New Technologies for Residential HVAC Ducts

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Executive Summary

There are many problems with residential duct systems as they are currently installed. It has been shown that they lose significant amounts of energy through leakage and conduction to their surroundings (Cummings et al. 1990, Davis 1993, Modera et al., 1991, Modera 1993, Modera and Jump 1995, Parker 1989, Parker 1993, Proctor et al. 1992, Treidler and Modera 1994). For electrical utilities this is of particular concern because the effects of this leakage and conduction are more pronounced during periods of peak electrical demand.

Unfortunately, the problems with duct systems are not widely recognized within the construction industry and there are no strong economic incentives to solve them. Duct system performance is not evaluated and HVAC contractors overcome duct system shortcomings by installing oversized equipment. Currently, most duct systems are installed with minimal insulation and by methods that give little thought to insuring proper sealing.

The lack of incentives for improved duct system performance has repressed innovation. With the exception of insulated plastic wireflex duct, residential duct systems are essentially unchanged since the 1920’s. ucts with higher levels of insulation have recently become available bu duct fittings have seen no change. Fittings are uninsulated, have a large potential for leakage, and are difficult to install in a manner which will insure no leaks.

This report summarizes the potential for new technologies for ducts, duct fittings, and insulation. It begins with a review of what technology is currently in use or available and found that the only inexpensive ducts in production are insulated wireflex ducts, sheet metal ducts, fiberglass board ducts, and uninsulated plastic ducts. For duct fittings, the market was found to be dominated by sheet metal fittings with some use of ductboard. Fittings that snap together were found for use with steel ducts but are too expensive for a residential setting. An uninsulated sheet metal duct which uses a rubber gasket was also found. Two companies are trying to develop plastic fittings, but their designs don't consider improving the method of attachment to wireflex duct.

A survey was conducted of California HVAC contractors to determine what methods they currently use, how concerned they are with sealing duct connections, and what fractions of their expenses go to duct materials and installation. It was found that insulated wireflex ducts and sheet metal fittings are used in almost all residential installations in California. Fiber board and sheet metal are used equally for plenums. It was found that there are basic misunderstandings about sealing duct connections. For example, gaskets were placed on registers in such a way that they would not prevent the register leaking air into the wall cavity. The use of duct tape to attach flexible duct was also a common practice even though it is common for duct tape to fall off after some time. The cost portion of the survey showed that HVAC equipment, duct materials, and duct installation are approximately equal parts of the contractors' costs.

Ideas are presented for new duct technologies that are foolproof to install, sufficiently insulated, and not prone to leakage. For ducts, the Gas Filled Panel (GFP) technology of Griffith et al. (1992) was FP ducts were developed and their qualities for manufacturing, ease of installation, compressibility, etc. were evaluated. A model was then made of the most promising design. Ideas for plenum fittings, attaching registers to boots, and attaching ducts to fittings were created and evaluated for their potential advantages. Several of the ideas for fittings are applicable to existing wireflex ducts and sheet metal fittings.

In order to be accepted, new designs would have to pass code requirements. The most difficult code requirement to pass economically is fire spread and smoke generation tests. The plastics currently used in buildings for windows and wall panels will not pass the stricter smoke generation criteria for duct materials.

Finally, we evaluated the major hurdle for acceptance of new technologies, economics. Analysis of initial costs for the GFP technology shows that it is more expensive than existing technology even before considering steps necessary to pass fire regulations. However, new fitting designs appear to be competitive with other options for improving ducts and offer simple payback times of no more than 6 years.

1.0 Introduction

Residential HVAC duct systems in California perform inadequately. Research has shown that installed duct systems have significant losses to their surroundings through both leakage and conduction (Cummings et al. 1990, Davis 1993, Modera et al., 1991, Modera 1993, Modera and Jump 1995, Parker 1989, Parker 1993, Proctor et al. 1992, Treidler and Modera 1994). For example, Modera et al. (1991) found that conduction losses averaged 23% of furnace output in California's mild climate. It was also found that the leakage of ducts was approximately 1 cm^2 of effective leakage area per m^2 of floor area. For a typical house with 140 m^2 (1500 ft^2) of floor area, this means the leakage in the duct system is equivalent to that from a 13 cm (5.25 inch) diameter hole.

The performance of duct systems is of particular interest to electrical utilities because research has shown that energy losses from ducts are disproportionately higher on days of peak electrical demand. Peak electrical demand in California occurs in the late afternoon on weekdays during heat waves. This is when cooling demand is high from commercial customers and more residential customers are using their air conditioners in the afternoon. On these days, duct performance is very low because most ducts are located in attics. Attics are at their highest temperatures and ducts therefore lose more energy to them by conduction. Also, the air sucked in by leaks in return ducts is hotter and increases the air temperature entering the cooling coil.

From a technical standpoint, the dismal performance of duct systems is a simple problem to correct. New connection methods, using snap-together fittings, would insure that installed ducts have negligible leakage. Increased levels of insulation would decrease conduction losses. However, this has not happened because residential HVAC contracting is a very competitive business where the only incentive is to keep first costs low. There are no standards for duct performance and consumers do not typically realize how poor duct system performance affects them. So HVAC contractors have tended to install poor duct systems and overcome their problems by oversizing the air conditioner. Since the consumer only considers air conditioner size, the oversizing convinces them they are getting a better system.

Because of the lack of incentives for improvement, ducts and duct fittings show few signs of innovation. Insulated wireflex duct is the one exception. It has lower labor and material costs than its competitors and has become the most commonly used duct in California. A glance at catalogues for HVAC fittings shows they are still made of sheet metal, just as they have been since the 1920's. We found residential duct fittings available in the United States which use gaskets or snap fittings to ensure a leak proof connection. One Swedish duct system was found which uses rubber gaskets to seal connections, but no consideration was given to insulation.

This project was divided into five primary tasks. First, we made a survey of existing and planned products for ducts and fittings. This included looking at products used in other applications as well as those being produced by duct manufacturers. To complement this review of existing products we conducted a phone survey of HVAC contractors to determine their methods of installation, costs, and materials used. We also asked about their opinions on some potential new duct technologies. Since little innovation had been found in either survey we worked on developing potential new designs for ducts and fittings. The ducts were assumed to be made of plastic and to compress more for shipping than curren products (i.e. flexduct), while the fittings were assumed to be of insulated plastic. The goal was a system which was sufficiently insulated, leakproof, and foolproof to install. Finally we considered the economic and code requirements which would have to be met by any new technologies.

2.0 Survey of Existing Technologies

To determine the range of existing technologies for ducts and fittings we used several methods. The Thomas Register was searched for duct products which emphasized ease of installation. The HVAC contractors who participated in our survey were asked if they used any unusual or exceptional products. Finally, contacts from industry and in the research community were asked about any products they had learned about.

Table 1 lists the insulation products we found while Table 2 lists the duct types we found. In both tables, names of some manufacturers are given. The list of manufacturers for insulated plastic wireflex ducts, sheet metal ducts, foam insulation, and glass fiber insulation are not complete. These products are made by many companies.

2.1 Survey of Duct and Insulation Products

Glass fiber insulated plastic wireflex ducts dominates the market in California. In many ways, it fits our requirements for new ducts. It has low material costs and is easier to install than its competeitors. No fittings are needed to go around corners because the duct bends and no time is spent on insulation because wireflex is insulated. In addition, wireflex compresses so well that all of the ducts for a typical house can be carried at once by one or two workers.

But wireflex is not an ideal product. At insulation levels higher than 23 $m^2{\cdot}°C/W$ (R-4 $hr{\cdot}ft^2{\cdot}°F/Btu$) it does not compress as easily. Ducts insulated to 23 $m^2{\cdot}°C/W$ will compress by a factor of 10 in length while ducts with twice as much insulation will compress by a factor of 7. The boxes for ducts insulated to 46 $m^2{\cdot}°C/W$ (R-8 $hr{\cdot}ft^2{\cdot}°F/Btu$) are 170% of the size used for R-4 insulated ducts. More importantly, no one has produced a foolproof method of easily attaching wireflex to fittings. All of the current methods, while simple to do in an open area, are potentially very difficult in an attic or crawlspace. This can lead to mistakes in installation by workers who are pressed for time. Other problems with wireflex are that its outer liner tears easily and the insulation can compress where the duct is supported. Finally, it is unclear how durable the plastics in insulated wireflex duct are. One contractor in the telephone survey described in Section 3.0 claimed that a significant portion of his business was replacing wireflex where the inner liner had disintegrated.

Among the technologies we found for ducts and duct insulation, there are three new technologies which have not been fully developed as potential alternatives for fiberglass insulation: gas filled panels (GFPs) for both ducts and insulation, the Haines system for ducts, and the “Ultimate R” for duct insulation. The other products listed have already benefitted from economies of scale and are not competitive with fiberglass insulation and wireflex ducts.

The Haines System for ducts would use a duct very similar to wireflex but with a foam as the insulation. Consequently, it offers little advantage over flex duct and would not change the performance of duct systems. The Ultimate R is a system of cardboard forms which are placed over duct systems which lay on joists in the attic. Cellulose is then sprayed over the duct to achieve an R-value of up to 39 ($hr{\cdot}ft^2{\cdot}°F/Btu$) with little effort. It is of interest how much savings will result from such a high insulation level but the technology is only of use where there is adequate space, a rare situation in California houses.

GFP’s are the one new technology we found for ducts which could offer significant advantages over existing products and be used in all situations. Their advantages are: they can be designed as ducts rather than add on insulations, can be made to compress completely for shipping and can achieve a higher insulation level for a given thickness. If new building codes require higher levels of insulation, the additional compressibility of GFPs and the higher specific R-value could be of value for squeezing ducts into existing spaces. The questions which must be answered about GFP ducts are: how much higher performance would be obtained, how much would this higher performance cost, and how will safety and performance requirements be met?

2.2 Survey of Duct Fitting Products

Table 3 shows the types of fittings which we found in the marketplace or in development. There are two companies which are trying to produce plastic fittings that attach to insulated wireflex duct. In both cases, wireflex duct would still be attached to the new fittings just as it is presently attached to sheet metal fittings. The advantages of the fittings are: insulation is incorporated into their design, they are less likely to be bent or torn and they can’t leak along seams like sheet metal fittings. One of the plastic fittings, Flexmate, is designed to easily be mounted to joists. This could reduce the number of supports needed for the ductwork.

TABLE 1. Existing duct insulation products found by surveying suppliers, contractors, the Thomas Register, and building science researchers.

Insulation Type	Manufacturer	Description	R-Value (°F·ft^2·h/BTU)	Contractor Cost ($/ft^2)
Special fittings for pipes	Accessible Products Company	precut foam for pipes and fittings. Tapes on.	4	-
	Foster® Products Corporation	PVC covers for insulation on bends in pipes. Tapes on.	1-8	-
	Manville CertainTeed	fiberglass pipe insulation	5 per inch.	-
fiberglass duct insulation	CertainTeed	fiberglass duct wrap	5-11	0.16-0.32
loose-fill insulation	the ultimate “R”	blown in cellulose insulation held in place by cardboard forms.	up to 38	-
gas filled panels	LBL Windows Group[a] design	made of reflective foil and plastic baffles using techniques from the food-processing industry.	4-9 per inch	-
aluminum coated bubble plastic	Reflectix™, Inc.	bubble plastic used for shipping which has been coated with aluminum	4.7 per inch	0.51 for 1”

[a]currently being licensed for refrigeration applications

The basic conclusion for duct fittings is that little has changed since the 1920’s. The only common fittings which aren’t sheet metal are plenums and tees constructed of glass fiber board. Even these fittings have the ducts attached to them using sheet metal fittings.

None of the duct fittings we found seems to have given much attention to sealing the leaks which are known to exist in fittings. This is true even for the “innovations” we found. For example, the Haines system has a register face which just slides on the register boot with no gasket for sealing. There is considerable room for improvement in fitting performance with simple improvements such as placing gaskets in existing fittings.

3.0 HVAC Contractor Survey

We conducted a telephone survey of HVAC contractors for several reasons. We wanted to determine how ducts are installed and how much contractors know about leaks in duct systems. We also wanted to confirm what types of materials are used. Most importantly, we wanted to see how contractors’ costs break down between labor and materials. Finally, we wanted to assess reactions from HVAC contractors to our ideas for new technologies.

TABLE 2. Existing duct types found from by surveying suppliers, contractors, the Thomas Register, and building science researchers.

Duct Type	Manufacturer	Contractor Cost[a] [$/ft.]	R-Value [$°F \cdot ft^2 \cdot h/BTU$]	Description
sheet metal	Leslie Locke	$1.57	uninsulated	light gauge galvanized steel
solid plastic	General Plastics	$1.43		plastic for placing under slabs
foam-like plastic	Haines System	-	4	extruded foam -like material (w/vapor lining)
insulated flexible	J.P. Lamborn CertainTeed Dumas-Jaffner	$0.80-$2.00	4-8	flexible duct, surrounded by fiberglass insulation with an outer cover
fiberboard	CertainTeed Owens/Corning	$1.44[b]	4.3	ducts made of rigid fiberglass board with a facing usually made of aluminum

[a]for 8 inch diameter duct or 4 in by 12 in rectangular duct, as appropriate

[b]$\$0.54/\text{ft}^2$ for 1” thick

The population used for the survey was found through the Business to Business Yellow Pages for all regions of California. Out of 46 contractors called, 10 were available to take the survey. Five of the contractors were from Los Angeles County and five were from Northern California. Of the persons contacted, 6 were executives or owners.

Table 4 lists the type of business done by the contractors surveyed. Two of the contractors surveyed installed 1500 and 4000 systems each. All of the averages presented in the survey are weighted by the number of systems installed. So the averages are dominated by the two largest contractors with the other eight contractors determining the range of the responses.

TABLE 3. Existing fitting types found from by surveying suppliers, contractors, the Thomas Register, and building science researchers.

Type	Manufacturer	Product	cost[a]	Description
standard sheet metal	Leslie Locke	-	$5.49 (6” round to 10”x4” register boot)	light gauge aluminum or galvanized steel
special sheet metal ducts and fittings	Veloduct®	Veloduct®	-	special O-ring fittings for easy installation
	Nordfab, Inc.	Nordfab	-	quick release latches for ducts with raised lips at their ends
solid plastic	General Plastics	-	$7.48 (6” round to 12”x4” register boot)	fittings for placement under slabs
	Flex-Mate Products, Inc.	Flex-Mate	currently prototyping	Special insulated plastic fittings to attach to flexduct
foam-like plastic	Haines System[b]	-	$5.66 (6” round to 12”x4” register boot)	snap-on plastic fittings and boots. Fitting insulation is plastic
fiberglass board	-	-	-	usually for plenums, sometimes for wyes

[a]to contractor

[b]Australian product, not certified in United States

3.1 Material used

Table 5 lists the types of ducts, plenums, and fittings used by the contractors. As expected, insulated wire flex duct is the most commonly used duct type. For plenums, sheet metal and glass fiber board constructions are both common. The insulation levels on the plenums ranged from 12 $m^2 \cdot K/W$ (R-2 $hr \cdot ft^2 \cdot °F/Btu$) to 36 $m^2 \cdot K/W$ (R-6 $hr \cdot ft^2 \cdot °F/Btu$). For plenum fittings, no alternatives to sheet metal fittings were used. The sheet metal tab collar, which has a high potential for leakage, is most commonly used, although it is not used in a majority of installations.

3.2 Installation methods

One of the more interesting parts of the survey was the contractors' responses about their installation methods. These are summarized in Table 6. For attaching wireflex ducts, most of the contractors use tape only. They all used tape on both the inner and outer liners. However, the Air Diffusion Council (ADC) standard for flexible duct installation specifies that a strap should also be used on the inner liner. (ADC, 1991)

Highlights of the responses include:

- When connecting registers, most of the contractors applied gaskets on the faces of the register. This does not prevent the damaging leakage around the edge of the register boot and into the wall containing the boot An illustration of the leakage path is shown in Figure 1.
- Only 2 of the contractors used sealant on the plenum fitting. The others either did nothing or used tape, which can fall off.
- Six of the ten contractors used wall or floor cavities as ducts. Two of the six tried to seal the cavity with drywall. Another contractor applied insulation on the sheet metal pan used to seal the cavity. Four of the six contractors used methods which did not attempt to prevent leakage and conduction losses.

3.3 System cost estimates

We had the contractors estimate the breakdown of costs involved with installing a complete system in a standard new house. The house was assumed to be one story with slab on grade construction. The equipment and ducts were in the attic. Table 7 summarizes the contractors' responses. The most important point in the data is that the heating/cooling equipment, duct materials, and duct installation labor costs are all large parts of the contractors' cost. The contractors estimates of these costs only add up to 74% of the total system cost. The remaining 26% includes installing the equipment, administrative costs, etc.

3.4 Reaction of contractors to our ideas

The final section of the survey asked the contractors for their responses to our new ideas for ducts and fittings. They were first asked if they would consider a new type of plastic duct which was packed in a compressed form if R-8 insulation were required. Most of them expressed interest in gas filled panel ducts but only if there was no increase in price over glass fiber insulated wireflex. They did not consider the additional compressibility of the duct to be very useful. The contractors were also asked if they would consider using self-sealing snap-together insulated plastic fittings if they were required to avoid leak testing duct systems. Again the response was that they would be interested only if there was little or no increase in price. Several of the contractors implied that they would only use new products if they were required by code and all other contractors were using them.

In an attempt to find out about any new products for ducts or fittings, we asked the contractors whether there were any exceptional new products they used. Most said no and the others listed well known products like wireflex ducts, glass fiber board, and improved duct tapes. We also asked them what they felt was the part of duct systems which could be improved most. Instead of concentrating on easier to install technologies, 3 of them said they needed more room to work. Other responses included returning to sheet metal ducts and protecting ducts from mechanical damage. No one mentioned energy conservation concerns with leaky and insufficiently insulated ducts.

Several conclusions may be drawn from the HVAC contractors survey:

- HVAC contractors compete on bids for projects and are very concerned with low cost. This concern with low cost is not offset at all by concerns about performance.
- There is not much awareness of problems with the performance of duct systems or how to solve them.
- There is some fear of new technologies. Individual contractors don't feel comfortable using different methods than their competitors.
- Duct installation labor is a large fraction of the cost of an HVAC system, so technologies which save installation time will appeal to installers. However, they think wireflex is easy to install and will have to be convinced of the need for snap-fit connectors.

What these conclusions mean for new duct technologies is that any new products will either have to reduce the installers' costs or be supported by other incentives. Other incentives could be changes in code requirements, utility incentive programs, or informed consumer/builder pressure. These incentives would allow HVAC contractors to improve the performance of duct systems while still assuring their profit margins. We can also conclude, just as we did in the section on existing products, that there is a lot of room for improvement on current practices.

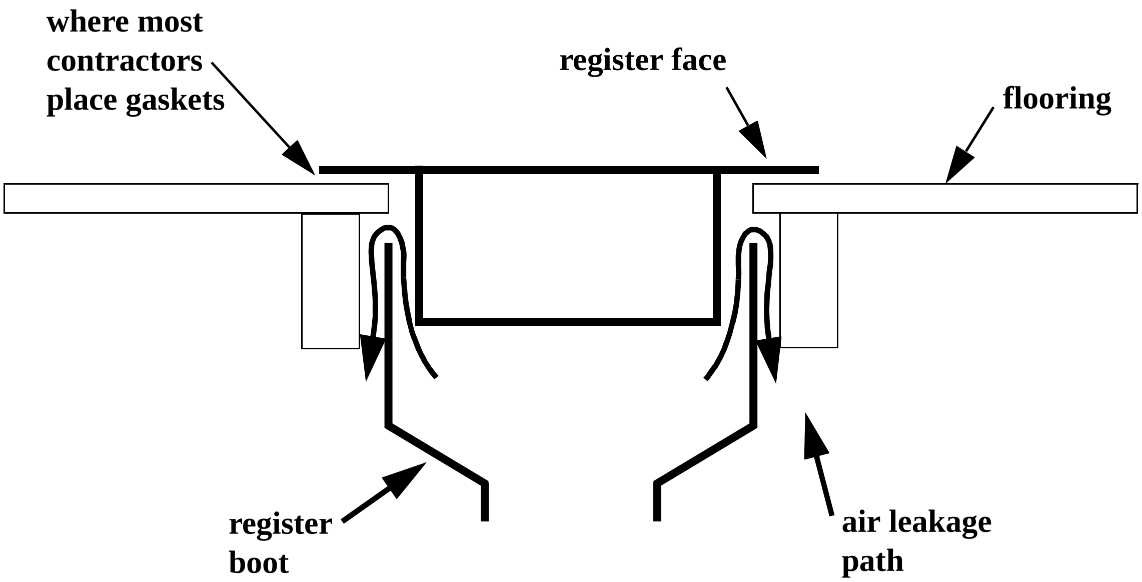

FIGURE 1. Schematic illustration of the leakage at duct registers. Most contractors place a gasket between the register face and the flooring/wall. This is necessary to eliminate leakage into the room when the register is closed, but it does not block the leakage path into the walls or crawlspace.

TABLE 4. Type and amount of business done by HVAC contractors in the survey.

Quantity	Average	Minimum	Maximum
# of systems installed per year	655	12	4000
% of business that is residential HVAC	90%	14%	95%
% of residential HVAC which is new construction	83%	0%	90%
average home size	214 m^2 (2300 ft^2)	170 m^2 (1800 ft^2)	325 m^2 (3500 ft^2)

TABLE 5. Types and amounts of materials used for duct systems by HVAC contractors in the survey.

Quantity		% of installed
Duct type	insulated wireflex	94%
	sheet metal	5%
	aluminum flexduct	1%
Plenum type	sheet metal	42%
	glass fiber board	58%
Plenum fitting	sheet metal tab collar	37%
	other sheet metal	63%

TABLE 6. Results from the survey of ten HVAC contractors for installation methods used to attach ducts and fittings.

Task	Method	# of contractors using
attaching wireflex to fittings[a]	duct tape on inner and outer liners	6
	duct tape on inner and outer liners plus screws	5
	plastic straps and tape	2
sealing the gaps between the plenum fitting and the plenum	tape	5
	sealant	2
	screws	1
	nothing	2
sealing the register to its boot	gasket on face of register	5
	nothing	4
	solid wood header[b]	1
using floor and wall cavities as ducts	never	4
	for return	3
	only in interior partitions, sealed with drywall	1
	sheet metal pan w/insulation on outside	1
	sealed with drywall	1

[a]The responses sum to more than ten because some contractors used more than one method.

[b]One contractor installed wood blocking to support the boot instead of just nailing to available joists.

TABLE 7. Breakdown of estimates of costs for new systems in the survey of HVAC contractors. All costs are customer costs.

Item		Costs					
		$ Amount			Percentages		
		Avg.	Min	Max	Avg.	Min	Max
system	furnace	$2,264	$1,800	$6,000	NA		
	gas furnace w/ a.c.	$3,145	$2,500	$8,500			
equipment	furnace	$589	$500	$1,400	26%	12%	35%
	gas furnace w/ a.c.	$1,205	$1,100	$2,000	38%	20%	44%
control equipment	furnace	$45	$40	$275	2%	1%	8%
	gas furnace w/ a.c.				1%	1%	5%
duct materials	furnace	$589	$550	$1,000	26%	16%	31%
	gas furnace w/ a.c.				19%	12%	22%
duct installation	furnace	$449	$175	$3,000	20%	10%	64%
	gas furnace w/ a.c.				14%	7%	42%

4.0 Potential New Designs and Technologies

In this section we will consider new designs for ducts and fittings. The economic and building code tests for these products are considered in the following two sections.

When considering new approaches to problems, the first step is to determine goals. What properties are desirable in a new duct system? Ideally, a system would have:

- no leaks
- insulation at all points
- low costs for installation and materials
- durability of the sealing and insulation

In order to insure that these goals are met, it is necessary that the system:

- require little fabrication on site (to reduce labor costs)
- have seals made by snapping parts together (to reduce labor costs and be foolproof)
- have mechanical, rather than adhesive, seals (for durability)

One vision of a “perfect” system is flexible ducts with universal connectors on their ends that snap into fittings and plenums. Excep for mounting register boots to studs or joists and installing the heating/cooling equipment, system installation would consist of snapping parts together. If the snap fit connection was reversible, then this “perfect” system would also be easy to expand or reconfigure.

There are many options besides the “perfect” system. These include:

- Requiring that all fittings be covered by insulation and that wireflex be attached with a nylon strap on the inner liner, as specified by the Air Diffusion Council (ADC, 1991). This would eliminate the problem of duct tape failing and reduce leakage losses. It would also increase installation time and make technologies which offer simpler installation more attractive even with higher material costs.
- Require that all fittings, including registers and plenum connections, have gaskets which insure a tight seal will be made between fittings. This would reduce leakage in a durable and foolproof manner while still allowing wireflex duct and fittings very similar to those currently in use.
- Require that snap-in fittings be used for all connections, including ducts to fittings. This would insure that the duct system is connected properly.
- Require that fittings have an approved method of attaching wireflex duct which is integral to the fittings. An example will be shown below.

In the following sections we separately consider new designs for insulation based on GFP technology, ducts made of the GFP insulation, and easier-to-install fittings.

4.1 Potential designs for new duct insulation

We focused on using gas filled panel (GFP) technology developed in another CIEE project (see Griffith et al, 1992). Griffith et al. developed this technology for use as appliance and building insulation and consequently chose designs which resulted in a rigid product that did not compress.

The idea for GFPs was to produce a superior insulation using plastics and existing food packaging technology. Heat transfer through the insulation is reduced by eliminating convection and radiation heat transfer. Convection is reduced by having small cell sizes. Radiation is reduced by using low emissivity coatings on layers between cells.

Our design method was to construct models of the insulation and then critique them for ease of manufacturing, compressibility, etc. New models were then made until we had produced several with good qualities. Figures 2-7 are drawings of the five most promising designs for duct insulation, which we have designated with letters A through E. In Table 8, estimates are presented of the properties, both good and bad, of the 5 designs.

All of the models seem appropriate for use as duct insulation. Design E seems particularly appropriate for a compressible duct design because it will open irreversibly when released.

4.2 Potential Designs for Ducts

All of the designs for duct insulation in Section 4.1 could be turned into ducts. Designs A-D are particularly appropriate to rectangular ducts while design E is appropriate for a circular duct. Since round ducts will have lower conduction losses and less material required for a given cross sectional area, we elected to construct a model of a round duct using design E. A schematic diagram of the model is given in Figure 7. The model was constructed with a thick inner layer of plastic (actually a 2 liter soft drink bottle). The insulation was made with plastic and the sheet on the outside of the duct was metalized polyester. The model could be folded in half and compressed to reduce its volume by a factor of 17. Another possible round duct, which could be made continuously in a spiral is shown in Figure 8.

For square ducts, any of the insulation designs A through D could be used to produce collapsible insulated ducts. None of these designs would be appropriate for return ducts without some internal bracing to prevent collapsing under pressure. As presently configured, they are therefore limited to the supply side of the duct system.

4.3 Potential designs for fittings

All of the connections in residential duct systems are candidates for improvement. The particular connections considered here are: connections of duct to fitting, connections of plenum fittings to plenums, and connections from register to register boot. All of the ideas presented below assume that insulation will be integrated with the fitting. This will both save labor and insure that the duct system is properly insulated.

4.3.1 Register to boot connections

The HVAC contractor survey results showed that it is not common knowledge within the industry that air leaks around the edge of the register boot and into the wall or floor. A simple gasket which would stop this is shown in Figure 9. Other possible gasket or seal options would be on the outside of the register boot, or to have lips on the boot which extend between the flooring (sheet rock in a wall) and the joists (studs). However, these other solutions require either more labor or placement of the seal in a location where the distance between the two surfaces is variable.

One reason that sheet metal registers and boots don't fit tightly is that the boots are often bent during installation. Tougher plastic fittings would eliminate this problem and allow closer tolerances. This would ensure leak-free connections of registers.

The ultimate solution for register to boot connections would be a matched register and boot which snap together. This could easily be integrated into an industry standard for registers, just as there are currently standard sizes for registers and boots.

4.3.2 Plenum fittings

The plenum is another point where improvements can be made on existing methods. The most commonly used fittings are tab collars. A diagram of a tab collar is shown in Figure 10. As can be seen in the figure, this type of fitting inherently requires sealing, but in our survey most contractors used only tape for sealing. Other fittings which are commonly used are better than the tab collar for sealing but we did not find any which did not rely on tape or sealant to eliminate leaks.

There are several options for improved duct plenum fittings. Ideally, the fittings would be attached to the plenum in a factory and be durably sealed. Short of that, fittings which create seals mechanically could be installed in the field. A simple option, which is used by at least one contractor in California, is to use a gasket between a bead on the fitting and the plenum. This is shown in Figure 11. Some more complicated ideas are shown in the Appendix.

4.3.3 Fitting to duct connections

Connecting the fitting to the duct is the most labor intensive part of assembling duct systems. The "perfect" duct system mentioned above would have connectors on the ends of ducts which snap together. In this case, connecting the duct system would consist of walking the ends of the duct from one connection to another. The type of connector could be taken from existing connectors used in the toy, automotive, or other industries which currently use plastic snap-together connectors.

One drawback to the "perfect" system is that it is not possible to cut the ducts. Contractors do cut wireflex duct in the field and would be resistant to the idea of precut ducts. Because of this, it is worthwhile to consider improved attachment methods for flexduct which do not require fittings on the duct. The attachment method shown in Figure 12 would reduce the labor time for installing ducts because it eliminates the outer strap. Adding an adhesive strip on the fitting or on the sheet which is pulled down could save even more installation time by making it unnecessary to tape the inner liner of the duct to the fitting.

4.4 Conclusions for potential new designs

There are simple ideas which could greatly increase the installed performance of duct systems. The improved performance would come from making installation foolproof and insulating duct fittings. We have presented several samples of new designs for ducts and fittings in this section. Technically, making improved duct systems is a simple problem. However, the constraints of economics, inherent conservativism in a competitive business and lack of code requirements mean there are no incentives for improvement.

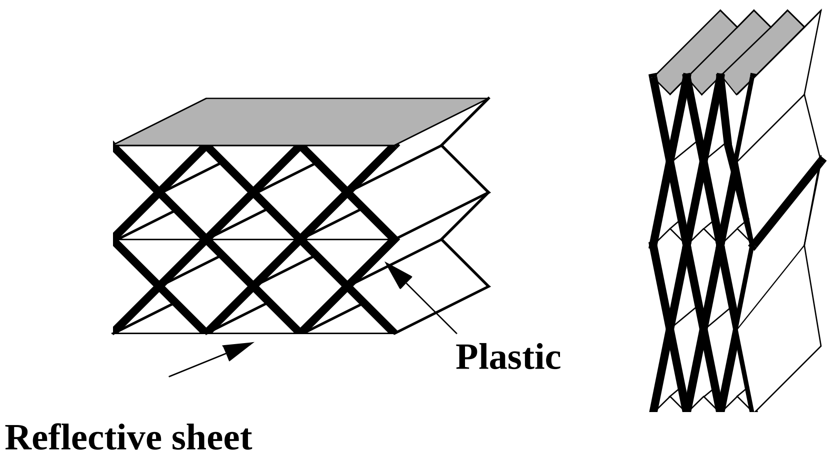

FIGURE 2. Potential design A for duct insulation. A cardboard and paper model was constructed.

5.0 Code and Rating Requirements for Ducts and Fittings

A hierarchy of the codes involving ducts is presented in Figure 13. Ducts are generally required to meet the National Fire Protection Association (NFPA) Standard 90B. This standard invokes Underwriters Laboratories Standard 181 and requires that the residential ducts be Class 1 ducts as defined by the standard. The types of tests performed to meet UL181 are listed in Table 9.

The primary concern for the plastic ducts and fittings we are considering is meeting the flame spread and smoke generation criteria for Class 1 ducts. Wireflex duct, which contains plastic, is able

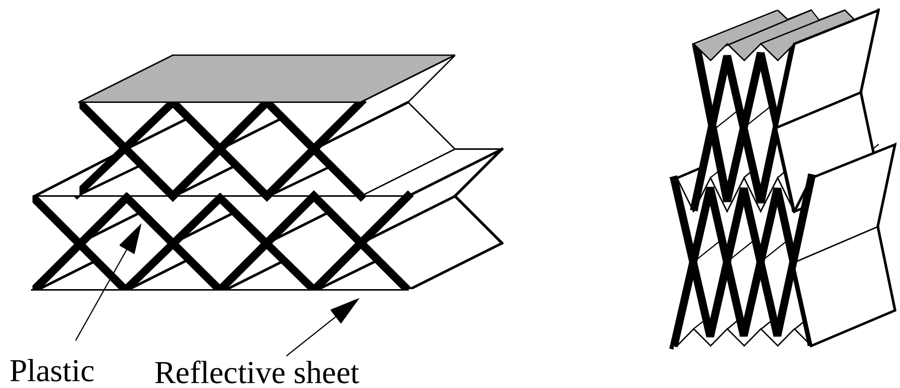

FIGURE 3. Potential design B for duct insulation. A cardboard and paper model was constructed.

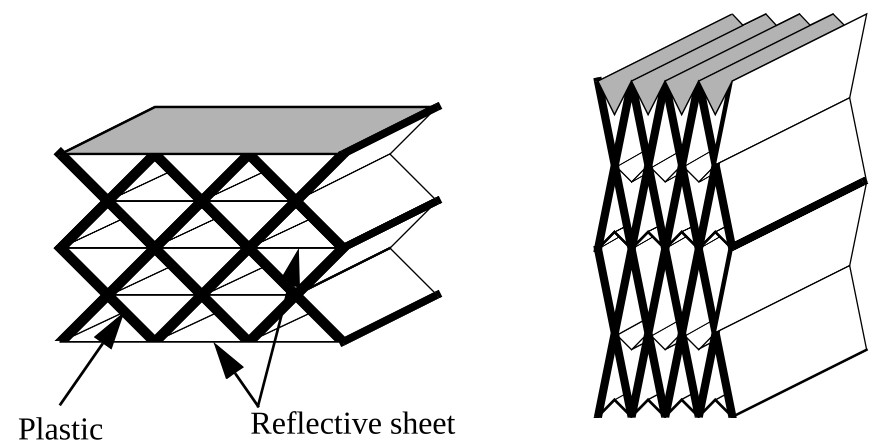

FIGURE 4. Potential design C for duct insulation. A cardboard and paper model was constructed.

to meet the standards because there is so little plastic that the quantity of smoke generated is below the limit set by the standard. Another concern is the flame penetration test. A sample of the duct material must be able to support a weight when it is placed over a burner. Wireflex duct is able to do this because of the mat of fiberglass insulation wrapped around it. It costs approximately $2000 to have a laboratory perform the flame penetration, smoke generation and flame spread tests.

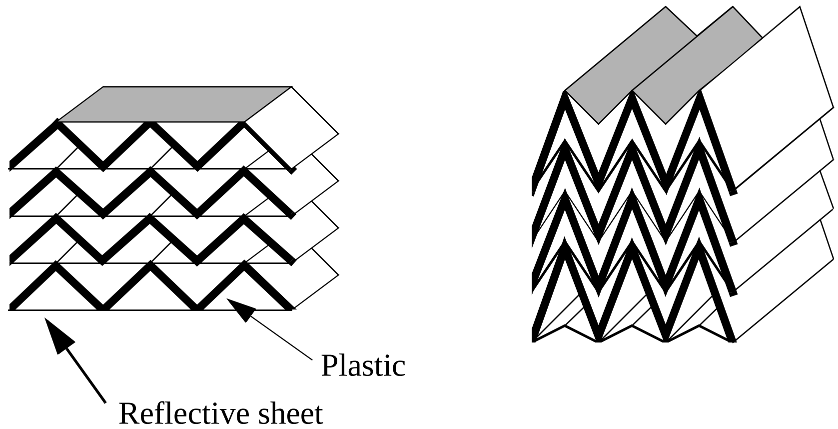

FIGURE 5. Potential design D for duct insulation. A cardboard and paper model was constructed.

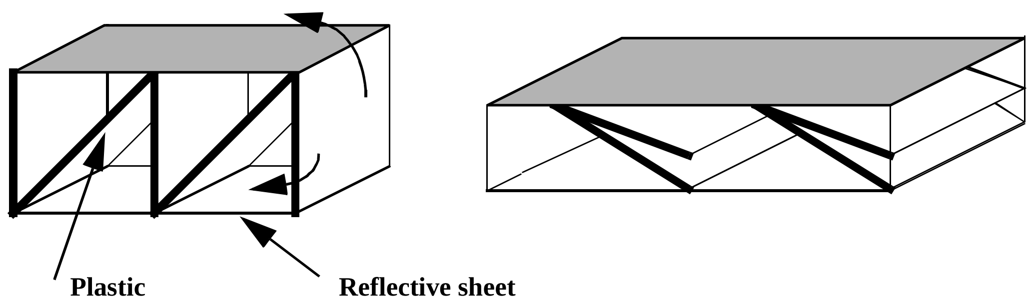

FIGURE 6. Potential design E for duct insulation. A cardboard and paper model and a sample of collapsible ductwork were both produced for this design.

Another non-economic hurdle which must be overcome by any new fitting or duct products is resistance to change by installers. Several of the contractors in the telephone survey implied that they would only make bids on jobs using the same types of materials as their competitors. It was also mentioned that they would only do the minimum necessary to meet local building codes because of cost constraints. These difficulties will have to be overcome by either utility rebate programs or changes in building codes.

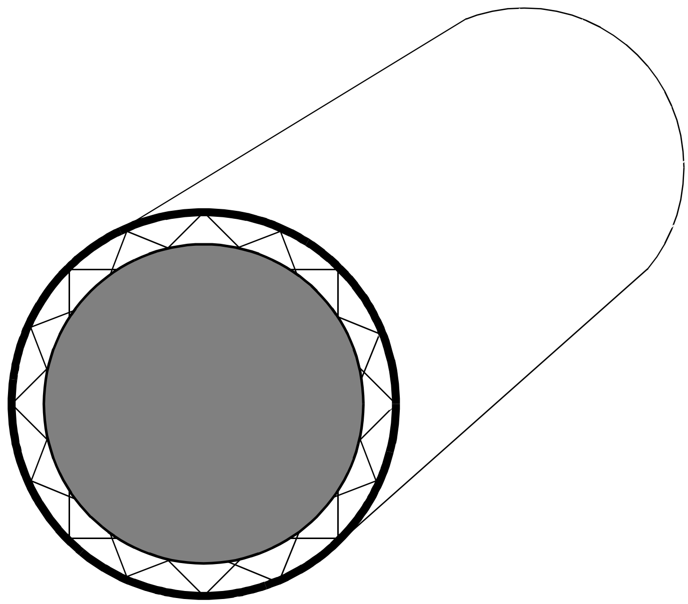

FIGURE 7. A potential design for a round duct using insulation design E. A plastic model was constructed of this design. The outer layer of the duct rotates relative to the inner layer to collapse the insulation. The inner layer of the duct can then be folded in half.

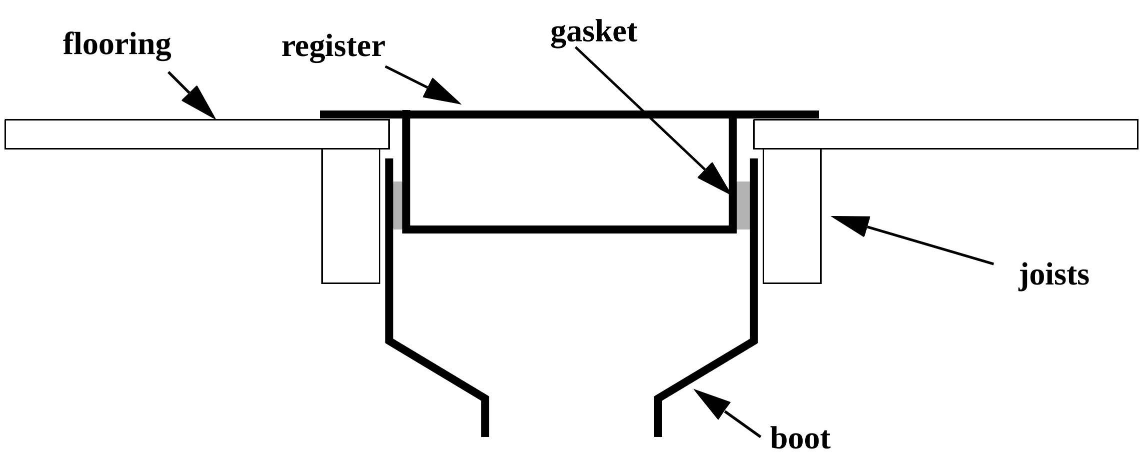

FIGURE 9. Side view of a register and register boot design which would seal against air leaking into the space behind the wall or below the flooring. The register would come with the gasket attached. In current installations, air leaks through the space where the gasket is shown.

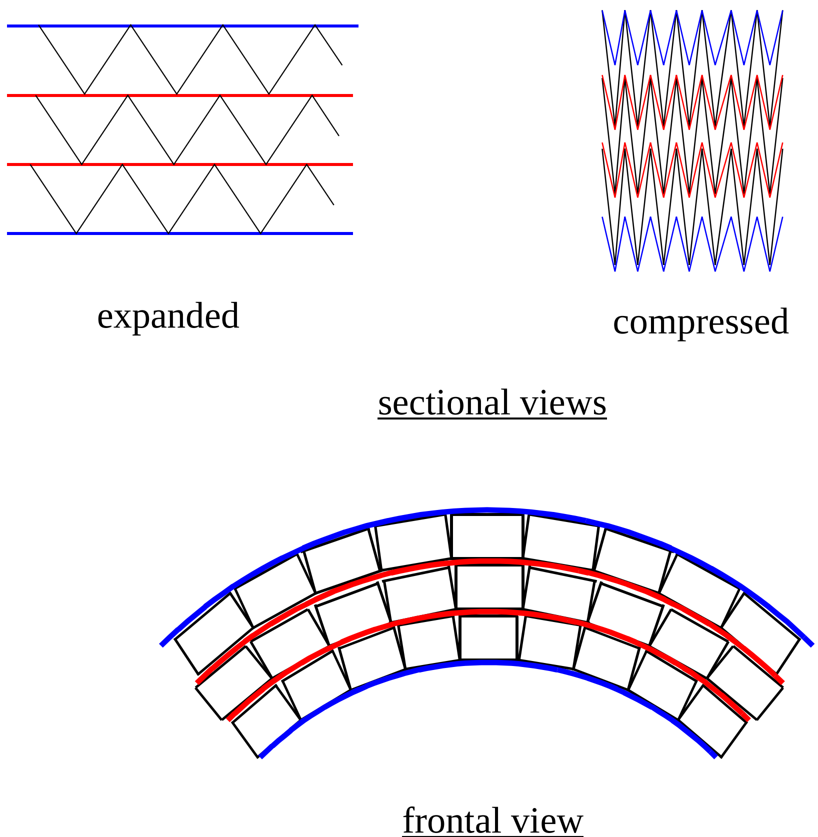

FIGURE 8. Proposed design for a collapsible insulated duct using insulation design D. The design could be produced in a spiral to allow for continuous manufacturing.

6.0 Cost Analysis of New Duct Technologies

What we have seen so far in this report is that ducts as installed do not perform acceptably and that contractors are under tight cost constraints. These difficulties make it necessary to carefully analyze new technologies for their effects on initial and operating costs. We begin by summarizing the costs associated with the most common type of duct system in California, flexible ducts in an attic with equipment located in the garage. We then assess the costs of GFP ducts and improved fittings. Since other options for improving duct systems exist, we compare improved duct fittings against the costs of other options. These comparisons of duct system improvements are for both annual energy costs and peak electrical demand.

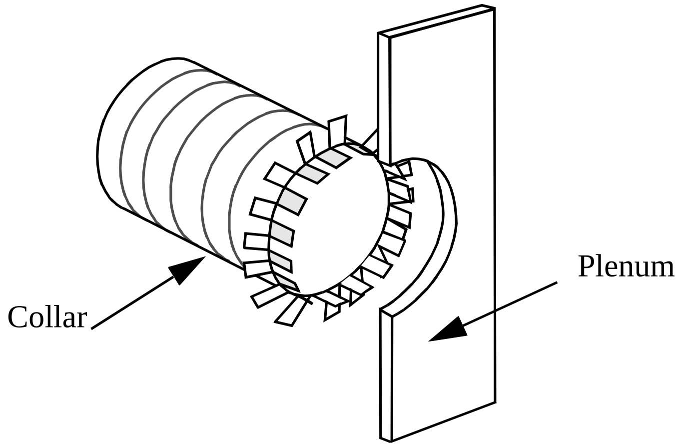

FIGURE 10. A current method for attaching ducts to plenums using a tab collar. Half of the tabs are folded back as shown. The fitting is then inserted into a hole in the plenum and the rest of the tabs are folded back to hold the fitting in place. Unless the hole is cut to tight tolerances, this connection must then be sealed. Most contractors use duct tape which is likely to fall off eventually.

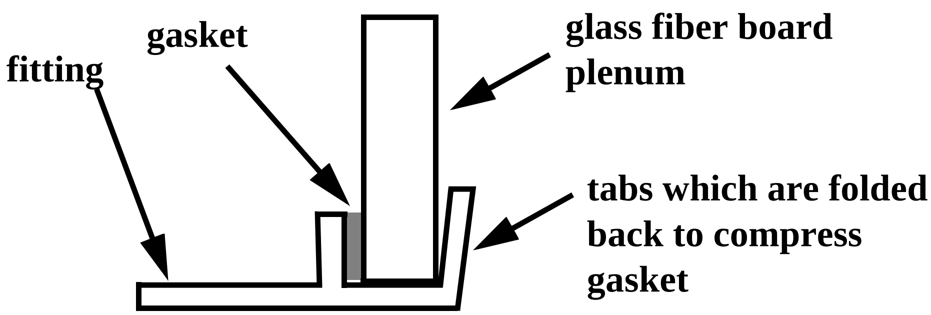

FIGURE 11. An improvement on the typical method of installing fittings into plenums shown in Figure 10. The tabs on the fittings are folded back to compress the gasket. The method is for use with glass fiber board plenums and is currently used by at least one contractor.

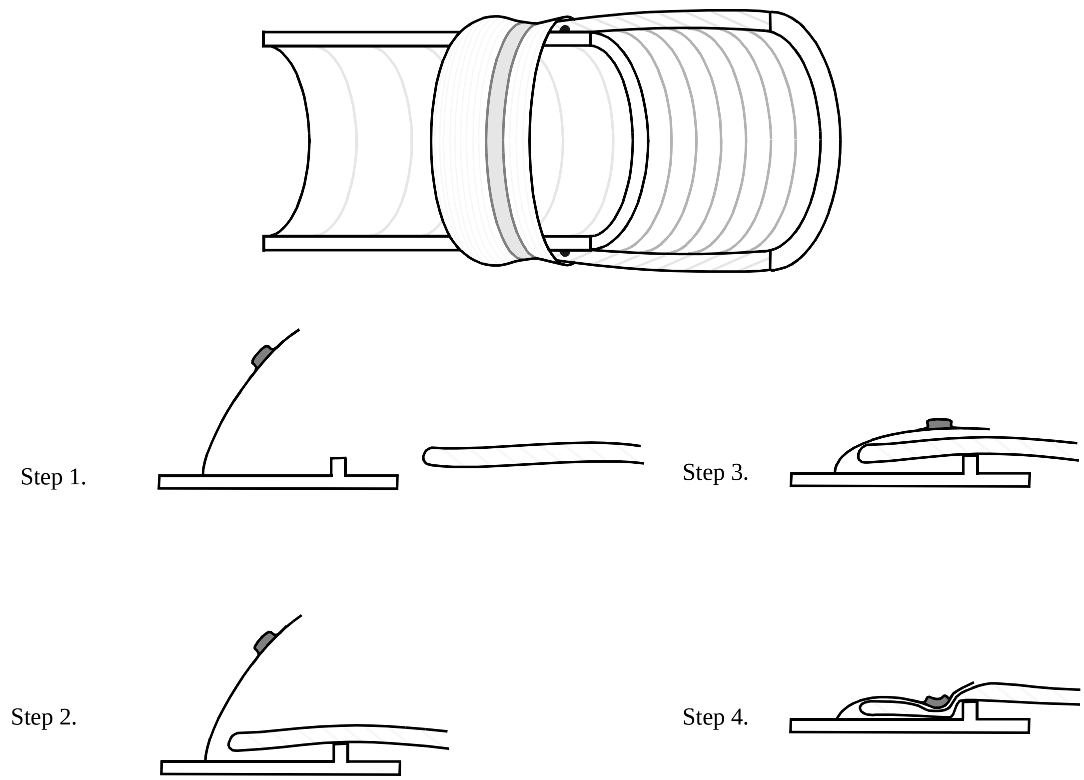

FIGURE 12. A potential new method for attaching wireflex duct to fittings. The intention of the design is to eliminate the taping and/or strapping which are currently done by installers.

6.1 Costs of Current Methods

Because the appeal of new types of duct fittings to HVAC contractors relies upon reducing labor costs, we must first quantify how much money is typically spent on installation. The sources we have used for this are: the survey of HVAC contractors in this report, the survey of existing products in this report and a construction estimating manual (Kiley and Moselle, 1995). We summarize their estimates of duct system costs in Table 10.

The most important point in Table 10 is the low cost of labor for flexduct systems using current methods, particularly relative to material costs. Material costs are at least three times labor costs. There is some disagreement between our sources. For labor costs, we see that our average of $400 from the HVAC contractor survey is twice as much as the $200 estimate of Kiley and Moselle. However, the

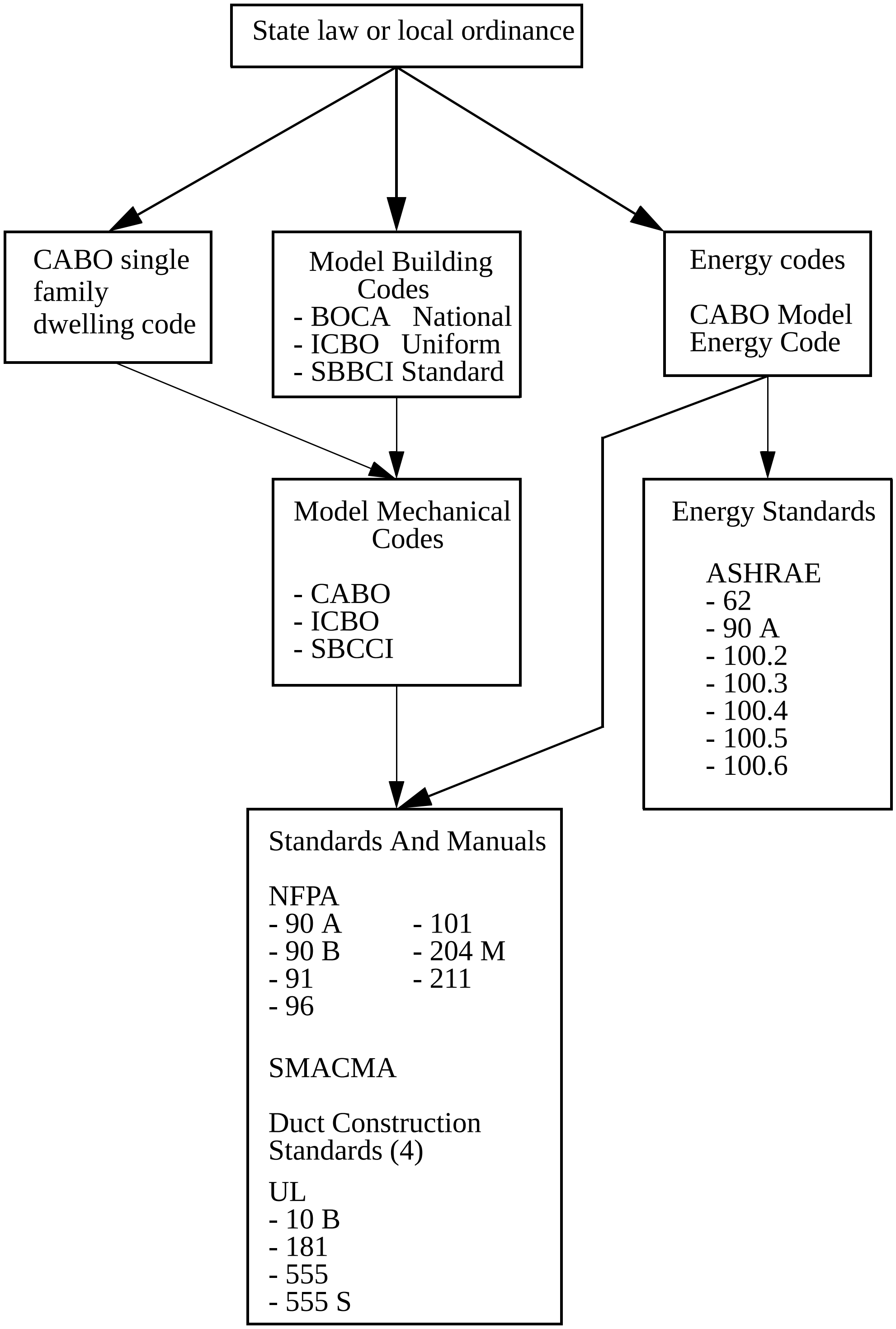

FIGURE 13. The hierarchy of building codes and standards which apply to ducts. The basic standard which residential ducts are required to meet is UL 181. All of the other codes and standards for ducts refer to UL 181.

TABLE 8. Evaluations of the properties of the five insulation models proposed in Section 4.1.

Categories	Description	A	B	C	D	E
Manufacturing		easy	easy	easy	easy	easy
Folds lengthwise	When used to make a duct, can the insulation be used in a design where the duct compresses lengthwise?	yes	yes	yes	yes	no
Folds to smaller diameter	When used to make a duct, can the insulation be used in a design where the duct compresses radially?	yes	yes	yes	yes	yes
Outward expansion	Does the insulation expand in the direction perpendicular to the compressing direction when compressed? It is better for shipping if it doesn't.	yes	yes[a]	yes	yes[a]	no
Compressibility		complete	good	good	good	good
Rigid / strong	Is the insulation rigid, or will pressure collapse it?	yes	yes	yes	yes	yes
Irreversible	Once expanded, will pressure cause the insulation to collapse?	no	no	no	no	yes
Cutting	Can the insulation be cut?	easy	difficult	easy	difficult	med
Has to be "inflated"	Does the design automatically expand or must it be manipulated to pop open from its compressed state?	no	no	no	no	Yes
Material springiness important	Does the design require materials which spring into shape?	no	no	no	no	yes

[a]very little outward expansion.

TABLE 9. Duct Test Program for Underwriter's Laboratory Standard UL181 (UL, 1990). This is the basic standard for flexible ducts. The test which causes the most concern for the GFP ducts and new plastic fittings is the surface burning characteristics, i.e. smoke generation and flame spread.

Test
Surface Burning Characteristics
Flame Penetration
Burning
Corrosion
Mold Growth and Humidity
Temperature
Puncture
Static load
Impact
Erosion
Pressure
Collapse
Tension
Torsion
Bending
Leakage

largest contractor in the survey reports a labor cost of $175. So it seems that $200 is a reasonable estimate of the cost to install a duct system.

There are also large differences in the estimates for the material costs for a duct system. Kiley and Moselle's estimate is almost double what we found in our work. Their estimate includes excess and the other estimates do not, so an estimate of $700 for material costs seems appropriate.

Given a labor cost to the contractor of approximately $25 per hour, including benefits and insurance, our estimate of labor costs corresponds to 1 man day. For a typical system with 8 supply registers, one return register, boots for all registers, 4 wyes, 2 supply plenum fittings, and one return plenum fitting, there are 23 fittings. So an improved fitting system could cost up to $5 extra per fitting and still be attractive to contractors if it cut installation time by 50%.

TABLE 10. Estimated breakdown of contractor costs for a duct system consisting of R-4 flexduct and sheet metal fittings. The data is from Kiley and Moselle (1995). These costs are comparable to the results of the HVAC contractor survey. The duct system has 8 supply registers, one return register.

	Estimated Costs [$]				
		from the HVAC contractor survey			
Item	from Kiley and Moselle (1995)	average	largest contractor[b]	material costs from our survey of available products[a]	Best estimate
labor	$200	$450	$175		$200
materials	$1100	$600	$550	$600	$700
Totals	**$1300**	**$1000**	**$725**		**$900**

[a]Used lowest cost sources for R-4 flexduct and sheet metal fittings.

[b]This contractor estimated he installed 4000 systems per year.

6.2 Estimated Costs of New Products

6.2.1 GFP Ducts

Cost estimates of costs for glass fiber insulated wireflex ducts and possible new GFP ducts are presented in Table 11. We estimate that GFP insulation will cost 2-5 times as much to manufacture. The costs of GFP ducts to contractors are estimated to be 2-3 times higher than for glass fiber ducts. The cost estimates for manufacturing GFP insulation are taken from Griffith et al. (1993). The estimate for GFP ducts assumes the same ratio of contractor cost for duct to insulation manufacturing cost as for flex ducts. The estimates for GFP prices attempt to take into account economies of scale, but they are for plastic materials which would not pass fire spread and smoke generation tests. Actual costs for GFP ducts could be higher. GFPs appear to be significantly more expensive than fiberglass insulated wireflex duct, while offering little improvement in performance. Because of this we will not present any analysis of the economic aspects of GFP ducts below.

The prices for GFPs in Table 11 are for the least expensive GFP's. These insulations do not have higher specific R-values than fiberglass insulation. The GFP insulations with higher specific R-values would cost significantly more.

TABLE 11. Estimates of costs and prices for flexduct and GFP duct. These costs are to the contractor.

		R-4 insulation		**R-8 insulation**		**R-12 insulation**	
		lineal cost	**system cost[a]**	**lineal cost**	**system cost**	**lineal cost**	**system cost**
Product	**type of cost**	**[\$/m] (\$/ft)**	**[\$/house]**	**[\$/m] (\$/ft)**	**[\$/house]**	**[\$/m] (\$/ft)**	**[\$/house]**
fiberglass insulation	manufacturing[b]	\$0.32 (\$0.10)	\$17	\$0.64 (\$0.19)	\$33	\$0.96 (\$0.29)	\$50
flex duct	to contractor[c]	\$2.6 (\$0.81)	\$135	\$4.34 (\$1.32)	\$225	\$6.08 (\$1.85)	\$315
GFP insulation	manufacturing[d]	\$1.44 (\$0.44)	\$75	\$1.92 (\$0.58)	\$100	\$2.55 (\$0.78)	\$130
GFP duct	to contractor[e]	\$8.00 (2.50)	\$410	\$8.50 (\$2.50)	\$440	\$11.00 (\$3.50)	\$570

[a]Assumes 33 m^2 of duct surface area.

[b]from Griffith et al. (1992)

[c]prices estimated by using the lowest price for R-4 ducts and then using the ratios between R-4 and the other insulation levels for all manufacturers.

[d]from Griffith et al. (1993)

[e]prices obtained by assuming the same ratio between manufacturing cost of duct and final price of duct as for flex duct. For flexduct manufacturing costs it is assumed that the "duct" in the flex duct added 50% to the manufacturing cost above that for the fiberglass insulation. We rounded the prices to the nearest \$0.50.

6.2.2 New Fitting Designs

Typical prices for sheet metal and existing plastic wyes and register boots are shown in Table 12. None of the plastic products listed is certified for use in attics in the United States. General Plastics manufacturers fittings that are used under slabs and is not required to meet fire codes. Genda is an Australian manufacturer and their products are used there, but the fittings are made of polypropylene and will not pass smoke and fire tests.

The costs listed in Table 12 show that existing plastic fittings are competitive in price with sheet metal fittings. However, using plastics which do not spread flame or generate smoke will increase prices. Another option would be to create sheet metal fittings which have insulation attached to them and have improved connection methods. Since fiberglass insulation would add no more than $1.00 in material costs to the fittings, it seems that these could compete with the existing systems. It seems conservative to assume that insulated quick connect fittings, whether of plastic or sheet metal, could be made for an average increase in costs of $10/fitting.

It is not clear whether the costs in Table 12 for plastic fittings reflect economies of scale. General Plastics and Genda are small relative to the industrial giants which produce fiberglass insulation.

TABLE 12. **Typical prices for existing sheet metal and plastic fittings. The costs are estimates of costs to contractors.**

Fitting	Size	Manufacturer	Price to contractor	Material
wye	multifit	General Plastics	$9.10	plastic
	8x8x8	many	$5.30	sheet metal
	8x6x6	Genda	$8.83	plastic polypropylene
	8x6x6	Genda	$9.66	plastic polypropylene insulated with foam insulation
register boots	6 to 12x4	Genda	$5.66	polypropylene plastic
	6 to 12x4	many	$5.49	sheet metal
	6 to 12x4	General Plastics	$7.48	plastic

In our cost/benefit analysis below we will assume that plastic fittings with snap-lock fittings will cost the consumer/utility $150 more for materials and save $50 in labor for a system which will reduce leakage by 50%. For a system which reduces leakage by 90% we will assume a cost of $250 for materials and the same $50 reduction in labor costs. These estimates are conservative given the competitive pricing for plastic fittings in Table 12.

6.3 Estimated Costs of Other Improvements to Duct Systems

In order to evaluate the desirability of new duct fittings, it is necessary to consider other possible improvements to duct systems. We consider three other improvements here: having a worker seal ducts in new construction before finish work is completed, adding insulation to R-8 and requiring that ducts be placed in the conditioned space. All of the energy savings and peak electrical demand reductions from these measures are estimated from Modera and Jansksy

For sealing ducts in new construction before finish work is completed, Modera (1992) found that 56% of the duct leakage area could be sealed in 30 worker-minutes. Allowing for transport and setup time Modera estimated that a single worker could seal the duct systems in 2-5 houses per day. Assuming a labor cost of $25 per hour, this implies an expense between $40 and $100 dollars per house for the contractor. We assume that a further 50% reduction in leakage (to 25% of the original leakage) would cost the contractor an additional $40-$100 per house.

Another potential improvement to a duct system would be to add more insulation. We estimate the cost of increasing duct insulation from R-4 to R-8 to be $150 for the typical home. This is based on contractor costs for fiberglass insulation.

Requiring ducts to be placed in the conditioned space is a very attractive option because it would virtually eliminate duct losses no matter how badly the duct system was constructed. As long as the the duct system is truly in the conditioned space, energy lost by any method would still reach the conditioned space. The costs for this measure are difficult to estimate. Anecdotal evidence from one builder is that there is no marginal cost for placing ducts in the conditioned space for multiple story homes. The ducts may be placed in the joist space between floors. This assumes that some form of open joist is used. For single story houses, there are costs involved for most houses. Assuming ducts would be placed in the ceilings of hallways, the ceiling their would have to be raised. In this case the cost to the contractor would be approximately $1000. This estimate comes both from a builder and by summing costs for sheet rock and carpentry in a construction estimation manual (Kiley and Moselle, 1995).

6.4 Cost Comparison of the Options for Improving Duct Systems

Table 13 contains estimates of the simple payback time for consumers of the various options for improving duct systems. Improved fittings are comparable to sealing ducts. However, it should be possible to have larger savings with the new duct fittings and the new duct fittings do not rely upon having properly trained installers. So the benefits from new duct fittings would be more secure. The simple payback time for adding duct insulation is comparable to that for new fittings, but it is not really a competitor for new fittings because it can be done in addition to reducing leakage.

The only option in Table 13 which is not comparable to the new duct fittings is requiring that all ductwork be in the conditioned space. For multiple story houses, this measure results in the largest savings and the smallest payback time. However, for single story buildings it has a long payback time because of additional construction required. These estimates do not account for downsizing of equipment, which is particularly important for the case of duct systems in the conditioned space.

Table 14 contains estimates of the cost per kilowatt reduction in peak demand to the utility of the various options for improving duct systems. Just as we found for reductions in annual energy use, all of the options appear comparable in terms of return on investment. The same arguments apply that the new fittings will be more reliable and that insulation is a complementary measure to reducing leakage.

TABLE 13. Estimation of the value of various duct system improvements to consumers.

strategy		annual energy cost savings[a]	initial cost to consumer[b]	simple payback time for consumer
new insulated duct fittings	50% leakage reduction	$16-$43	$150	3-9 years
	90% leakage reduction	$40-$100	$300	3-7 years
reducing the leaks in ducts by sealing	50% leakage reduction	$16-$43	$100	3-6 years
	75% leakage reduction	$25-$60	$200	4-8 years
requiring ducts and equipment to be placed in the conditioned space	single story	$85-$280[c]	$1500[d]	6-18 years
	multiple story	$85-$280[c]	$200[e]	1-3 years
require extra insulation to R-8		$14-$51	$150[f]	3-10 years

[a]from Modera and Jansky (1994). This gives the range of savings for various cities in California where air conditioning would be used. Fresno has the largest savings and San Diego the smallest.

[b]assuming a 50% markup by the contractor.

[c]These savings are relative to an attic duct system with the equipment located in the garage. Savings would be higher for equipment in the attic and lower for ducts or equipment in a crawlspace or basement.

[d]Cost estimate of $1500 both from a contractor's estimate and Kiley and Moselle (1993)

[e]For multiple story residences, ducts may be placed between floors at no cost if a truss joist system is used.

[f]derived from an additional cost of $0.32/linear foot of 8" diameter duct and assuming 150 feet of duct ina house.

TABLE 14. Estimates of the value of various duct system improvements to utilities for decreasing peak electrical demand.

strategy		reduction in electrical demand (kW)[a]	initial cost to utility[b]	specific cost of reduction ($/kW)
new duct fittings which reduce leakage by:	50%	0.6	$150	$170
	90%	1.1	$300	$180
testing and sealing the leaks in ducts by:	50%	0.6	$60-$150	$100-$250
	75%	0.8	$120-$300	$150-$400
requiring ducts and equipment to be placed in the conditioned space	single story	1.6	$1500	$600
	multiple story	1.6	$200	$125
require extra insulation to R-8		0.7	$150[d]	$200

[a]from Modera and Jansky (1994).

[b]assuming a 50% markup by contractor

[d]derived from an additional cost of $0.32/linear foot of 8" diameter duct and assuming 150 feet of duct in a house.

7.0 Conclusions and Recommendations

This project has investigated the potential for new technologies in the HVAC duct systems to reduce the energy losses of ducts as they are installed in residences. A survey of existing products showed no existing products with significantly improved performance which are appropriate to the residential market. Two companies were found to be developing insulated and easier to seal duct fittings but both are still in the product development stage.

A telephone survey of HVAC contractors was performed and revealed that installation labor and duct materials represent significant percentages of contractors' costs. The contractors' reactions to potential new products showed a willingness to consider new products but not at higher costs. The contractors were found to use installation methods which did not ensure proper sealing at fittings and to not realize the faults in these methods.

Several designs for insulation and ducts using GFP technology were created and evaluated. Economic calculations showed that GFP ducts would be significantly more expensive than glass fiber insulated wireflex duct even before considering the costs of fire resistant plastics. Consequently, the development of ducts based on GFP technology does not seem worth further research.

The value of new duct fittings which would improve sealing of duct systems was compared against other options for improving duct performance. New duct fittings show promise relative to the sealing ducts with existing methods. The one option which could potentially be much more valuable than the new duct fittings is requiring ducts to be placed within the conditioned space.

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