

While some manufacturers just list the highest overall Sound Power Level, other manufacturers will choose to show the Sound Power Level for all octave bands, from 63 through 4,000 Hz. Although not as common some manufacturers will also list low sound level bands down to 31.5 Hz and high sound level bands up to 8,000 Hz.

Sound Pressure Level, L_p

Sound Pressure Level (L_P) also describes the acoustical power, expressed in decibels (dB) that radiates from a piece of mechanical equipment, however the measurement will occur at a distance from the unit. The Sound Pressure Level will vary depending on the distance from a sound source and the acoustical environment. Typically, the Sound Pressure Level is given as a value in decibels at a distance, i.e.: L_P is 40 dB at 3 ft.

In summary, both the Sound Power Level and Sound Pressure Level measure the sound radiating from a unit. However, Sound Power Levels are independent of the environment while Sound Pressure Levels depend upon both the source location and the environment.

HVAC AIR DISTRIBUTION SYSTEM SOUND LEVEL MEASUREMENT

Like mechanical equipment, there are also several different ways to measure the sound level for the complete HVAC air distribution system. The most commonly used definitions include A-Weight Sound Level, NC Criteria and RC Criteria.

A-Weight Sound Level, dB (A)

Noise regulations for outdoor applications typically use the term A-Weighted Sound Level, expressed in dB(A). Many engineers, architects, designers and regulatory bodies will use this term to specify the acceptable outdoor noise levels for their communities. Although not as common, it is important to note that this term does occasionally apply to noise regulations for indoor applications in a building or a piece of equipment as well.

NC Criteria, NC-XX

Noise regulations for indoor applications typically use the term NC Criteria, expressed as a rating number, such as NC-35. Many engineers, architects, designers and regulatory bodies will use this term to specify the acceptable indoor noise levels for a building or piece of equipment. This term has been around since the mid 1950s and was once fairly common.

NC Calculation Procedure:

1. Plot 63 through 8,000 Hz octave band.
2. Record sound levels on a chart of curves.
3. Determine the highest sound data protrusion along the chart of curves.
4. The highest point will determine the overall NC Criteria rating.
5. Report Point of Tangency to determine what frequency sets the NC value.

RC Criteria, RC-XX(X)

Noise regulations for indoor applications where a subjective quality of the sound levels exists will use the term RC Criteria, expressed as a rating number plus a subjective quality descriptor such as RC 35(N). RC Criteria takes into account the subjective quality of sound, and not just the level at which it occurs. Many engineers, architects, designers or regulatory bodies use this term to specify the acceptable indoor noise levels for a building or piece of equipment.

Although a newer way to measure sound than NC Criteria, RC Criteria currently remains the sound rating of choice for many individuals in the industry. One reason for the measurement's popularity is that the rating measures both the sound level and quality of the HVAC air distribution system. In addition, this measure does include low frequencies down to 16 Hz and also guidelines for judging the potential for noise induced vibration.

RC Criteria measures the quality of sound using five different categories. The term "neutral" describes the desired sound quality rating while all other measurements remain undesirable. It is important to note that it is particularly difficult to quantify the degree of potential annoyance from either an "R" or "H" condition.

Sound Quality Measures:

1. N = Neutral Spectrum (desired).
2. R = Rumble, Low Frequency.
3. H = Hiss, High Frequency.
4. T = Tonal, Discrete Frequencies.
5. RV = Acoustically Induced Perceptible Vibration.

RC Calculation Procedure:

1. Average the 500, 1,000, and 2,000 Hz octave band sound data to determine the RC rating magnitude. (This is the Preferred Speech Interference Level).
2. Define the RC curve by plotting a straight line with a –5 dB/OB slope.
3. Assign an "R" rating if any of the sound levels in the frequency range below 1,000 Hz exceed the curve by more than 5 dB.
4. Assign an "H" rating if any of the sound levels in the frequency range at or above 1,000 Hz exceed the curve by more than 3 dB.
5. Assign a "RV" rating if either the 16 or 31.5 Hz sound levels protrude up into the "A" or "B" range.
6. Assign a "T" rating if noticeable tones are present.
7. Assign an "N" rating if none of the above conditions are met.

SOUND LEVEL TOLERANCE

The following scale demonstrates the impact of changes in the sound level, as measured by increasing or decreasing dB levels. Understanding how changing sound levels impacts individuals perception of noise is important when determining the acceptable variations in mechanical or HVAC air distribution system noise levels.

Level Change (dB)	Subjective Change	Change In Sound Energy	Specification Application
1	Not detectable	11% change	--
3	Barely detectable	100% change	Excellent for facilities where sound is critical (theatre)
5	Clearly noticeable	300% change	Excellent for facilities where sound is non-critical (office)
10	Twice as loud	1,000% change	

Based on the information listed above, the tolerance for variance in sound should range between 3 and 5 dB for both the NC and RC Criteria ratings. Specifying an acceptable 3 dB variation represents a very tight specification and applies best to facilities where sound levels are extremely critical. Such applications might include movie theatres or performing art centers.

Specifying an acceptable 5 dB variation represents a more reasonable specification tolerance and applies best to facilities where sound levels are important, but not critical. Such applications might include office buildings or retail establishments.

Sample specification statement: *“For a design noise criteria of NC or RC(N) of XX, up to a 5 dB point increase will be allowed in the field measurements.”*

ASHRAE Sound Criteria Guidelines Table

The following table shows the ASHRAE developed RC Guidelines from Table 34 in Chapter 47 Sound and Vibration Control (Ref. 1).
Table 34: Design Guidelines for HVAC-Related Background Sound in Rooms[1]:

Room Types	**RC(N) (QAI[f] □ 5 dB[a,b])**
Residences, Apartments, Condominiums	25 to 35
Hotels/Motels	
- Individual rooms or suites	25 to 35
- Meeting/banquet rooms	25 to 35
- Corridors, lobbies	35 to 45
- Service/support areas	35 to 45
Office Buildings	
- Executive and private offices	25 to 35
- Conference rooms	25 to 35
- Teleconference rooms	25 (max)
- Open-plan offices	30 to 40
- Corridors and lobbies	40 to 45
Hospitals and Clinics	
- Private rooms	25 to 35
- Wards	30 to 40
- Operating rooms	25 to 35
- Corridors and public areas	30 to 40
Performing Arts Spaces	
- Drama theaters	25
- Concert and recital halls[c]	
- Music teaching studios	25
- Music practice rooms	30 to 35
Laboratories (with fume hoods)	
- Testing/research, minimal	
- Speech communication	45 to 55
- Research, extensive telephone use, speech communication	40 to 50
- Group teaching	35 to 45
Church, Mosque, Synagogue	
- General assembly with critical music programs[c]	25 to 35
Schools[d]	
- Classrooms	25 to 30
- Large lecture rooms	25 to 30
(without speech amplification)	25
Libraries	30 to 40
Courtrooms	
- Unamplified speech	25 to 35
- Amplified speech	30 to 40
Indoor Stadiums, Gymnasiums	
- Gymnasiums and natatoriums[e]	40 to 50
- Large seating-capacity spaces with speech amplification[e]	45 to 55

[a] *Values and ranges are based on judgment and experience, not on quantitative evaluations of human reactions. They represent general limits of acceptability for typical building occupancies. Higher or lower values may be appropriate and should be based on a careful analysis of economics, space usage, and user needs.*

[b] *When quality of sound in the space is important, specify criteria in terms of RC(N). If quality of sound in the space is of secondary concern, the criteria may be specified in terms of NC or NCB levels of similar magnitude.*

[c] *An experienced acoustical consultant should be retained for guidance on acoustically critical spaces (below RC 30) and for all performing arts spaces.*

[d] *Some educators and others believe that HVAC-related sound criteria for schools, as listed in previous editions of this table, are too high and impede learning for affected groups of all ages. See ANSI Standard S12.60-2002 for classroom acoustics and a justification for lower sound criteria in schools. The HVAC component of total noise meets the background noise requirement of that standard if HVAC-related back-ground sound = RC 25(N).*

[e] *RC or NC criteria for these spaces need only be selected for the desired speech and hearing conditions.*

[f] *Table uses Quality Assistant Indicator (QAI), from the revised RC Mark II sound criteria descriptor. Note that the original RC sound descriptor is fine to use for design and commissioning activities. RC Mark II has been found best for diagnostic purposes. For more information on sound criteria refer to Chapter 7 Sound and Vibration in reference 2 and also in the Chapter referenced above.*

SOUND CHARACTERISTICS: SOURCE, PATH AND RECEIVER

If examined as an entire system, sound as it pertains to the air distribution system can appear overwhelming. Breaking down the entire system into three main components, Source, Path and Receiver, allows for easier and more efficient design, evaluation and troubleshooting activities.

Terms:

1. Source = Equipment or object that actually creates the sound (ex: packaged rooftop unit or air handler).
2. Path = Equipment or objects that delivers the sound to the space (ex: ductwork or diffuser).
3. Receiver = Person or object that hears / receives the sound (ex: person, animal or inanimate object).

Sound Source

Source refers to the equipment or object that actually creates the sound. Items in the source category typically create sound that will travel through either the air or a physical structure to an indoor or outdoor location. Sources can be common or known as in the case of supply fan dB ratings or uncommon and unknown (not rated) such as the specific sound that radiates from just the compressors and fans located in a condenser section.

Indoor Sound Source: Airborne
Several sound sources such as fans, equipment casing and even airflow create sound that will travel by air to the indoor area. Fans are one of the most common known and rated airborne indoor sound sources. Examples include supply fans at the air discharge outlet and air return inlet. Most manufacturers will list their equipment’s Sound Power Levels for these categories.

Although often overlooked, airflow is also another typical known and rated airborne indoor sound source. Examples include high velocity air that interacting with the mechanical system components produces high and low frequency sounds and turbulence noise. Sound levels or information from items such as the casing surrounding a supply, return or exhaust fan or the movement of compressors and fans in the condenser section are seldom known or provided for.

Indoor Sound Source: Structure Borne
Fans, compressors and airflow also create sound that will travel through a physical structure to the indoor area. This sound typically travels through the structure in the form of a vibration. On lightweight building structures this vibration can have a large impact and care should be taken to separate the structure from the equipment using vibration isolation curbs or components. The vibration levels for mechanical equipment are typically an unknown and non-rated sound source.

Outdoor Sound Source: Airborne
Mechanical equipment is the primary source that creates sound that will travel through the air to an outdoor location. The A-Weighted Sound Level rating provides the sound a piece of equipment will generate at a given distance from the machinery. Outdoor sound sources typically do not travel through a physical structure.

Sound Path

Path refers to the equipment or objects that delivers the sound to the space. There are several main paths that sound can travel including routes through the supply duct and return duct work and air distribution systems as well as the bottom of the equipment casing.

Indoor Sound: Supply Path

One of the most common areas of sound for a mechanical piece of equipment will come from the discharge air outlet. Although less common, sound can also come from the side of the roof curb. Depending on the ductwork system configuration, the sound from the mechanical equipment cans even cause problems as far along as the inlet at the air terminal unit or directly at the supply grille, register or diffuser.

Indoor Sound: Return Path

Like in the supply path, the most common areas of sound in the return path for a mechanical piece of equipment will come from the air return inlet. Watch out for a return ductwork system that is relatively short and has an elbow just below the return air intake on the bottom of the unit. While this configuration may be adequate for applications such as warehouses and stores with high ceilings, it can produce unacceptable results for other occupied spaces. Adding an internal duct liner or taking other preventative steps may solve this issue.

Indoor Sound: Bottom of Equipment Casing

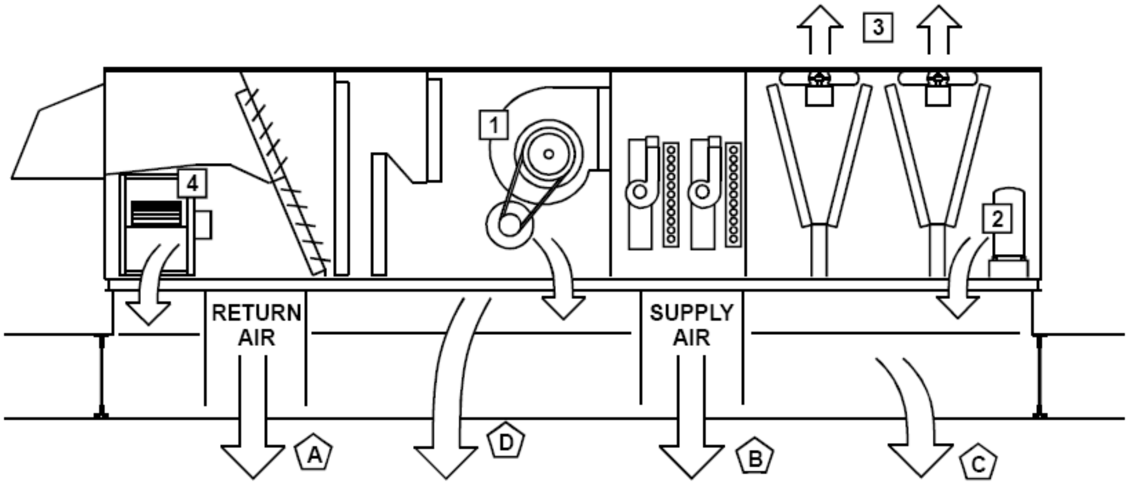
The bottom casing of a piece of mechanical equipment can serve as a sound path from items such as fans and compressors (most common source). At this point, there is not a standardized method for obtaining the sound data from this sound path. For most applications and equipment, the sound from the equipment casing typically remains of secondary concern to the sound from the discharge and return air openings. Exceptions to this rule include equipment that has been set on a roof curb that is entirely open to the building below.

Outdoor Sound Paths

Outdoor sound paths are typically related to sound radiated from the condenser section (compressor and fans), outside air intake, and exhaust and relief air outlets). The condenser section is typically the major contributor to the outdoor sound path, especially when the receiver has a line-of-sight view of the condenser section.

While screen walls and sound barriers can provide significant sound reductions, there are some issues to watch out for. Screen walls and sound barriers that are either too close or too tall can short circuit the airflow through the condensing section, delivering warmer than ambient cooling air directly back into the condenser coils. This may decrease the thermal performance. Be sure to follow the manufacture’s guidelines to prevent this effect.

For additional information on how to properly reduce or block outdoor sound, please reference Appendix III.



Sources of Unit Noise
1. Indoor blower
2. Compressors
3. Outdoor fans
4. Exhaust fans

Sound Paths
A. Return duct
B. Supply duct
C. Unit base
D. Building

Sound Receiver

Receiver refers to the person or object that actually hears the sound. As discussed before, the receiver does not always have to be a person; it might be an animal or piece of sensitive electronic equipment. Ratings such as the NC and RC Criteria apply to the area the receiver occupies and help to set the specification for what is an acceptable or unacceptable sound level.

SOUND ANALYSIS

The design phase of a project is the ideal time to perform the HVAC air distribution sound analysis. Performing an accurate and comprehensive analysis is one of the best ways to ensure the HVAC air distribution system will deliver acceptable sound levels in the most cost effective manner. This also helps to eliminate expensive rework or long term problems if rework is not an option due to excessive costs.

If a building owner chooses not to spend the money to fix the sound issues, other problems may arise as a result of the poor design and higher than acceptable sound levels. For instance, several studies have been conducted and show that noisy office areas can affect the productivity of office workers while noisy classroom areas are distracting to students and can have a negative impact on the learning effectiveness of children.

INDOOR SOUND ANALYSIS

Performing an indoor sound analysis requires some basic information including the architectural, structural and mechanical drawings. This information provides the basic layout of the mechanical equipment location on the roof as well as the air duct distribution system. It is also advisable to have the equipment schedules and submittal information to obtain accurate equipment Sound Power Levels.

Thanks to computer programs, electronic spreadsheets and various calculation methodologies there are numerous ways to actually perform the sound analysis. One of the best references for performing this type of analysis is from chapter 47 of ASHRAE's 2003 Applications Handbook[1], titled Sound and Vibration Control. Example 8 from this section, entitled HVAC Noise Reduction Design Procedures, provides a calculation tutorial procedure for a packaged rooftop unit. This specific example considers the supply air outlet, return air inlet and supply duct breakout as well as the regenerated sound from the ductwork airflow.

ARI Standard 885 – 1998 (with 2002 Addendum), Procedure for Estimating Occupied Space Sound Levels in Application of Air Terminals and Air Outlet[3], also provides some valuable information. This includes sound attenuation of duct elements and the acoustical room effect required to convert from Sound Power Levels to Sound Pressure Levels in different spaces and with various duct borne and breakout noise levels.

During the sound analysis remember that ductwork has a limited amount of sound transmission loss and high sound levels inside the ductwork can breakout and potentially cause a problem. This typically occurs close to the mechanical equipment.

OUTDOOR SOUND ANALYSIS

Performing an outdoor sound analysis requires some basic information including the type of sound barrier, screen or parapet wall. Chapter 47, Sound and Vibration Control, in the ASHRAE 2003 Applications Handbook, also serves as a great reference tool for determining how to perform an outdoor sound analysis.

ACOUSTICAL DESIGN PROCESS

The acoustical design and construction of a facility should proceed along well-established procedures and processes. A summary of the basic steps is as follows:

Summary of Basic Steps:
1. Establish acoustical criteria for sound isolation, interior room acoustics, and background sound levels.
2. Use space planning to establish acoustical compatible adjacencies and accommodations.
3. Select architectural and mechanical building systems that will meet the acoustical criteria needs.
4. Use selected building systems in design of rooms and spaces that will meet functional needs and sizes.
5. Review materials and equipment required for construction to meet acoustical needs.
6. Observe construction to be sure acoustical criteria will be met.
7. Test acoustical performance after construction is completed.
8. Perform any modifications as needed to meet acoustical requirements.
9. Retest, as required, to verify acoustical performance.

HVAC AIR DISTRIBUTION SYSTEM DESIGN GUIDELINES

There are several simple ways to help ensure an HVAC air distribution system meets the required sound power levels. These include:

Guidelines:
1. Perform a comprehensive sound analysis.
2. Follow the acoustical design process procedure.
3. Understand and be aware of sound rating specifications including NC / RC / NR / A-weighted (dBA).
4. Use a balanced sound spectrum approach because the quality of sound is often as important as the level. It is important to eliminate distinct tones, clicks, rumbles, and other annoying sounds and noticeable vibration.
5. Avoid placing the mechanical equipment and ductwork in or close to sound sensitive location such as conference rooms or offices.
6. Design ductwork according to Sheet Metal and Air Conditioning Contractors' National Association, Inc. (SMACNA) guidelines including 1) HVAC Duct Construction Standards, Metal and Flexible 2) Guidelines for Roof Mounted Air-Conditioner Installations.
7. Select diffusers that have a NC Criteria rating point at least 10 dB below room design criteria. Watch out for unacceptable diffuser noise in sound critical areas such as meeting spaces.
8. Use good ductwork design and the appropriate air diffusion equipment to minimize sound levels from high airflow velocities, turbulence and vibration.
9. Be careful of additive effects. Multiple smaller source contributions can add up overall.
10. When selecting air terminal units do not exceed 2/3 rated capacity and limit inlet static pressure to 1 to 1.5" wc if possible (2" maximum). Also avoid extreme high and low fan speeds.
11. When installing air terminal units, do not rigidly mount terminals to structure and limit use of flexible ductwork to 3' from air terminal unit to GRD inlet.

For additional information regarding HVAC air distribution system sound level design, product selection and remediation techniques, please review the Additional Design Guideline Information or Appendix sections of this document.

ADDITIONAL DESIGN GUIDELINE INFORMATION

Outdoor Sound Path, Screening

One of the best ways to reduce sound from an outdoor sound path is to use either simple or acoustically lined screening walls. At a minimum, the sound barrier must block the line of sight between the top of the mechanical equipment and the receiver location of concern. For increased effectiveness, make sure the barrier has a height that is at least three feet over the difference between the receiver's direct line of sight and the mechanical equipment. See the Appendix for more information. (We need to add Appendix with Design Guidelines, Sound Barrier discussion, and Calculation Example.)

While these walls are extremely effective, there are several issues to watch out for. First, make sure the unit and walls have not been positioned in a manner that might allow the discharge air from the condenser fan to re-circulate back through the condenser coil. This will reduce the thermal efficiency of the mechanical equipment and under extreme conditions can cause the unit to overload and possibly shut down under high demand requirements. Follow the manufacturer's guideline on placement of the mechanical equipment next to obstructions and obstacles.

Outdoor Sound Path, Mechanical Components

Compressors, condenser fans and even outside air intake or relief air discharge louvers can be a significant source of sound. The best way to prevent any issues is to select equipment that has a sufficient unit sound level to meet the application requirement. Although it is possible to retrofit or replace specific components with items that have a lower sound rating, this action typically has a high cost and low satisfaction level as compared to selecting the right equipment during the design and specification phase of the project.

Supply Ductwork

Using acoustical duct treatments and good ductwork design can help lower overall air distribution sound levels and help control ductwork breakout sound. Specific steps include:

Acoustical Duct Treatments:
1. Internally line the sheet metal ductwork with fiberglass duct liner that has a thickness of at least 1" thickness and a density of at least 1-1/2 lbs./cu. ft. for basic sound prevention performance.
2. Use a 2" thickness duct liner to increase the ductwork attenuation, especially at lower frequencies.
3. Use special double wall ductwork with interior perforated metal sheet to reduce sound transmissions within the ductwork (will likely add cost and cost and weight).
4. Use package or modular duct silencers or "sound traps" in special circumstances where the situation calls for a high amount of attenuation in a limited length (will likely cause increased pressure drop).
5. Use sheetrock directly on ductwork.
    a. Screw two layers of 5/8" type 'X' sheetrock directly to all sides of the ductwork.
    b. Start at the base of the mechanical equipment and continue past the sound critical area.
    c. Note that this process will add between 4 to 5 lbs/sq. ft. of weight.
    d. Increase strength or number of support straps and/or hangers to account for the extra weight.
6. Use a sheetrock enclosure around the ductwork.
    a. Enclose the ductwork with sheetrock.
    b. Include low-density (around 0.75 to 1.0 lbs/cu. ft.) fiberglass insulation with a minimum 2" thickness.
    c. Place insulation between the ductwork the sheetrock enclosure.
    d. Use one or more layers of sheetrock as needed.
    e. Differs from the example above in that the sheetrock enclosure will not directly contact the ductwork.

Return Ductwork

Although the sound levels in the return path are not as high as the supply path, care should be taken to treat the return path in a similar manner as the supply path mentioned above. Following many of the same basic guidelines and acoustical ductwork treatments can help reduce the sound levels and prevent potential noise problems.

It is important to note that sound levels can be especially high for return air systems with little or ductwork. In these situations, the sound energy concentrates in a small region instead of being dissipated over a longer duct run. This can lead to potential sound level problems.

The use of several smaller intakes is popular in many of today's return path ductwork designs. These designs increase the acoustical end reflection loss and help to prevent noise issues. Using a square cut rather than a taper or flair cut will also help to increase the end reflection loss and further improve sound level control.

Air Terminal Units and Grilles, Registers and Diffusers

The last elements in the sound path typically include a supply air outlet grille, register, or diffuser (GRD). These components receive conditioned air from one of two sources, either directly from a packaged rooftop unit or through an air terminal unit as in the case of variable air volume zoning systems. In some cases, the sound path may also include a return air outlet, which is most common on ducted systems. Because the air outlets are either close to or in the occupied space, the potential for noise problems remains an important concern.

Air terminal units feature sound ratings based on ARI Standard 880, which uses the ASHRAE Standard 130 test method. Sound power levels typically include both discharge and radiated sound level data from the 125 to 4,000 Hz octave frequency bands. While application ratings in terms of NC Criteria are available, they can be extremely confusing and are a common source of application error because the actual room the equipment will serve does not have the same acoustics as the one that has been used for the rating.

For best design, use and specify sound power levels, not the NC Criteria rating. Next, perform acoustical calculations using ARI Standard 885 to ensure that the equipment meets the design sound criteria. In addition, calculations based on the ASHRAE Algorithm type procedures are also useful.

Air outlet grills, registers and diffusers (GRDs) feature sound ratings based on ARI Standard 890, which uses the ASHRAE Standard 70 test method. Sound power levels typically include both supply and return application sound level data for the 125 to 4,000 Hz octave frequency bands. Ratings for this equipment have been catalogued in terms of a special version of the NC Criteria, which subtracts 10 dB from the actual rating point. The industry has adopted this practice as standard, based on the fact that the procedure accounts for the conversion of sound power levels to sound pressure levels due to the acoustical room effect.

It is important to note that different rooms have different acoustical effects, which depend on a variety of factors including how reverberant the space is, the number of GRDs present and the distance of the outlet or inlet from the receiver. These factors may cause the actual equipment to operate at very different noise levels than the 10 dB as defined in the test data. Once again, best practice calls for acoustical calculations per ARI Standard 885 to ensure the equipment meets the sound design criteria. In addition, calculations based on the ASHRAE Algorithm type procedures are also useful.

For modulating diffusers (equipment that features an air terminal unit, grill, register and diffuser in one combined piece of equipment) it is best to perform a complete sound analysis that considers all the various components. This equipment is common on many variable air volume zoning systems.

Indoor Sound Levels and Equipment Location

Placement of mechanical equipment is key to helping control indoor sound levels. For many projects however, sound does not play a prominent role in where to place the equipment. Instead the ductwork location often determines the final placement of the equipment because of the desire to limit the amount of ductwork required for air distribution within the building. This priority may result in placing equipment above sensitive sound areas such as conference rooms or enclosed offices.

If possible, it is often best to place the equipment over non-critical sound locations such as service areas or restrooms. These areas do not have the same sound dampening requirements or potential problems if louder than anticipated sound levels do occur. Placing mechanical equipment in these areas can also help save on construction costs by reducing sound eliminating equipment such as lined ducts or spring isolation curbs and components. More importantly, it may also eliminate the need for costly rework in the case that louder than anticipated sound levels do occur.

In addition, care should also be taken to place equipment near structural support columns instead of center spans. The extra support helps to mitigate the sound from unit vibration, once again potentially saving money for sound elimination components or costly rework.

Structural Considerations

Roof

Ideally the building's roof and structure should consist of building materials that are relatively stiff and have a high surface mass. One example of such material is a 4" thick slab of concrete. The Sound Transmission Class (STC) for this material is approximately 50, an excellent rating that helps control the sound levels transmitted from the mechanical equipment to the occupied space. Unfortunately while this material has an excellent STC rating, it is also exceedingly heavy at 40 lbs. per sq. ft. and as a result is often too expensive or impractical for many commercial facilities.

While concrete does an excellent job of helping to control and reduce sound, unfortunately many commercial buildings features roofs made from 22 gauge corrugated metal deck resting on bar joists with extra structure added as needed for heavier mechanical equipment such as large packaged rooftop units. This type of roof construction typically only weighs around 4 lbs. per sq. ft., is much more economical than concrete and has a Sound Transmission Class (STC) of approximately 35. Note that the STC rating is a measure of the sound transmission loss of a material layer determined per ASTM. Numerically it is the sound transmission loss at 500 Hz while satisfying requirements set forth in Standard E90 for laboratory measurements and E336 for field measurements.

Related to sound control and reduction, it is important to note that the lower rated STC materials will not perform as well as the concrete slab. It is important to take additional precautionary steps to control sound when dealing with this type of buildings.

Ceiling

Like building roof construction, different building ceiling materials will also have different sound transmission loss and attenuation properties. Ranked from best to worst, materials that help control sound include fiberglass with special backings such as aluminum foil, mineral board, sheet rock and plaster ceiling tiles. Standard fiberglass tiles provide little sound transmission loss and attenuation.

For additional information on ceiling material sound ratings please reference AARI Standard 885 and Chapter 47 of the ASHRAE HVAC Applications Handbook[1].

Attenuation

Placing fiberglass batts on top of any of these ceiling tile materials can help increase the sound attention, however only at higher frequencies. This helps to reduce the high frequency sound transmissions commonly found in around ceiling return grilles and luminary slots. This preventative measure does little for low frequencies.

Vibration Isolation

Vibration isolation is a popular way to help reduce HVAC air distribution system sound levels. Vibration isolation equipment includes such items as vibration isolation curbs and internal vibration mounts for supply and exhaust fans, motors and compressors. Vibration isolation curbs come in a wide variety of configurations from a large number of specialty curb manufacturers. Internal vibration isolation mounts for components typically features 2" static deflection springs. For the best isolation of components, the mechanical equipment design will isolate the entire assembly such as the compressors and compressor deck. It is also important to note that on units with variable speed fans the lowest operating speed will typically dictate the amount of required static deflection.

When installing the mechanical equipment there are several simple precautions an installing contractor should take when using vibration isolation for curbs or components. First, make sure that all shipping bolts and fasteners have been removed from the curbs, fan and compressor sections. Failure to do so will result in potential damage to the unit and / or no sound transmission loss or attenuation. Also make sure that all connections to the mechanical equipment featuring rigid connections such as drain lines, electrical power conduit and ductwork have been attached with rubber lined clamps and supports.

The use of either vibration isolation curbs or component mounts in the equipment depends on a variety of factors including the overall unit sound levels, placement of the mechanical equipment on the roof as well as the building roof and structure materials. In general, buildings with heavy roof construction and closely spaced building columns do not require any vibration isolation while buildings made of lightweight materials with long gaps between building columns or unit placement above sound critical areas may require additional vibration isolation measures. Low sound units may not receive a large benefit from adding vibration isolation tactics while louder equipment may require these measures.

Supply Fan Operating Conditions

When it comes to HVAC air distribution problems with high sound levels at low frequencies, many individuals fail to properly diagnose the problem, instead just treating the symptoms. Although a popular diagnosis, mechanical vibration and ductwork system problems are typically not the root cause, even though there is often considerable ductwork rumble due to the air turbulence problems present. Therefore, while treating this problem with vibration isolation, stiffer ductwork or sheetrock walls may seem like the logical choice, many times these measures prove ineffective because they do not solve the actual problem.

Often times supply fan operating conditions are the root cause of high sound levels with low frequency problems. These problems can occur in both forward curved and backward inclined supply fans if they operate in the zone of unstable operation. Supply fans that have the ability to increase or decrease speed due to the use of a variable frequency drive are often times a good choice to avoid high level low frequency sound problems.

Receiver Room Acoustics

Enclosed spaces that feature high ceilings, deep ceiling plenums, large room volumes, and greater separation distances between sound sources and receivers will reduce the sound impact from HVAC mechanical equipment. To improve the acoustical room effect and lower interior sound levels, use acoustical absorptive ceilings and wall panels and install carpet instead of harder floor materials such as ceramic tiles.

Existing HVAC Air Distribution Systems

Even with the best sound analysis and design, noise problems do occasionally occur in commercial buildings. This can happen for a variety of reasons including when the use of a space has changed and now, what was once a non-critical noise area such as a storage closet, has been converted to an office space or a conference room.

Because there are so many variables in the air distribution equipment, this application and design guideline cannot provide a comprehensive set of solutions. Each situation requires detailed analysis to determine the root cause of the sound source and the best way to solve the problem. It is important to note that there is often a solution for almost any sound problem; it just takes the proper amount of time and money to solve the issue. The challenge is typically not finding a solution; it is finding the most cost effective and time sensitive solution.

While there is no one single comprehensive solution that will solve all sound problems, there are several solutions that are worth mentioning:

<u>Solutions:</u>
1. Increase the length of internally lined ductwork to provide more duct borne sound attenuation.
2. Lower the airflow velocity to reduce airflow generated sound and turbulence in the duct system.
3. Increase the mass of equipment or ductwork to improve sound transmission loss and lower breakout and casing radiated sounds.
4. Use vibration isolation tactics for mechanical equipment components or roof curbs.
5. Alleviate low frequency sound issues by changing the system operating conditions to help ensure supply fans do not operate in the zone of unstable operation.

REFERENCES

1. ASHRAE, *HVAC Applications Handbook*, 2003, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

2. ASHRAE, *Fundamentals Handbook*, 2005, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

   For ASHRAE membership request and reference information from the ASHRAE Bookstore, please go to www.ashrae.org.

3. ANSI/ARI Standard 885–1998 (with 2002 Addendum), Procedure for Estimating Occupied Space Sound Levels in Application of Air Terminals and Air Outlet, Air conditioning and Refrigeration Institute, 4100 North Fairfax Drive, Suite 200, Arlington, VA 22203, U.S.A.

APPENDICES

Appendix I

The following provides additional information for the design of HVAC systems from a suitable sound level standpoint. It applies to both central station air handling units and central plants and also to typical rooftop unit HVAC air distribution systems. The HVAC Noise Reduction Design Procedure makes use of information taken from Chapter 47 of the ASHRAE HVAC Applications Handbook with some additional comments specifically for packaged rooftop unit applications.

HVAC Noise Reduction Design Procedures:
These HVAC air distribution systems design procedures address the 63 to 4000 Hz octave band frequency range. Although it is desirable to extend this frequency range down into the 31.5 Hz octave band, acoustical calculations below the 125 Hz octave band are not reliable. With few exceptions, if acoustical design criteria are met at 4000 Hz, then the 8000 Hz requirements should also be met.

These guidelines and other guides maximize the probability of meeting acoustical design criteria in the 31.5 to 8000 Hz octave bands. Thus, there is a reasonable probability that the acoustical design criteria will be met when the following requirements are met:

Requirements:
1. Must design systems in accordance with the equipment selection, placement, and integration guidelines in ASHARE HVAC Applications Handbook, Chapter 47, Sound and Vibration Control, other ASHRAE guides and manufacturers' application notes and bulletins.
2. Must perform acoustical calculations based on Chapter 47 and equipment manufacturer information. Indicate that the system will not exceed the selected acoustical design criteria values in the 63 to 4000 Hz octave band frequency range.

The suggested design procedure uses the RC Criteria rating although the designers can use other ratings, such as the NC Criteria or NCB Criteria.

Design Procedure:
1. Determine the design goal for HVAC air distribution system noise for each critical area according to its use and construction. Choose the desirable RC criterion from guideline Table 34 from the Chapter. A balanced sound spectrum is often as important as the overall sound level.
2. Select equipment and fittings, such as air inlet and outlet grilles, registers, diffusers, and air terminal and fan-coil units that radiate sound directly into a room and will be quiet enough to meet design goals.
3. Complete an initial design and layout of the HVAC air distribution system using acoustical treatments such as lined ductwork and duct silencers where appropriate. Consider supply, return, and exhaust air paths.
4. Add the sound attenuation and sound power levels associated with the central fan(s), fan-powered terminal units (if used), and duct elements between the central fan(s) and the room of interest. Then convert to the corresponding sound-pressure levels in the room. For a more complete estimate of resultant sound levels, start at the air handling unit or fan and consider regenerated and self noise from duct silencers and air inlets and outlets caused by the airflow itself. Investigate both the supply and return air paths in similar ways. Investigate and control possible duct sound breakout when fans are adjacent to the room of interest or roof-mounted fans are above the room of interest. Combine the sound contribution from all paths into the occupied space of concern. See Example 8 for a sample calculation procedure for supply and return air paths, including duct breakout noise contributions. See the Example in Appendix II below.
5. If the mechanical equipment room or rooftop unit is adjacent to the room of interest, determine the sound-pressure levels in the room of interest associated with sound transmitted through the mechanical equipment room wall or roof/ceiling. Consider such equipment as air handling units, packaged rooftop units, ventilation and exhaust fans, chillers, pumps, electrical transformers, and instrument air compressors. Also consider the vibration isolation requirements for equipment, piping, and ductwork.
6. Combine on an energy basis (see Example 8 for sample calculation procedures) the sound-pressure levels in the room of interest associated with all sound paths between the mechanical equipment room or roof-mounted unit and the room of interest.
7. Determine the corresponding RC Criteria level associated with the calculated total sound-pressure levels in the room of interest. Take special note of the sound quality indicators for possible rumble, roar, hiss, tones, and perceivable vibration.
8. If the RC level exceeds the design goal, determine the octave frequency bands in which the corresponding sound pressure levels have been exceeded and the sound paths associated with these octave frequency bands. If resultant noise levels are high enough to cause perceivable vibration, consider both airborne and structure-borne noise.

9. Redesign the system, adding additional sound attenuation to paths that contribute to excessive sound-pressure levels in the room of interest. If resultant noise levels are high enough to cause perceivable vibration, then major redesign and possible use of supplemental vibration isolation for equipment and building systems may be required.
10. Repeat Steps 4 through 9 until the desired design goal has been achieved. Involve the complete design team where major problems have been found. Often, simple design changes to building architectural and equipment systems can eliminate potential problems once the problems have been identified.
11. Repeat Steps 3 through 10 for every room that requires analysis.
12. Make sure that noise radiated by outdoor equipment such as air-cooled chillers and cooling towers will not disturb adjacent properties or interfere with criteria established in Step 1 or any applicable building or zoning ordinances.

Appendix II

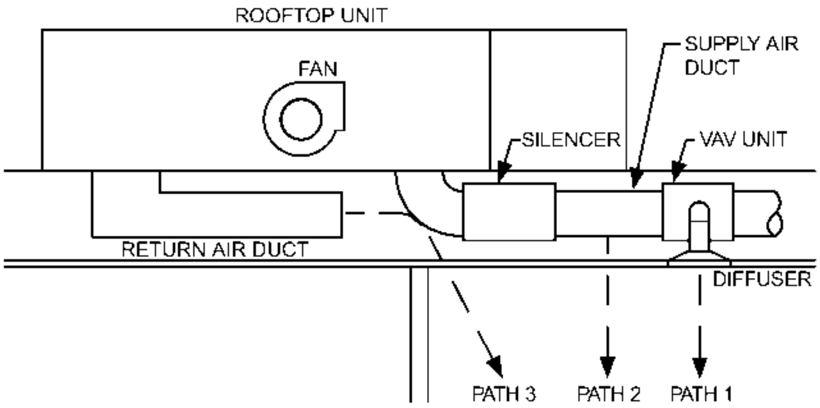
The following provides additional information for the sound analysis of a packaged rooftop unit HVAC air distribution system. The example is taken from Chapter 47 of the ASHRAE HVAC Applications Handbook.

Example 8 (From Chapter 47 of the ASHRAE HVAC Applications Handbook[1])
Chapter 47 demonstrates the proper way to calculate equipment- and airflow-generated sound-power levels and sound-attenuation values associated with the elements of HVAC air distribution systems. This example shows how the combined information can determine sound-pressure levels associated with a specific HVAC air distribution system. A summary of tabulated results has been listed for reference.

The packaged rooftop unit supplies air to the HVAC air distribution system (Figure 34). The receiver room has been located directly below the unit. The room has the following dimensions: length = 20 ft, width = 20 ft; and height = 9 ft.

This example assumes that the roof penetrations for the supply and return air ducts have been sealed and there are no other roof penetrations. The supply side of the rooftop unit is ducted to a VAV terminal control unit serving the room in question. A return air grille conducts air to a common ceiling return air plenum. The short rectangular return air duct directs return air back to the rooftop unit.

Fig. 34 - Sound Paths Layout



Sound Path Examination:
1. Path One = Fan airborne supply air sound that enters the room from the supply air system through the ceiling diffuser.
2. Path Two = Fan airborne supply air sound that breaks out through the wall of the main supply air duct into the plenum space above the room.
3. Path Three = Fan airborne return air sound that enters the room from the inlet of the return air duct.

Path 1, Manufacturer's Fan Supply Air and Return Air Information:

		Octave Band Center Frequency, Hz						
No.	**Description**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**
1	Fan—Supply air, 7000 cfm, 2.5 in. s.p.	92	86	80	78	78	74	71
3	22 in. wide (dia.) unlined radius elbow	0	–1	–2	–3	–3	–3	–3
	Sum with noise reduction values	92	85	78	75	75	71	68
4	90° bend without turning vanes, 12 in. radius	56	54	51	47	42	37	29
	Sum sound power levels	92	85	78	75	75	71	68
5	22 in. dia. by 44 in. high pressure silencer	–4	–7	–19	–31	–38	–38	–27
	Sum with noise reduction values	88	78	59	44	37	33	41
6	Regenerated noise from above silencer	68	79	69	60	59	59	55
	Sum sound power levels	88	82	69	60	59	59	55
7	22 in. dia. by 8 ft unlined circular duct	0	0	0	0	0	0	0
10	Branch pwr. div., M-22 in. dia., B-10 in. dia.	–8	–8	–8	–8	–8	–8	–8
	Sum with noise reduction values	80	74	61	52	51	51	47
11	Duct 90° branch takeoff, 2 in. radius	56	53	50	47	43	37	31
	Sum sound power levels	80	74	61	53	52	51	47
12	10 in. dia. by 6 ft unlined circular duct	0	0	0	0	0	0	0
13	Terminal volume register unit (gen. attn.)	0	–5	–10	–15	–15	–15	–15
14	10 in. dia. by 2 ft unlined circular duct	0	0	0	0	0	0	0
15	10 in. wide (dia.) unlined radius elbow	0	0	–1	–2	–3	–3	–3
	Sum with noise reduction values	80	69	50	36	34	33	29
16	90° bend without turning vanes, 2 in. radius	49	45	41	37	31	24	16
	Sum sound power levels	80	69	51	40	36	34	29
17	10 in. dia. diffuser end ref. loss	–16	–10	–6	–2	–1	0	0
	Sum with noise reduction values	64	59	45	38	35	34	29
18	15 by 15 in. rectangular diffuser	31	36	39	40	39	36	30
	Sum sound power levels	64	59	46	42	40	38	33
19	ASHRAE room correction, 1 ind. sound source	–5	–6	–7	–8	–9	–10	–11
	Sound pressure levels—receiver room	59	53	39	34	31	28	22
	Sound pressure levels—receiver room (without regenerated noise considered)	59	49	27	9	1	–3	4

1. Entry #1 = Manufacturer's supply air fan sound power levels.
2. Entry #2 = Sound attenuation associated with the 22 in. diameter unlined radius elbow.
3. Entry #4 = Regenerated sound power levels associated with the elbow attenuation. Requires tabulation to determine sound power levels at elbow exit.
4. Entry #5 = Dynamic insertion loss values of the duct silencer.
5. Entry #6 = Silencer regenerated sound power levels
6. Add logarithmically the sound power levels from entries #1, 2 and 3, denoted by (Log Sum) in the tables where the value in decibels equals 10 log10 (10*A*/10 + 10*B*/10) with *A* and *B* being the values in decibels. Similarly, the dynamic insertion loss values of the duct silencer (5) and the silencer-regenerated sound power levels (6) are included in the table and tabulated.
7. Include the attenuation associated with the 8 ft section of 22 in. diameter duct, entry #7, and the branch power division, entry #10, associated with sound propagation in the 10 in. diameter branch duct.
8. After entry #10, the sound power levels that exist in the branch duct after the branch takeoff are calculated so that the regenerated sound power levels (11) in the branch duct associated with the branch takeoff can be logarithmically added to the results.
9. The sound attenuation values associated with the 6 ft section of 10 in. diameter unlined duct, entry #12, the terminal volume regulation unit, entry #13, the 2 ft section of 10 in. diameter unlined duct, entry #14, and 10 in. diameter radius elbow, entry #15, are included in the table.
10. The sound power levels at the exit of the elbow are then calculated so that the regenerated sound power levels, entry #16, associated with the elbow can be logarithmically added to the results.
11. The diffuser end reflection loss, entry #17, and the diffuser-regenerated sound power levels, entry #18, are included in the table.
12. The sound power levels tabulated after entry #18 represent the sound power levels at the diffuser in the receiver room. Note, that the end reflection from a duct in free space and flush with a suspended acoustical ceiling are assumed to be the same.
13. The final entry in the table is the "room correction," which converts the sound power levels at the diffuser to their corresponding sound pressure levels at the point of interest in the receiver room.

Path 2, Manufacturer's Fan Supply Air and Return Air Information:

No.	Description	63	125	250	500	1000	2000	4000
1	Fan—Supply air, 7000 cfm, 2.5 in. s.p.	92	86	80	78	78	74	71
3	22 in. wide (dia.) unlined radius elbow	0	–1	–2	–3	–3	–3	–3
	Sum with noise reduction values	92	85	78	75	75	71	68
4	90° bend without turning vanes, 12 in. radius	56	54	51	47	42	37	29
	Sum sound power levels	92	85	78	75	75	71	68
5	22 in. dia. by 44 in. high pressure silencer	–4	–7	–19	–31	–38	–38	–27
	Sum with noise reduction values	88	78	59	44	37	33	41
6	Regenerated noise from above silencer	68	79	69	60	59	59	55
	Sum sound power levels	88	82	69	60	59	59	55
7	22 in. dia. by 8 ft unlined circular duct	0	0	0	0	0	0	0
8	Branch pwr. div., M-22 in. dia., B-22 in. dia.	–1	–1	–1	–1	–1	–1	–1
	Sum with noise reduction values	87	81	68	59	58	58	54
9	Duct 90° branch takeoff, 2 in. radius	63	60	57	54	50	44	34
	Sum sound power levels	87	81	68	60	59	58	54
20	22 in. dia. by 20 ft, 26 ga. duct breakout	–29	–29	–21	–11	–9	–7	–5
21	2 ft by 4 ft by 5/8 in. lay-in ceiling	–10	–13	–11	–14	–19	–23	–24
22	Line source—Medium-dead room	–6	–5	–4	–6	–7	–8	–9
	Sound pressure levels—receiver room	42	34	32	29	24	20	16
	Sound pressure levels—receiver room (without regenerated noise considered)	42	30	22	12	1	–6	2

1. Entries #1 through #7 in Path 2 are the same as in Path 1.
2. Entry #8 = Branch power division
3. Entry #9 = Corresponding regenerated sound power levels associated with sound that propagates down the main duct beyond the duct branch
4. Entry #20 = Sound transmission loss associated with the duct breakout sound
5. Entry #21 = Sound transmission loss associated with the ceiling, which considers the integrated lighting and diffuser system including the return air openings
6. Entry #22 = Sound transmission loss associated with the "room correction", converting the sound power levels at the ceiling to corresponding sound pressure levels in the room.
7. Although not specifically considered in this example, noise radiated by a VAV terminal unit can also serve as a significant sound source. Consult the manufacturer for both radiated and discharge sound data.

Path 3, Manufacturer's Fan Supply Air and Return Air Information:

No.	Description	63	125	250	500	1000	2000	4000
2	Fan—Return air, 7000 cfm, 2.5 in. s.p.	82	79	80	78	78	74	71
23	32 in. wide lined square elbow w/o turning vanes	–1	–6	–11	–10	–10	–10	–10
	Sum with noise reduction values	81	73	69	68	68	64	61
24	90° bend w/o turning vanes; 0.5 in radius	77	73	68	62	55	48	38
	Sum sound power levels	82	76	72	69	68	64	61
25	32 in. by 68 in. by 8 ft lined duct	–2	–2	–5	–15	–22	–11	–10
26	32 in. by 68 in. diffuser end ref. loss	–5	–2	–1	0	0	0	0
21	2 ft by 4 ft by 5/8 in. lay in ceiling	–10	–13	–11	–19	–19	–23	–24
27	ASHRAE room correction, 1 ind. sound source	–8	–9	–10	–11	–12	–13	–14
	Sound pressure levels—receiver room	57	50	45	29	15	17	13
	Sound pressure levels—receiver room (without regenerated noise considered)	56	47	42	28	15	17	13

1. Entry #2 = Manufacturer's return air fan sound power levels
2. Entry #23 = Sound attenuation associated with a 32 in. wide lined square elbow without turning vanes
3. Entry #24 = Regenerated sound power levels associated with the square elbow.
4. Entry #25 = Insertion loss associated with a 32 in. by 68 in. by 8 ft rectangular sheet metal duct with 2 in. thick, 3 lb/ft3 fiberglass duct lining
5. Entry #26 = The diffuser end reflection loss
6. Entry #21 = Transmission loss through the ceiling, which considers the integrated lighting and diffuser system, including the return air openings

7. Entry #27 = The room correction, converting the sound power levels at the ceiling to corresponding sound pressure levels in the room.

Total Sound Pressure Levels from All Paths:

Description	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**
Sound pressure levels Path 1	59	53	39	34	31	28	22
Sound pressure levels Path 2	42	34	32	29	24	20	16
Sound pressure levels Path 3	57	50	45	29	15	17	13
Total sound pressure levels—All paths	61	55	46	36	32	29	23
Sound pressure levels—receiver room (without regenerated noise considered)	61	51	42	28	15	17	14

	Octave Midband Frequency, Hz						
	63	125	250	500	1000	2000	4000
Rooftop supply air, 7000 cfm at 2.5 in. of water	92	86	80	78	78	74	71
Rooftop return air, 7000 cfm at 2.5 in. of water	82	79	73	69	69	67	59

The total sound pressure levels in the receiver room from the three paths are obtained by logarithmically adding the individual sound pressure levels associated with each path. From the total sound pressure levels for all three paths, the NC value in the room is NC 42, and the RC value is RC 34(R-H), which is a combination of lower-frequency rumble and higher-frequency hiss.

If the regenerated noise from airflow through the ductwork, silencer, and diffuser is not taken into consideration, the NC value in the room is NC 42, and the RC value is RC 26(R-H). Although the calculation procedure is simplified, the typically higher-frequency regenerated noise is not accounted for in the overall ratings, especially in the RC value; its numeric magnitude is often set by the higher-frequency noise contribution. At a minimum, the self-noise or regenerated noise of the silencers and outlet or inlet devices such as grilles, registers, and diffusers should be considered along with the attenuation provided by the duct elements and dynamic insertion loss of the silencers.

Fig. 35 - Supply Air Portion Layout for Example 8

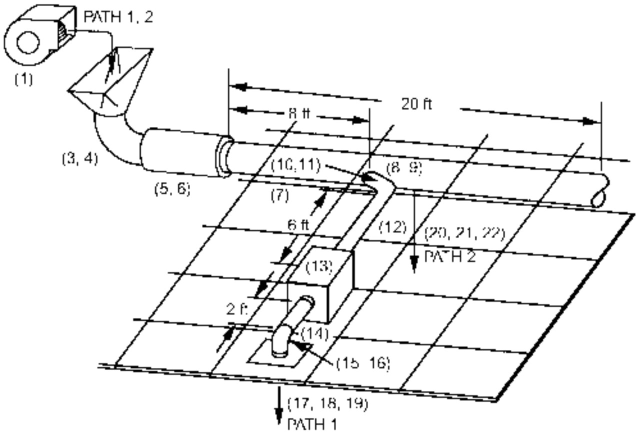
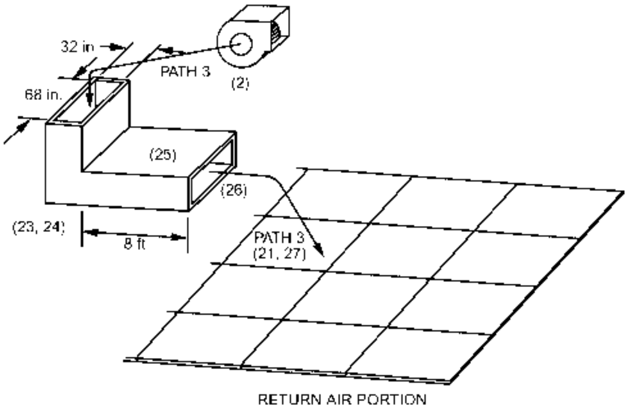


Fig. 36 - Return Air Portion Layout for Example 8



Solution:

Paths 1 and 2 are associated with the supply air side of the system. Figure 35 shows the part of the supply air system associated with the receiver room. The main duct is a 22 in. diameter, 26 ga, unlined, round sheet metal duct. The flow volume in the main duct is 7000 cfm. The silencer after the radiused elbow is a 22 in. diameter by 44 in. long, high-pressure, circular silencer.

The branch junction 8 ft from the silencer is a 45° wye. The branch duct between the main duct and the VAV control unit is a 10 in. diameter, unlined, round sheet metal duct. The flow volume in the branch duct is 800 cfm. The straight duct section between the VAV control unit and the diffuser is a 10 in. diameter, unlined, round sheet metal duct. The diffuser is 15 by 15 in. Assume a typical distance between the diffuser and a listener in the room is 5 ft.

The duct breakout sound is associated with the main duct, which has a length of 20 ft running over the room. The ceiling is comprised of 2 ft by 4 ft by 5/8 in. lay-in ceiling tiles with a surface weight of 0.6 to 0.7 lb/ft2. The ceiling has integrated lighting and diffusers.

Path 3 is associated with the return air side of the system. Figure 36 shows the part of the return air system associated with the receiver room. The rectangular return air duct is lined with 2 in. thick, 3 lb/ft3 density fiberglass duct liner. For the return air path, assume the typical distance between the inlet of the return air duct and a listener is 10 ft.

A commercially available HVAC sound analysis computer program typically performs many of the calculations associated with this type of example; however, hand calculation is often adequate for simpler building systems. The analysis for each path begins at the rooftop unit (fan) and proceeds through the different system elements to the receiver room. The element numbers in the tables correspond to the element numbers contained in brackets in Figures 35 and 36.

Appendix III

Sound Barriers

A sound barrier is a solid structure that intercepts the direct sound path from a sound source to a receiver. It reduces the sound pressure level within its shadow zone. Figure 32 illustrates the geometrical aspects of an outdoor barrier where no extraneous surfaces reflect sound into the protected area. Here the barrier is treated as an intentionally constructed noise control structure. If a sound barrier is placed between a sound source and receiver location, the sound pressure level *Lp* in Equation (24) is reduced by the insertion loss (IL) associated with the barrier.

Table 39 gives the insertion loss of an outdoor ideal solid barrier when
- No surfaces reflect sound into the shadow zone, and
- The sound transmission loss of the barrier wall or structure is at least 10 dB greater at all frequencies than the insertion loss expected of the barrier.

The path-length difference referred to in Table 39 is given by Path-length difference = $A + B – D$ (25) where A, B, and D are as specified in Figure 32.

Fig. 32 - Noise Barrier

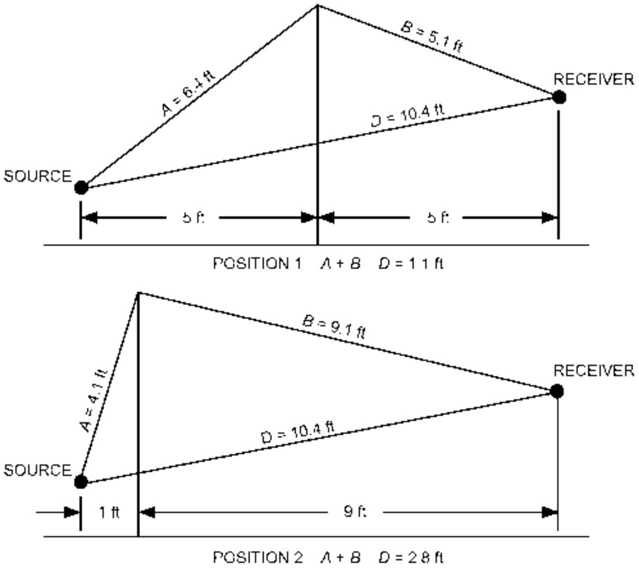


Table 39 Insertion Loss Values of Ideal Solid Barrier:

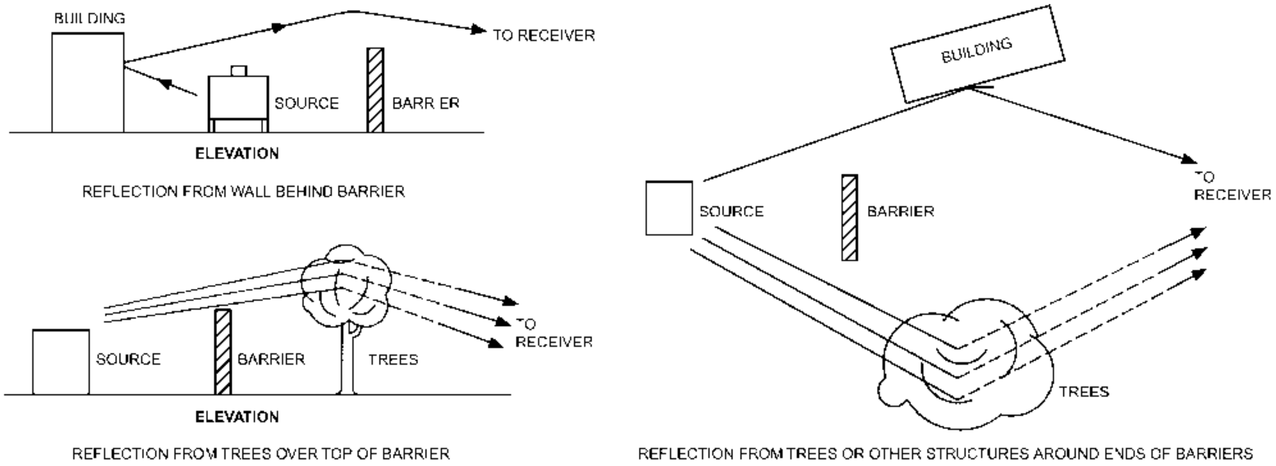
Path-Length Difference, ft	Insertion Loss, dB Octave Midband Frequency, Hz							
	31	63	125	250	500	1000	2000	4000
0.01	5	5	5	5	5	6	7	8
0.02	5	5	5	5	5	6	8	9
0.05	5	5	5	5	6	7	9	10
0.1	5	5	5	6	7	9	11	13
0.2	5	5	6	8	9	11	13	16
0.5	6	7	9	10	12	15	18	20
1	7	8	10	12	14	17	20	22
2	8	10	12	14	17	20	22	23
5	10	12	14	17	20	22	23	24
10	12	15	17	20	22	23	24	24
20	15	18	20	22	23	24	24	24
50	18	20	23	24	24	24	24	24

The limiting value of about 24 dB is caused by scattering and refraction of sound into the shadow zone formed by the barrier. Practical constructions such as size and space restrictions often limit sound barrier performance to 10 to 15 dBA. For large distances outdoors, this scattering and bending of sound waves into the shadow zone reduces barrier effectiveness. At large distances, atmospheric conditions can significantly affect sound path losses by amounts even greater than those provided by the barrier, with typical differences of 10 dBA. For a conservative estimate, the height of the sound source location should be taken as the topmost part of the sound source, and the height of the receiver should be taken as the topmost location of a sound receiver, such as the top of the second-floor windows in a two-floor house or at a height of 5 ft for a standing person.

Reflecting Surfaces

No other surfaces should be located where they can reflect sound around the ends or over the top of the barrier into the barrier shadow zone. Figure 33 shows examples of reflecting surfaces that can reduce the effectiveness of a barrier wall.

Fig. 33 - Reflecting Surfaces That Can Diminish Barrier Effectiveness



Width of Barrier:
Each end of the barrier should extend horizontally beyond the line of sight from the outer edge of the source to the outer edge of the receiver position by a distance of at least three times the path-length difference. Near the ends of the barrier, the effectiveness of the noise isolation is reduced because some sound is diffracted over the top and around the ends. Also, some sound is reflected or scattered from various non-flat surfaces along the ground near the ends of the barrier. In critical situations, the barrier should completely enclose the sound source to eliminate or reduce the effects of reflecting surfaces.

Reflection from a Barrier:
A large, flat reflecting surface, such as a barrier wall, may reflect more sound toward the source than there would have been with no wall present. If the wall produces no special focusing effect, reflections from the wall will produce levels on the side of the barrier facing the source that are 2 to 3 dB higher. Using acoustical absorption on the barrier surface (source side) mitigates this increase.

Roof Top Located Barrier:

Use of sound barriers around roof top units, air cooled chillers and condenser units is quite common. Often they provide visual screening and also some beneficial. Is always beneficial to add acoustical absorption inside the barrier at the equipment but it is seldom done except in more sound critical situations where a maximum amount of sound reduction is needed. Thus the insertion loss are found to be lower in the field. Be conservative in the design process and do not attempt to maximize the insertion loss. Realize the insertion loss can be significant but perhaps limited.

If high amounts of sound reduction are required consider other means as necessary. Often screen walls are open at the base for airflow. These openings should not be ignored when considering the sound attenuations. On many buildings there is a parapet wall around the roof perimeter. This parapet wall can act also a sound barrier that might help to minimize the effect of the opening at the bottom of the screen. In summary, remember if one has a line-of-sight view of the equipment or portions of the equipment around, under, and over the top of the sound barrier that the insertion loss and sound reduction will be limited.