Ductwork

A guide to proper installation and sealing

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Manual D

Manual D is the residential duct design manual that is published by the Air Conditioning Contractors of Association (ACCA). It covers duct types, applications, selections, principles of multi-speed and variable speed blowers, pressure loss, operating point, duct sizing calculations, duct leakage and conduction losses. Ducts should be sized according to the highest load for that zone. Ducts should be laid out in a way that accounts for load zones, structural material, framing orientation and occupant comfort (have you ever had a ceiling register pointed at the bed?). Duct sizing according to Manual D is a code requirement in the 2003 International Residential Code (M1601.1).

Ducts are usually made out of one or more of the following: sheet metal, pre-fabricated flex duct, duct insulation board and building cavities.

Sheet metal ductwork has a lower friction loss rate than the other types of ducts. Fungi typically won't grow on metal ductwork (although they will grow on the dust and trash that can accumulate in the ductwork!), the installation is usually more expensive, the joints and seams leak unless they are well-sealed, and it must be insulated.

Pre-fabricated flex duct took the craftsmanship away from duct design and installation and replaced it with a completely random method of installation. Now, it can be left to the installer to interpret where the duct should go, what size should be used, while rejecting standards in favor of chance and randomness. The odds are stacked against a proper flex duct installation from the beginning because the main advantage of the material (it's cheap) is also the main disadvantage (it's cheap). Flex duct has no seams but tends to leak at the joints- a lot! It is fairly fragile and is easily compressed, pinched, crushed and otherwise abused if it is not respected. Flex duct contains an inner pressure liner and an outer layer of insulation covered with a vapor retarder (usually a shiny foil that also acts as a radiant barrier). In order for flex duct to operate properly, it must be installed properly (straight runs; supported every 5' with at least a 1" wide strap; sag no more than ½" per foot of run; be cut to the proper length; and not be pinched to change direction or make a connection). The code governing flexible duct installation is written by the Air Diffusion Council and is referenced by SMACNA and NAIMA in their installation standards (which the International Code Council, in turn, references in M1601.1.1).

Rigid duct insulation board is also used to create ducts by field fabrication. Usually, the pieces are attached to each other by some form of tape and are used to create plenums, trunk lines, and distribution boxes. Duct insulation board is a dense, glass fiber mat that has a shiny foil on the outside. Some manufacturer's make a product that has an inner liner as well that is treated with a mildew and fungi retarder. It must be carefully sealed in order to be airtight, but provides excellent noise control. An ideal duct board would have the foil on both the outside and inside.

The last category of duct material is actually not duct material- it is a building cavity that is used as a duct! This can lead to all kinds of issues, such as extreme amounts of duct leakage (wood shrinkage due to temperature and humidity differences), poor insulative characteristics, positive or negative pressure zones may be created within these cavities (driving an increase in house exfiltration or infiltration), and sometimes, other trades don't realize that it is a duct. Many times we find plumbing lines and cable or electrical wires pulled through a site built return (Honestly, I thought it was a chase!), or multiple holes drilled through the "duct" before it became a duct! BUILDING CAVITIES SHOULD NEVER BE USED AS DUCTS!

Principles of good duct design

First, try to get the ductwork inside the building envelope. This reduces the duct leakage to the outside (which has an energy penalty) and generally improves performance. While there is no blatant energy penalty for duct leakage to the inside of the building envelope, it can create a comfort penalty (air not getting where it should) and may create indoor air quality issues by creating specific pressure zones that may draw air from bad sources. Well-sealed ductwork within the building envelope is a priority issue. Getting the ductwork inside the building envelope may simply require redefining the building envelope to include an attic, crawlspace or basement. Perhaps a drop ceiling can be installed in a hallway or a soffit built around the edges of the room. Maybe a special truss design can be used that allows the ductwork to be installed within a conditioned zone of the attic. There are many creative ways (exposed ductwork) to get ductwork inside the conditioned space (and some of them are less expensive than others!)

Flow balancing dampers are inexpensive and allow the amount of airflow into a room (or zone) to be altered. They should be installed in the duct at an accessible location upstream of the duct supply register. This may be at the take-off from the trunk or plenum, or may be in-line on the duct run itself. The key is to have the damper installed in an accessible location.

Sheet metal elbows should be used for making tight turns. Sheet metal has a lower friction rate than flex duct, making it easier for the proper amount of airflow to reach the register. Flex duct turns should be gradual, with the radius of the turn greater than the diameter of the flex duct. In terms of reducing airflow, every 90° bend is the equivalent of adding 30' or more of straight length to the duct run.

Duct runs should not originate within 1 foot of the plenum cap or from the plenum cap itself. Ducts shouldn't originate within 1 foot of the end of a trunk line or from the end of the trunk line. Duct run take-offs should be spaced at least 1 foot apart on the plenum or trunk line.

Duct installation

As long as the ductwork is installed according to the general principles outlined above, what we are really after here is duct sealing. Duct leakage costs the American consumers around $5 billion per year, wasting the equivalent energy used by 13 million cars per year, and is equal to the estimated annual oil production from the Arctic National Wildlife Refuge. It takes about 7 billion trees to offset the carbon dioxide released by the production of this wasted energy. This is why duct sealing is so important. It has been estimated that by retrofitting duct sealing measures and testing all new duct systems to verify a lower leakage rate, the State of California may be able to prevent having to build a 1 GigaWatt power generation plant.

One of the main factors driving the link between duct leakage and efficiency is the location of the leak. Ductwork installed in a conventional attic can drop the efficiency of the system by 50%. When that ductwork is installed in a semi-conditioned buffer zone (unconditioned basements inside the building envelope, inter-floor spaces), the efficiency ranges between 50-100% of the system. Ductwork and air handlers installed in a cathedralized (unvented, insulated along the roofline) attic use about 45% less energy than systems installed in conventional (vented) attics. Ductwork and air handlers installed in cathedralized attics carry a 3-5% energy penalty over systems installed completely inside conditioned space.

Ducts are usually sealed with either cloth duct tape, foil tape, foil tape with a UL181 rating, or mastic.

Cloth duct tape should not be used to seal duct work. It doesn't work in the lab, it doesn't work in the field, and it just doesn't work anywhere. It may be used to temporarily hold pieces of ductwork together, but cannot be relied upon to seal ductwork. Cloth duct tape should never be found holding ductwork together in new construction, particularly in locations that have adopted the International Codes which require the use of duct tape with a UL181 rating (International Energy Conservation Code 503.3.3.4.3).

Plain foil tape is also often used ("You can't pull that tape off if you tried!") by contractors who are unaware of the requirements for a UL181 rating. The foil tapes must be attached to clean, dry surfaces and pressed to remove tiny air bubbles. If they are not installed correctly, leakage can (and will) occur.

Foil tape that has a UL181 rating has had to pass an adhesive test for 24 hours and meet flame and smoke spread requirements. There are different types of UL181 listed tape; the UL181A tape is for duct insulation board and UL181B tape is for flex duct. Within those designations are specialties: for duct board there are UL181A-P (pressure sensitive), UL181A-M (butyl adhesive, also called mastic tape), and UL181A-H (heat sensitive) while flex duct has UL181B-FX (pressure sensitive) and UL181B-M (butyl adhesive). Over time, these tapes will fail (the grand lesson is that all tapes are temporary), generally due to the exposure to heat from the surrounding environment (like attics). In order to receive the UL181B rating, the tape must have a mechanical hose clamp installed over it. This rarely happens in the field, but will help prevent delamination and shrinkage of the tape. Even the "mastic" tape will start to lose its effectiveness over time (7-8 years). The best sealant is water-based mastic, a required sealant in beyond code programs such as EarthCraft House™.

Mastic is a water based adhesive that can be applied with a brush, hand applied wearing rubber gloves or with the bare hands. When applied properly (the key to all sealants), it forms an airtight barrier and "glues" the components together. Mastic (like all duct sealants) should be applied to the pressure barrier of the duct system, not the insulation. On metal ductwork, it is the sheet metal. On duct insulation board, it is the shiny foil exterior surface. On flex duct, it is the inner plastic core liner. On building cavities used as ducts, mastic should be applied everywhere (especially to the person who installed that system!). It is absolutely critical that the sealant is applied to the pressure boundary! Mastic is faster, less expensive, more durable and messier than tape.

The way to apply mastic for flex duct:

1. Apply mastic to the sheet metal fitting
2. Slide the pressure liner over the mastic on the fitting
3. Apply mastic over the pressure liner and fitting
4. Install a mechanical clamp over the mastic on the pressure liner and fitting

Cover the connection with the duct insulation and install a mechanical clamp over the insulation (or use tape- it doesn't matter!)

Mastic application over duct insulation board joints and seams is very similar, but the installer may use tape to hold the pieces together. Then, the mastic is brushed on over the tape and the width of the tape on each outer edge (so the mastic is 3x as wide as the tape). If it is just applied over the tape, when the tape fails, the mastic fails (not really, but the leakage will occur).

The key places to seal the thermal distribution system are the air handler (where pressures are highest), air handler -plenum connections, plenum-take off collar connections, duct-collar connections, duct-splitter connections, duct-duct connections and duct-boot connections. For metal ductwork, the longitudinal seam must be sealed as well as the duct joints. It is also important to seal the seams in metal elbows. I know one contractor who has his crew paint the sheet metal connections with mastic whenever they have down time. This way, the time in the field is reduced and he can visually inspect at least part of every job.

Ducts outside conditioned space must be insulated to at least R-8, and ducts inside conditioned space should also be insulated to avoid condensation issues (usually R-4 or R-6).

Another consideration of good duct design is designing the return airflow path. The return grille should be sized according to the amount of airflow needed (if it is too small, the air handler can be “starved” for air). A filter grille should be sized to permit 2 cubic feet per minute per square inch of grille surface area, and non-filter grilles sized for 2 ½ cubic feet per minute of square inch of grille surface area. If a 2 ½ ton system is installed (~ 1,000 cfm), a filter grille would need to be at least 500 square inches (about 3.5 ft^2) and a non-filter grille would need to be at least 400 square inches (about 2.8 ft^2). In addition to grille sizing, the return duct should be sized to accommodate the needed airflow. The return duct should be greater than the sum of all the supply ducts serving the same zone (a good rule of thumb is 120% larger than all the supply ducts added together). If the home has a single central return, a system must be designed that prevents the bedrooms from becoming pressurized when the doors are shut and avoid the creation of a depressurized zone in the space containing the return duct. According to M1403.1 of the 2003 IRC, heat pumps must have a return duct at least 6 square inches per 1,000 Btu’s of output capacity.

In one home I worked on, when the bedroom doors were closed with the air handler on (a central return system) pressure imbalances were caused ranging from +2.7 Pa to +5.0 Pa w.r.t. the main body of the home. This drives up infiltration in the main portion of the home and exfiltration in the bedrooms. It also increases the amount of duct leakage on the return side as well as the other problems already mentioned earlier with pressure imbalances. These zones needed to be equalized.

This pressure equalization can be done by constructing high-low transfer grilles (a grille high on the bedroom side and low on the hallway side) that are connected through a sheet metal or duct board lined stud cavity in an interior wall. This system can have the problem of not being recognized as a duct, so it should be labeled. Alternatively, a jumper duct can be used to connect the bedroom with the other zone. A register is installed in the ceiling and is connected to a flex duct that terminates at another register in the ceiling of the hallway zone. The flex duct has sound-absorptive properties for those concerned about privacy and should be sized larger than the sum of the supply ducts to the bedroom zone. One contractor I know has connected multiple jumper ducts to a single sheet metal barrel containing a baffle system; this was then connected to a single large duct to the hallway. This could be replicated by using duct insulation board boxes as well (a spider system).

Of course, the ideal solution to obtain pressure equalization among the zones is for there to be a properly sized return duct connecting each zone with the return plenum on the mechanical system.

Key Points for Duct Installation

1. Try to get the ductwork inside the building envelope.
2. This reduces the duct leakage to the outside (which has an energy penalty) and generally improves performance.
3. Flow balancing dampers are inexpensive and allow the amount of airflow into a room (or zone) to be altered. The key is to have the damper installed in an accessible location.
4. Sheet metal elbows should be used for making tight turns. Sheet metal has a lower friction rate than flex duct, making it easier for the proper amount of airflow to reach the register. Flex duct turns should be gradual, with the radius of the turn greater than the diameter of the flex duct.

5. Duct runs should not originate within 1 foot of the plenum cap or from the plenum cap itself.
6. Ducts shouldn't originate within 1 foot of the end of a trunk line or from the end of the trunk line.
7. Duct run take-offs should be spaced at least 1 foot apart on the plenum or trunk line.
8. Design the return airflow path.
9. The return grille should be sized according to the amount of airflow needed.
10. A filter grille should be sized to permit 2 cubic feet per minute per square inch of grille surface area, and non-filter grilles sized for 2 ½ cubic feet per minute of square inch of grille surface area.
11. In addition to grille sizing, the return duct should be sized to accommodate the needed airflow. The return duct should be greater than the sum of all the supply ducts serving the same zone (a good rule of thumb is 120%).
12. If the home has a single central return, a system must be designed that prevents the bedrooms from becoming pressurized when the doors are shut and avoid the creation of a depressurized zone in the space containing the return duct.
13. This pressure equalization can be done by constructing high-low transfer grilles (a grille high on the bedroom side and low on the hallway side) that are connected through a sheet metal or duct board lined stud cavity in an interior wall.
14. Alternatively, a jumper duct can be used to connect the bedroom with the other zone. A register is installed in the ceiling and is connected to a flex duct that terminates at another register in the ceiling of the hallway zone.
15. Of course, the ideal solution to obtain pressure equalization among the zones is for there to be a properly sized return duct connecting each zone with the return plenum on the mechanical system.
16. Seal the ducts with mastic. Duct leakage is estimated to cost the American consumers around $5 billion per year, wasting the equivalent energy used by 13 million cars, and is equal to the estimated annual oil production from the Arctic National Wildlife Refuge.

Summary

Ductwork is one of the more critical elements of building high performance homes that is also the most overlooked. Many times we find that the HVAC unit is grossly oversized to compensate for shoddy duct installations. This has a cascade effect that goes far beyond a simple mechanical equipment installation to issues involving homeowner comfort, indoor air quality, increased operating costs, increased maintenance costs and durability.

The modern codes (and beyond code programs) require that ducts be sized according to Manual D; that flex duct is installed in straight runs, no sags greater than 1/2" per foot of run, no pinches or compression, gradual turns with a radius greater than the duct diameter; duct sealing with UL-181 listed sealants or mastics; designed return air paths; R-8 insulation on ducts outside conditioned space; and take-offs be spaced properly.

Just as critical as the duct layout and quality installation is the proper sizing of the ductwork. Here are two tables compiled from research from Building Science Corporation and Southface Energy Institute, respectively, that indicate the relationship between duct size and flow.

HVAC contractors should also use ACCA Manual J, 8th edition, for the load calculation, Manual S for selecting the equipment, and Manuals RS and T for general principles in designing the layout for optimum comfort.

CFM of Flex Duct at Given Velocities								
		Velocity (feet per minute)						
Diameter (inches)	**Area (inches^2)**	**250**	**300**	**350**	**400**	**450**	**500**	**550**
4	12.6	22	26 31	35	39	44		48
5	19.6	34	41 48	55	61	68		75
6	28.3	49	59 69	79	88	98		108
7	38.5	67	80	94	107 120	134		147
8	50.3	87	105 122	140	157	175		192
9	63.6	110	133 155	177	199	221		243
10	78.5	136	164 191	218	245	273		300
12	113.1	196	236 275	314	353	393		432
14	153.9	267	321 374	428	481	535		588
16	201.1	349	419 489	559	628	698		768
18	254.5	442	530 619	707	795	884		972
20	314.2	545	654 764	873	982		1091	1200
22	380.1	660	792	924	1056 1118	8 1132	0	1452
24	452.4	785	942	1100 1125	7 1141	4 1157	1	1728
26	530.9	922	1106 1129	0 1147	5 1165	9 1184	4	2028
28	615.8	1069	1283 1149	7 1171	0 1192	4 2213	8	2352
30	706.9	1227	1473 1171	8 1196	3 2220	9 2245	4	2700

Adapted from "Design Process For: Sizing Cooling and Heating System Capacity, Room Air Flows, Trunk and Runout Ducts, and Transfer Air Ducts"

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Duct Sizing Recommendation Chart		
Based on ACCA Duct Slide Rule		
.09 friction rate (IWC/100 ft EL)		
Duct Diameter	Flex Duct	Metal Duct
4"	0-25 CFM	0-36 CFM
5"	26-50 CFM	37-65 CFM
6"	51-75 CFM	66-110 CFM
7"	75-116 CFM	111-160 CFM
8"	116-160 CFM	161-230 CFM
9"	161-240 CFM	231-310 CFM
10"	241-290 CFM	311-410 CFM
12"	291-460 CFM	411-660 CFM
14"	461-700 CFM	661-1000 CFM

Chart source: unpublished field research performed by Adam Deck & Mark Newey, Southface Energy Institute, www.southface.org

References

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About the Author

A native of Southern California, Brett is a 4th generation carpenter & builder. Raised in a traditional construction background, he started to apply the principles of building science to the homes he built as the Construction Director for the Habitat for Humanity affiliate in Chattanooga, TN. As a result of those efforts, this affiliate was one of 16 affiliates worldwide that earned an energy efficiency award from Habitat for Humanity International at the 25th anniversary conference in Indianapolis in 2001.

Brett has extensive field experience performing HERS ratings, residential commissioning, energy audits, mold and moisture assessments, building envelope pressure tests, and duct system pressure tests in addition to his experience in construction management and techniques. He has been a licensed contractor in Tennessee and has over 15 years of experience in the residential construction industry, working in both land development and construction. He is now the Vice President and General Manager of IBS Advisors, LLC, specializing in the integration of building science, design and best construction practices.

Brett currently teaches many seminars and workshops on high performance home building, the International Energy Conservation Code, moisture control and homeowner education to groups as varied as the American Institute of Architecture to affordable housing providers. A former program manager at Southface, he was the point person for expanding the EarthCraft House program regionally into Alabama, South Carolina and Tennessee. He is a nationally certified Home Energy Ratings System (HERS) Rater in addition to being a Residential Energy Services Network (RESNET) certified HERS Rater Trainer and Quality Assurance Designee, the highest level of national certification available in the residential energy efficiency field. He also provides building science-based training to builder groups and utility companies, including teaching the Certified HERS Rater Course.

Brett has served on the Advanced Rater Task Force for RESNET, the Affordable Housing Task Force for LEED for Homes and has conducted workshops for the Building America Program (DOE) and State Energy Offices throughout the Southeast.

Brett is married, enjoys classical foil fencing with his wife and four sons and resides in Geronimo, Texas.

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