Duct Design Basics

by Hank Rutkowski

Intelligent duct layout and proper placement of supply and return outlets are key to even, efficient heating and cooling

No single air distribution system is ideally suited for the heating and cooling needs of every house. In each case, design and installation are affected by envelope construction details, climate, cost, building and energy codes, noise levels, and the need for zone control. All of these factors contribute to the location of supply outlets and return openings and to the duct geometry.

Locating Supply Outlets

The comfort afforded by a forced-air heating or cooling system depends, in part, on whether the supply outlets are located at the perimeter, on the ceiling, or on an inside wall.

Perimeter supply outlets blanket portions of the exterior walls with supply air using floor, baseboard, or low sidewall outlets designed to discharge the air straight up the wall. If outlets are sized correctly, the discharge pattern will extend up to the ceiling (never use outlets that blow air into the interior of the room). Traditionally, perimeter systems have been recommended for homes in cold climates, because they provide more comfort at floor level, especially on slabs and exposed floors.

Ceiling supply outlets perform best during cooling mode, so they are commonly used in homes in warm climates. Air discharge should be parallel to the ceiling and, if ceiling outlets are sized correctly, extend to the walls. (Discharging cold air straight down will cause the air to stratify along the floor.) During the heating season, a slab or exposed floor can become cold in rooms with ceiling outlets.

High inside-wall supply outlets should also discharge air parallel to the ceiling toward the outside wall (see Figure 1). Correctly sized outlets will extend the discharge pattern to the outside wall, and high-velocity air will not drop into the occupied zone (a common problem associated with high sidewall outlets during cooling season). Like ceiling systems, sidewall outlets perform best in cooling mode, so they are more suitable for homes located in warm climates. Slabs and exposed floors may feel cold during the heating season.

Return Duct Systems

In a "high-return system," all return openings are installed in ceilings or high on the walls; in a "low-return system," return openings are installed in the floor or low on a sidewall. Neither system, however, has much effect on the air motion within the room, so which one you use depends on the location of the hvac equipment and duct runs. Thus, high-return systems are typically used when air-handling equipment is located above the ceiling; low returns, for equipment below the floor.

Return path. The return-air system must establish a low-resistance path between every room and the return side of the blower cabinet. If these paths are not established, the airflow through some or all of the supply air outlets will be affected. For example, if a closed door isolates one or more rooms from a central return-air opening, the isolated rooms will be pressurized and the flow of supply air into these rooms will be inadequate. In this case, the doors act like balancing dampers, shutting off the flow of air to the isolated rooms. The reduction of airflow to the isolated rooms also causes an increase in airflow to the remaining rooms, throwing the system out of balance: Some rooms get too little air and other rooms get too much air. This could cause increased infiltration through the building envelope into rooms under negative pressure, resulting in decreased comfort due to drafts and adverse health effects from the introduction of pollutants, such as spores and fumes, into the conditioned space.

Return in every room. The ultimate return-air system consists of a ducted return for every room that could be isolated from the rest of the house. This strategy guarantees adequate airflow, even if the interior doors are closed, and provides more privacy because there is no need to install transfer grilles or to undercut the doors. In addition, this type of return system is quiet, and the return grilles can be relatively small.

Ducting a return to every room, however, is geometrically complex, requires more space, increases the equivalent length of the return path and the number of potential leakage points, and is relatively expensive.

Central return. A single central return is the least expensive system to install. (In multilevel homes, a central return should be installed on each level.) Usually the return duct is short, occupying a minimum amount of space, and the return-side pressure drop is small. Each isolated room, however, must be equipped with an air transfer opening — either a grille or door undercut. Also, equipment noise may reach the living space, and the large return-air grille may be unattractive.

Multiple returns. A return-air system that has multiple air openings is a good compromise: It combines the performance benefits of individual room returns with the space-cost benefits of a single central return. A return-air opening is provided for every major room, and transfer grilles or door undercuts are used for secondary rooms.

Supply-Duct Geometry

Supply-air duct runs can be arranged in three basic configurations: trunk and branch, radial, and perimeter loop. (Return ducts also follow this geometry, although trunk-and-branch systems are more common than radial and perimeter-loop return duct systems.) Each of these configurations has different spatial requirements, performance characteristics, and installation costs. Sometimes two or more types are required for a single structure.

Trunk-and-branch systems are versatile because they can be installed in a basement, a crawlspace, an attic, or above a dropped ceiling. For this reason, this duct geometry is commonly found in single-story, two-story, and split-level homes. The two most common types of trunk-and-branch systems are often called “extended plenum” and “reducing plenum” (Figure 2, next page).

Extended plenum systems consist of a relatively large trunk duct with a number of small branch ducts to deliver supply air to each room. An extended plenum is easy to fabricate and is inexpensive to install: The trunk is just a straight section of rectangular or round duct, and simple fittings and boots are used to connect the branch ducts and the supply air outlets.

Ideally, the blower equipment should be centrally located with respect to the floor plan of the house. In this case, two plenums extend across the length of the house, producing a reasonably balanced system because there are no large differences between the lengths of the various duct runs.

Quite often, however, the blower equipment cannot be centrally located, and one long plenum must extend across the length of the house. This geometry produces large differences in the lengths of the various duct runs, and the branch ducts nearest to the blower receive less air.

Reducing plenums improve the performance of long extended plenums. The trunk reduction tends to equalize the losses from branch duct takeoff fittings, making it easier to move air into the branches nearest to the blower.

Historically, duct design manuals have recommended that the plenum

High Inside-Wall Outlets

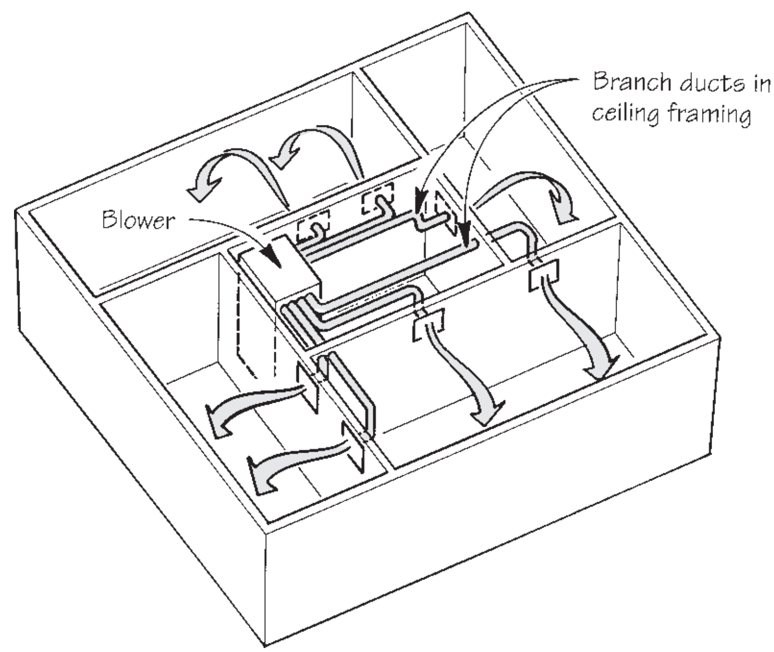

Figure 1. *Supply outlets located high on an inside wall should be sized so that air discharged parallel to the ceiling reaches the outside wall. Sidewall outlets work best during the cooling mode in warm climates, but occupants will be uncomfortable if high-velocity air drops prematurely from the ceiling.*

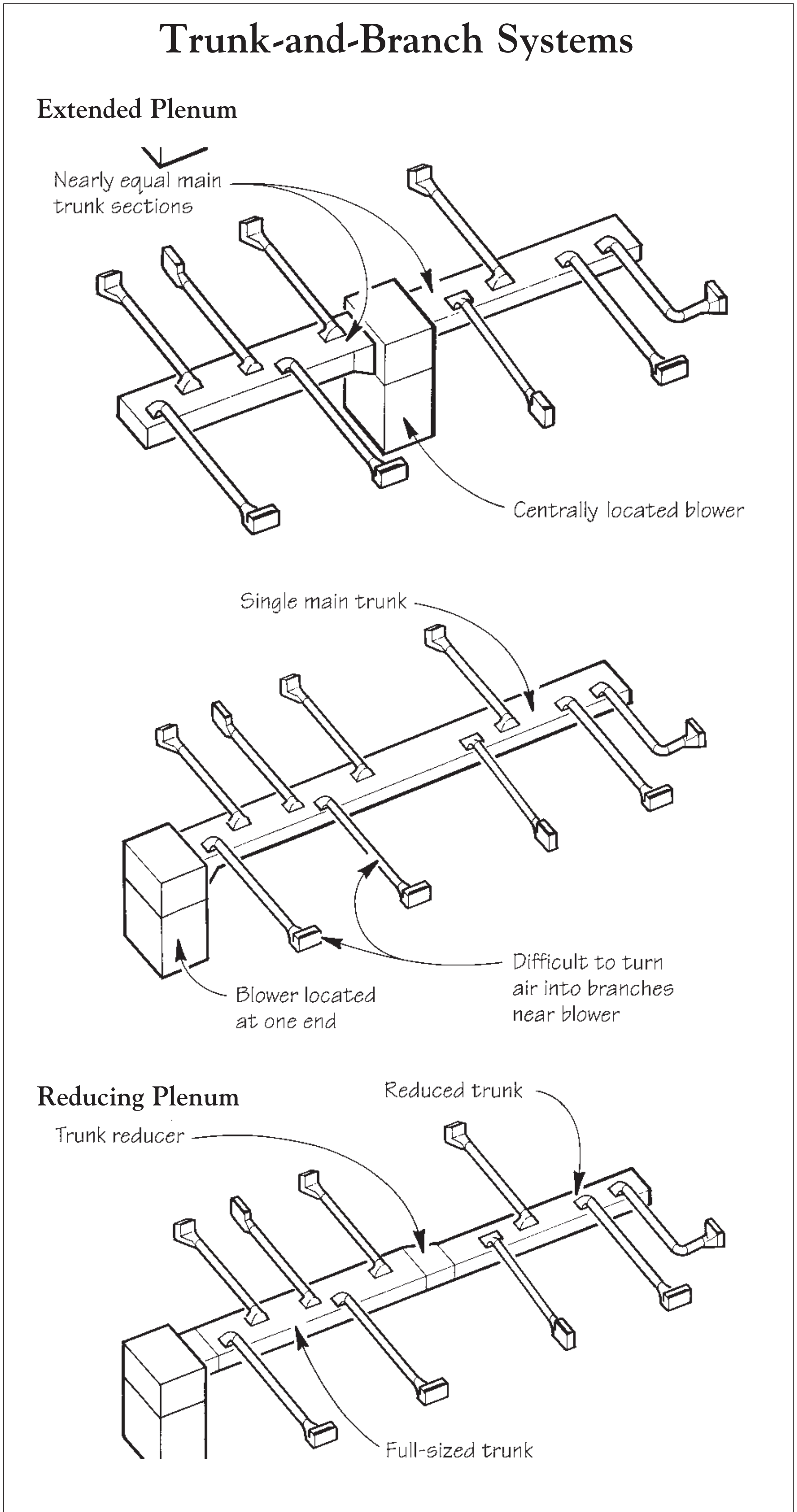

Figure 2. *An efficient extended plenum consists of a centrally located blower that delivers air to a large trunk duct on either side (top). The blower may be located nearer to one end (middle), but duct losses from many small branch ducts degrade performance. One solution is a reducing plenum (bottom), which equalizes branch-duct losses.*

reduction be located at a point about 24 feet downstream from the blower. This location is arbitrary, however, because it is based on the assumption that a substantial number of branch ducts will be installed in the first 24 feet of the trunk, and that a comparable number of branch ducts will be installed downstream of the reduction. Since this may not always be true, it is better to use the velocity of the air in the plenum as the criterion for establishing the location of the trunk reducer. Reduce the plenum at the point at which air velocity drops to about 50% of the velocity in the section nearest the blower. For example, when branch ducts cause the air velocity in the trunk to drop from 900 fpm (feet per minute) to 450 fpm, the plenum should be reduced.

Variations. Depending on the floor plan of the house, one of several variations of trunk-and-branch systems may be appropriate (Figure 3). A reducing trunk system is similar to a reducing plenum duct, except that the cross-sectional area of the reducing trunk is decreased after every branch takeoff. This type of trunk-duct geometry is commonly used in commercial work, where the "equal friction" method is used to size the duct runs. Less sheet metal is required to fabricate a reducing trunk duct, but more labor is required to build each section of duct at a different size. For small systems, it is usually less expensive to use either an extended or a reducing plenum.

Some trunk-and-branch systems have a primary trunk and two or more secondary trunks, a duct geometry suitable for a home that spreads out in two or more directions. The diverting tee at the end of the main trunk run performs the same function as the reducer fitting used in the reducing plenum system. The secondary trunks also have a smaller cross-sectional area than the main trunk duct.

Another option is a flexible duct system, which is easy to fabricate and inexpensive to install. This system consists of large-diameter flexible trunk ducts, triangular or rectangular junction boxes (usually fabricated from duct board), and smaller-diameter flexible branch ducts. Flexible ducts are normally used for attic installations, but basement and crawlspace installations are possible. Regardless of where the duct system is located, flexible duct runs should be cut to length and installed as straight as possible: Kinked turns, coils, and loops will create unnecessary pressure losses and reduced airflow.

Radial and Loop Systems

In a radial duct system, branch ducts are arranged in a radial pattern around a supply plenum (Figure 4, next page). These systems are easy to install and inexpensive, because there is no trunk duct. Traditionally, the blower equipment is centrally located with respect to the supply air outlets, but symmetry is not mandatory: If duct runs are sized correctly, any amount of offset is acceptable.

The radial geometry is often used for duct systems embedded in a concrete slab, because a low perimeter supply system provides superior comfort during the heating season. But radial duct systems are also installed in attics and crawlspaces and in basements if there is enough headroom. Use rigid ducts if runs are embedded in a slab; flexible materials, which are easier to work with and less costly to install, are commonly used for attic duct runs. Radial ducts can also be used above a dropped ceiling to feed air to high sidewall outlets located on interior walls.

Radial systems are usually designed to serve one level, but two or more radial systems can be used for multiple levels.

Perimeter-loop systems. In houses built on ground slabs in a cold climate, a perimeter-loop system is particularly effective at maintaining comfort at the floor level during the heating season. In this respect, the loop geometry is somewhat better than a radial arrangement, but the advantages are offset by the increased difficulty of designing and the higher cost of installing a loop.

Cavity Plenums

It is possible to reduce the installed cost of the duct system by using a crawlspace or a hall ceiling cavity as a supply-air or return-air plenum. The Air Conditioning Contractors of America does not recommend this practice, but plenum systems can provide acceptable performance and comfort if certain installation requirements are satisfied.

A crawlspace supply plenum uses a perimeter air distribution system, but without any duct connections between the supply-air openings in the hvac

Trunk-and-Branch Variations

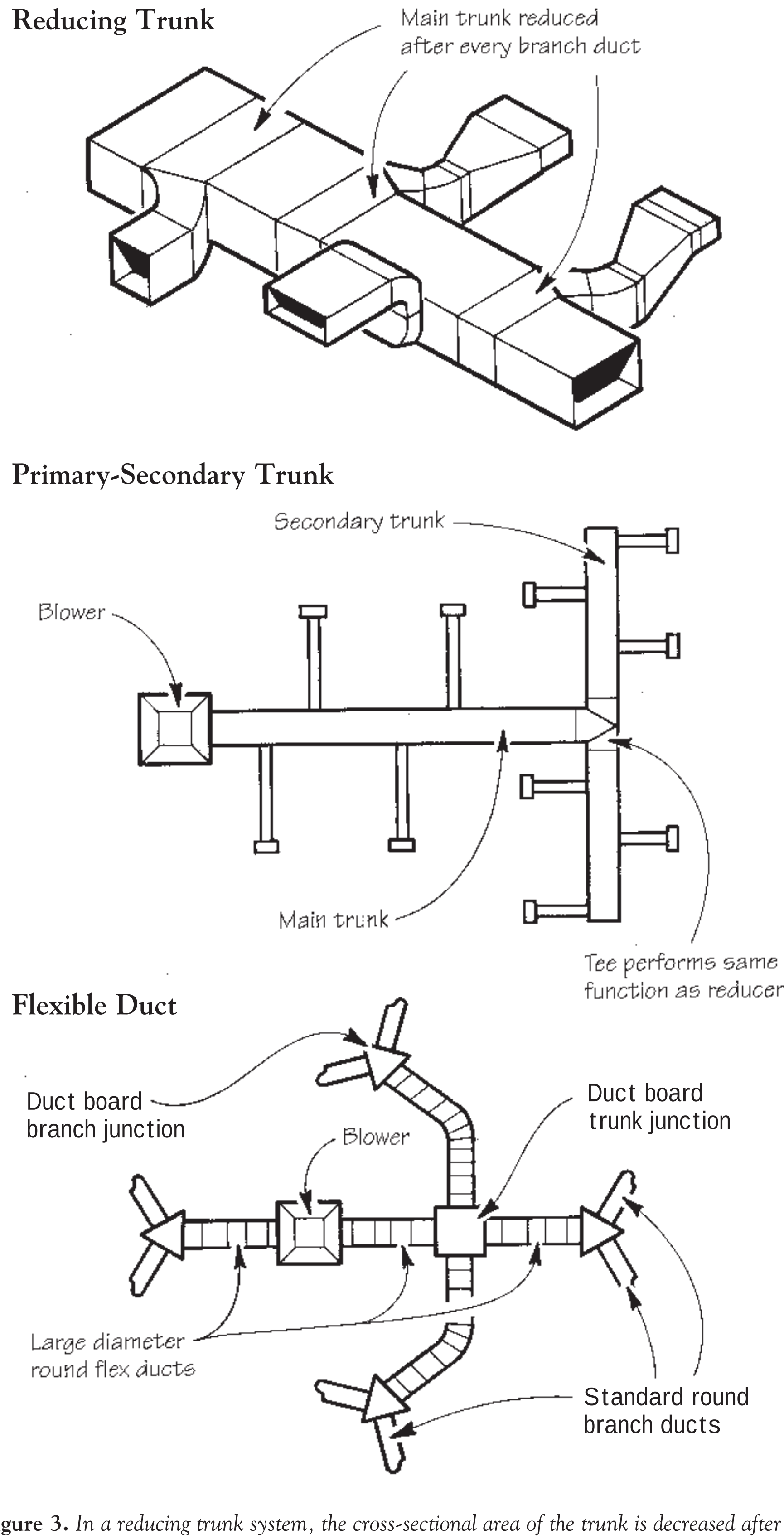

Figure 3. *In a reducing trunk system, the cross-sectional area of the trunk is decreased after every branch takeoff (top). In a primary/secondary system (middle), the diverting "tee" at the end of the main trunk run performs the same function as a trunk reducer fitting. A flexible duct system (bottom) consists of large-diameter flexible trunk ducts and smaller-diameter flexible branch ducts, connected by triangular or rectangular junction boxes.*

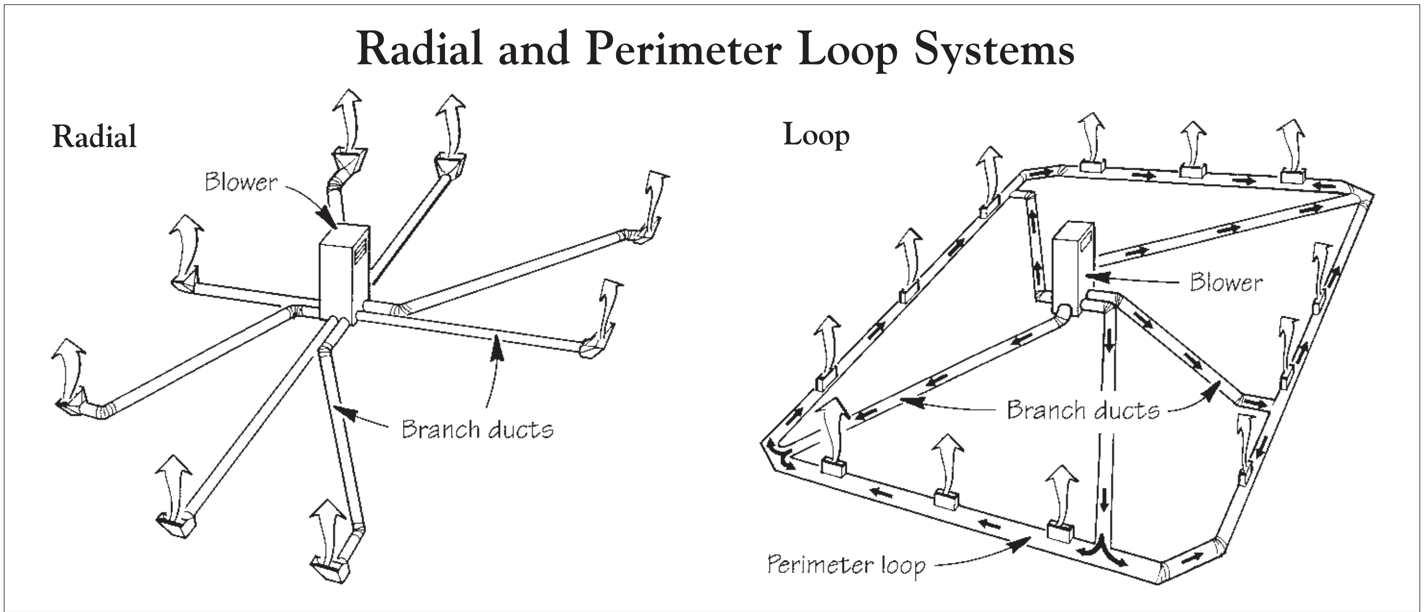

Figure 4. *With correctly sized branch ducts, the blower equipment in a radial duct system need not be centrally located (left). A perimeter loop system (right) performs better than a radial system in cold climates, but is much more expensive to install.*

equipment cabinet and the supply-air terminals (Figure 5). Similarly, ceiling cavity supply plenums are used in conjunction with a high inside-wall air distribution system (although it is also possible to run ducts from the plenum to ceiling outlets).

These systems will work only with high plenum pressure: 0.15 inches water gauge for ceiling cavity plenums; 0.15 to 0.20 inches water gauge for crawlspace plenums. (When used for return air, a crawlspace or ceiling plenum will maintain negative pressure.) This is the amount of pressure required to move the air through the short duct runs that feed air to the supply-air diffusers. These feeder ducts are required for balancing: They ensure that air will approach the outlet uniformly and that air will leave the outlet with enough velocity to be thrown up to the ceiling.

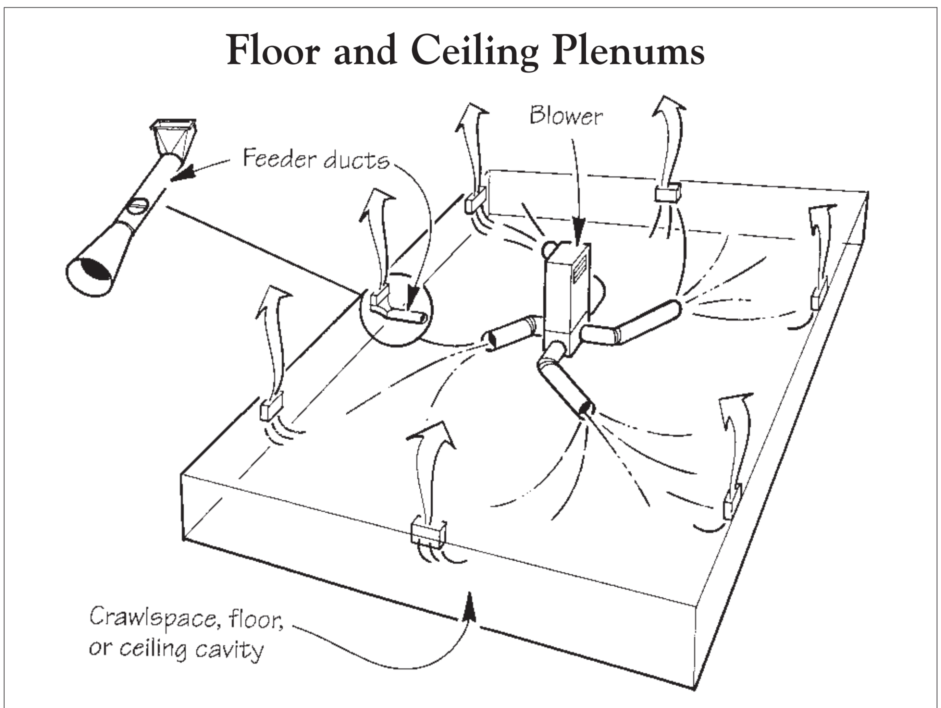

Figure 5. *In a crawlspace supply plenum, there are no duct connections between the hvac equipment cabinet and the supply-air terminals. Instead, short feeder ducts are used to boost supply outlet performance. Precautions must be taken, though, to insulate the cavity and to seal against moisture.*

Plenum designs have several problems, however, including air leakage, heat loss, moisture and odor absorption, and air outlet performance. For a plenum system to work, follow these guidelines:

- Seal the entire crawlspace or ceiling cavity so it can be pressurized (or depressurized, in the case of a return-air plenum).
- Insulate the walls of a crawlspace plenum and the top of a ceiling plenum. During the winter, the temperature in the crawlspace or ceiling cavity will be about 30°F higher than room temperature. Insulate all surfaces of a return-air plenum.
- Cover the crawlspace floor and walls with a vapor retarder. This will ensure that supply air does not absorb moisture, mildew, and odors from the soil or from moisture leaking or migrating through the walls.
- Connect each supply outlet with a short “feeder duct” that includes a converging transition and a stub duct with a hand damper and an aerodynamic boot.
- Locate the furnace outside the crawlspace. Burner performance could be adversely affected by the positive pressure in a supply plenum or by negative pressure in a return plenum. ■

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