WHITE PAPER

Acoustics

How duct liner can be an effective tool for quieting airborne and structure-borne noise in the critical 250 to 1000Hz range.

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WHITE PAPER

Sound Advice

Low Frequency Noise in Ducts: A Sound Argument for the Benefits of Foam Insulation

Insulation materials have traditionally been applied to the interior or exterior of duct for a combination of purposes, including thermal efficiency, condensation control, and noise control. Of these, effective noise control is by far the most challenging. It is important to remember that a conventional duct liner and, to an even lesser extent, duct wrap, will only resolve a portion of the noise issues in any building. An effective noise attenuation strategy begins at the design stage and utilizes a combination of methods including mechanical layout, vibration isolation, and duct insulation.

Duct insulation is available in a variety of materials. This paper explores the ability of elastomeric foam duct insulation to resolve common low frequency noise problems and challenges the notion that elastomeric foam lags behind fibrous materials in terms of sound attenuation.

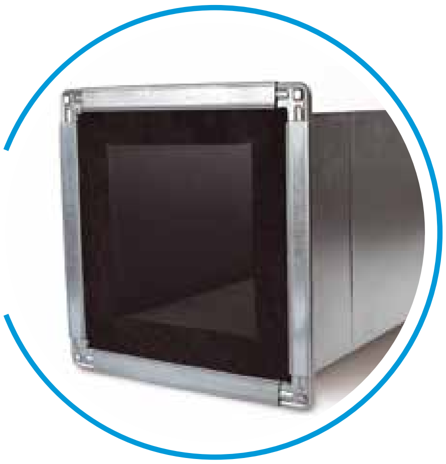
Types of Noise Associated with Duct

The standard definition of noise, which is any unwanted sound, is a deceptively simple summation of a complex issue that can have a tremendous impact on our living, work and learning environments. According to the National Institute for Occupational Safety and Health, ambient noise also affects people's health by increasing general stress levels and aggravating stress-related conditions such as high blood pressure, coronary disease, peptic ulcers and migraine headaches.[1] Productivity and learning are affected as well. To effectively amend noise problems in buildings, and specifically the noise that is carried through ductwork, we must first understand the nature of noise and how it travels. Acousticians like to talk about sound in terms of two categories: structure-borne sound and airborne sound. The latter, airborne sound, is the noise we actually hear. It can and will travel anywhere there is air. A simple example of this is the noise generated from a radio, which travels through the air in the form of pressure waves and is received by the person listening. Structure-borne sound results from a physical vibration of materials caused by some impact event or other form of mechanical excitation (e.g. a hammer striking the wall).

However, the noise we hear when a hammer strikes the wall is actually the airborne sound that results from a structure-borne sound (vibration).

In most cases, structure-borne sound travels through the building structure via construction materials, frame

and interior elements. It eventually becomes airborne sound that can be heard at some distance from its source, perhaps several floors away. Airborne sound can also become structure-borne causing surrounding surfaces to vibrate. Consider a sheet metal duct, which is a virtual wind tunnel through which any noise can travel. It provides a structural and an airborne path for noise generated by mechanical equipment like fans and chillers. It can also transmit noise from virtually any other source in the building, e.g. people, speakers and machines. This airborne-to-structure-borne conversion can repeat multiple times until the sound source is switched off.

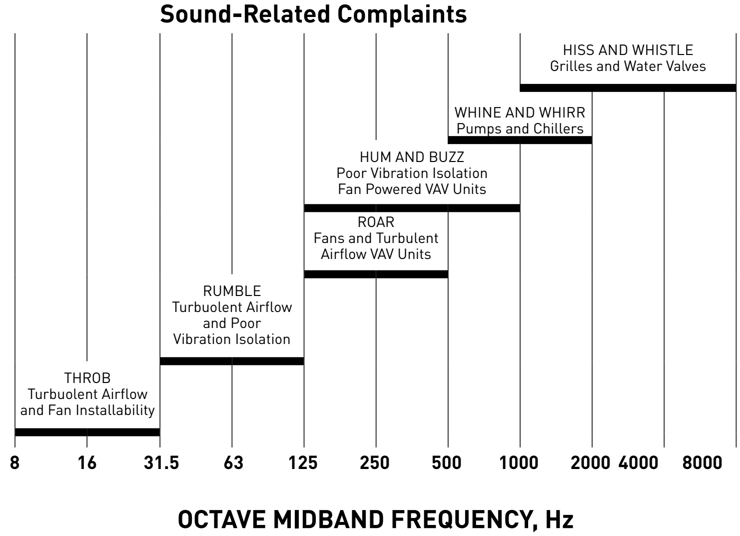


This is why good acoustic engineering in a building requires an integrated noise control strategy. Structure-borne noises are most effectively controlled using vibration-isolation and / or other structural isolation techniques. Acoustic duct lining is mainly efficient for controlling airborne noise and can, to an extent, minimize the panel vibration.

Significance of Frequency

Figure 1, taken from the ASHRAE Chapter on "Sound and Vibration Control," breaks down the likely sources of sound-related complaints in an HVAC system. All of these noises can travel through the air in the duct in the form of sound waves or through the duct panels in the form of mechanical vibration. As the graph illustrates, sources for sound-related complaints in a mechanical system are typically broadband, and range from the low frequency "THROB" of turbulent airflow and fan instability to the high frequency "HISS AND WHISTLE" of grills and water valves.

Figure 1 – Frequency Ranges of Likely Sources of Sound-Related Complaints



Source: "Sound and Vibration Control" 2003, ASHRAE

ANSI S3.1 – 1977 identifies 500Hz, 1000Hz, and 2000Hz as the key frequencies for speech intelligibility.

Problematic noises in the lowest frequency ranges (below 125 Hz) are those that are most effectively dealt with at the design stage since they are mostly related to poor equipment isolation and system instability, and therefore cannot be solved with duct lining or duct wrap. In some cases installing additional silencers and/or altering the duct layout to sustain laminar airflow and correcting fan instability can remove these noises.

At the other end of the scale are high frequency noises (above 1000Hz), most often associated with the "hiss and whistle" through grills and water valves, although virtually any aerodynamic noise can contribute to the high frequency noise in duct. High frequency noise from diffusers occurs downstream, and is therefore not applicable to a discussion about duct noise. Furthermore, higher frequency noise tends to degrade on its own as a result of the directional changes that are typical within a ductwork system.

It is also worth noting that the American Standard ANSI S3.1 – 1977 identifies 500Hz, 1000Hz, and 2000Hz as the key frequencies for speech intelligibility. This means that noise in those frequencies is arguably the most disruptive to the human ear when it comes to conversation and should be minimized, particularly in spaces such as classrooms and lecture halls.

Generally, most of the problematic noise in a ductwork system lies in the 125 to 1000 Hz range (or 2000Hz depending on duct size). This is the range that can and should be addressed with duct liner.

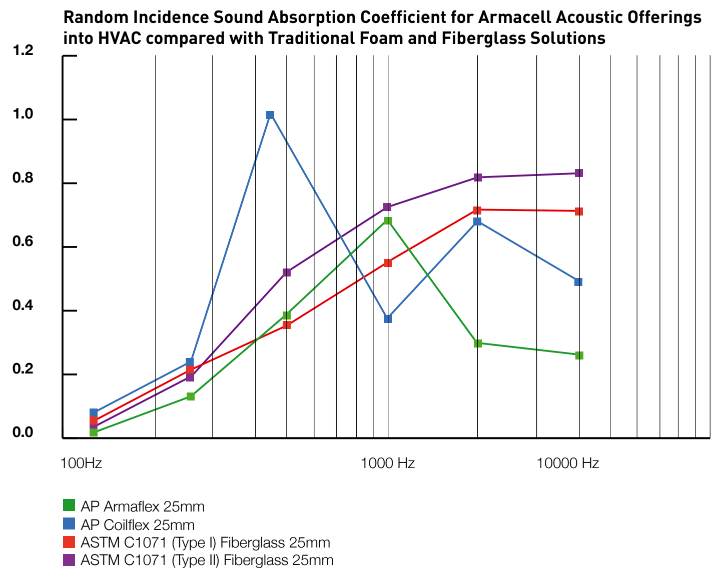
Comparative Performance of Elastomeric Foam at Critical Frequencies

Now that we've established the frequency range that is typically the most problematic in an HVAC system (a fact that is generally well-known and accepted by acoustic engineers), it's time to explore how duct liners, particularly elastomeric foam, react to low frequency noise environments.

Commonly used fiber-based duct liners absorb sound primarily through viscous and frictional losses of the air oscillating inside the material. Noise is reduced because of frictional effects inside the material. These materials, in typical 1-inch thicknesses, are effective over a relatively broad range of frequencies, but their sound absorption performances diminish significantly at 500 Hz and below. Thus, when low frequency noise is anticipated as a problem, greater thickness (and length) of fibrous material is required or else the designed sound attenuation will not be achieved.

Elastomeric foam products, such as ArmaFlex and CoilFlex, react to sound quite differently. Unlike fiberglass, which allows sound (in the form of varying air pressure) to freely enter into the spaces between the fibers, closed- cell elastomeric foam is too highly resistive to enable the viscous friction of air inside to develop an effective absorption mechanism. However, instead of simply reflecting the sound like many other types of rigid foam materials, the physical properties of elastomeric foams are such that their structure mechanically responds to the incident sound. This response can be particularly pronounced at certain frequencies, depending on the material's chemical formulation, elasticity and thickness. In the case of ArmaFlex and CoilFlex, a significant proportion of the incident sound energy is converted into movement of the foam and eventually into heat.

Table 1: Sound Absorption: (ISO 354 & ASTM C423)



AP CoilFlex's total noise reduction coefficient rating remains higher than both Type I and Type II fiberglass between 125 Hz and 500 Hz.

Table 1 compares the Sound Absorption Performance of ArmaFlex and CoilFlex with Type I and Type II Fiberglass at one-inch (25 mm) thicknesses. Focusing on frequencies between 125 Hz and 500 Hz some important revelations occur. CoilFlex offers superior sound absorption performance over this entire range, particularly at 500 Hz where its sound absorption is 1.03 compared to Type I fiberglass, which is only half as effective at 0.52.

Closed-cell ArmaFlex performance compares well to fiberglass insulation up to 1000Hz. CoilFlex's total noise reduction coefficient rating (the average of the measurements at 250, 500, 1000, and 2000Hz) remains higher than both Type I and Type II fiberglass between 125 Hz and 500 Hz.

The performance of these products at their respective frequencies disputes some commonly held notions that elastomeric foam lags behind fibrous materials in terms of sound attenuation.

Tables 2 and 3 show the performance of duct with 1" and 2" fiberglass lining. Note that the difference in performance between 1" and 2" fiberglass is in the 250, 500 and 1000Hz regimes. The performance between 1" and 2" fiberglass is similar for 2000Hz and above and also for 125Hz. Logically, a thicker insulation system would only be considered if you did not meet the low frequency requirement with 1" fiberglass, otherwise it would be an unnecessary additional cost. However, it is a common practice to use thicker fiberglass linings or insulate the duct channel for greater distances whenever additional low frequency reduction is required. As we've noted, this is a likely case in almost any HVAC system.

Table 2 Insertion Loss for Rectangular Sheet Metal Ducts with 1 in. Fiberglass Lining

	Insertion Loss, dB/ft Octave Midband Frequency, Hz					
Dimen in. x in.	**125**	**250**	**500**	**1000**	**2000**	**4000**
6 x 6	0.6	1.5	2.7	5.8	7.4	4.3
6 x 10	0.5	1.2	2.4	5.1	6.1	3.7
6 x 12	0.5	1.2	2.3	5.0	5.8	3.6
6 x 18	0.5	1.0	2.2	4.7	5.2	3.3
8 x 8	0.5	1.2	2.3	5.0	5.8	3.6
8 x 12	0.4	1.0	2.1	4.5	4.9	3.2
8 x 16	0.4	0.9	2.0	4.3	4.5	3.0
8 x 24	0.4	0.8	1.9	4.0	4.1	2.8
10 x 10	0.4	1.0	2.1	4.4	4.7	3.1
10 x 16	0.4	0.8	1.9	4.0	4.0	2.7
10 x 20	0.3	0.8	1.8	3.8	3.7	2.6

1-inch Fiberglass Lining

Table 3 Insertion Loss for Rectangular Sheet Metal Ducts with 2 in. Fiberglass Lining

	Insertion Loss, dB/ft Octave Midband Frequency, Hz					
Dimen in. x in.	**125**	**250**	**500**	**1000**	**2000**	**4000**
6 x 6	0.8	2.9	4.9	7.2	7.4	4.3
6 x 10	0.7	2.3	4.4	6.4	6.1	3.7
6 x 12	0.6	2.3	4.2	6.2	5.8	3.6
6 x 18	0.6	2.1	4.0	5.8	5.2	3.3
8 x 8	0.6	2.3	4.2	6.2	5.8	3.6
8 x 12	0.6	1.9	3.9	5.6	4.9	3.2
8 x 16	0.5	1.8	3.7	5.4	4.5	3.0
8 x 24	0.5	1.6	3.5	5.0	4.1	2.8
10 x 10	0.6	1.9	3.8	5.5	4.7	3.1
10 x 16	0.5	1.6	3.4	5.0	4.0	2.7
10 x 20	0.4	1.5	3.3	4.8	3.7	2.6

2-inch Fiberglass Lining

Finally, elastomeric foam will provide some degree of vibration isolation when applied to the exterior of the duct and vibration damping when it is applied to the interior or exterior. Elastomeric foam stabilizes the duct wall, which otherwise vibrates very easily. When duct walls vibrate, noise that breaks in and breaks out of the ductwork is amplified. A well-adhered elastomeric foam insulation damps this vibration, which in turn reduces the amount of break-out sound and internal airborne noise.

Exterior applied elastomeric foam also provides a separation layer between the duct and any building elements that are in direct contact with it; this also minimizes vibration. The use of elastomeric foam at the Print Works Bistro (referenced at the end of this article) is an excellent example of the product's vibration damping capability.

Beyond Acoustics

Now that we have a more balanced perspective on elastomeric foam acoustic performance in a typical HVAC system, it's important to explore some of its other attributes and their contribution to the overall performance and longevity of a duct system.

Armacell manufactures two types of elastomeric foam duct liners: Those in the ArmaFlex family and CoilFlex. Both products have the following features in common:

• Non-fibrous, erosion-resistant structure that withstands velocities of 10,000 ft/min. Neither ArmaFlex nor CoilFlex requires costly encapsulating films or inner metal wall.

ArmaFlex Duct Wrap has a closed cell structure that provides exceptional moisture resistance, adding to its long-term performance.

ArmaFlex and ArmaFlex SA Duct Liners have a closed cell structure that provides exceptional moisture resistance, adding to its long-term performance.

CoilFlex is highly conformable, ideal and cost-effective for coil line duct fabrication, with excellent long-term acoustic value.

Their surface is smooth, cleanable and resistant to tears and punctures. Even if tears or punctures occur, the structural material holds together without compromising performance.

- Thermal properties, which meet the requirements of ASHRAE 90.1 and the International Energy Conservation Code.
- Flame spread index of less than 25 and a smoke developed index of less than 50 for all thicknesses up to and including 2" when tested according to ASTM E 84.
- Built-in EPA-registered Microban® antimicrobial protection to inhibit the spread of mold inside the ducts.
- GREENGUARD Gold certification for low emitting products.
- Low VOC, formaldehyde-free, and nonparticulating.

Elastomeric foams are typically expected to last the life of the duct system. Because they are fiber-free, and moisture resistant (particularly closed-cell ArmaFlex) they are far more likely to survive a serious mold incident and never need replacement. This is one of the reasons that ArmaFlex is a preferred choice for condensation control and is frequently used on refrigeration and cold water piping, where moisture is a particular concern. In fact, ArmaFlex can be cleaned and remediated like any hard surface material – presenting a major safety net for facilities like schools where chronic mold problems have resulted in thousands of dollars in equipment replacement. With either product, there is virtually zero likelihood of further degradation due to tears or punctures.

Fiber-free duct systems are a requirement of most healthcare facilities, and many schools and colleges are following suit. An article in The Construction Specifier magazine acknowledges that fiber-free ducts are perceived to be less of a health risk to installers and building occupants.[2] When it comes to designing a fiber-free environment, uninsulated duct is a poor option because of thermal inefficiency and poor acoustics. The only other option, used in some cases with fiberglass to contain fibers, is dual wall duct, but it proves cost prohibitive in most cases. Elastomeric foams provide a viable, affordable option.

When choosing between elastomeric foam products, the building owner and/or designer will need to carefully weigh the benefits in terms of the specific needs and budget for the project. CoilFlex can be a more affordable installation since it can be applied using traditional coil line duct fabrication methods, just as fiberglass liner might be applied to duct in a sheet metal shop. It is more flexible than traditional elastomeric foams and therefore bends easily in the corners of rectangular duct so that it need not be applied in four separate pieces, one for each side. It also offers better acoustical performance over the most critical frequencies, making it attractive for facilities like schools and offices where sound levels negatively impact concentration and productivity.

ArmaFlex, on the other hand, has superior performance in terms of moisture control because it is a closed-cell product. It has a built-in moisture retarder, making it a better solution for applications where condensation is perceived to be a greater threat.

In either case, there are all-inclusive benefits to both products that enhance their value in the face of increasing concerns over indoor air quality and overall sustainability.

Elastomeric Foam: An Educated Perspective

Those who fully understand the particular acoustic values of elastomeric foam also appreciate its role in an HVAC system. Kirill V. Horoshenkov, Professor of Acoustics, Department of Mechanical Engineering at the University of Sheffield, England is one of those people.

Prof. Horoshenkov, who is also on the Editorial Board for the Journal of the Acoustical Society of America states, "ArmaFlex is a multifunctional foam that offers a unique combination of good acoustic and excellent thermal insulation properties. The acoustic properties of this material are reflected in its excellent vibration isolation and acoustic resonance absorption performance."

Prof. Horoshenkov adds that "...it is ArmaFlex's unique combination of sound absorption and vibration isolation behavior that offers benefits for low frequency noise problems that are commonly problematic in ductwork and enclosures."

In practice, elastomeric foam products have resolved noise issues, even in the least forgiving of situations. A case-in-point is the Print Works Bistro at the LEED® Platinum Certified Proximity Hotel in Greensboro, NC. The HVAC start-up of this restaurant revealed an unacceptable noise level – one certain to detract from the ambience and disrupt patrons' conversations. The culprit was the rooftop air handler and the subsequent "rumble" through the ductwork. With only 48 hours to go before the grand opening of the restaurant, lining the already installed ductwork was not an option. To further complicate matters, the ductwork was exposed, in keeping with the restaurant's post-industrial décor.

To resolve the problem, Joe Millikan, PE, President of Superior Mechanical, Inc. and LEED AP, installed ArmaFlex elastomeric foam insulation inside the rooftop unit and also on the exterior of the ductwork that hung from the ceiling inside the restaurant. The duct insulation was painted to match the décor so aesthetics were unaffected. More importantly, the problematic noise was gone.

"ArmaFlex saved the day," said Millikan. "There's really no other product out there that does everything this product does."

You can read the full case study of the Print Works Bistro at http://www.armacell.us/resources/job-stories .

Microban antimicrobial product protection is limited to the product itself and is not designed to protect the users of these products from disease causing micro-organisms, or as a substitute for normal cleaning and hygiene practices. Microban is a registered trademark of Microban International, Ltd.

GREENGUARD Certified products are certified to GREENGUARD standards for low chemical emissions into indoor air during product usage. For more information, visit ul.com/gg.

Footnotes:

1. From the January 2010 Scientific American Mind, "How does background noise affect our concentration?"

2. From the January 2010 The Construction Specifier, "Sound Advice: Duct liners for acoustic control and indoor air quality."

All data and technical information are based on results achieved under the specific conditions defined according to the testing standards referenced. It is the customer's responsibility to verify if the product is suitable for the intended application. The responsibility for professional and correct installation and compliance with relevant building regulations lies with the customer. Armacell takes every precaution to ensure the accuracy of the data provided in this document and all statements, technical information and recommendations contained within are believed to be correct at the time of publication. By ordering/receiving product you accept the **Armacell General Terms and Conditions of Sale** applicable in the region. Please request a copy if you have not received these.

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ABOUT ARMACELL

As the inventors of flexible foam for equipment insulation and a leading provider of engineered foams, Armacell develops innovative and safe thermal, acoustic and mechanical solutions that create sustainable value for its customers. Armacell's products significantly contribute to global energy efficiency making a difference around the world every day. With 3,100 employees and 24 production plants in 16 countries, the company operates two main businesses, Advanced Insulation and Engineered Foams. Armacell focuses on insulation materials for technical equipment, high-performance foams for high-tech and lightweight applications and next generation aerogel blanket technology.

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