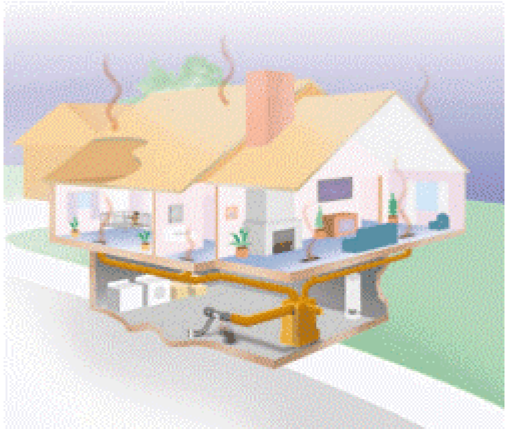


An Introduction to Residential Duct Systems

Background

Residential Thermal Distribution Systems generally refer to the method of distributing heating and cooling throughout a house. This includes the most popular systems that blow air through ducts and other systems that use water (e.g., radiant floors and hot water radiators) and electricity (e.g., baseboard heaters). Studies by LBNL (Lawrence Berkeley National Laboratory) and other researchers have shown that forced air systems have the potential for significant energy losses because of air leaks and their installation outside the heated and cooled parts of the house. Recent research funded by DOE (Department of Energy) has concentrated on forced air distribution systems and found that typically a quarter of the energy (and therefore money) used for heating and cooling is wasted through duct system energy losses.

The problems with forced air systems:

- **They are installed outside**. In many places in the country the ducts (and the furnace and air conditioning coils) are located in attics, crawlspaces, garages, basements and other locations outside the heated or cooled parts of the house. Ducts in these locations not only leak air to and from outside, but any heat lost through the walls of the duct (by heat conduction) is also lost to outside instead of heating and cooling the house. This combination of air leaks and heat conduction losses means that a great deal of the energy (and money!) used to heat or cool the house actually ends up outside. It should be noted that in some places basements are lived in and are considered part of the conditioned space of the house. It is also common for these houses with conditioned basements to have all the ducts, the furnace and the air conditioner in the basement where any air leaks or heat conduction losses go to the basement and are therefore NOT lost to outside. In these cases the energy (and monetary) penalty for leaks and conduction losses is negligible. However, systems with lots of leaks will not supply sufficient heating or cooling to rooms in the house located far from the furnace or air conditioner, making these rooms uncomfortable for the occupants. In other words - losses from ducts count, even if they are not lost directly to outside.

- **They leak.** Air leaks in and out of ducts at all the connections within a system (e.g. at plenums and behind registers). This leakage means that air that occupants have paid to have heated or cooled escapes from the heating or cooling system and does not heat or cool the house. Also, air leaks into the heating or cooling system increase the amount of outside air that must be heated or cooled. Outside air is usually cooler (for heating) or warmer and more humid (for cooling) than air inside the house and the heating or cooling capacity of the system is then used to heat or cool this outside air instead of the air in the house. Even with the heating and cooling system off, the leaks in the ducts increase the ventilation rate of the house - increasing the need for heating or cooling. The "leakage" from water and electric based systems is much more rare due to the somewhat catastrophic nature of leakage from these systems. In fact, building codes are extremely sensitive to leakage from water and electric based systems and there are strict controls regarding construction and installation of these systems due to the safety problems associated with their possible failure.

Duct Installations

In almost all new houses (and many existing houses) in California and elsewhere in the U.S., the most popular place to put the duct system is in the attic. Unfortunately, this is one of the worst places to put the ducts, particularly when cooling a house in the summer. Attics become extremely hot on summer afternoons (temperatures over 150° F are common) due to the sun shining on the roof. This heats up the ducts and the air inside them (particularly air leaks into ducts on the return side of the system). This results in air coming through the registers at higher temperatures and decreases the ability of the air conditioning system to cool the house. In particularly poor systems, the air supplied to the house through the registers can be HOTTER than the air in the house and the air conditioner actually heats the house!

Duct systems tend to be ignored during building design and it is the installing contractor who has to decide where to put all the ducts. This results in systems that are difficult to maintain, service and retrofit or repair (to reduce losses). If you go and look in your attic, you will probably be met with a sight something like this where ducts fill much of the attic space in no organized fashion. Can you see the furnace in this picture? How would you change the furnace filter or repair this system?

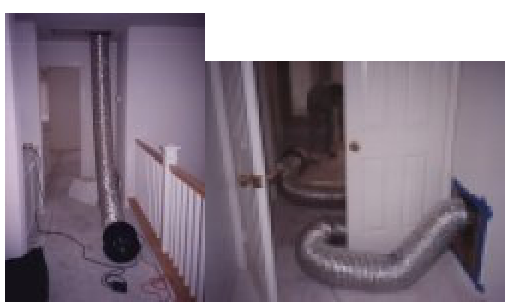
Where Ducts Leak

Measurements of air leakage from ducts have shown that in most houses this leakage is more important than conduction losses and so much work at LBNL has focused on duct leaks. Ducts are usually made from sheet metal (more common in older houses) or flexible plastic duct (used in almost all new houses - as shown in image (a)). Little or no air leaks out through the plastic or metals walls of these ducts. The air leaks out at the connections: from the furnace/air conditioner to the duct, at branches in the duct system (image b), and at connections from the duct to the registers (image c). Lastly, one of the greatest leakage problems occurs when there simply isn't any duct, and the walls or floors of the house are used as the "duct system" (image d).

(a)  (b)  (c)  (d) 

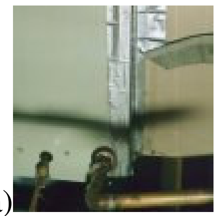
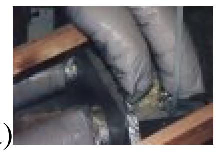
Leakage Testing

A key aspect of recent work has been to look at different methods for measuring air leakage from ducts. A common method is to seal over the air supply registers and blow air into the system. This method is used for duct efficiency credits by utilities in energy efficient home rebate plans and by the California Energy Code, Title 24 (prepared by the California Energy Commission). Because the intentional air outlets (the registers) are sealed any air blown into the system must be leaving through the leaks. By measuring the pressures in the ducts and the quantity of air blown into the ducts we can characterize the effective size of all unintentional air leaks in the duct system. Other tests include pressurizing the house at the same time as the ducts or using the fan in the furnace or air conditioner and measuring pressure changes in the house with the system operating. Alternative methods are currently being pursued through workshops with duct leakage testing experts and the results of these workshops will be used to provide utilities, home energy raters and code enforcement officials with improved and standardized test methods. ASTM (The American Society for Testing and Materials) has a standard test method for duct leakage testing that we will be rewritten based on the results of field-testing and these workshops.



Duct Sealing

Of course, when ducts are originally installed, an attempt is made to seal up the connections. After gathering anecdotal evidence from many sources regarding the failure of duct sealant methods, we have begun to document sealant failures and also perform laboratory tests on sealants to determine which sealants perform better than others. The most common sealant is duct tape and we have found that it often peels off duct systems leaving a characteristic residue (a & b) that is the remains of the adhesive. On new installations, tape may fall off due to poor surface preparation because ducts are installed in dirty and dusty locations and conditions. On other than brand new systems, the tape falls off as it ages and the adhesive dries out and the tape tends to wrinkle (c & d).

(a)  (b)  (c)  (d) 

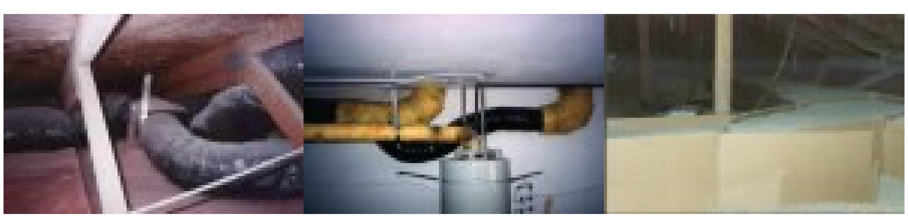
Duct Sealant Testing

To confirm the anecdotal evidence regarding duct tape failures we developed a laboratory test procedure that alternately blows hot and cold air through sample duct connections. This test does not simulate what happens to ducts in a specific installation, but it does provide a basis for comparison between different duct sealants. 19 different sealants including: cloth, metal foil and plastic backed tapes, mastic and an aerosol sealant. The major result was that the only sealant to fail was the cloth-backed tapes. This result generated considerable media interest led to numerous newspaper articles, press releases, radio interviews and even a mention on NPR's "car talk". ASTM is currently drafting a standard test procedure based on their experiments that can be used by others to rate the relative longevity of duct sealants. The following figure shows eight samples in their test apparatus.

Duct Insulation

Usually ducts are only insulated if they are outside the conditioned space. Older duct systems made of sheet metal are often found in basements and have no insulation. Some of these older sheet metal ducts have an asbestos based thin layer of insulation added to them. This thin layer of asbestos gives the ducts a small increase in thermal resistance. Occasionally, these poorly insulated sheet metal ducts can also be found in unconditioned spaces, such as attics or crawlspaces.

Ducts in new houses are often made of insulated flexible plastic duct. This duct is usually labeled on the outside liner with its R-Value. The R-value, with higher R-values denoting better performance, indicates the heat stopping ability of insulation. Most flexible plastic ducts have R4 insulation (compared to about R1 for un-insulated sheet metal ducts). In some cases a mixture of insulation will be seen. For example, glass fiber insulation without a paper, plastic or foil backing is often used around duct connections and plenums. In recent years, innovative methods for insulating ducts have been developed. For example, ducts can be laid on the attic floor; they are then surrounded by cardboard channels and cellulose insulation is blown in around and over the ducts.



When houses or heating/cooling systems are renovated, insulation is added to existing ducts, because it can be cheaper than replacing the ducts. The following illustration shows ducts being wrapped in foil-backed insulation (often called "duct wrap"). The potential for energy and cost savings can be significant, particularly when adding insulation to poorly insulated ducts. Even when ducts are inside the living (conditioned) space these conduction losses can be important because the losses from long duct runs can lead to rooms being uncomfortable because they not receive enough heating or cooling.

The term "duct efficiency," indicates how much energy entering a duct system is provided to the house, thus, higher efficiency ducts are better. To evaluate the effects of duct losses, LBNL has been involved in the development of ASHRAE Standard 152P "Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems" (ASHRAE 1999). Using the calculation procedures in the standard allows us to estimate the effects of duct insulation on duct system efficiency. Note that only the seasonal efficiencies from 152P are discussed here because they are the most appropriate for estimating energy consumption in buildings. The effects at peak conditions will be greater than those shown here due to the more extreme weather conditions, and therefore more extreme duct location temperatures. Examples are given here for typical systems in six cities chosen to represent a wide range of weather conditions. The maximum benefit gained by insulating ducts is when the ducts are in locations that have acute temperatures. These effects are highly variable - being greater for more extreme climates and duct locations, so it is necessary to take these variables into account when assessing the cost-effectiveness and other benefits of duct insulation.

As insulation is added from R2 to R8 there are diminishing returns with each step. If we also include practical space considerations (R8 adds about six inches (150 mm) to the duct diameter) a couple of optimum options appear. For new installations that can be more flexible about duct size, R6 ducts are good for most cases. Similarly, if decisions are being made about adding insulation to ducts, and the ducts already have R4.2 or greater insulation, then it is unlikely to be a practical and cost-effective measure to add insulation. Below this level however, ducts do receive considerable benefit from the added insulation. Lastly, in some cases the added insulation has very little benefit particularly when the ducts are in locations where temperature differences between air in the ducts and their surroundings are negligible.

Changing the Marketplace

With regard to energy losses, work on the development of proposed ASHRAE Standard 152P (that is currently being redrafted after its public review). This standard will be used by building designers, by the home energy rating industry and in building and energy codes to account for duct system energy losses more precisely than current practice. For example, a simplified version of the proposed standard has already been incorporated into the Alternative Calculations Manual in the California State Energy Code (Title 24) for low-rise residential buildings. In addition to incorporating this calculation procedure we have provided technical advice for Title 24, including recommended leakage levels for ducts, information required to perform the necessary testing and energy loss calculations and advice for sampling houses to be tested. A very important aspect of the changes to Title 24 is that field-testing will be required to obtain an energy credit for having good ducts. This is a considerable change from previous practice in building/energy codes where a simple specification for performance of a building component was given and no testing required to determine if the specification was met. A lot of electricity is wasted by California's type duct systems!

Comfort and Sizing

Air conditioning cooling capacity is often measured in "tons". A ton of cooling represents the heat energy required to melt one ton of ice in 24 hours. Because duct systems lose energy that is supposed to heat or cool the house, they change the effective capacity of the heating and cooling equipment. For example, a three-ton air conditioner connected to a duct system of 70% efficiency effectively becomes a two-ton air conditioner. Given that the homeowner has paid for the three ton unit and pays its operating costs (it still consumes all the electricity required for three tons of cooling) they need to know just how much of what they have paid for they are getting. A way of doing this is to evaluate the whole heating and cooling system by looking at the actual heating or cooling delivered at the air supply registers to the occupied space. For cooling we have coined the phrase "Tons at the register" (TAR) to describe this number. This capacity at the register is what is needed to keep the occupants comfortable.

We have also developed a sophisticated computer simulation tool that calculates building loads, duct losses and equipment performance (based on weather, refrigerant charge and extra loads due to poor ducts). We have used this tool to estimate how fast a house can be cooled down after it has been allowed to heat up all day. This is called the PULLDOWN time and is a critical factor in keeping occupants comfortable. The quicker a system pulls down the indoor temperature to that set by the occupants the better the system because the occupants have to spend less time in an overheated house. We used field tests in real houses to determine input data for the simulations.

Simulation results showed that improved ducts (low leakage) and improved system installation (moving ducts into conditioned space form the attic) can allow the use of a smaller nameplate capacity air conditioner without reducing the TAR or the pull-down time. (A three-ton unit can be used rather than a four ton for a typical house in Sacramento, CA.) If system nameplate capacity is unchanged, either improving duct systems (to minimize air leakage) and correctly installing the equipment, or moving the ducts to inside the conditioned space results in the pull down being reduced by more than an hour, so the occupants become comfortable sooner.

Frequently Asked Questions

Q: **What can I do to improve the Thermal Energy Distribution (TED) system at my house?**

A: Two things: 1) you can give your heating system a tune-up. If you have an air conditioner or a heat pump the technician should check the freon charge in your system. If you have a gas furnace the technician will clean and check the heat exchanger for safety. 2) You can seal the leaks in your ducts. This means sealing up all the holes where heated or cooled air can leak into unconditioned spaces - attics, basements, or wall cavities. You should be warned, however, because there are potential problems if the sealing is not done properly.

Q: **Should I have my ducts cleaned?**

A: Duct cleaning can be useful in some circumstances, but the real answer is to keep dirt out of the ducts in the first place. That means making sure that you have a filter on the return side of your system - either at the return grille or near the furnace, where the return duct enters the air handler. The filter should be changed every 4-6 months, or when it gets dirty. Making sure that your air filter is clean will also improve the performance of your system overall. If the filter is very dirty the system may be compromised because the fan cannot pull the correct amount of air through the system.

Q: **I have a gravity heating system. Should I replace it because it is old and inefficient?**

A: Not necessarily—there are trade-offs. The combustion efficiency of a modern furnace is about 80%. Gravity furnaces have lower combustion efficiency. However, they are quite reliable because they have very few moving parts. Also, the duct systems connected to gravity furnaces generally have fewer losses than those connected to forced air furnaces because the air in the duct is at a lower pressure. The ducts are generally larger (lower resistance) so that the lower pressure air can make it to the living space. If you do decide to switch the furnace, but retain the same duct system, the airflow to the living space will generally be very high because of the low resistance of the ductwork.

Q: **Is it true that forced air distribution systems make the house drier in the winter?**

A: Possibly, but not necessarily. Forced air distributions systems only make the house drier if they are not working properly. If there are large leaks in the return ductwork then dry outside winter air will be drawn into the house through those leaks. This will tend to dry the air in the house. Conversely, hot water systems that are not working properly sometimes add moisture to the house. Steam or hot water systems usually have a pressure relief valve which releases moisture to the room when the pressure in the system gets too high. The main reason for houses being dry in the winter is building envelope leakage. Warm indoor air leaks out through holes in the attic plane, and is replaced by cold outside air leaking in at the floor. This cold air is dry compared to the warm air that was lost. The colder it gets outside, the more air leaks out of those holes.

Q: **The ducts in my basement are wrapped with asbestos. Should I have the asbestos removed?**

A: Asbestos is harmless as long as it is not airborne. It causes a problem because it forms very small particles, which travel fairly deep into the lungs if they are inhaled. A professional can remove asbestos or it can be covered with an impermeable surface, which prohibits the particles from becoming airborne. (Generally the particles do not become airborne unless they are disturbed.) If you have any concerns about asbestos consult a professional.

Q: **I have heard that duct tape should not be used to seal ducts. What materials should be used?**

A: The products that should be used to seal ducts are mastic, butyl tape, foil tape, other heat approved tapes, basically, anything except duct tape.

Q: **My ducts are located in the basement. Should I insulate the ducts? Should I insulate my basement ceiling?**

A: This is a difficult question because each case is different. If the basement is conditioned then the basement ceiling does not need to be insulated, however, the ducts should still be insulated (so that they deliver their heat to the space where it is supposed to go.) In general, if the basement is unconditioned then the basement ceiling and the ducts should be insulated. One possibility is to insulate them together. Fiberglass insulation can be installed between the joist bays underneath the ducts, thus the ducts are on the "warm" side of the insulation, although they are still located in the basement. The fiberglass should be held in place by netting or insulation supports. Another option is to use what is called a BIB system - blown in cellulose insulation. A contractor will install a membrane on the bottom of the floor joists, and then will fill each joist bay with blown in cellulose.

Q: **Why is it so much hotter on the second floor of my house than the first floor when the central air conditioner is running?**

A: There are several reasons: First, there is usually more load upstairs. Heat conduction through the ceiling and solar gain from skylights add significantly to the cooling load of a house. The radiation from a warm ceiling also adds to the load. The ceiling of the second floor heats up due to conduction from the attic space as well as radiation from the attic roof. Second, the cooling system is generally not designed to meet the higher loads on the second floor. Often cool air delivery is calculated based on room size rather than load. A third possible reason for the upstairs of a house being hotter than downstairs during the cooling season, is that the cold air return may be located on the first floor. The warm air on the second floor may not be making its way into the air handler to get cooled. The situation can be exacerbated by thermal stratification (because heat rises) before the system turns on, meaning the upstairs is hotter to start with. Zone controls can help to alleviate the problem, as can proper duct sizing according to loads.