



Sound Advice

Duct liners for acoustic control and indoor air quality

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Photo by David Moore

THERE IS A SCENE OFTEN SHOWN IN MOVIES, WHERE A COVERT OPERATIVE OR HIGH-STAKES JEWEL THIEF CRAWLS THROUGH AIR-CONDITIONING DUCTWORK. HE INCHES HIS WAY THROUGH A GLEAMING MAZE OF NAKED METAL. IT IS NEITHER HOT NOR COLD. IT IS TOTALLY QUIET. AND WHEN HE FINALLY EMERGES, THERE IS NO SOUND OF HIS MOVEMENTS TO FOREWARN HIS NEMESIS.

Inside actual ductwork, there are things Hollywood does not display: tempered and high-speed air, noise, and airborne microbes. There is also something else interacting with all these factors—duct liner. These products cut noise transmission through ventilation systems and improve thermal efficiency.

Fibrous duct liners have been used for years, and their performance for noise and thermal control is proven. However, in sensitive applications like hospitals, laboratories, or other clean environments, fibrous liners are not allowed due to the potential for the fibers to become dislodged and airborne. Additionally, many owners and engineers now require non-fibrous liners due to their own safety assessments, health and environmental concerns, and liabilities that may be associated with fibrous materials in HVAC systems.

In applications where fibrous duct liners are not desirable or not allowed, non-fibrous liner can perform the same functions and meet required performance standards. This article examines the use of specially coated polyimide foam products for this application.



Glass fiber (shown left) is the most commonly used material for duct liners. It is manufactured in flexible batts and rigid boards. Glass fiber ductliner (top right) usually has a black coating.

Photos courtesy Steven H. Miller and David Moore

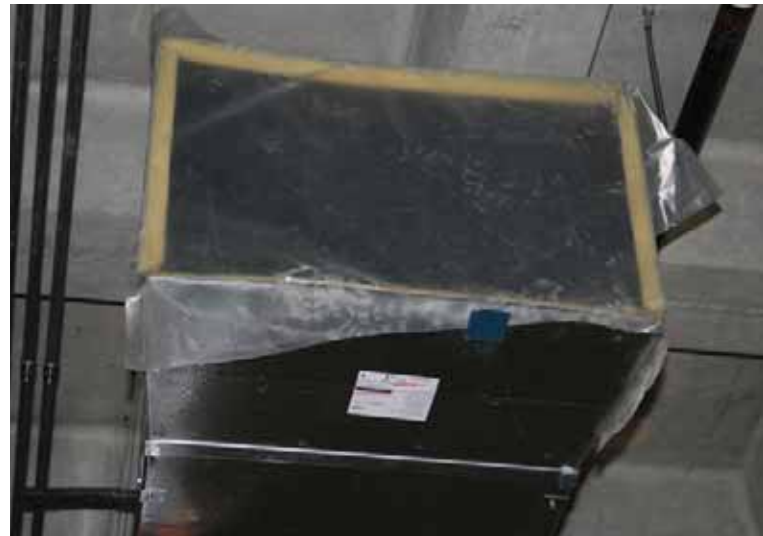
Why duct liners?

Ducts carrying air through buildings also transmit sounds; HVAC equipment (e.g. fans and compressors) is the main source of this noise.

The housing of an HVAC unit can be acoustically insulated to limit the radiating noise, and can be acoustically isolated from the rest of the building by soundproofing the equipment room or placing the unit outside, on the roof, or hidden in the basement. However, the unit has acoustical ‘windows’ into the rest of the building in the form of ductwork, and those cannot be sealed off.

When noise escapes into an open, unrestricted space, the sound level drops rapidly as it moves farther away from the source. (A sound wave’s air pressure varies as the inverse square of distance from the source.) However, a duct is not an open environment, but a ready-made sound transmission tube. Pressure waves are then reflected off the sides of the tube, zigzagging down its length. Hard, smooth tubing is efficient at conducting sound with minimal dissipation—so much so the first sound recordings were made without a microphone or amplifier, just raw-source sounds conducted down a conical tube to the recording apparatus. Ducts with square or rectangular cross-sections not only transmit sound, but can also emphasize selective frequencies.

This noise transmission may be reduced by two means. The HVAC unit is connected to the metal ducts by about 150 mm (6 in.) of flexible fabric duct that prevents the unit’s vibrations from being transferred. The noise propagating through the air in the ducts is best dealt with by placing sound-absorbing materials inside the ductwork. Lining even a small percentage of the total length can effectively dissipate the force of sound waves.



HVAC ducts are lined with sound-absorbing material to reduce noise emanating from the central HVAC equipment. This duct, from the Daniel J. Evans Library at Evergreen State College (also pictured on at left), is lined with coated polyimide foam, an acoustic material suitable for acoustic control in projects where non-fibrous duct liners are required. (The duct is temporarily covered with plastic sheeting to keep dust and debris out until installation is complete.)

Photo © Stephanie H. Ayers. Photo courtesy Evonik Foams.

To be ideal for an application, lining materials must have certain required properties:

- sound absorption;
- a thin section (so the liner does not significantly reduce the cross-section of open air pathways);
- heat resistance;
- flame spread and smoke developed limits; and
- mold resistance.

Since many ducts are insulated for thermal efficiency, the liner’s thermal resistance also becomes a factor in design decisions seeking to gain two functions from one product. Insulation intended exclusively for thermal resistance is generally applied on the duct exterior, but it could theoretically be reduced or eliminated over sections of duct lined on the interior. Therefore, the thermal insulating value of acoustic material should be considered.

DUCT LINER PERFORMANCE STANDARDS

ASTM C 1071, *Standard Specification for Fibrous Glass Duct Lining Insulation (Thermal and Sound-absorbing Material)*, the performance standard for fibrous duct liners, is frequently referenced when contrasting the performance of both fibrous and non-fibrous liners.

When compared to ASTM C 1071, coated polyimide foam duct liner provides similar performance to fibrous liners, making it a viable alternative.

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Test Method	Performance Standard
ASTM C 518, C 177, or C 1114 (i.e. thermal conductivity at 23.9 C [75 F])	0.038 W/(m C) (0.27[Btu·in.]/[hr·sf·F])
ASTM C 1104 (i.e. water vapor sorption)	Not more than three percent by weight.
ASTM C 1338 (i.e. standard practice G 21)	No fungal growth.
ASTM C 411 (i.e. temperature resistance)	Air stream surface has no evidence of flaming, glowing, smoldering, visible smoke, delamination, cracking, deformation, or reduction in thickness.
ASTM C 1071 (i.e. erosion resistance)	Insulation should not break away, crack, peel, flake off, or show evidence of delamination or continued erosion when air is passed through typical duct sections.
ASTM C 1304 (i.e. odor emission)	Cannot have a detectable, objectionable odor recorded by more than two of five panel members.
ASTM E 84, UL 723, NFPA 255 (i.e. surface burning characteristics)	Flame Spread Index = 25 Smoke Developed Index = 50
NFPA 259 (i.e. combustion characteristics)	Potential Heat \leq 8.141kJ/kg (3500 Btu/lb)
ASTM 665 (i.e. corrosiveness)	Pass.
ASTM G22 (i.e. bacterial resistance)	0—no bacterial growth.

Polyimide foam duct liner has been developed for applications where non-fibrous materials must be used. An acrylic coating serves as a protective barrier against dust and moisture, helping resist mold growth. An inch of polyimide foam has a noise reduction coefficient (NRC) equal to or exceeding that of an inch of most glass fiber duct liners.

Photo courtesy Evonik Foams

with the cube of RPM. Therefore, to maintain energy efficiency while mitigating noise, duct liner is typically used instead of attenuators.

Just as duct liners absorb noise emanating from HVAC systems, they can also be employed to prevent ducts from becoming a conduit, carrying noise from one room of the building to another. Ducts joining two rooms can be designed in a U-shape and lined, which effectively dissipates room-to-room transmission and protects speech privacy.

Required properties

Whether it is fresh, supply, return, or exhaust air, the intended contents of ducts are often heated or cooled. Therefore, liner materials must meet certain criteria for withstanding heat and maintaining dimensional and chemical stability under changing temperature conditions. For example, building codes relating to fire safety require duct liner products to meet a <25 Flame Spread Index and a <50 Smoke Developed Index per Underwriters Laboratories (UL) 723/ASTM E 84/National Fire Protection Association (NFPA) 255, *Standard Test Method for Surface Burning Characteristics of Building Materials*. (See “Duct Liner Performance Standards.”)

The air in ducts may also contain a variety of airborne microbes. It is important the liner be resistant to bacterial and fungal growth. This attribute is particularly important in ducts where moist air is present.

Sound attenuators are another option that effectively combat HVAC system noise, but they can take a high toll on energy efficiency. These products can be designed to reduce sound levels over specific frequency ranges. Mounted inside ducts, they create an obstruction in airflow that adds static pressure to the mechanical system. This pressure must be overcome by increasing the speed or size of the HVAC fan, which correlates to increased horsepower required and energy used.

Fan laws state static pressure increases with the square of revolutions per minute (RPM), and horsepower increases

Where non-fibrous material is needed to line ducts, polyimide foam provides the best acoustic performance and stability under high heat.

Thermal insulation is an important aspect of duct design, but there are limitations. Resistance is increased in proportion to the thickness of insulating material. However, augmenting the dimensions of insulation around the interior perimeter of the duct narrows the passageway available for airflow, which is the duct's main function. If high thermal resistance is needed, exterior insulation may be necessary, but exterior thickness can be reduced over sections lined on the inside, as long as the combined material reaches the required R-value.

Health considerations

As mentioned, fibrous duct liners have been standard for decades, but an increasing number of building projects include requirements for non-fibrous products. This may be due to concerns about dusting—caused by high-velocity air—releasing glass fibers into the environment. (This potential is tacitly acknowledged in the published best practice of applying edge sealer on cut edges of glass fiber liner to help stabilize the fibers.)

Another concern may be the possibility of sensitization from long-term exposure, as well as occupational health and safety issues of construction workers. In addition, many common glass fiber products are stabilized with a binder containing urea-formaldehyde (UF), a known health risk.

Sheet metal workers who fabricate ducts and install insulation have high exposure to glass fiber. They routinely protect themselves when installing it by wearing eye protection, particle-resistant masks or respirators, gloves, and long-sleeved shirts.

The Sheet Metal Occupational Health Institute Trust (SMOHIT) was established in 1986 with the express purpose of determining the rates of disease and other occupational illnesses among sheet metal workers related to asbestos. One of its key findings included that sheet metal workers who had high exposure to synthetic vitreous fibers, such as fiberglass, were diagnosed with more bronchitis and obstructive lung disease, compared to workers who were not exposed.

Whether glass fiber poses an actual health consideration to building occupants is beyond the scope of this article. However, the marketplace reality is that risks are perceived, and requirements for non-fibrous duct liners are prevalent. This is especially true in instances of buildings serving primarily sensitive populations, such as children in schools and health-compromised patients in hospitals. It also applies to clean room and similar high-tech environments.

For projects where non-fibrous materials are needed, foam liners have been developed—including products made from polyimide, polyolefin, and elastomeric foams. Of these, polyimide foam tends to provide the best combination of acoustic performance and stability under high heat—up to 121 C (250 F). Polyolefin and elastomeric

foams do not have the same temperature resistance as this material, and they exhibit lower acoustic performance. Open-cell polyimide foam—an acoustic and thermal insulator that is lightweight and has excellent fire and heat resistance—can equal or exceed the sound-absorbing performance of similar thicknesses of glass fiber. According to ASTM C 356, *Standard Test Method for Linear Shrinkage of Preformed High-temperature Thermal Insulation Subjected to Soaking Heat*, polyimide foam has a hot shrinkage of 0.1 percent. Its low density—12.8 kg/m³ (0.80 pcf)—also makes it a candidate for situations where glass fiber would be too heavy for the load restrictions of the ductwork.

Originally developed by the National Aeronautics and Space Administration (NASA) for use in space vehicles, polyimide foam liners meet the same performance criteria as glass fiber in terms of response to heat and flame. The material exceeds UL 723/ASTM E 84/NFPA 255, and is almost as efficient in thermal resistance as glass fiber of similar thickness.

The foam should be coated on at least one surface with an acrylic product serving as a protective barrier against dust and moisture, helping resist mold growth. Polyimide is a low-emitting product in terms of volatile organic compounds (VOCs), enhancing its ability to be used in applications with sensitive indoor air quality (IAQ) requirements. Due to its performance with regard to IAQ, it has been certified under the Greenguard Children & Schools program.¹

Installation of polyimide foam is similar to standard glass fiber rigid plenum liner board, so contractors experienced in installing these products already possess the knowledge to install foam. However, workers installing foam generally do not feel the need to wear masks, respirators, gloves, or long sleeves.

Achieving the sounds of silence

The duct liner attenuates noise, which combines two actions:

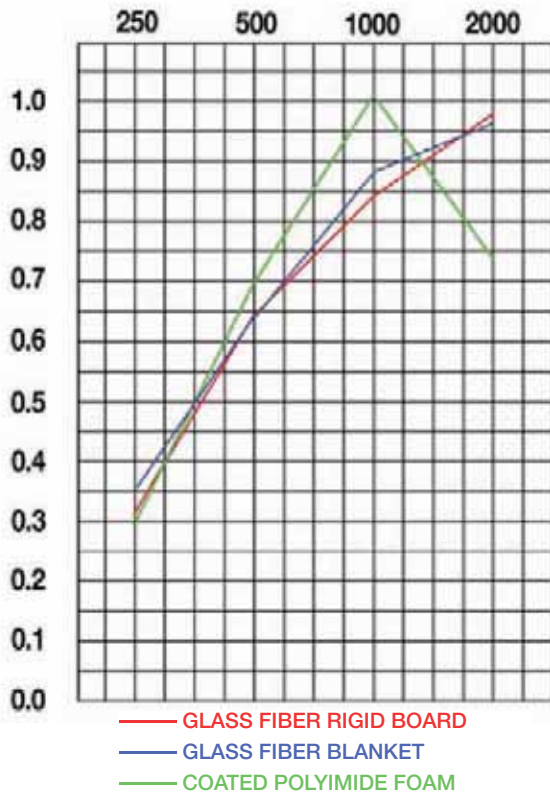
- scattering (*i.e.* redirecting of sound waves from their original path of propagation by use of reflection); and
- absorption (*i.e.* converting sound to other forms of energy, generally heat).

Therefore, the primary action of duct liner is not to contain noise or filter it out, but to break it up and weaken its force.

Acoustical control materials perform this function to different degrees at different frequencies (itches) of sound. To quantify a specific material's noise-reducing ability, the full range of frequencies is divided into six bands from low-pitched tones to high-pitched ones (usually 125, 250, 500, 1000, 2000, and 4000 Hz).

FIGURE 1

NOISE REDUCTION OF 25-MM (1-IN.) THICKNESS DUCT LINERS



Rigid glass fiber and polyimide foam data are each from a major manufacturer. Glass fiber blanket data averaged from three products by major manufacturers.



Polyimide foam is a soft, lightweight, fire-resistant material used as thermal and acoustic insulation in a variety of industries for demanding applications.

Photo courtesy Evonik Foams

HOW TO SPECIFY DUCT LINERS

1. Show locations and length of duct liners in drawings or schedules.
2. Select duct liner products, keeping in mind all project requirements including acoustics, air quality, energy efficiency, and building codes.
3. When a proprietary specification is acceptable, it may be sufficient to identify a brand of duct liner and the required thickness.
4. For a performance-based specification, the following should be specified:
 - noise reduction coefficient (NRC) or absorption coefficients for the individual octave bands;
 - whether fibrous or non-fibrous materials are acceptable (if the latter is required, the most frequently used product is polyimide foam with 12.8 kg/m³ (0.8 pcf) density and a black, acrylic coating); and
 - thermal conductivity (K-value) or thermal resistance (R-value).

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The acoustic absorption of the material is measured at each of these ranges using ASTM C 423, *Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method*, and ASTM E 795, *Standard Practices for Mounting Test Specimens During Sound Absorption Tests*. The average of the measurements of the four central frequencies (250, 500, 1000, and 2000 Hz) is the noise reduction coefficient (NRC).

Since a given material's NRC is an average, special attention must sometimes be paid to the details of the material's performance. If the sound source for which one is designing has exaggerated noise output in a specific frequency range, it is worthwhile to check the material's performance with respect to that range (Figure 1).

The duct liner materials outlined in Figure 1 exhibit an NRC of 0.70 at 25 mm (1 in.). However, there are differences when comparing glass fiber rigid plenum board, glass fiber 'blanket' liner, and coated polyimide foam, at individual frequencies. In the lowest range considered for NRC (*i.e.* 250 Hz) the three materials perform similarly (glass fiber blankets do slightly better than the other two). In the 500- and 1000-Hz range—where much of human speech is centered—foam is 10 to 20 percent more effective than either glass fiber material.

Typically, the lower frequency ranges pose the most concern when dealing with sound transmission. The lower frequency ranges travel through air for a greater distance without dissipating. The higher frequencies tend to disperse on their own when given enough

distance. This can be observed by listening to a passing car stereo—the lower tones (*i.e.* bass) can be heard for a long distance, whereas the higher frequencies are not heard until the car draws closer.

The level of noise attenuation attained in a duct is determined by the available surface area of acoustic material (*i.e.* the duct liner perimeter multiplied by the linear feet of lined duct). The number that expresses this attenuation is called 'insertion loss.'

The length of duct needing to be lined is calculated using the documented noise output of the fan system and the insertion loss factor of the candidate liner materials. Noise contributed by the HVAC system then becomes part of a more complex decision about the specific acoustic requirements of each space in the building, taking into account all noise sources, the room's physical properties, and its intended use.

For general environments, acceptable noise reduction can often be achieved by lining only the first 3 to 6 m (10 to 20 ft) of ductwork adjoining the fan system. Limited lining of this kind reduces fan noise, but usually will not eliminate it. For spaces with exacting sound requirements (*e.g.* performance or sound studios), it may be necessary to line the entire duct length.

For example, the Daniel J. Evans Library at The Evergreen State College (Olympia, Washington) recently underwent an extensive remodel with strong emphases on sustainability, IAQ, energy efficiency, and effective use of technology. The plan included conventional library space and media production facilities, including sound recording studios and editing spaces.



A sheet metal worker cuts polyimide foam duct liner for the Daniel J. Evans Library project. His cutting template is the same piece of sheet steel the liner will be attached to in the duct.

Photo © Stephanie H. Ayers. Photo courtesy Evonik Foams.

Acceptable noise levels for the library areas were designed similar to general use commercial space. For cost efficiency, the ductwork supplying these areas was only lined for about the first 1.5 m (5 ft) from the HVAC equipment. However, the media center required extremely quiet conditions, and the entire length of its ducting was lined.

Based on previous experiences, the owner mandated no fibrous materials be used in the ducts. This excluded glass fiber and cotton liners. Closed cell neoprene foam was evaluated, but while it had high thermal insulating value, its acoustical performance was considered inadequate for the project. Polyimide foam was then employed with success.

Summary

Studies of workplace and educational environments have revealed noise control is a potent tool in productivity improvement and job satisfaction.² There are similar implications regarding the functioning of other indoor spaces and acoustics.

Proper application of duct liners can be a cost-effective solution to noise reduction. For buildings where fibrous liners are unacceptable, polyimide foam duct liner offers a solution that does not compromise performance and contributes to better indoor air quality—another important aspect of improving the functionality and livability of the built environment. **CS**

Notes

¹ Visit www.greenguard.org.

² For more information, see “Sound Solutions: Increasing Office Productivity Through Integrated Acoustic Planning and Noise Reduction Strategies,” a 2006 report by the American Society of Interior Designers (ASID) and a group of product manufacturers.

ADDITIONAL INFORMATION

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Abstract

While the noise and thermal control performance for fibrous duct liners have been proven, some hospitals and schools, as well as laboratories and other clean environments, do not allow these products. To meet required performance standards for temperature management and acoustics in these cases, non-fibrous liner made of specially coated polyimide foam can be used.

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