TASK SHEET 1F

VENTILATION NOISE ISSUES

A Paper for the University of Washington written by:

Russ Lewis, P. Eng.
of

Rowan Williams Davies & Irwin, Inc.

RWDI
CONSULTING ENGINEERS
& SCIENTISTS

Exposure Control Technologies, Inc.

ECT, Inc.

October 13, 2009

Introduction

The predominant source of noise in laboratories is the ventilation systems that provide a comfortable and safe environment with respect to air quality. When not designed appropriately, these systems can create health and safety issues caused by excessive noise. In addition to ventilation system noise, the layout and finishes within the laboratory can either aggravate or improve the problem.

Proper acoustics and noise design of a laboratory requires that all significant noise sources, transmission paths, and room acoustics issues be considered. Typical considerations include:

- Duct systems – carry fan noise into the labs
- Internal equipment – biosafety cabinets, refrigerators, fans, centrifuges, etc.
- Interior acoustics - controls sound reflections within a space
- Room partitions – controls noise coming in or out of labs
- Vibration isolation – controls structure-borne noise

Unless otherwise stated, recommendations contained in this report are based on the experience of RWDI in the design of laboratories.

Safety and Health

Safety with respect to acoustics and noise in a laboratory requires the ability of occupants to communicate and understand instructions clearly. This is best defined as speech intelligibility, which is dependent on two key factors; background noise levels, and the reverberation of sound within the space. Good speech intelligibility enables clear communication about manipulation of specimens and chemicals, which could be dangerous if mishandled, and also reduces the potential for damage to equipment and instrumentation.

Occupants of noisy spaces with poor speech intelligibility often suffer from vocal strain. In teaching environments, vocal strain can affect the long-term well-being of staff and can lead to lost-time injuries.

Other health effects associated with noisy environments include poor concentration and fatigue.

Fibrous materials are commonly used for both room treatments and in ducts/silencers to control noise. Fibrous materials are susceptible to entrapment of chemicals, particulate, or bacteria; however there are alternatives, but they typically have a cost or space penalty associated with them. The use of duct liners is discussed below – see ‘Equipment’.

Education

Good speech intelligibility and low background noise levels are essential for learning and maintaining order in a teaching setting. High levels of background noise can create the perception that additional noise within the space will go unnoticed, often resulting in more noise and in disruptive student behavior. Poor speech intelligibility and high levels of background noise also cause instructors to shout to be heard which can both give the perception of an instructor losing control, and create a sense of intimidation in the students.

Acoustics Consultants

Engaging a qualified acoustics consultant is an important step in achieving the objectives discussed in this document. The field of acoustics, noise and vibration can pose complex challenges; solutions that appear to be logical extensions of basic concepts may not be functional or cost effective. Furthermore, solutions that are effective in one frequency range may not be effective in others. It is important that acoustic consultants have appropriate training and experience. Many acoustics consultants have backgrounds in mechanical engineering or physics, coupled with experience gained working in the field. A lead acoustics consultant, meaning a person who is the most senior individual consulting either on their own or as the leader of a team, should preferably have a masters level degree specialized in acoustics plus a minimum of eight years experience. A second choice would be a bachelor's level degree in a related field plus eight years of experience. Individuals performing acoustic measurement should have a minimum of 3 years experience working under the direction of a lead acoustics consultant. There are now a number of schools (e.g., Pennsylvania State University, Rensselaer Polytechnic Institute, University of Nebraska) offering specialized graduate and undergraduate training in architectural acoustics, including HVAC mechanical systems, and vibration. These educational and experience factors should be considered when engaging acoustics consultants.

Criteria

The most important criteria requirements for laboratories are background noise and speech intelligibility.

Background noise is quantified in several ways. The most commonly used form is the noise criteria (NC) method defined by ASHRAE. Other methods available and also described by ASHRAE, include the RC, dBA, NCB, and RC Mark II methods. While all methods have units that are based on decibels (dB), it is necessary to know the noise pressure level octave-band spectrum in order to calculate each.

dBA – This is the overall A-weighted sound spectrum of noise. It provides an easily calculated single-number indicator of the relative level of noise as perceived by a human. As with any single number indicator it must be interpreted with care. Two noises with the same dBA level can sound very different to a listener. The octave-band adjustments (weights) used to calculate overall levels in dBA are applied to reflect the varying sensitivity of the human ear. HVAC equipment is often rated in dBA at a specified distance. While this is of some use, it is important to obtain the actual octave-band spectrum for equipment, preferably as sound power, rather than relying on an overall dBA level.

NC – This is the most commonly used method for characterizing HVAC noise; it was developed in 1957. While it is simple in application, it gives no indication of overall sound quality, or indication of the presence of low frequency noise known as rumble. It remains the most commonly used measure, particularly by equipment manufacturers. A useful approximation (Long 2006) is:

$$NC \approx 1.25\,(L_A - 13) \quad \text{where } L_A \text{ is the room noise level in dBA.}$$

NCB – NCB was developed in 1989 as an improvement to the original NC method. It can incorporate additional assessments of the presence of rumble and hiss.

RC and RC Mark II – The RC method, developed in 1981, was recommended by ASHRAE for characterizing HVAC noise up to 1999. Since 1999, ASHRAE has recommended the RC – Mark II method. RC and RC Mark II include lower frequency octave bands (16.5 Hz and 31.5 Hz) and have a system for characterizing sound quality. RC Mark II (1997) has incorporated a procedure for estimating the occupancy satisfaction.

RWDI recommends using the NC approach, in conjunction with assessment of detailed octave-band spectral information as required. NC is appropriate in many situations because of its widespread acceptance, compatibility with manufacturers' information and recognition by members of the design team. If there is increased concern for sound quality characterization of hiss and/or rumble, based largely on knowledge of user expectations and previous experiences, then we suggest the use of RC. RC Mark II is a useful and recommended by ASHRAE, but is also somewhat more complicated in application and more importantly, less well recognized. Any of these methods can be effectively used by an experienced and knowledgeable acoustical consultant. It is more important that the limitations of the approaches be recognized, and situations in which more detailed assessments are required are indentified and considered.

Laboratory background noise levels are dependent on the intended use of the space. Table 1 lists common laboratory types and their background noise requirements. Bradley (2002) has identified the need for NC < 30 for good speech intelligibility in classrooms. The recommendations provided below recognize the challenges in controlling ambient noise in laboratories, and their intermittent use in classroom teaching mode.

Table 1. ASHRAE Guidelines (ASHRAE 2007) for Laboratories with Fume Hoods

Room Type and Use	Design Guidelines for HVAC-Related Background Sound in Rooms RC(N) or NC
Testing/research, minimal speech communication	45-55
Research, extensive telephone use, speech communication	40-50
Group teaching	35-45

Achieving acceptable speech intelligibility requires consideration of room acoustics as well as background noise. Sound absorptive surfaces are required for good speech communication as an integral part of noise control within a laboratory space.

RWDI conducted a study of twelve university teaching laboratories with a range of different sizes and designs. The results of these measurements are shown in Table A-2 in Appendix A.

For smaller teaching laboratories (<750 sq.ft.) it is recommended that the ceiling be finished with an acoustical lay-in tile ceiling (NRC ≥ 0.8) or equivalent wall/ceiling treatment.

For larger teaching laboratories (> 750 sq.ft.), a combination of ceiling and wall treatment is recommended to improve speech intelligibility. The total area of treatment should be equal to or greater than the plan area of the space, but should be evenly distributed on the ceiling and two walls. Acoustically absorptive wall treatments must be located so that they do not interfere with constructive reflections of sound that are supportive of speech intelligibility. Design input from an experienced acoustical consultant is required.

For non-teaching laboratories, it is recommended that some acoustically absorptive materials be included in the finish schedule to control reverberation; this will improve background noise levels and speech intelligibility. As a minimum, it is recommended that mineral lay-in tile ceilings (NRC ≥ 0.5) or an equivalent wall/ceiling treatment be used.

The extent of required treatments can be calculated by the acoustical consultant, particularly for room with higher ceilings, 10 feet or more, using the speech transmission index method outlined with the measured data presented in Appendix A, Table A-5.

Equipment

Laboratories place high demands on the mechanical systems that serve them and often require large, noisy equipment. Table A-1 in Appendix A lists typical equipment associated with laboratory ventilation systems and provides recommendations for equipment selection.

The use of duct liner materials, particularly fiberglass, has become a significant issue from a human health/indoor air quality perspective. The conclusions of the University of California Indoor Air Quality Work Group, which recommend exclusion of duct liners in laboratories in particular, are often quoted. ASHRAE (2007) now refers the reader to the International Agency for Research on Cancer (IARC; www.iarc.fr) and the North American Insulation Manufacturers Association (NAIMA; www.naima.org/main.html), and provides no specific recommendation. It is interesting to note that the previous ASHRAE Handbook – HVAC Applications (2003) somewhat downplayed the risks of duct lining, perhaps indicative of the difficulty of arriving at a clear consensus on the human health aspects.

RWDI recommends that the use of duct liner be evaluated on a case-by-case basis, considering:

- the substances likely to be present in the air moving through the ductwork,
- the proposed duct lining material,
- the ability to clean the duct and/or replace the lining,
- the location to which the air is being delivered,
- the air velocity in the ductwork, and,
- the range of temperature and humidity conditions to which the duct will be exposed.

The following recommendations are for systems serving laboratories only; they indicate the conditions under which lining may be acceptable if it cost prohibits control of noise to noise critical spaces using other means.

Supply

Duct liner may be appropriate if velocities throughout the supply system are kept below the limits shown in Table 2 and Table 3, using the values for rectangular duct for both rectangular and round ducts, and using the values stated for NC35 for spaces of NC 35 or more. This will minimize the scour of the duct lining material itself.

Return Air Systems

Duct liner may be appropriate for return air systems, subject to the provisions for supply systems listed above, if the air is part of a system serving only the laboratories in question or similar spaces, and if it is determined that the humidity levels in the laboratory are not elevated above typical building values.

Exhaust Air Systems

Duct liner will not be acceptable in exhaust systems because of concern for accumulation of materials from fume hoods and potential for elevated humidity in exhaust systems.

Excessive levels of noise also have significant adverse health effects. Laboratory areas may be considerably louder than is desirable when duct liner is not a design option, and when space and budget constraints eliminate the practicality of alternative noise reduction strategies. It should be understood that removing duct liner as a noise control option in a situation where conditions are appropriate for duct liner may cause adverse health effects rather than prevent them.

Ventilation System Layout

It is good practice to separate noise sources from noise receptors by as much distance as is practical. If noise is considered in early design stages as a part of the initial space planning, it is often possible to achieve excellent control over noise for little cost. This is true for duct layouts as well. Longer duct runs provide greater separation between noisy equipment and the spaces they serve.

Mechanical rooms should be separated from noise sensitive spaces, ideally with buffering spaces (e.g., storage space, restrooms, corridors etc.) between the mechanical room and the noise sensitive spaces. Where this is not possible, anticipate cavity wall construction, floating floors and/or resiliently suspended sound barrier ceiling systems. These alternatives both take up valuable space and, in the case of floating floors and resiliently suspended ceilings, can be very costly. When left to the later stages of design they are often cut to reduce project costs, resulting in spaces that do not meet even basic background noise requirements.

It is important to leave space for silencers in the ductwork, preferably immediately outside mechanical rooms, in spaces that are not noise sensitive. If the silencers must go inside a mechanical room, they require a high sound transmission loss (TL) casing, or must be enclosed with a drywall enclosure to prevent the 'quiet side' from being impacted by mechanical room noise. All 'quiet side' ducts in the mechanical room must also be enclosed.

Figure A-1 in Appendix A illustrates a number of silencer layouts. Which layout is preferred will depend on:

- the ambient noise level in the mechanical room, including duct breakout noise
- the allowable noise levels in adjacent spaces,
- the transmission loss of the partitions between adjacent spaces, and,
- the noise level on each side of the silencer in relation to the noise level in the room in which it is located.

Many alternatives are possible; the important thing is to plan ahead and allow sufficient space for a silencer and any necessary lagging.

The following three cases identify alternatives for the location of silencers. See **Figure A-1** in Appendix A for illustrations of these cases. In considering these cases, please note that:

- Break-in noise occurs when noise in a space (often a noisy mechanical room) 'breaks in' to a duct or silencer, raising noise levels in the ductwork.
- Break-out noise occurs when noise in a duct 'breaks out' to the room surrounding the duct, raising noise levels in the room.
- Circular ducts are less prone to break-in and break-out noise than rectangular ducts of equivalent area, because they have fewer noise transmission modes.
- Break-out noise is not necessarily an undesirable characteristic, since it can beneficially 'bleed off' duct noise levels in spaces that are not noise-sensitive, such as utility rooms or in spaces above ceilings that have good noise isolation – i.e. sheet rock or high transmission loss ceiling tiles.

Case 1 Silencer penetrates wall between mechanical room and adjacent space that is not noise-critical

- Break-in and break-out noise can often be avoided, or rendered insignificant, by locating the silencer so its noisy end is in the mechanical room and its quiet end is in an adjacent space.
- If mechanical room noise significantly exceeds noise in silencer and/or ductwork, then lag portion of silencer on mechanical room side, and possibly the duct between the AHU and the silencer (to prevent break-in noise).
- If noise level in silencer significantly exceeds noise level in the adjacent room, then lag portion of silencer on adjacent room side (to prevent break-out noise)

- This is often an efficient case requiring little or no lagging of the silencer and ductwork.

Case 2 Silencer is entirely inside mechanical room

- May be a good solution for quieter mechanical room.
- May be necessary if adjacent space is noise sensitive.
- Usually necessary to lag ductwork on quiet side of the silencer to prevent break-in noise
- May be necessary to lag the silencer if particularly noisy mechanical room.

Case 3 Silencer is entirely inside adjacent space

- May be necessary to lag ductwork in mechanical room if mechanical room is extremely noisy.
- Likely necessary to lag ductwork between silencer and wall shared with mechanical room
- May be necessary to lag the silencer itself.

Figure A-2 provides an example of duct and silencer lagging. Wrapping ducts and/or a silencer in mass-loaded vinyl, (usually 1 or 2 psf) is often presented as a solution. This approach may be adequate if it is thoughtfully specified and inspected during construction. Too often such approaches fail because of gaps in coverage and lack of proper sealing. Here are two sources of information on the use of mass-loaded vinyl:

http://www.soundseal.com/pdfs/SS-105-72res.pdf

http://www.kineticsnoise.com/industrial/pdf/knm-100alq.pdf

Silencer lengths will increase where shorter duct runs are present. Options exist for both straight and elbow type silencers. Leave three duct diameters of straight duct between silencer and fans, transitions and elbows.

Main ducts should be placed over spaces that are less sensitive to noise, such as corridors, storage areas and restrooms. Where this is not possible, duct flow velocities should be limited and duct enclosures may be required. See Table 3 below for recommendations.

Care must also be taken to select ducts that are not so over-sized that they require dampers to be excessively closed, creating regenerated noise. Oversize ducts have lower levels of mid and high frequency flow noise, but do transmit greater amounts of low frequency noise from fans. When calculations indicate that the choice of a duct size falls between two sizes, it is good practice to choose the larger size when space permits.

It is very important to avoid high pressure drops throughout the system, apart from wasting energy, such excessive pressure drops can cause not only regenerated mid and high frequency noise, but can also result in loud low frequency resonances that are difficult or impossible to control once created.

Table 2. Maximum ASHRAE Recommended Main Duct Airflow Velocities

Main Duct Location	**Design NC**	**Maximum Airflow Velocity in a Rectangular Duct (fpm)**	**Maximum Airflow Velocity in a Circular Duct (fpm)**
In shaft or above drywall ceiling	45	3500	5000
	35	2500	3500
	25	1700	2500
Above suspended acoustic ceiling	45	2500	4500
	35	1700	3000
	25	1200	2000
Duct located within occupied space	45	2000	3900
	35	1500	2600
	25	900	1700

Notes:
1) Branch ducts should have airflow velocities of about 80% of the values listed
2) The presence of elbows and other fittings can increase airflow noise substantially, depending on the type of elbow or fitting, therefore, duct airflow velocities should be reduced particularly for fittings before final runs (see Table 3)
3) Final run-outs to outlets should have air velocities 50% less than the values shown (see Table 3).
4) Applicable to control flow noise breakout in the occupied space through ductwork walls.

Branch and final run-out ducts flow velocities must also be limited. See Table 4 for recommended maximum air speeds for different conditions and noise criteria.

Table 3. Maximum Recommended Air Speed in Branch and Final Run-out Ducts with and without Thermally Lined Flex Duct

Condition	Maximum Noise Criterion						
	NC-20	**NC-25**	**NC-30**	**NC-35**	**NC-40**	**NC-45**	**NC-50**
	Maximum Air Speed (fpm)						
Branch ducts with 5 ft of thermally lined flex duct	625	750	975	1200	1400	1600	1800
Final Run-out Ducts with 5 ft of thermally lined flex duct	325	500	675	850	1000	1150	1300
Between outlet and takeoff or elbow without thermally lined duct	300	350	425	500	560	630	700

Notes:
1) Air speed in exposed ducts should not exceed 1000 fpm unless the ducts are properly lagged or encased, in which case air speeds should not exceed 2000 fpm.
2) Values are for supply ductwork. Add 100 fpm for return/exhaust air ductwork.
3) Assumes the flex duct is properly aligned to the diffuser and duct without offsets, to avoid generated noise at the diffuser.

Variable air volume (VAV) boxes should be placed outside spaces requiring NC 35 or less. If they must be placed in a space requiring NC 35 or less, they must be equipped with a silencer, and will likely to require an enclosure. VAV boxes should be as far from the outlet/inlet as possible.

In cases where there is a ceiling with fair to good acoustical noise isolation characteristics, it is recommended that a flex duct be used for the final elbow connecting the duct to the terminal unit (e.g., diffuser, grille, etc.). The flex duct should not exceed 6 feet in length, be installed fully extended and be the minimum length required to make the necessary connection. It must be well aligned, with a smooth corner to avoid creating turbulence (noise) in the airflow. The centre-line radius must not be less than one duct diameter. The flex duct must also be well aligned with the terminal unit to avoid excessive noise at the connection. This will require careful inspection during construction. It is very common to find that flex duct has been cut excessively long and that it contains tight coils and bends.

The flex duct must not contact other objects in the ceiling space and must be adequately (at least 4 inches) separated from hot equipment. Here are several links with information regarding the use of flexible ducts:

http://www.dca.state.ga.us/development/constructioncodes/publications/1ONE.pdf

http://www.flexibleduct.org/ADC_Disc.asp

Terminal units should be selected to be 10 NC points below the target background noise level for the design flow rate, and should be located away from areas of communication (i.e., away from lecturing position and away from student seating area). Placing terminal units around the perimeter of the room is best with students seated centrally for lectures.

Layout of Laboratory

Laboratories are best set up with all noise producing equipment located around the perimeter rather than above students or teachers. This allows for better communication for teaching purposes within a central area. Noise producing equipment includes exhausts and intakes, fume hoods, and any other lab equipment (e.g., refrigerators, centrifuge, autoclave (blower fan), bio-safety cabinet, etc.).

For teaching purposes, fume hoods are best located around the perimeter rather than as a central cluster where they become obstructions for teaching. A perimeter location also provides the benefit of clear visual sightlines, which can improve safety through improved supervision, ability to provide visual cues or non-verbal communication, and for emergency egress.

Alcoves for fume hoods typically create a quieter space by separating the fume hoods from teaching areas, but also create barriers that impair supervision and communication while in use.

Smaller labs put students and teachers closer together, which is a benefit for speech intelligibility (i.e., less strain on teachers and better attention and comprehension from students). Larger laboratories can provide a similar benefit by placing the lecturing position at the center of one of the longer walls (in rectangular plans), which reduces the student to teacher distance.

Higher ceilings are undesirable due to an increase in the volume of the space and an increase in unwanted reverberation.

Acoustically absorptive finishes for the ceiling and walls are recommended as described in the criteria section above. While such finishes help to improve communication by reducing reverberation and background noise, they can collect chemicals, particulates, and bacteria. Additional costs should be anticipated for available washable finishes, where required.

External Noise

Most laboratory buildings have significantly more ventilation equipment than buildings supporting offices and teaching space only. The higher volume of air required demands larger fans and heating/cooling equipment. Larger equipment typically produces more noise, which impacts both the indoor and outdoor environments.

Noisy intakes and exhausts can impact labs and nearby buildings, especially where equipment or intakes/exhausts are in close proximity to windows. Allow for space in mechanical rooms and in duct runs for silencers on exhausts and intakes to outside locations.

Other means of mitigating external noise emissions may include use of plenums, acoustic louvers and noise barriers. Windows are usually the limiting factor for indoor/outdoor noise transmission. Upgrading to better acoustical performance windows can be an effective means of mitigation. As with duct systems within the building, separation through distance, duct length, or by creating noise barriers/attenuators is necessary to reduce noise levels. It is important to note that barriers can conflict with exhaust re-entrainment requirements and should be reviewed with a re-entrainment consultant..

Noise impacts on nearby buildings and outdoor pedestrian areas must be considered. It is important to check local legislation, codes, regulations, and/or ordinances to determine the site requirements. City regulations provide a "do not exceed" limit for daytime and night-time noise that varies with property use (see Seattle Municipal Code, Chapter 25.08 - Noise Control, Subchapter III - Environmental Sound Levels for requirements in Seattle and King County).

Some institutions, such as the University of Michigan, have voluntarily developed have established a policy of limiting impacts on neighbors by setting criteria that specify a maximum change to existing background noise levels at nearby receptors. While not required, it is a good strategy for maintaining relations with the surrounding community. A noise impact study requires a baseline noise survey to determine pre-construction noise levels, which can be compared to the future condition to determine change/impacts.

External noise modeling should be done early in the design of the building using proper modeling techniques to determine impacts on surroundings and the building on itself. Models such as Cadna/A, SoundPlan, ENM, etc. can be used. Noise model studies are often required in building construction permitting. Setting up a basic external noise model early in a project often proves useful for efficiently addressing inevitable design changes as a project progresses.

Vibration

Vibration isolation of all mechanical and electrical equipment (including ducting, piping and conduit) is an important part of controlling noise and vibration within a building. The primary purpose of vibration isolation systems is to limit the transmission of vibration into the structure, which is carried through the structure as structure-borne noise and re-radiated acoustically in spaces that can be distantly separated from the source. Structure-borne noise is very difficult to attenuate by means other than vibration isolators.

Proper selection and installation of vibration isolation systems (which may include but is not limited to spring isolators, rubber/neoprene isolators, inertia bases, and hangers with spring or neoprene elements) is an essential part of a complete noise control system.

Other Considerations

For teaching labs, there are other means of improving the function of the space without requiring more stringent background noise limits. Noise can also be limited by operational controls such as:

- Keeping sashes closed when not in use, and particularly while teaching,
- Providing areas for pre-lab lectures away from fume hoods or in separate rooms,
- Providing audio/video alternatives such as; screens to show demos, cameras to monitor students, or by pre-recording laboratory demonstrations and having students view them before labs (pre-lab quizzes provide confirmation of viewing).

In a research environment where funding is highly dependent on maintaining a competitive edge, privacy is often of significant concern. Communication within a loud space requires increased vocal effort that may be heard clearly in quieter adjacent spaces such as corridors or offices. Limiting background noise within the laboratory is an important part of maintaining privacy, but partition construction (including doors, windows, penetrations, and duct layouts to control "cross-talk") should also be considered in this type of environment to maintain privacy and/or security.

Noise from laboratories can impact more sensitive adjacent spaces such as offices, conference rooms, or classrooms. Transfer of noise should be controlled through proper partition design and construction. Penetrations through walls, floors, and ceilings should be sleeved and sealed as appropriate. See Figure A-3 in Appendix A for an example of penetration treatments. Direct duct runs between spaces should be avoided; see Figure A-4 in Appendix A. It is preferable to have central supply and return ducts with individual duct runs into each room to avoid "cross-talk" issues.

While many of the items identified in this document could be addressed by the architect or the mechanical system designer, there is potential for a detrimental combination of factors to be overlooked. An acoustical consultant is required to review the ventilation system and room design and their interaction with the building. This input is required early in a project, while it is still possible to allocate space for necessary silencers, and to keep noise and vibration sources sufficiently separated from sensitive receptors.

Summary

Safety and health of staff and students is paramount in laboratory design. Ventilation systems are an important design component; the high demands that labs place on the ventilation systems require them to be larger and more complex other ventilation systems which creates the potential for increased noise levels. Noise exposure is a significant health issue.

Noise in a laboratory can have adverse effects on the safety and health of staff and students, and can impact the quality of education. Speech intelligibility is essential in meeting these requirements and requires control of reverberation within the laboratories in addition to control of background noise levels in the space.

Ventilation system noise is transmitted via multiple paths, interacting with many other building components; as a result, ventilation noise issues must be addressed by considering all aspects of the design. Attempting to design for noise using a single approach will limit the functionality of the space for its intended use.

References

ASHRAE (2007). 2007 ASHRAE Handbook, HVAC Applications. Chapter 47, Sound and Vibration Control. © 2007 Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., www.ashrae.org.

ASHRAE, 1995. *Standard 110 – Method of Testing Performance of Laboratory Fume Hoods*. American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc.

City of Seattle. Department of Planning and Development, Chapter 25.08 - Noise Control, Subchapter III - Environmental Sound Levels for requirements in Seattle and King County.

Energy and Utilities Board, Alberta (2007). Directive 038 – Noise Control. http://www.ercb.ca (provides useful detailed information regarding instrument and measurement requirements, now Alberta Energy Resources Conservation Board, pdf available for download).

Egan (1988). M. David Egan, Architectural Acoustics. © 1988. New York, NY. McGraw-Hill Book Company.

Long (2006). Marshall Long, Architectural Acoustics. © 2006. San Diego, CA. Elsevier Academic Press.

Lord (1980). Harold Lord, Noise Control for Engineers. © 1980. Malabar, FL. McGraw Hill Book Company.

National Research Council (2002), J.S. Bradley, Acoustical Design of Rooms for Speech: Construction Technology Update No. 51, March 2002. http://www.nrc-cnrc.gc.ca/eng/ibp/irc/ctus/ctus-n51.html.

Appendix A - Acoustical Evaluation Methods

A common issue in creating spaces that are free of excessive noise and vibration is the lack of attention to construction deficiencies. It is important that the acoustical consultant have scope to be involved during all phases of design and construction. Often acoustic consultants are engaged too late in the project to ensure good space planning and accommodation of sufficiently large silencers, and leave the project before construction commences.

During commissioning, it is essential that appropriate acoustical measurements be taken to properly evaluate building performance. Measurements must be made by an experienced acoustical consultant or acoustical technician.

Instruments

Equipment must meet the minimum technical specifications in the International Electrotechnical Commission (IEC) publication 60804, or its latest revision, for Type II sound level meters. Instruments must be capable of measuring third-octave band spectra. This is particularly useful for diagnostic purposes. If necessary, for example in the case of issues or complaints involving tonal noise, consultants may be asked to provide narrow-band measurements (performing FFT measurements). Further, it may be necessary to perform long-term monitoring and audio recording, necessary in the case of intermittent noise issues where monitors must be set up to run and record for extended periods. Such equipment is readily available for rental, but requires an experienced acoustical consultant or technician to operate.

Instruments must have calibration certification stickers provided by the manufacturers indicating when the next calibration is due. Dates of calibration must be reported when measurements are provided. Instruments must be calibrated immediately before and after a set of measurements is taken, using a calibrator that has its own calibration certificate. Dates of time and calibration must be recorded.

Performing and Reporting Measurements

Measurements will be reported as un-weighted third octave band and octave band values, together with the single-number measures of noise level that are appropriate to the project: dBA and NC, RC or other specified measure. Measurements will be taken at locations that represent typical occupant locations in the affected spaces. Background noise level from the HVAC system will be measured with all other noise-producing equipment turned off, unless otherwise specified in the design documents. Measurements will be taken at representative times, to ensure that all HVAC equipment is operating and that the noise of people talking and using the space are not included in the measurements.

Measuring the noise output by an individual piece of equipment, for example to verify a specification of sound power or sound pressure at a given distance, presents many acoustical challenges and is not always feasible in the field. This will normally require multiple measurements with other noise producing equipment shut off. If the radiating area is large problems associated with measurement in the acoustical near-field will further complicate the measurements and may require specialized sound intensity measurement.

Where noise exceeds design requirements, information is to be extracted from the air balancing report, including duct and exit velocities, pressure drops across VAV boxes and other information as may be required by the design situation. Where there are multiple sources of noise, systems and equipment must be run individually, to the extent that this is possible, so that excessive noise sources can be clearly identified.

Noise Mitigation

Noise in HVAC systems is mitigated by a combination of acoustic isolation and sound absorption techniques. Methods and materials that are effective for one of these approaches are seldom useful for the other. Placement of acoustic absorption on a wall for example may reduce the reverberant noise level in the room, but will not significantly improve the effectiveness of the wall in preventing noise from penetrating to an adjacent space.

Noise isolation involves creating a physical barrier that prevents the transmission of sound from a noisy area to an adjacent quiet area. In general, effective noise isolation requires adequate physical mass, (so lightweight materials are generally ineffective), adequate thickness (particularly where mid and low frequency sound is to be isolated) and must be sealed airtight. Lightweight constructions are only useful in blocking high frequency sound. Doubling the mass of an isolating enclosure will typically improve its performance by about 5 dB, though complications can arise involving the resonance frequencies of design elements that can reduce their acoustical performance dramatically at certain frequencies. An experienced acoustical consultant is required.

Small gaps in coverage can transmit very large amounts of noise and defeat the purpose of an enclosure, as can flanking noise that is transmitted through adjacent structural members or improperly constructed partition penetrations. See Figure A-5.

It is sometimes practical to enclose noisy equipment or ductwork with GWB. In addition to providing any necessary maintenance access, it is important to provide some space between the equipment being isolated and the layers (usually a minimum of 2) of GWB. Fiberglass or mineral wool batt, usually 2 to 4 inches in thickness, should be present in the cavity, as in wall construction. Care must also be taken to provide cooling air for enclosed equipment, which can significantly complicate the design of such enclosures.

Sound absorbers and barriers are only effective when their size is significant in relation to the quarter-wavelength of the noise of concern. Note that at 125 Hz the quarter-wavelength of sound is over two feet, so it is not possible to achieve effective absorption of low frequency sound with thin materials, regardless of how specialized and 'acoustically advanced' such materials are claimed to be.

Table A- 1. Recommendations for Selection of Equipment

Equipment	**Recommendations**
Fans	• Choose quiet fans (slow and large diameter are better for noise) • Airfoil and forward curved designs are typically 10 dB quieter than straight blade radial or vane-axial fans (10 dB is perceived to be a 50% noise reduction). • Plug-type fans are typically quieter than enclosed centrifugal fans • Multiple fan, wall-type systems are generally quieter than single large fan systems.
Silencers	• Reserve at least 5 feet of straight duct space for silencers on intake and outlet for all fans. • Elbow silencers provide improved attenuation at low frequencies. • For a laboratory setting, exposed fibrous liners are rarely acceptable, particularly in exhaust silencers susceptible to entrapment of chemicals, particulates or bacteria. • Hospital-type silencers are available with protective plastic films that protect the fibrous materials from the air flow. • No-media (packless) silencers are also available, but provide less attenuation than typical media-type silencers, therefore additional silencer length may be required.
Ducts (general)	• Good transitions are essential to avoid rumble in duct systems. This typically requires straight sections of a minimum 3 duct diameters in length between transitions. • Duct velocities are discussed further in the section below, but in general larger ducts with lower flow rates are best for avoiding flow induced noise and rumble. • Large pressure drops across various duct components typically create turbulence and noise. Lower pressure drops are desirable from a noise perspective and must be specified with acoustic requirements in mind. • Acoustical duct linings protected by a plastic film and a perforated metal cover can be considered for reducing noise transmission in some systems. This must be evaluated on a case-by-case basis.
Valves	• Valves are a major source of sound in HVAC systems. • Valve noise is difficult to attenuate because of the close proximity to the room inlet/outlet. • Sound characteristics are highly dependent on flow volume and pressure drop.

Equipment	Recommendations
	• Where possible choose quieter valves. Aerodynamic (venturi) valves are preferred over opposed blade dampers. • Over-sizing valves (running them at low flow ratings) or running multiple valves can be an effective means of reducing valve noise. • Pressure drops below 1 inch are preferred. This is another reason to locate noise sensitive spaces as far as possible from air handlers. • Integral valve silencers provide benefit to attenuating valve noise, but are not always adequate to meet desired background noise levels. • Duct space should be made available for a minimum of a 3-foot silencer on the room side of valves.
Flex Duct	• Reduces noise significantly when installed properly. • Best placed above ceilings with good acoustic transmission loss (noise breaks out and is absorbed in ceiling plenum). • Avoid tight bends that create noise through turbulence.
Terminals (diffusers and grilles)	• Can be the most significant source of background noise. • Difficult to attenuate. • Square or round diffusers are quieter than strip diffusers due to slower velocities. • Sock diffusers are quietest because of a low throw/low speed supply. • Should be selected at 10 NC points below the target background noise level.
Equipment in the laboratory (not necessarily ventilation equipment)	• Choose quiet lab equipment whenever possible (centrifuge, refrigerator, autoclave (blower fan), bio-safety cabinet, etc.) • Consider pressure drops of selected equipment (hoods, bio-safety cabinets)

Table A- 2. RWDI Measurements of Background Noise and Reverberation Time in Twelve University Teaching Laboratories

Laboratory	Speech Transmission Index[1,2]	Background Noise NC	Reverberation Time in seconds
1	0.61	41	0.37
2	0.60	40	0.47
3	0.57	44	0.50
4	0.56	45	0.42
5	0.56	40	0.56
6	0.55	42	0.49
7	0.53	41	0.58
8	0.52	34	1.13
9	0.51	43	0.53
10	0.51	35	1.21
11	0.34	54	1.14
12	0.31	55	1.29

Note: 1) Excellent conditions STI > 0.8, Good conditions STI > 0.6, Fair STI ≈ 0.5, Poor STI < 0.4

$$STI = \frac{\overline{(S/N)} + 15}{30}$$

$$\overline{(S/N)} = \sum_{k=1}^{7} \omega_k (S/N)_k$$

In each octave band from 125 Hz to 8000 Hz:

$$(S/N)_k = 10 \log \frac{\bar{m}}{1-\bar{m}} \text{ , where } \bar{m} = \text{average of 14 values of } m(f_m)$$

$$(S/N)_k \text{ is bounded by } \mp 15 dB$$

$$m(f_m) = \frac{1}{\left[1+\left(\frac{2\pi f_m T_{60}}{13.8}\right)^2\right]^{1/2}} \frac{1}{1+10^{-(\frac{S}{N})/10}}$$

Where f_m = 14 modulations frequencies from 0.63 to 12.5 Hz

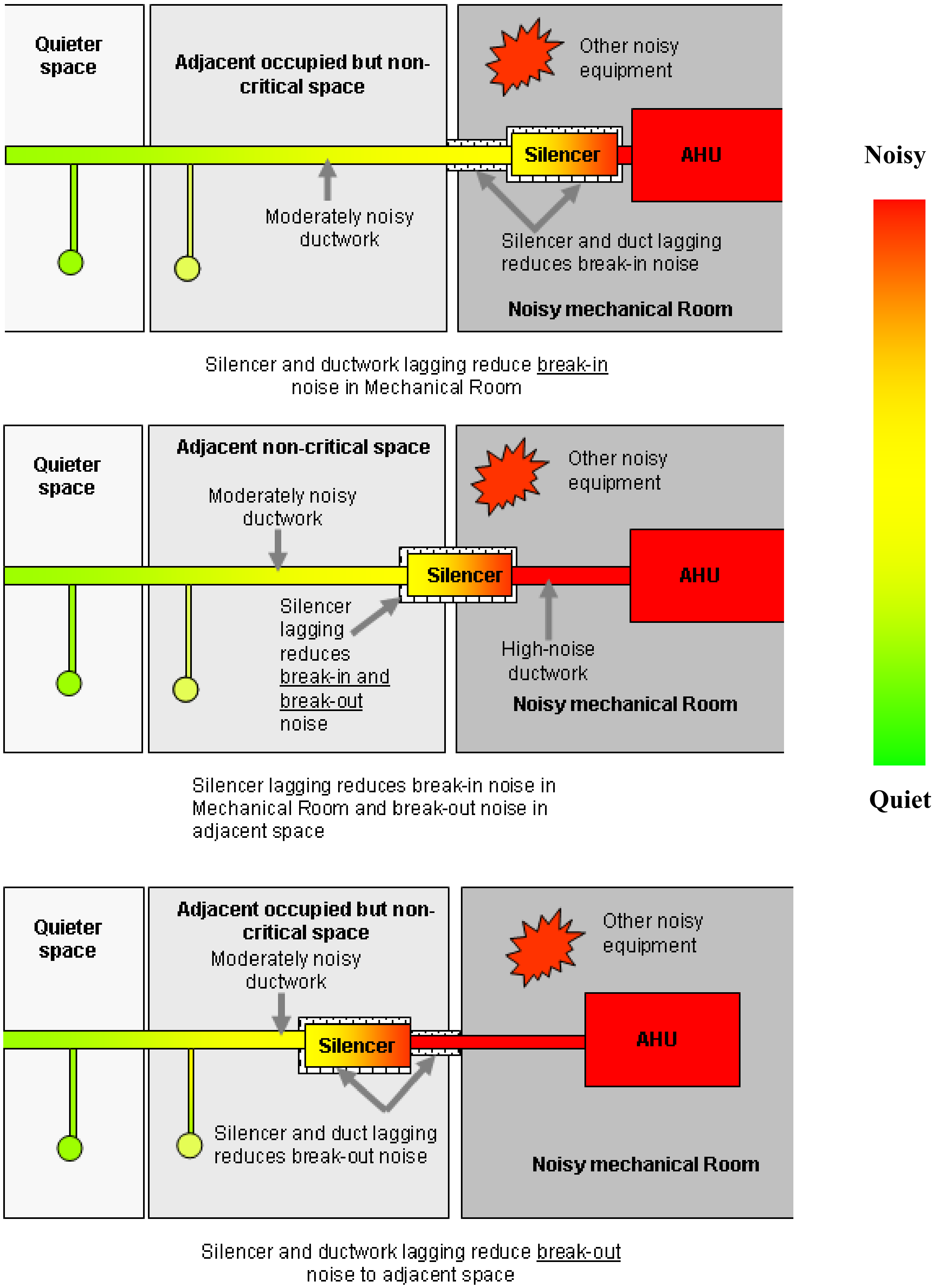

Figure A-1 - Three Possible Silencer Locations and Lagging Cases

Note: it is not always necessary to lag silencers.

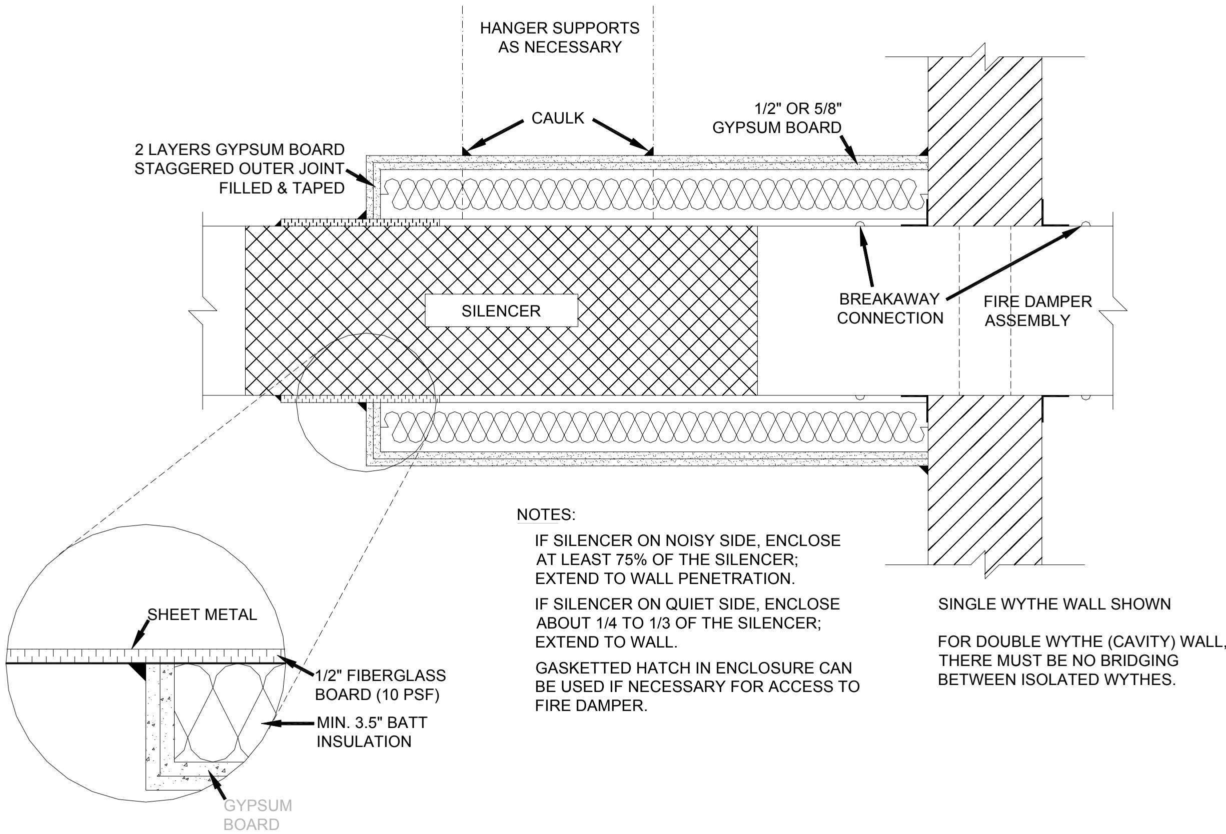

Figure A-2 - Typical Enclosure for Silencer Using Gypsum Wall Board

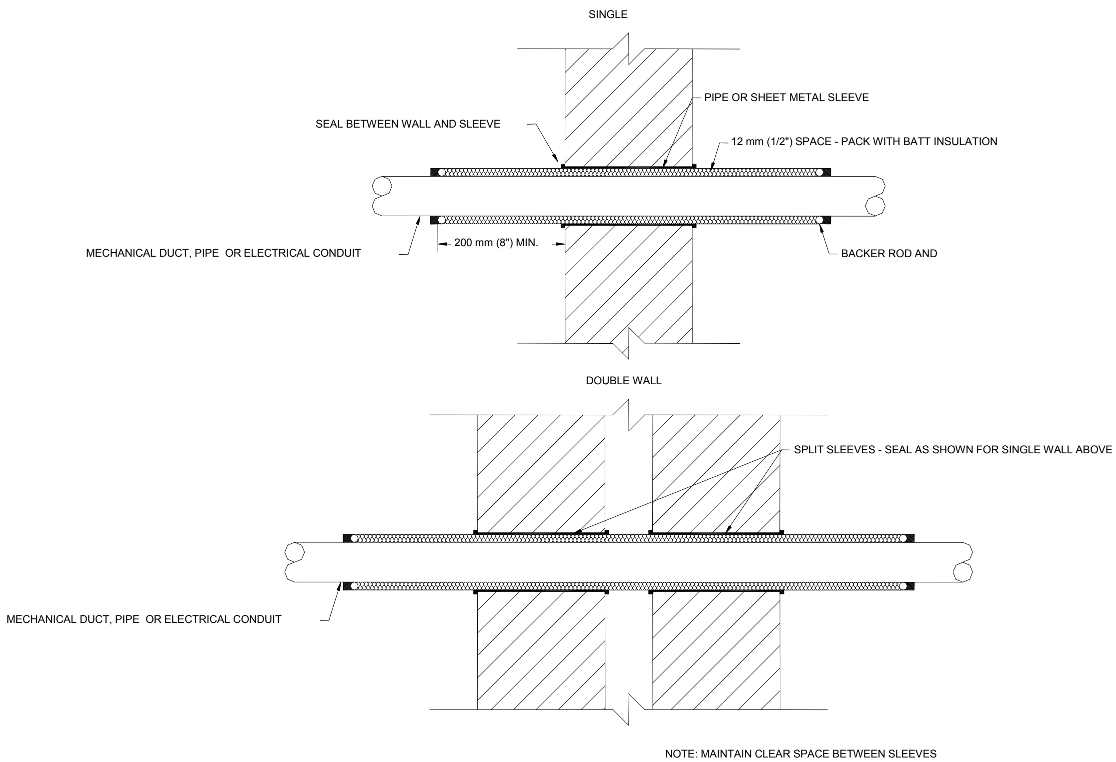

Figure A-3 - Wall Penetration Detail

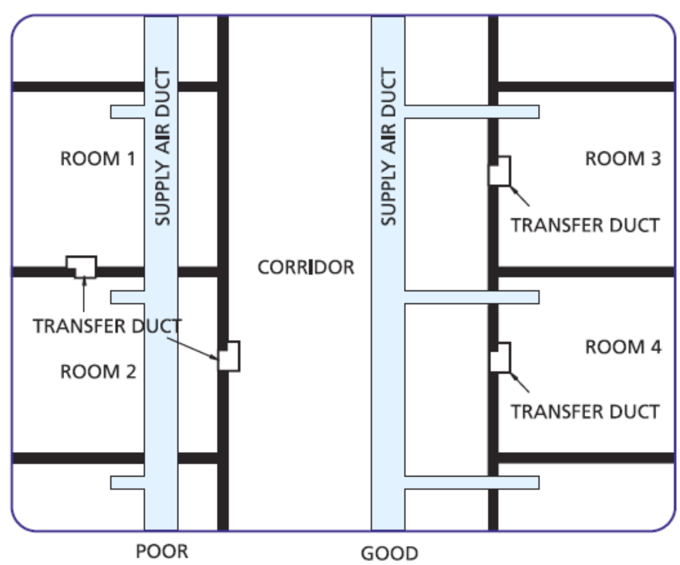

Figure A-4 Direct Duct Runs Through Rooms Can Compromise Partitions, Thus Reducing Privacy and Freedom from Distraction

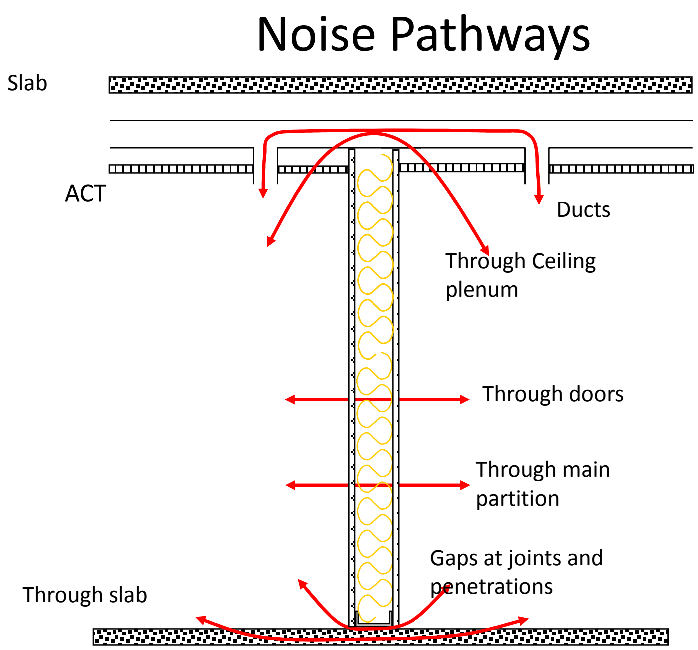

Figure A-5 - Flanking Noise Pathways

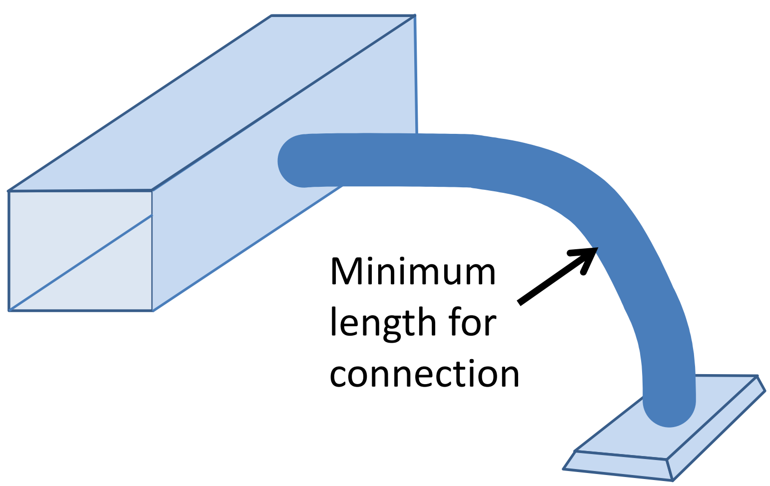

Figure A-6 - Example of Correct Installation of Flex Duct

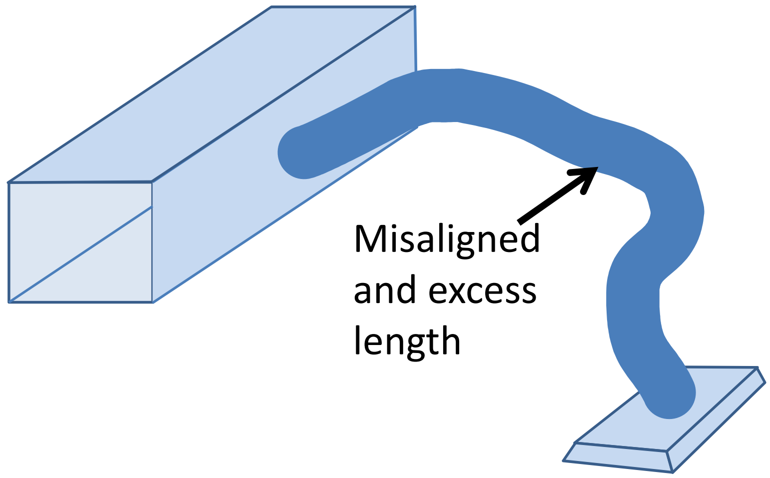

Figure A-7 - Example of Incorrect Installation of Flex Duct