A REVIEW OF THERMAL ACOUSTICAL AND SPECIAL PROJECT REQUIREMENTS DATA IN DESIGNING A DUCT SYSTEM

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ABSTRACT

The primary foci in designing a duct system is: 1) Delivery of the correct amount of air; 2) Delivery of air at an acceptable temperature with minimum temperature drop; 3) Delivery of air quietly; and, 4) A system which is applicable to the project conditions. The Sheet Metal and Air Conditioning Association (SMACNA) and the Thermal Insulation Manufacturers Association (TIMA), have done considerable testing on air loss and temperature drop on operating HVAC systems.

It is important to note that these tests show that air leakage through unsealed joints is the most significant factor in heat loss. No amount of insulation can make up for a 24 percent air leakage rate in an unsealed, rectangular sheet metal system. Acoustical data is not as readily available. ASHRAE is currently testing acoustical companies; however, this information is not yet available. Based on testing by Owens/Corning Fiberglas, duct attenuation in dB's per lineal foot at 500 H_z of various insulating materials can range from 2.9 dB's to 3.7 dB's.

The last area to consider in designing a duct system is project conditions. This area is not as technically oriented as the other three; however, it is crucial in designing a duct operable system. Items to consider are susceptibility to abuse, concealed or exposed duct, how critical the acoustics are, duct clean out requirements, climate conditions, residential versus commercial construction, and new versus retrofit construction. Without revealing the properties of each system, a failure or a less than acceptable environment for occupants could occur.

AIR LEAKAGE

Probably the most neglected design criteria for duct work is air leakage. Testing by SMACNA (HVAC Air Duct Leakage Test Manual, First Edition, August, 1985), and TIMA (Thermal Transmission Data for Operating Duct Systems, 3/83), show that air leakage through unsealed joints is the most significant factor in heat loss.

Four variables affect leakage: 1) static pressure; 2) footage of duct work; 3) openings; and, 4) workmanship. SMACNA has evaluated leakage of various systems and assigned a factor to each duct class and seal class. The leakage class is what is permissible leakage in CFM/100 square feet of duct surface. The SMACNA results are in TABLE 1.

TABLE 1

Duct Class	1/2, 1, 2 WG	3 WG	4, 6, 10 WG
Seal Class	C	B	A
Sealing Required	Transverse Joints Only	Transverse Joints/Seams	Joints, Seams, Penetrations
Leakage Class			
Rectangular Metal	24	12	6
Round Metal	12	6	3
Fiberglas Duct Board	6		
Unsealed Rectangular Duct	48	48	48

Appendix A of the SMACNA HVAC Air Duct Leakage Test Manual gives leakage as a percent of flow in a system by Leakage Class, fan CFM, and static pressure. The leakage in a 1" static pressure system can be as high as 24 percent in Leakage Class 48 to a low of 1.5 percent in Leakage Class 3. With this wide a range, it is very important that the engineer carefully choose what type of duct work to specify and evaluate alternatives carefully.

Using the SMACNA test results is the most practical way to calculate leakage in design. It is very expensive and normally disruptive to the jobsite to test for leakage. Proper sealing methods can normally be visually inspected. If a project is specified "according to SMACNA - XX Edition", proper sealing is required and should be enforced.

THERMAL PERFORMANCE

TIMA testing of operating duct systems agreed with SMACNA testing that the air leakage is the most significant factor in heat loss. No amount of insulation can make up for a 24 percent air leakage rate. The TIMA test was a calibrated hot box with a section of operating duct work running through it. U Values were measured where U is the coefficient of heat transmission measured in BTU/hr-ft2-°F. The lower the U, the better the insulation value. All test ducts were sealed because unsealed systems had more energy loss by leakage than by heat transfer, and the results were meaningless. TABLE 2 shows the retults of the TIMA test indicating flexible duct and wrapped sheet metal as the most thermally effecient.

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TABLE 2

SYSTEM			AIR VELOCITY,FPM	
			1000	2000
Uninsulated Sheet Metal		U-Value	.64	.68
Lined Sheet Metal (1-inch 2lb/ft3)		U-Value	.23	.31
Wrapped Sheet Metal (2-inch, 3/4 lb/ft3)	25% Compression	U-Value	.16	.16
	50% Compression	U-Value	.19	
Fiberglas Glass Duct 1-inch		U-Value	.19	.21
Insulated Flexible Duct 1-inch	Pervious Liner	U-Value	.21	.29
	Impervious	U-Value	.18	.18

ACOUSTICS

In most cases, duct design deals with solving nuisance noise levels and not health hazard noise levels. For this reason, data presented will address the nuisance noise problem and not the health hazard problem. If the complexity of a noise control situation is deemed to difficult to solve, there are many experienced acoustical engineers and consultants in the United States who can help solve the problem.

There are three primary ways to control noise: 1) at its source; 2) along its path; and, 3) at the receiver. Controlling noise at its source can be achieved by proper selection of equipment, redesign of the equipment, or proper support of equipment to reduce vibration. Along its path, sound energy can be absorbed or blocked by acoustical material. The positioning of the receiver by excluding him from the noise can solve the third problem. In duct design we are primarily concerned with controlling noise along its path; however, most acoustical problems are best solved by combining all three. In discussing noise reduction in ducts along their path, data will be presented in duct attenuation in dB per linear foot. Duct liners absorb sound caused by air handling equipment at the perimeter of the ducts as it moves through the length of the duct. To understand this data, a definition of terms is necessary.

Attenuation - to lessen in intensity and severity.

dB (decibel) - a logarithmic measure of the relative loudness of a sound.

Frequency - the number of cycles per second measured in hertz (H_z). 1000 H_z means 1000 cycles per second.

It is also important to note that current data on duct attenuation is disputed and being retested by ASHRAE. The new data is not available at this time. Because of this, data should be reviewed on a comparison basis and not as actual figures in calculating acoustical performance.The data in TABLE 3 is from Owens/Corning Fiberglas Acoustical Research Laboratory accredited by the federal government's National Voluntary Laboratory Accreditation Program. All tests are conducted according to noted test methods. (See TABLE 3).

Based on the data in TABLE 3, if you had a 12" X 24" sheet metal duct and you needed to reduct noise at 500 H_z, the best liner in terms of noise reduction would be 2" of duct liner board, the largest attenuation of dB's at 3.8.

TABLE 3

Table III-1
Duct Attenuation in dB per lineal foot of duct liner (1)

(1) = Tested at air velocity of 2000 fpm.
(2) = P/A 3 based on 12"x24" duct.
P/A 4 based on 12"x12" duct.
P/A 5 based on 8" x 12" duct.
P/A 6 based on 6"x12" duct.
P/A 8 based on 6"x6" duct.
*P/A = The inside perimeter of a lined duct in feet divided by the cross sectional free area of the duct in square feet.

Product	P/A*(2)	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
Duct Liner 1.5 pcf 1" thick	3	.5	.5	1.5	2.8	4.0	2.7
	4	.6	.8	2.0	3.4	3.9	3.6
	5	.5	1.2	2.1	3.4	5.1	3.8
	6	.2	1.1	2.4	3.5	3.9	3.7
	8	.4	1.7	3.1	4.0	4.8	4.4
Duct Liner 1.5 pcf 2" thick	3	.9	1.1	3.2	4.6	3.5	2.6
	4	.9	1.5	3.0	4.1	3.9	3.8
	5	.5	1.8	3.4	4.7	5.3	4.1
	6	.4	1.3	3.1	3.6	3.9	3.5
	8	.4	1.8	3.7	4.2	4.8	4.4
Duct Liner 2.0 pcf 1" thick	3	.7	.6	1.7	2.9	4.1	2.8
	4	.6	.7	2.0	3.4	4.1	3.7
	5	.2	1.1	2.1	3.5	5.3	3.8
	6	.3	1.0	2.4	3.4	3.8	3.4
	8	.4	1.7	2.9	3.9	4.6	4.4
Duct liner board, 1" thick	3	.4	.5	1.7	4.4	3.8	2.2
	6	.3	.9	2.7	4.7	5.2	4.1
Duct liner board, 2" thick	3	.6	1.0	3.8	4.7	3.6	2.3
	6	.4	2.0	4.1	4.7	5.1	3.7

Note: Attenuation data for duct liners are based on sound pressure levels measured in a reverberation room after sound passes through a 10-foot specimen and enters the reverberation room. These tests were conducted according to ASTM method E477-73. Attenuation data for other duct systems may differ from these values, and may be higher or lower depending on the distribution of sound energy in various propagating duct modes, length of lined (or unlined) duct sections which create discontinuities in the boundary conditions along the perimeter, and exit conditions at duct terminations.

Table III-2
Duct Attenuation in dB per lineal foot of duct board (1)

(1) = Tested at air velocity of 1200 fpm.
(2) = P/A 3 based on 12"x24" duct.
P/A 6 based on 6"x12" duct.
*P/A = The inside perimeter of a lined duct in feet divided by the cross sectional free area of the duct in square feet.

Product	P/A*(2)	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
475 EI 1" thick	3	1.1	.9	2.3	3.3	3.8	2.1
	6	.4	1.4	3.3	3.9	5.0	3.7
800 EI 1" thick	3	1.0	.8	2.4	3.4	3.9	2.2
	6	.3	1.4	3.4	4.1	5.2	4.0

Table III-3
Duct Attenuation in dB per lineal foot of flexible duct

Product	Dia	Octave Band Center Frequencies, Hz 125	250	500	1000	2000	4000
Flexible Duct 1½" wall thickness	4"	.7	1.3	4.2	4.1	4.1	3.0
	5"	1.2	1.4	2.6	3.9	4.0	2.6
	6"	1.3	1.4	3.2	4.0	4.1	2.4
	7"	1.1	1.7	3.1	3.9	3.8	2.0
	8"	.8	1.3	3.3	3.6	3.3	1.9
	9"	.8	1.3	2.8	3.6	3.6	1.8
	10"	.6	1.1	3.0	3.4	3.0	1.7
	12"	.8	1.4	2.7	3.1	2.9	1.3
	14"	.3	.6	2.6	3.1	2.7	1.2
	16"	.4	.6	1.7	2.4	2.1	1.0

All tests were conducted according to the Air Diffusion Council, Flexible Air Duct Test Code FD72. The data presented here are reduced from insertion loss tests on a 9 foot length of duct at an air velocity of 2,500 feet per minute.

PROJECT CONDITIONS

In addition to the above three criteria, specific project requirements must be evaluated. Questions to ask are: will the ducts be subject to abuse; are they concealed or exposed; do they have to be cleaned out; what are the condensation problems; is it new or retrofit; is it residential or commercial construction. Each type of duct has its pros and cons.

TABLE 4 recaps the leakage, thermal, and acoustical properties of each type of duct, (1-Good; 2-Fair; and, 3-Poor). In addition, various other properties are evaluated. For example in a high abuse area, it would not be good to specify flexible duct or duct wrap because of their low resistance to punctures. As we all know, it would be impossible to clean out a lined sheet metal duct or fiberglass duct. Specifications on a remodel project should include flexibility for jobsite redesign without prohibitive expense. It is very important to look at all requirments when specifying what type of duct work or insulation to use. Looking at one property could mean disaster. (SEE TABLE 4)

SUMMARY

Testing by SMACNA and TIMA show that air leakage through unsealed joints is the most significant factor in heat loss. Leakage at 1" static pressure (in W.G.), can be as high as 24 percent in an unsealed rectangular sheet metal system to as low as 1.5 percent in a totally sealed round system, (flexible duct). This is significant in that no amount of insulation can make up for a 24 percent air leakage rate. TIMA testing of operating duct systems agreed with the SMACNA testing that air leakage is the most significant factor in heat loss. Therefore, TIMA tested sealed ductwork to compare various insulation methods for thermal effectiveness. The test results showed that uninsulated sheet metal at 1,000 FPM air velocity had the highest U-Value of .64 (the higher the U-Value, the more heat loss). Lined sheet metal (1" 2.0 pcf density) had a U of .23; wrapped sheet metal (2" .75 pcf density) at 25 percent compression had a U of .16; fiberglass duct 1" thick was .19 U-Value; and insulated flexible duct 1" thick had a .18 U-Value. This data indicated wrapped sheet metal or flexible duct would be the best system in terms of leakage and thermal U-Values. However, this would leave two of the important criteria unaddressed.

Choosing the type of ductwork (sheet metal, fiberglass, or flexible duct) and insulation (liner, wrap, or no insulation), depends on acoustical requirements and project conditions. Acoustical data is disputed and currently being retested by ASHRAE. However, based on testing by Owens/Corning Fiberglass the duct attenuation in dB per linear foot at 500 H_z of various insulation materials is as follows:

Duct Liner (6" X 6" Duct)		ASTM E477-73
1"	1.5 pcf	3.1
1"	2.0 pcf	2.9
2"	1.5 pcf	3.7

TABLE 4

	Acoustics	Thermal	Leakage	Abuse	Condensation	Cleaning	Appearance	Pressure Low	Pressure Med	Pressure High	Redesign
Unlined Sheet Metal (Sealed)	3	3	2	1	3	1	1	1	1	1	2
Wrapped Sheet Metal (Sealed)											
Flexible Insulation	3	1	2	3	2	1	3	1	1	1	2
Rigid Insulation	3	1	2	2	2	1	2	1	1	1	2
Fiberglass Duct Board	1	1	1	2	1	3	2	1	2*	3	1
Flexible Duct	2	1	1	3	1	3	3	1	2	3	1
Lined Sheet Metal (Sealed)	1	2	2	1	1	3	1	1	1	1	3

*Manufacturer should be called for specific recommendations on fabrication and installation.

Duct Board (6" X 6" Duct)	ASTM-73
1" 475 EI	3.3
1" 800 EI	3.4
Flexible Duct (6")	ADC, Flexible Air Duct Test Code FD72
1-1/4" Wall Thickness	3.2

All of the above technical data is not worth using if project conditions are not considered. Items to be considered are susceptibility to abuse (mechanical rooms), concealed or exposed duct, how critical the acoustics are (theaters), duct clean out requirements (hospitals), climate conditions (North Texas versus South Texas for example), if it is residential or commercial construction, and whether it is new or retrofit construction. Without reviewing the properties of each system, a failure or a less than acceptable environment for occupants could occur.

Four areas must be carefully reviewed in designing an efficient acceptable duct system. They are: 1) air leakage; 2) thermal performance; 3) acoustics; and, 4) jobsite conditions.

REFERENCES

"HVAC Air Duct Leakage Test Manual", First Edition, 1985; Sheet Metal and Air Conditioning Contractors National Association, Inc.

"The Thermal performance of Operating Duct Systems"; March, 1983; Thermal Insulation Manufacturers Association.

"Noise Control Manual", Fifth Edition, November, 1985; Owens/Corning Fiberglas Corporation.

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