10 Redesign of Gymnasium Ductwork – Replace Sheet Metal with Fabric Duct

AE Mechanical & Acoustical Breadth

10.1 Introduction

Better acoustics and improved air quality in large, open areas of the school will help to enhance the learning environment for students by providing quieter and more comfortable spaces. The largest open area in the school is the gymnasium. The gymnasium will be used for sports practices, sporting events, and gym classes for all students. Teaching, coaching, learning, and cheering in this large, open environment can become stressful on the ears and also can become quite stuffy when filled to capacity.

10.2 Problem Statement

The current ductwork in the gymnasium is sheet metal with insulation. This creates a noisy environment, which is certainly not cohesive for a learning/coaching environment. It also is costly to install and maintain. Fabric ductwork will be installed in place of the sheet metal ductwork to better the acoustics, possibly reduce costs, and create a more comfortable environment.

10.3 Goal

The analysis will focus on bettering the acoustics in the gymnasium by replacing the typical sheet metal ductwork with a fabric duct system. The benefits of using the new ductwork will be researched, such as the reduction of noise in the gymnasium, cost savings, cleanliness, installation and schedule impacts, and an overall more comfortable learning environment. It is the ultimate goal of this research to determine if changing to fabric duct is worthwhile for the WCA.

10.4 Methodology

1. Perform a quantity takeoff of the current gymnasium ductwork, including size, shape, quantity, and location.
2. Determine the air flow requirements for the space.
3. Estimate the cost, schedule, and installation time of the current system.
4. Research other gymnasiums that have used a fabric ductwork system, in particular the Rec. Hall Expansion Project at Penn State.
5. Research the benefits of using a fabric ductwork system over a typical sheet metal system.
6. Redesign the mechanical ductwork with fabric ductwork, ensuring that the air flow requirements are met for the space.
7. Perform acoustical analysis of the new space with the fabric ductwork.
8. Determine the cost, schedule, and installation time of the new system.

9. Conduct a comparative analysis of the two systems, with the primary focus on acoustics and the secondary focus on cost, schedule, installation, air quality, and availability.
10. Make a recommendation on which system is more suited for the WCA Gymnasium Building.

10.5 Tools/Resources

1. Research fabric ductwork manufacturers' websites
2. Penn State's Office of Physical Plant (OPP)
3. Washington Christian Academy Construction Documents
4. R.S. Means 2007
5. Forrester Construction Company
6. Penn State Architectural Engineering Faculty

10.6 Expectations

After conducting the research and appropriate calculations addressed above, I expect that the fabric ductwork will provide a more acoustically pleasing environment for occupants. Additionally, I expect the new system to be less expensive, more easily installed, and an overall better choice for the WCA Gymnasium.

10.7 Current Mechanical System in Gymnasium

- Roof Top Units:
  - 1,600 cfm (800 cfm outdoor air), serves lobby and offices
  - 6,000 cfm (3,000 cfm outdoor air), serves gymnasium and locker rooms
- Sheet Metal Ductwork
  - Spiral sheet metal, double wall
  - Glass fiber insulation with K-value of 0.29
  - Aluminum jacket 0.025" thick surrounds insulation
  - Painted white
- Quantities
  - 16" diameter: 100 LF
  - 22" diameter: 40 LF
  - 28" diameter: 20 LF
  - Flex Duct: 24 LF
  - Supply: (4) 1,500 cfm diffusers
  - Return: (2) 3,000 cfm grilles
  - 6,000 cfm enters gymnasium
- Schedule for Installation
  - 10 days RTUs
  - 25 days ductwork

10.8 Advantages of Fabric Ductwork

The advantages to using a fabric ductwork system are far reaching. First and foremost, the manufacturer's of fabric ductwork claim that the air is delivered to spaces more quietly than if delivered by metal ductwork. In large spaces that require a lot of airflow, such as the gymnasium, air is delivered without the resonating properties found in metal. Fabric duct provides sound absorption qualities with no additional insulation necessary.

Second, the air supplied to the open area is more uniformly discharged in comparison to a typical sheet metal system with evenly spaced diffusers. Hot and cold spots are practically eliminated because air is supplied all along the fabric ductwork, not in localized spots, which can be seen in Figure 10.. This creates much more comfortable spaces for occupants.

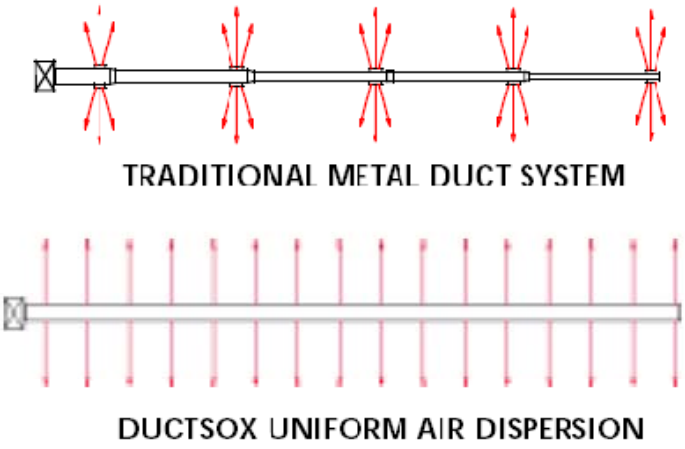

Figure 10.1 *DuctSox* Air distribution comparison

Notice how the traditional system only allows air to be distributed in specific, concentrated areas. This may create drafts and uneven air temperatures throughout a space. The fabric ductwork represented by the *DuctSox* picture, releases air uniformly through designated holes or the porous fabric material.

Table 10.1 Comparative benefits of using fabric ductwork over sheet metal ductwork.

	Fabric Ductwork	Sheet Metal Ductwork
Acoustics	• Better • Reduces resonance	• Worse • Turns create turbulence
Air Distribution	• More uniform	• Concentrated near diffusers
Installation	• 90% faster that Sheet Metal[13]	• Much more intensive (hrs, crew)
Weight	• 1 psf [14]	• 40 psf [14]
Environmental Factors	• Resists scratches, dents common from volleyballs, basketballs, etc.	• Easily scratched or dented during installation, common physical activities
Condensation/Dust	• Porous fabric allows air flow through material • Prevents condensation/dust accumulation on exterior surface	• Metal allows air flow only through specified outlets • Condensation/dust accumulate on exterior surface

[13] According to "Features, Advantages, and Benefits" of Fabric Ductwork found at Ductsox.com
[14] Comparing a 60" fabric duct to a 60" spiral metal duct, 18 ga., single wall

Color	• Optional colored fabric matches walls/ceilings • Silk screening allows for team names, logos on ductwork	• Optional painted exterior surface • Likely to scratch & need touch-ups
Maintenance	• Vacuum or machine washable • Easily removed and re-hung • No lifting machinery needed	• Expensive • Usually requires 3rd party • Lifting machinery needed

10.9 Redesign of the Gymnasium Mechanical Ductwork with Fabric Ductwork

There are many manufacturers of fabric ductwork. Berner International Corporation (www.Berner.com) creates a fabric ductwork system referred to as *Posi-Flow*. There are design steps that the manufacturer recommends, and this section will highlight how the design decisions were made.

Step 1: Determine Application

Application	Fabric Type				Airflow Pattern				Suspension Type Supported		
Indoor Swimming Pools	PV	CP	PE		SF	GF	LD		Snap Clip	Halo Hook	Track
School Classrooms	PV	CP		UP		GF	LD				Track
Gymnasiums	**PV**	**CP**	**PE**		**SF**	**GF**	**LD**		**Snap Clip**	**Halo Hook**	**Track**
Supermarkets	PV	CP	PE	UP	SF	GF	LD	MF	Snap Clip	Halo Hook	Track
Warehouses	PV	CP	PE		SF	GF			Snap Clip	Halo Hook	
Manufacturing Plants	PV	CP	PE		SF	GF			Snap Clip	Halo Hook	
Restaurants	PV	CP		UP		GF	LD	MF	Snap Clip	Halo Hook	Track

Figure 10.2 Application determination chart

Step 2: Select Fabric Type

From Step 1, the suggested fabric types are PV: Polyester Vinyl Coated, CP: Coated Polyester, or PE: Polyethylene. After researching the manufacturer's data on each, the best choice is coated polyester.

CP Series Coated Polyester
"Versatile and aesthetically pleasing. Ideal for schools, sports arenas, supermarkets, swimming pools and retail stores. Water repellent, flame resistant and UV treated. Multiple colors available to complement surroundings."
(http://www.berner.com/commercial_fabric.php5?sec=fabric&top=4&sub=3)

Step 3: **Select Color**

Colors
White
Gray
Lakeside
Royal
Black

Figure 10.3 Color selection chart

This decision would be made by the owner. The WCA could choose to match the wall color in order to blend in, or choose a brighter color to become an architectural feature of the space. There is also the option of silk screening, which allows school/team names and logos to be printed on the ductwork. Currently, the ductwork is scheduled to be painted white.

Step 4: **Determine Size of Ductwork**

According to the Berner manufacturing data, the fabric ductwork can be used as a direct replacement of sheet metal. This means size and quantity. Therefore, a total length of 184 LF of fabric ductwork is needed to supply the required 6,000 cfm to the space. The longest straight run is 50 LF; however the ductwork typically comes in lengths of 25 LF. Therefore, eight pieces of fabric duct will be needed.

Step 5: **Select Airflow Pattern**

From Step 1, the suggested airflow patterns are SF: Super Flow, GF: Gentle Flow, or LD: Linear Diffusers. The best choice for the gymnasium is the super flow, mainly because the ductwork is located approximately 26’ above the finished floor and the air has to be able to reach the floor level effectively.

Super Flow: Propel warm ceiling air to cooler floor areas

- Long throw air jets.
- Provide air circulation 30-40’ beyond their profile
- Propel warm ceiling air to cooler floor areas
- For heated, cooled or untempered air
- For 10’ & above finished floor installation

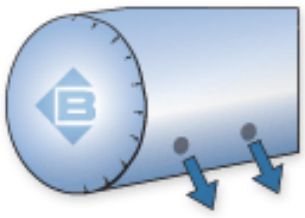

Figure 10.4 Airflow diagram

Step 6: **Choose Suspension Type**

From Step 1, the suggested types of suspension are Snap Clip, Halo Hook, or Track. The snap clip is recommended for standard installation. It runs on a cord that can easily be strung from the steel joists, therefore no structural redesign will be necessary. The fabric duct is connected to clips, which are simply snapped onto the cord and run across

like a shower curtain. This makes maintenance very easy. The ductwork will be able to slide to the maintenance person and a mobile mechanical lift will not be necessary.

Standard Installation

Used with cable suspension, turn buckles and clamps. Available In:

- Zinc plated
- Black powder coated
- Black plastic
- Stainless steel

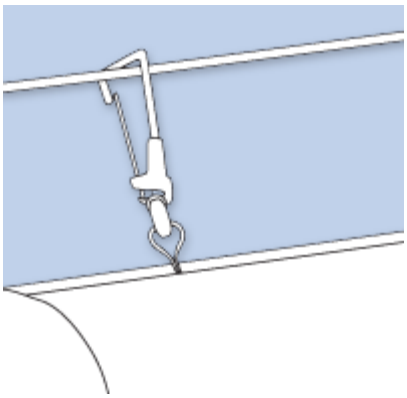

Figure 10.5 Suspension diagram

Step 7: **Choose Filtration System**

It would be up to the owner to decide which filtration method they would like to use. There is already a 2" thick glass fiber air filter for each RTU that has a 65% efficiency. An additional air filter in the fabric ductwork would provide better air quality and help keep airflow through the ductwork steady. This DuctSox filtration system is meant to serve in addition to a prefilter (which is the 2" glass fiber). This zip-in filtration system cleans the air directly before it is dispersed to the breather, and the prefilter keeps the mechanical unit clean. They work together to improve the indoor air quality.

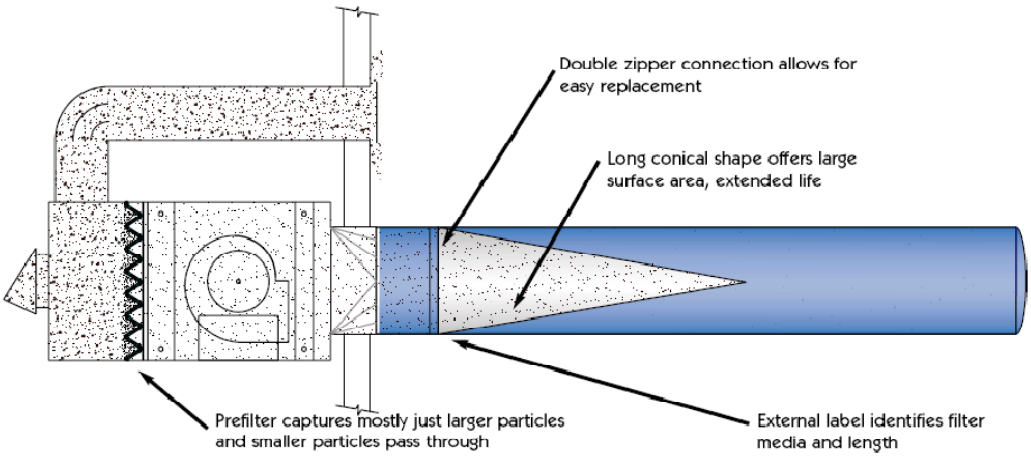

Figure 10.6 Filtration system diagram from *DuctSox.com*

10.10 Acoustical Analysis of the Fabric System

Acoustics is the science that deals with the production, control, transmission, reception, and effects of sound. Mechanical systems create noise and vibrations which may hinder the acoustical quality of a space. The WCA Gymnasium will be used for gym classes, sporting events, performances, speeches, and other various activities. This means that the space needs to be able to acoustically accommodate a conversation between two people and 1,225 screaming spectators.

Fabric ductwork is credited with improving the acoustics of a space. This is due to the fact that sheet metal, which has almost no absorptive quality, is being replaced with polyester fabric, which has a much higher absorptive quality.

Noise Criterion (NC)

Noise criterion was established in the United States for rating indoor noise, noise from air-conditioning equipment etc. According to DuctSox.com, by using fabric ductwork the resulting decibel level is well below or in the lower average of the recommended 20-35 NC rating. An NC rating of 20-30 is considered very quiet to quiet, and an NC rating of 30-35 is moderately noisy. Figure 10.7 shows that the fabric ductwork is continually rated in the very quiet to quiet range.

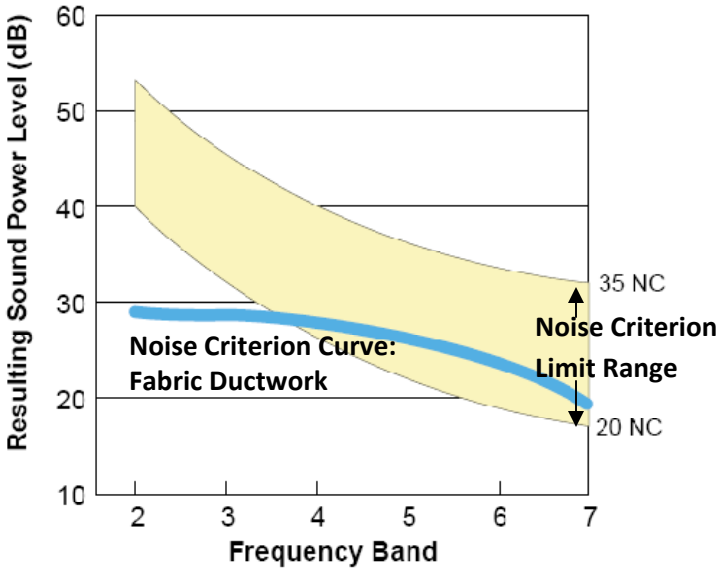

Figure 10.7 NC diagram from *Ductsox.com*

To further examine the noise criteria, a representative NC graph is shown below comparing the typical sheet metal ductwork vs. the proposed fabric ductwork. In this graph, Noise Rating (NR) is simply another term used for Noise Criteria (NC).

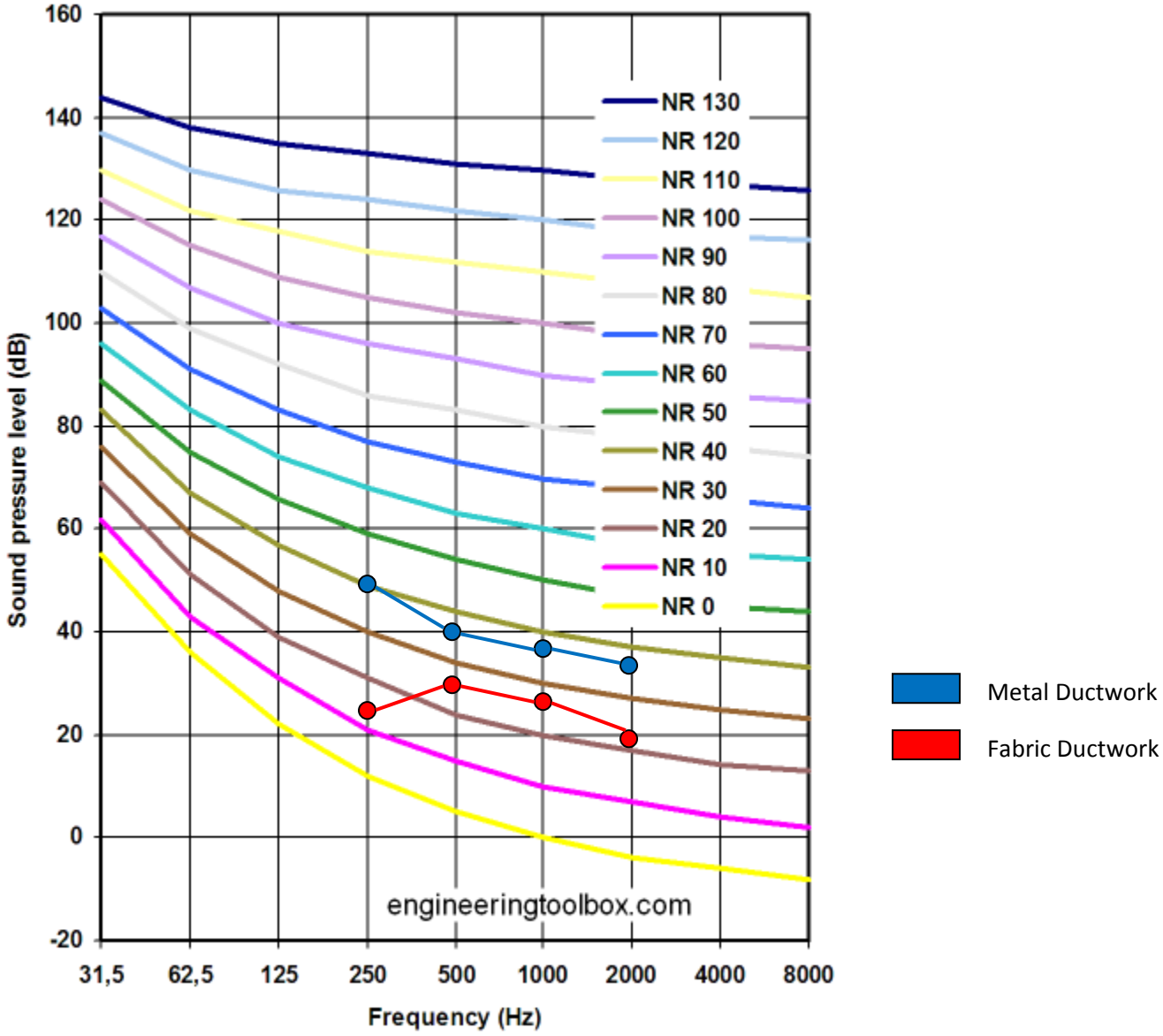

Figure 10.8 Comparative Noise Criteria chart of metal and fabric ductwork

For a gymnasium an NC rating of NC-25 to NC-40 is normal. From this chart, the metal ductwork has an NC rating of NC-40, which is at the highest recommended level. The fabric ductwork has an NC rating of NC-25, which is at the lowest recommended level. A lower noise criteria rating is better, therefore the fabric ductwork is much more efficient in absorbing noise. Additionally, the absence of diffusers in the proposed fabric duct system eliminates any highly concentrated areas of noise.

Reverberation Time

The Reverberation Time in a room is the time it takes before the sound pressure level has decreased by 60 dB after the sound source is terminated. In other words, it is the amount of time a sound bounces around a room until it is absorbed by something. Reverberation Time calculations are important for a space because it is a strong indicator of the acoustical comfort of the space. Different spaces have different reverberation time goals. Too high of a time creates a live space, while too low of a time creates a dead space. Reverberation time for gymnasiums typically range from 1.5 seconds to 2.5 seconds. Below is a summary of the reverberation time calculations for the WCA Gymnasium.

Table 10.2 Comparison reverberation time calculations for metal ductwork vs. fabric ductwork.

Reverberation Time				S	α	α	a = Sα	a = Sα	
Material	**Dim. A (ft)**	**Dim. B (ft)**	**Qty.**	**Area (sf)**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**	
Metal Ceiling	100	74	1	7400	0	0	0.0	0.0	
Hard Wood Floor	100	74	1	7400	0.3	0.3	2220.0	2220.0	
	100	35	2	7000					
CMU Block Walls	74	35	2	4820					
				11820	0.09	0.09	1063.8	1063.8	
	10	4	16	640					
	10	12	3	360					
Tectum Panels	10	16	2	320					
	4	4	4	64					
				1384	0.85	0.99	1176.4	1370.2	
Glass Windows	12	10	3	360	0.18	0.12	64.8	43.2	
	1.33	100	1	836					
Ductwork	1.83	46	1	529					
	2.33	34	1	498					
Metal				1862	0	0	0.0	0.0	
Fabric				1862	0.2	0.18	372.4	335.2	
						Metal ductwork ΣSα	4525.0	4697.2	
						Fabric ductwork ΣSα	4897.4	5032.3	
						Room Volume (ft^3)		259,000	
						Reverberation Time **T= 0.05 V/a**	2.86	2.76	*with metal*
							2.64	2.57	*with fabric*
							Reduction of 0.19-0.22 seconds		

By switching to fabric ductwork, the reverberation time would decrease by an average of 0.21 seconds. This is only a 7% reduction, which is not a significant decrease in time. The material with the largest impact on the acoustics in the space is the tectum acoustical wall panels. It is stated, however, that a Sound Absorption Coefficient (α) difference from 0.1-0.4 results in a noticeable reduction of noise. Between the metal ductwork and the fabric ductwork, the difference of α is 0.2. This is a significant difference between materials. Therefore, it can be concluded that the change of material does reduce noise in the room, but does not have a dramatic effect on the entire room due to the large size of the room and the acoustical wall panels.

Noise Reduction (NR)

The noise reduction is the reduction in reverberant noise level in a space. This reduction would result from changing the sheet metal ductwork to the fabric ductwork. The NR is affected by the size of the room and the amount of absorption within the room.

$$NR = 10\log\frac{a_2}{a_1}$$

$$NR = 10\log\frac{5032.3}{4697.2}$$

$$NR = 1.1 \text{ dB}$$

This calculation shows that there would be noise reduction of 1.1 decibels in the gymnasium after the switch. This is not a significant reduction in decibels. This is most likely due the proportion of ductwork to the space. The room has a very large volume and proportionally the ductwork does not take up much of that space.

Noise Reduction Coefficient (NRC)

The efficiency of a sound absorptive material is known as the Noise Reduction Coefficient (NRC). A higher NRC indicates a more absorptive material.

NRC Steel: 0.00-0.05

NRC Fabric: 0.20

The difference between the NRC is 0.15. This proves that there is a significant difference between the absorptive properties of the metal ductwork vs. the fabric ductwork. The fabric ductwork is much more likely to absorb sound in the gymnasium.

10.11 Cost Comparison

Fabric ductwork typically costs 20%-80% less than metal ductwork. This cost analysis will compare material, labor, and shipping costs. Data was obtained from *2007 R.S. Means Building Construction Cost Data*, *2007 R.S. Means Mechanical Cost Data*, and *UPS.com*.

Location Factor:

Olney, Maryland was not on the location list and the WCA is not actually in Washington, D.C. Therefore, the most fair and accurate method available was to use an average.

Average for all listings in Maryland	.865
Washington, D.C.	.98
Location Factor Average:	.92

Time Factor: Not used because data is from 2007

Table 10.3 Cost breakdown of current sheet metal ductwork system.

Mechanical Equipment	Size	Qty.	Material Unit Cost	Labor Unit Cost	Material Total Cost	Labor Total Cost	Total Cost M+L
Double Wall Spiral Duct[15]	16" dia.	100 LF	6.55	15.19[16]	655.0	1,519.0	$2,174
	22" dia.	34 LF	10.80	23.66[16]	367.2	804.4	$1,172
	28" dia.	20 LF	15.48	29.61[16]	309.6	592.2	$902
				Sum	1,331.8	2,915.6	$4,248
Flex Duct[15]	16" dia.	24 LF	5.16	13.13[16]	123.8	315.1	$439
Diffusers[15]	16" dia.	4 ea.	53.00	42.00	212.0	168.0	$380
Flex. Fiberglass Ins.	1 ½"	1525 SF	0.19	1.94	289.8	2958.5	$3248
				TOTAL	$1,958	$6,357	$8,315
				LF = 0.92	$1,800	$5,850	**$7,650**

Table 10.4 Cost breakdown of proposed fabric ductwork system.

Mechanical Equipment	Size	Qty.	Material Total Cost	Labor Total Cost	Total Cost M+L
Fabric Duct	16" dia.	100 LF	768.0	1139.2	$1,907
	22" dia.	34 LF	305.0	603.3	$908
	28" dia.	20 LF	217.0	444.2	$661
		TOTAL	$1,290	$2,185	$3,475
		LF = 0.92	$1,187	$2,010	**$3,200**

Table 10.5 Cost comparison summary.

Ductwork	Material Cost	Labor Cost	Total Cost
Metal	$1,800	$5,850	$7,650
Fabric	$1,190	$2,010	$3,200
Difference	$610 saved	$3,840 saved	**$4,450 saved**

Table 10.5 shows that by switching to the fabric ductwork system, the owner could save $4,450. The total mechanical contract for the gymnasium is approximately $190,000. This yields a savings of approximately 2.5% of the mechanical cost for the gymnasium. The largest savings is on the labor cost; this is because fabric ductwork is more easily and quickly installed. Vast and additional savings would also come from the reduction of shipping costs.

[15] Some of the unit costs had to be interpolated or extrapolated as needed.
[16] As directed by *R.S. Means 2007*, 40% was added to the labor cost because the installation height was between 30'-35'.

Table 10.6 Shipping cost comparison of metal ductwork system and fabric ductwork system.

Ductwork	Weight (lbs.)	Shipping Cost[17]
Metal	7,360	$5,360
Fabric	230	$160
	Difference	**$5,200 saved**

This estimate is conservative. The fabric ductwork could be manufactured in the nearby town of New Castle, PA. The metal ductwork could be manufactured in a much further location. However, to keep comparison's sake conservative, both shipping costs were calculated from New Castle, PA to Olney, MD.

- The total cost of the spiral metal ductwork with shipping is $13,010.
- The total cost of the fabric ductwork with shipping is $3,360.
- By using the fabric ductwork, the owner could save $9,650; a 74% reduction.
- This corresponds to a 5% savings in the gymnasium mechanical contract.

10.12 Schedule Comparison

Installation of the fabric ductwork is remarkably faster than the sheet metal system. This is reflected in the labor costs described in section 10.11. The main reason for this is that the sheet metal ductwork is installed using a scissor lift, piece by piece. The installation height of the ductwork is above 30', which results in additional time and cost. Fabric ductwork, on the contrary, is run along a track or snapped to a cord, and strung across the gymnasium. This is all possible from one location once the track or cord is mounted. The original gymnasium schedule allows 25 days for the installation of mechanical ductwork in the gymnasium. From installation information obtained on Berner.com, a typical crew of three can install up to 50' of fabric ductwork a day. This accounts for installing the suspension system and hanging the ductwork. If this is the case, the fabric ductwork could be installed in 4 days. This results in a significant savings of 21 days from the gymnasium schedule.

[17] Shipping costs retrieved from UPS.com. Costs account for typical ground shipping. Both are from New Castle, PA to Olney, MD.

10.13 Conclusion & Recommendation

Replacing the current sheet metal ductwork with fabric ductwork in the WCA Gymnasium is a prudent decision. The goals and expectations of this breadth study were met and exceeded. The fabric system improves almost every mechanical aspect of the gymnasium, whether great or small. The largest positive impacts are the improvement of the air quality and air distribution, the ease of maintenance, the cost savings, and the schedule reduction. These four areas are significantly improved upon without any additional work. Smaller positive impacts are the betterment of the acoustics and the higher customization level.

Figure 10.9 *DuctSox* Florence, Texas gymnasium with customized fabric ductwork

While these benefits are less dramatic than the previously mentioned; they are improvements none the less. As far as acoustics are concerned, switching to fabric duct results in remarkable improvements to the space. However, the proportional effects to the entire room are minimal. The acoustical improvements would not, by itself, be a reason to switch to the new system. But couple the acoustics with the multitude of other benefits, and it's a win-win situation.

The Washington Christian Academy owner has two primary concerns, budget and quality. In other words, they want to get the absolute best quality school for the budget they have. They are not seeking to cut corners; high quality is worth financing. With the substitution of fabric duct, the owner could achieve the best of both worlds; save money and have a higher quality gymnasium space. The owner would save money, finish earlier, and have a maintenance friendly system while the occupants would be more comfortable from an acoustic and air quality perspective. Switching to the fabric ductwork is a logical, beneficial choice for the WCA Gymnasium.