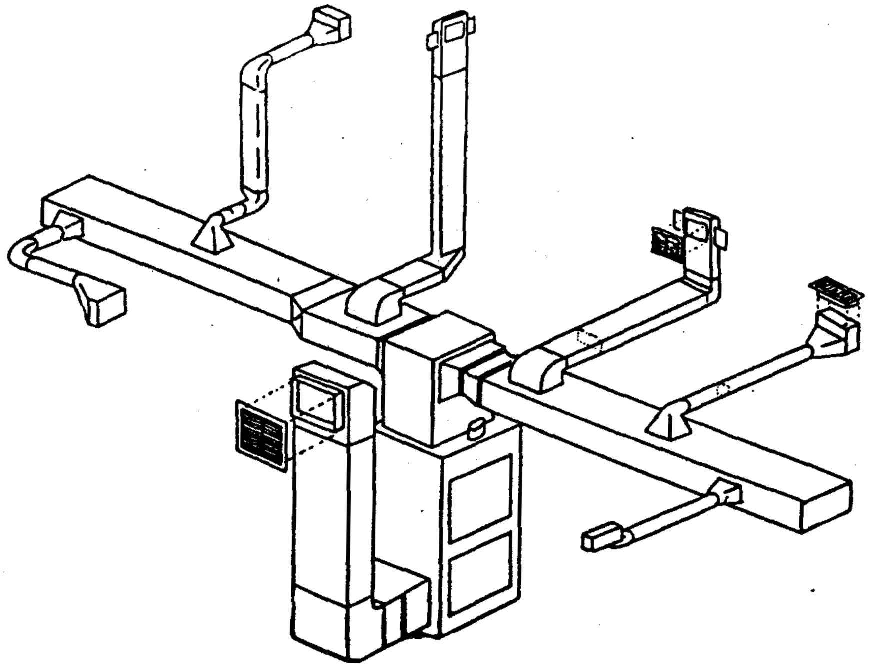

Residential Duct Systems

Selection and Design of Ducted HVAC Systems

Ronald K. Yingling, Donald F. Luebs, and Ralph J. Johnson

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Introduction

Sharply rising prices for energy, increasing buyer conern about heating and cooling costs and the fact that the great majority of new homes are now being built with some type of ducted-air distribution system makes this Residential Duct Systems guide particularly timely.

The purpose of this guide is to provide home builders and their associates with sufficient information to enable them to evaluate Heating, Ventilating and Air Conditioning (HVAC) system designs and to deal more effectively with HVAC contractors and the trade. Tables, charts, rules-of-thumb, examples of duct layouts, and equipment and product illustrations are used extensively. The text is presented in trade language to make it more useful. Ductwork and alternative duct systems are emphasized, but information is also provided on equipment selection, installation and operating costs and design of the total HVAC system. Publications, especially useful to builders, on thermal protection, designing and building energy conserving homes, load calculation, and detailed design of duct systems are referenced.

This guide is not intended as a design manual for use by professional engineers or HVAC contractors. Sufficient information is presented, however, to enable builders to do a preliminary design for the system. Its primary usefulness will be in evaluating various proposed designs and making alternative selections and modifications to provide a cost effective system for comfort conditioning in today's energy efficient homes.

Much of the available material on ducted HVAC systems provides design, installation and performance information based on the types of homes built several decades ago, but which are not being built today. The NAHB Research Foundation, Inc., has extensive information on housing characteristics related to thermal performance that shows that home builders have substantially increased the level of thermal protection for new homes over the years. The typical new home today is much more energy efficient than it was many years ago when most of the HVAC design data was developed. Excellent comfort conditions in such energy saving homes can often be provided with a more simplified system that will cost less to install and operate.

A special section on ducts for homes having high levels of thermal protection is included to provide information on simplified and less costly systems.

Chapter 1 discusses the nuts and bolts of ductwork and fittings, and introduces terminology unique to the duckwork trade. Alternate materials for ductwork are presented, including relative costs as well as advantages and disadvantages. Various duct fittings are illustrated with accompanying descriptions of their application and relationship to the total system. These illustrations include components used for rectangular trunk duct, wall stack, and round and oval ducts. The functions of registers, grilles, and diffusers are described with examples of the different types frequently installed in residences.

Chapter 2 describes types of air distribution systems available for residences. In addition to general guidelines and limitations affecting their design, characteristics of each type of system are discussed including relative ease of fabrication and installation, performance, adaptability to different constructions, and concealment characteristics as well as relative cost. Systems presented include extended plenum trunk and branch systems, radial distribution systems, reducing trunk systems, and a special section on gravity systems for coal or wood furnaces requiring no blower or other mechanical assist.

Examples of typical installations for each of these systems are illustrated for one-story, two-story, split-level, and bilevel homes with slab, crawl space and basement constructions. Accompanying each example are pertinent comments, installation tips and operating characteristics. This chapter also has a section on return-air systems, including a comparison guide on the advantages and disadvantages of central and individual returns, the use of structural spaces for return-air passages in place of ductwork, and design tips for improving sound attenuation.

The final chapter covers heating and cooling loads, alternate HVAC equipment, and final system design and sizing. Numerous rules-of-thumb and short-cut estimating techniques are included. These can be useful in evaluating alternate systems, assessing HVAC contractors' proposals, and even developing preliminary designs. Brief discussions on heating and cooling loads and analyses of mechanical equipment, a costly and critical element of all HVAC systems, are included. Different equipment types and configurations are illustrated with descriptions of application, available output ranges, relative costs, and unique features. Simplified diagrams and descriptions of the refrigeration cycle and heat pump operation are also included. Equipment efficiencies and operating costs are summarized in Table 2 for typical HVAC equipment and fuels. Table 3 summarizes the characteristics of the different equipment types. The various aspects of final system design are outlined including quick reference tables for approximating equipment airflow and duct sizing, a description of air patterns generated by supply outlets and returns, guidelines for register and grille locations, and tips on duct sizing.

Information pertinent to HVAC designs for homes with high levels of thermal protection is presented including reduced heating and cooling loads and associated lower capacity mechanical equipment and simplified distribution systems, which can reduce the cost of HVAC systems.

1. Components of an Air Distribution System

The air distribution system consists of supply and return ductwork, plus the registers and grilles. Supply ducts convey air to the spaces that are to be conditioned. Registers are designed and located to direct the air pattern according to conditioning requirements. They generally have adjustable dampers that can be used to regulate the volume of air being delivered. Return-air ducts allow conditioned air to circulate back to the equipment.

Alternate Duct Materials

Although sheet metal is the predominant material used to fabricate duct systems, other materials used include several forms of fiberglass and certain materials used in concrete slabs. Selection of materials depends on cost, availability, and special system requirements.

Sheet Metal Ductwork

The most common duct material is galvanized sheet steel. It has several advantages:

- Relatively inexpensive
- Lightweight and durable
- Widely available in many sizes and gauges
- Easily fabricated into both rectangular and round shapes
- Readily formed into special transitional fittings
- Smooth surface offering low resistance to air flow.

Sheet metal is used as a standard in fitting and ductwork sizing guides. When installing alternate materials, allowance sometimes must be made for higher internal friction or increased friction loss because of less efficient fittings.

Metal ductwork is adaptable to most HVAC systems in residential construction, including those within habitable spaces, basements, crawl spaces and attics. Metal ducts can also be embedded in concrete slabs, but other materials may be more practical for this use since metal ducts must be asphalt-coated for protection and must be tied down securely to avoid floating when concrete is poured.

Fiberglass Ductwork

Where duct insulation is required, as in attic systems, fiberglass ducts are sometimes preferred. Although generally more costly than standard metal ductwork, fiberglass ducts can provide cost savings in certain installations. Among it features are—

- May be cost effective when an insulated duct system is specified
- Particularly adaptable to overhead or attic systems in warmer climates
- Vapor barrier included as an intergral part of the duct material
- Provides excellent sound attenuation
- Requires less skill and fewer special tools than metal
- Available in rigid panels (duct board), performed rigid round duct, and flexible round duct.

Fiberglass Duct Board

Rigid fiberglass duct board is used primarily to form rectangular trunk duct and fittings. The most common stock size is 1-inch thick, 4 by 10 foot panels, although other thicknesses and sizes are available.

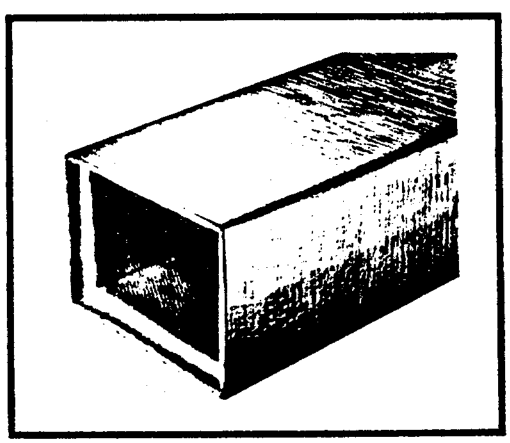


Fig. 1. Rectangular duct of fiberglass duct board

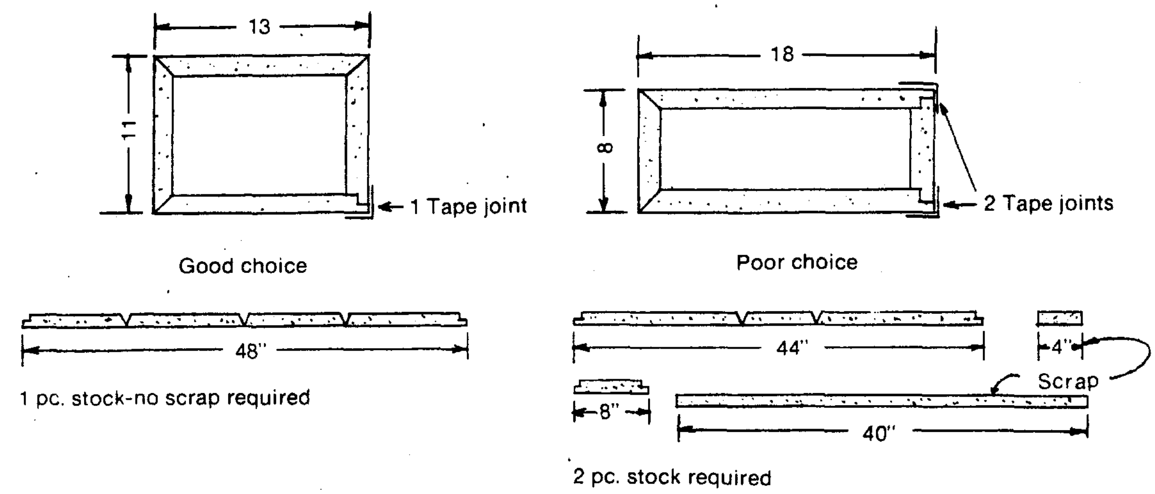


Fig. 2. Fiberglass duct fabrication

The necessary cuts, laps and grooves can be made with a few simple hand tools. Special production shop equipment is also available. Joints are generally secured by stapling and taping, using a reinforced vapor-barrier tape similar to the outer skin material. Where joints require additional strength, such as at equipment and branch takeoffs, a metal reinforcing collar may be used on the inside of the fiberglass duct.

Careful preplanning is important when fabricating duct from duct board to minimize waste. Unlike sheet metal scrap, which can be made into fastner cleats and small fittings, most scrap duct board is of little value. Here are ways to help eliminate waste—

- Preplan cuts, laps and folds for maximum utilization of board sizes
- Keep designs simple with fewest possible number of trunk-duct size reductions and changes of direction
- Consider use of nonstandard duct sizes for maximum use of material if space limitations are not a constraint, e.g. an 11 by 13 inch duct fabricated from 48 inch wide stock provides the same air flow as an arbitrary 8 by 18 inch duct which would require 52 inches of stock. (See figure 2).

Rigid Round Fiberglass Duct

Rigid round fiberglass duct is factory-formed from materials similar to duct board with a reinforced vapor barrier jacket on the outside. It is available in sizes from 4 inch inside diameter and up, and is typically used for individual branch ducts in extended plenum duct board systems. Cutting and joining techniques are similar to those for duct board. A special metal collar is available for connecting rigid round duct to the fiberglass trunk duct. Standard metal elbows can be used to change direction of air flow, and then be insulated.

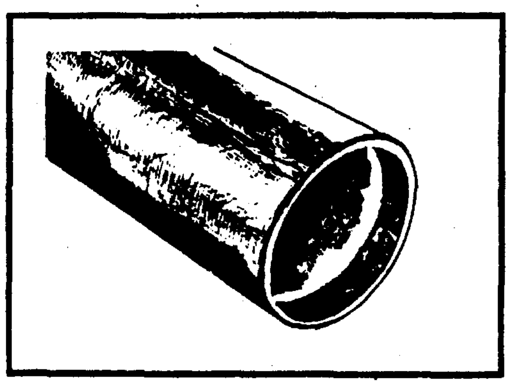


Fig. 3. Rigid round fiberglass duct

Flexible Fiberglass Duct

Many installations can be simplified by using flexible duct instead of rigid round. Although more costly than rigid round, flexible duct requires no fittings between the trunk duct and the outlet, and offers substantial labor reductions. It is particularly adaptable to overhead distribution systems with ceiling outlets. It is constructed from blanket insulation covered with a flexible vapor-barrier jacket on the outside and supported on the inside by a vinyl or fabric-covered helix wire coil. A special metal collar is available for connecting flexible duct to trunk duct. Flexible duct also may be used in conjuction with metal trunk ducts. Flexible duct is avaiàble in 25 foot lengths as well as precut shorter lengths.

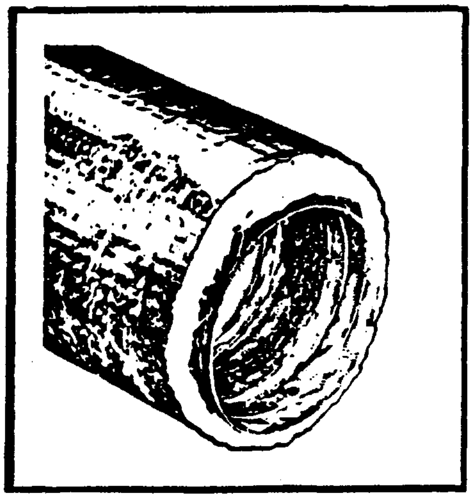


Fig. 4. Flexible fiberglass duct

Ductwork in Concrete Slabs

Cement asbestos pipe, clay tile, and newer types of plastic and plastic coated metal duct are used where ducts are to be embedded in a concrete slab. An advantage of the older heavier materials is that they will not float when the slab is being placed. However, the newer materials offer other advantages:

- Lower initial costs in both labor and materials.
- Materials are designed primarily for use as ducts. Older materials were essentially adapted from plumbing applications.
- Standard metal boots, collars, and plenums more compatible with newer materials, e.g. cutting, fitting, fastening.
- Joints more readily waterproofed to prevent infiltration of ground water.
- Avoids problems associated with potential health hazard of materials containing asbestos.

Duct Liner

Available in ½ and 1 inch thicknesses, duct liner is a specially treated, rigid fiberglass insulation used to line the inside of rectangular metal ductwork. One-inch thick material is used primarily for thermal protection of duckwork that passes through unconditioned spaces. One-half-inch thick material is frequently used as acoustical insulation for reducing air and equipment noises. Duct liner is installed with a special adhesive to the inside of ductwork or to flat stock prior to forming. The adhesive may be supplemented with special metal clips at critical points.

Duct Wrap

Available in 1½ and 2 inch thick 4 foot wide rolls, duct wrap is a fiberglass blanket insulation with a flexible vapor barrier facing. It is used primarily to insulate metal ductwork passing through unconditioned spaces. Duct wrap provides better thermal protection than duct liner but is of little benefit acoustically. It is installed by wrapping the outside of the ductwork and tapping the joints.

Major Ductwork Components

Duct systems generally include a furnance plenum, trunk ducts, branch ducts and various tran-

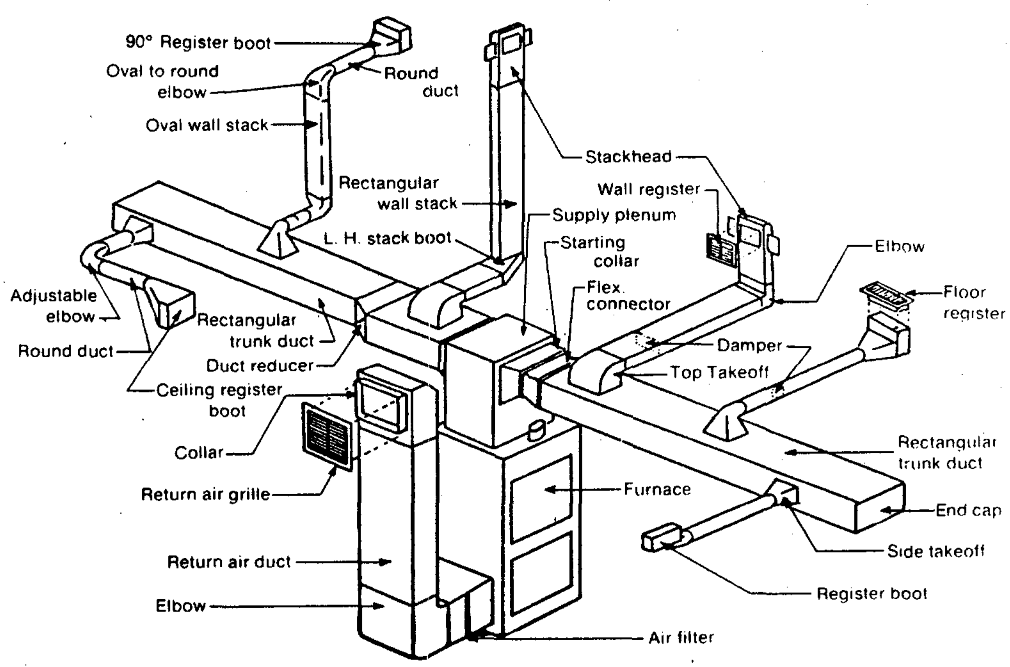


Fig. 5. Composite duct system

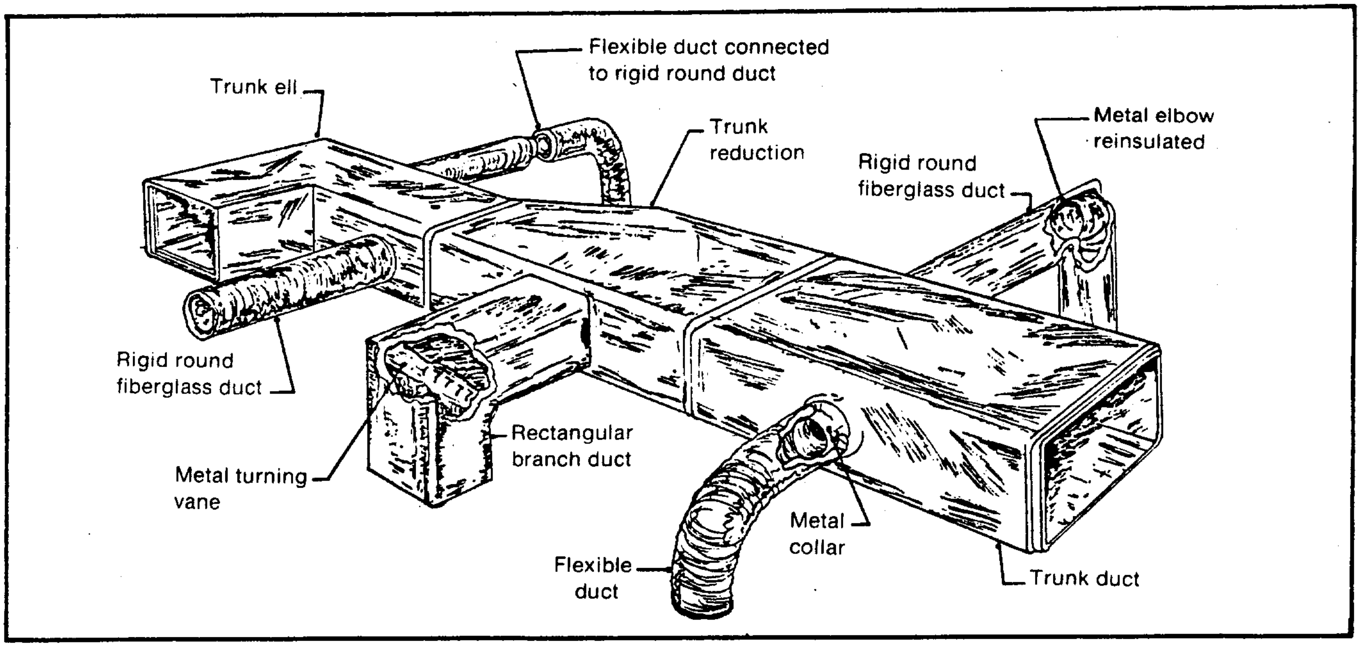


Fig. 6. Fiberglass duct system

sitional fittings. Fig. 5 shows a composite sheet metal duct system incorporating a variety of fittings used in residential work. Although both rectangular and round branch ducts are included, these types normally would not be mixed in the same installation.

Fig. 6 illustrates a composite fiberglass duct system, indicating how various components are used in a typical installation.

Where changes in direction or reductions occur in ductwork, a transition fitting is desirable to minimize air friction and turbulence within the duct system. Individual components of the duct system are discussed in the following sections including plenums, trunk ducts and fittings, and round, oval, and rectangular branch ducts and fittings.

Plenum

This fitting is a collector box, to which the major trunk ducts are connected. It is attached directly to the equipment. A plenum is used on the supply side of most systems, and in certain instances on the return side. It must be custom fabricated to fit the opening size of the equipment and to meet other job requirements. It may be insulated or not, as needed. When air conditioning is added, the evaporator coil usually is housed in the plenum.

Trunk Ducts and Fittings

Trunk ducts are the main supply (or return) ducts which connect directly to the plenum and from which branch ducts extend to individual outlets. Trunk ducts and fittings are normally rectangular to provide for—

- ease of fabrication, handling and installation
- concealment within structural spaces
- less cumbersome, neater looking installation.

Starting Collar

This fitting is attached to a rectangular hole cut into the side of the plenum and provides a transitional reduction in the size of trunk duct being

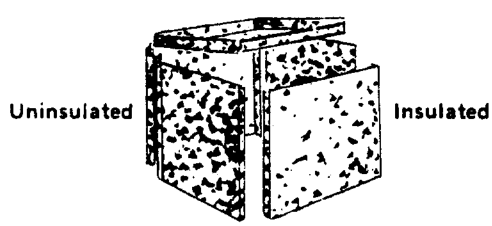


Fig. 7. Plenum

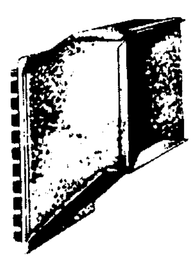


Fig. 8. Starting collar

installed. It is sometimes omitted to reduce cost, with the trunk duct connecting directly into the plenum.

Flexible Connector

This fitting consists of a canvas material bonded to a metal fitting at each end. An optional item, it is installed between the starting collar and trunk duct to isolate the duct system from mechanical vibration and equipment noise. It can also provide some installation tolerance where the two ends are not in exact alignment.

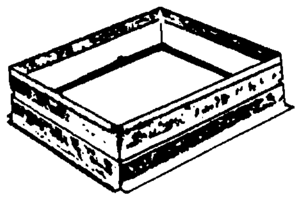


Fig. 9. Flexible connector

Damper

A damper, another optional item, may be installed in each trunk duct connected to the plenum to permit balancing of major house zones.

Trunk dampers are used to—

- Allow for corrective balancing when trunk ducts are not ideally sized
- Permit balancing of standardized duct systems in tract homes where house orientation or exposure affect heating or cooling requirements
- Provide means of adjusting air volumes when changing between heating and cooling seasons, especially in multilevel homes.

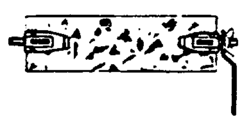


Fig. 10. Damper

Trunk Duct

Trunk duct is the major component of most systems. Although available in a wide range of sizes, most residential trunk duct is fabricated in sections 8 inches high and 8 inches to 32 inches wide in increments of 2 inches. The length of each section is normally 4, 5, or 8 feet depending on the fabricator's stock metal sizes. Trunk duct is often fabricated in two L-shaped halves to simplify handling, with final assembly being made in the field. Ducts 12 inches and wider should have a cross break, i.e an X crease on each face, which adds rigidity and eliminates "oil canning" noises when the blower starts and stops.

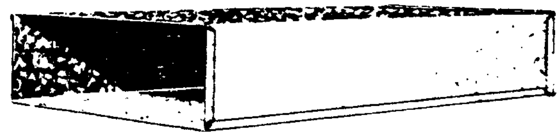


Fig. 11. Trunk duct

Elbows

Elbows and angles are used in the trunk duct for vertical or horizontal direction changes.

Horizontal elbows are installed to change direction within a space such as a basement or an attic.

Vertical elbows are installed where trunk ducts change elevation, as in a split-level home, or turn upward, as in a central return. Elbows in trunk ducts should be constructed with a radius throat (see illustration) rather than a square throat to minimize friction and turbulance and to provide an even flow of air.

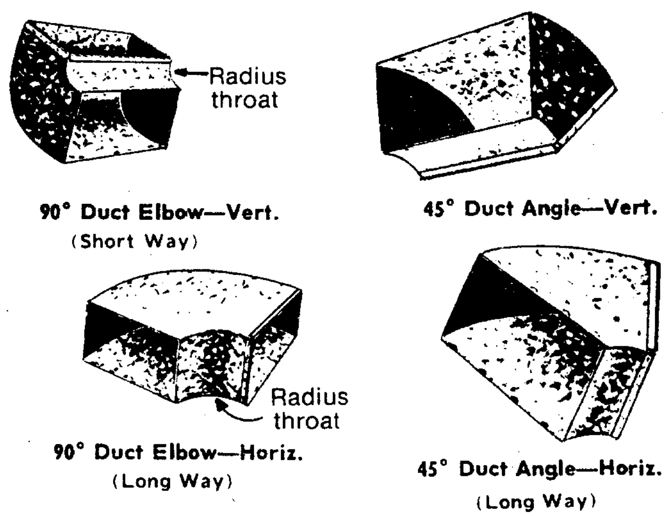


Fig. 12. Elbows and angles

Reducers

Reducers allow for a smooth transition from one trunk duct size to a smaller size. They are fabricated

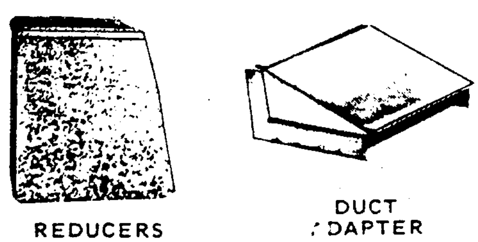


Fig. 13. Reducers and adapters

for a specific duct size at each end. Reducing adapters are more universal and may be used to reduce any duct width by a specified amount, typically 4 inches, without requiring a special fitting.

End Cap

End caps are used at termination of duct runs.

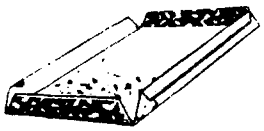


Fig. 14. End cap

Round Branch Ducts and Fittings

Branch ducts are the smaller, individual ducts that run from the main trunk duct to individual outlets. The use of round branch ducts has become increasingly popular because of several advantages—

- Less costly than rectangular duct
- Good air flow characteristics
- Fewer types of fittings required
- More readily available

Takeoffs

These fittings are used to tap into the side or the top of the trunk duct. It forms a transition from a larger rectangular hole in the trunk to the round branch duct.

Top takeoffs are used where branch ducts are to be located within a joist space; side takeoffs are used where this is not possible or not required. A special universal takeoff has an adjustable elbow, allowing it to be used in a variety of applications. The takeoff fitting is sometimes eliminated and the round duct or elbow is connected directly into the trunk duct in highly competitive work. However, this practice can result in air leakage, poor air flow, and marginal performance.

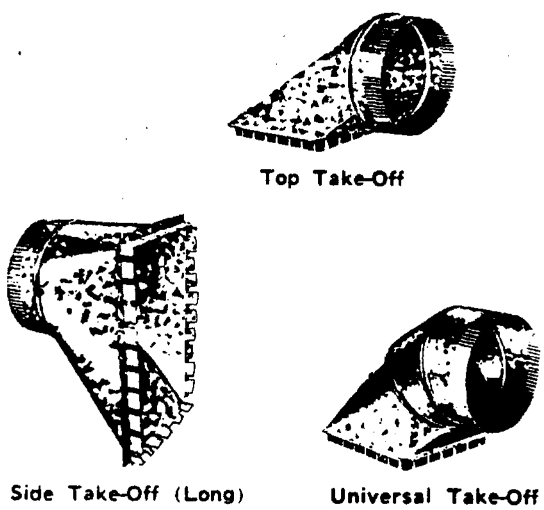


Fig. 15. Takeoffs

Round Duct

Round duct is used primarily for horizontal branch ducts. It is usually shipped nested in bundles, and the longitudinal seam is snapped together in the field. Common lengths are 2,5, and 10 feet.

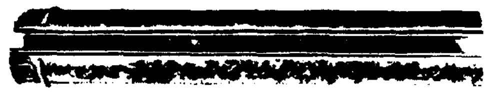


Fig. 16. Round duct

Elbows

Most elbows for round duct systems are adjustable to any angle up to 90 degrees. This type of adjustable elbow can adapt to most requirements. An adjustable 45 degree elbow is also available.

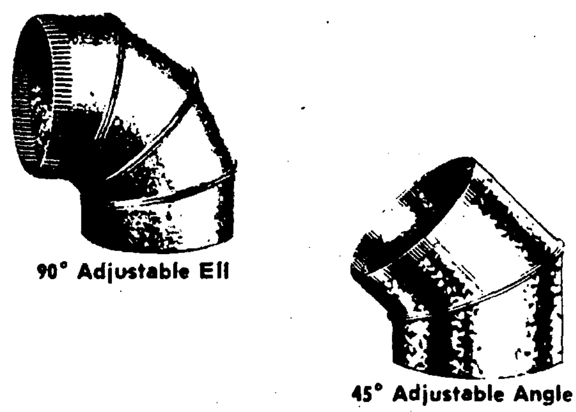


Fig. 17. Adjustable elbows

Round Dampers

Dampers are sometimes used in branch ducts where some balancing of individual outlets may be

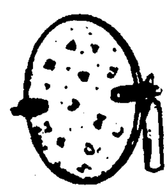


Fig. 18. Damper

required. This is sometimes advisable in systems which utilize a single standard trunk size, such as an extended plenum, which may result in some branches being over-supplied.

Register Boots

Register boots provide a transition from round duct to a rectangular opening for a floor or ceiling register. Some boots incorporate an integral balancing damper. However, where accessible, a balancing damper, located in the branch duct close to the trunk, provides more positive and quieter air volume control.

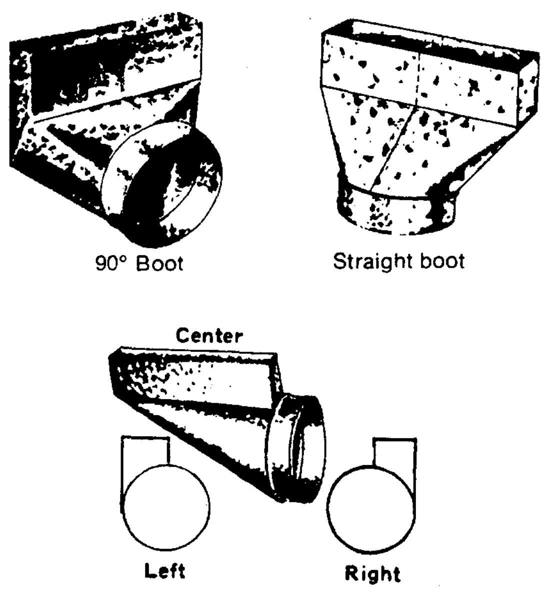


Fig. 19. Register boots

Oval Duct and Fittings

This variation of round duct may be used in place of rectangular wall stack. It has the same circumference as equivalent round duct, but has been flattened sufficiently to allow it to fit within a 2x4 stud space. Standard oval fittings are also available. Advantages include—

- Adaptability—coordinates well with round duct systems
- Low cost—oval duct is approximately one-half the cost of the rectangular equivalent
- Simplicity—a few universal round and oval fittings replace a multitude of special rectangular fittings
- Performance—systems perform comparably with rectangular wall stack and fittings.

Oval Duct

Oval duct is commonly available in 5 and 6 inch round equivalent, and 5 to 10 foot lengths. Typically, oval duct is shipped in nested bundles. Longitudinal seams are snapped together in the field similar to round duct.

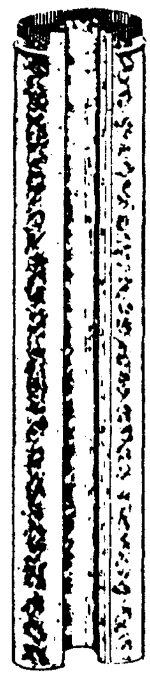


Fig. 20. Oval duct

Oval to Round Boots

These fittings are used to change direction and to make a transition from round to oval shape. In conjuction with adjustable round elbows, it replaces virtually all elbows, angles and transition fittings normally used in a rectangular branch duct system.

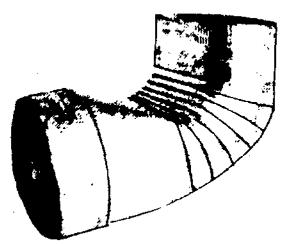


Fig. 21. Oval to round boot

Oval Elbows

Oval elbows are used occasionally to change direction of oval pipe, for example, where partitions are offset.

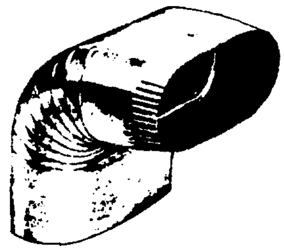


Fig. 22. Oval elbows

Stackheads

Oval stackheads terminate an oval wall stack where an outlet occurs in the wall. Where the stackhead attaches to studs, metal ears for nailing it to studs and attaching register screws.

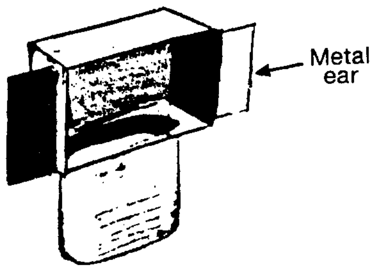


Fig. 23. Oval stackhead

Rectangular Branch Ducts and Fittings

Rectangular branch ducts are fabricated with the same sheet metal equipment and tools as larger trunk ducts. While the less expensive round duct has become popular for use as branch ducts, rectangular duct is still useful in wall stacks in two-story applications and wall-outlet distribution systems. It also is commonly used with several types of exhaust hoods.

Takeoffs

These fittings are used to tap into the trunk duct, and to make a transition from a larger area at the trunk to a smaller duct size. Both top takeoffs and side takeoffs are used.

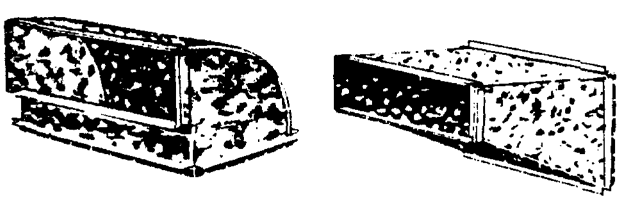


Fig. 24. Top and side takeoffs

Wall Stacks

Wall stacks are small rectangular ducts used as vertical risers within walls. The most common depth is 3¼ inches, which allows the stack to fit within 2x4 wall framing. Widths range from 8 inches to 14 inches; stock lengths range from 2 feet to 8 feet.

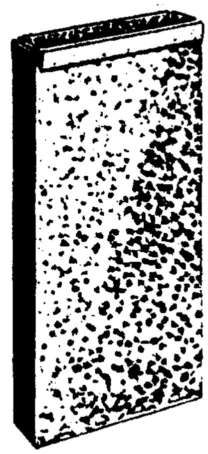


Fig. 25. Wall stack

Branch Elbows and Angles

Elbows and angles are fabricated for both horizontal and vertical applications to change direction of rectangular branch ducts.

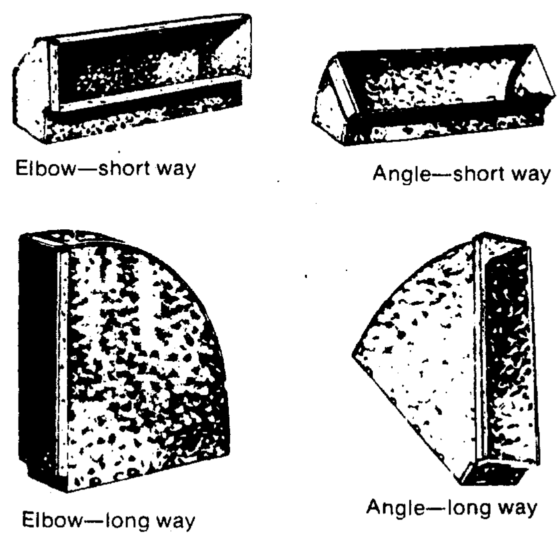


Fig. 26. Branch elbows and angles

Left, Center, and Right Boots

The left, center and right boots are special types of elbows, used to route wall stack into partitions perpendicular to the trunk duct.

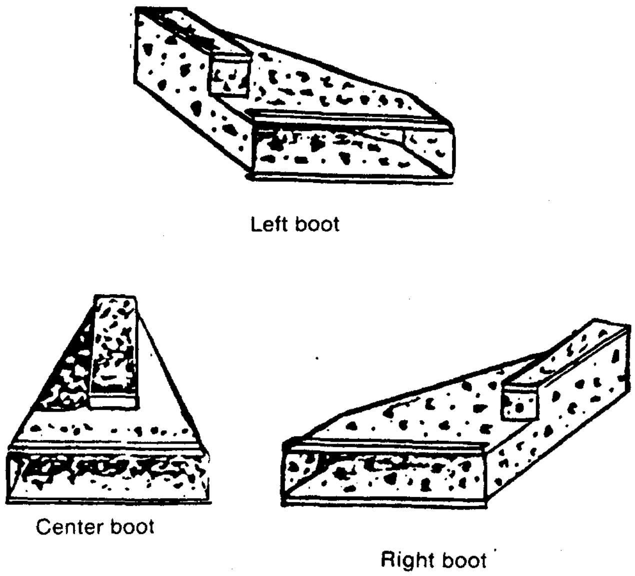


Fig. 27. Left, center, and right boots

Dampers

Dampers may be used in rectangular branch ducts where individual balancing is required. They sometimes are advisable in systems that utilize a single, straight trunk size, such as extended plenums, where some branches may be oversupplied.

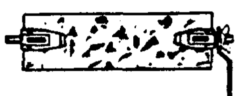


Fig. 28. Damper

Stackheads

Stackheads, available in several configurations, are designed to terminate branch ducts where outlets occur in the wall. Where a stackhead is attached to studs, metal ears provide for nailing and attaching register screws.

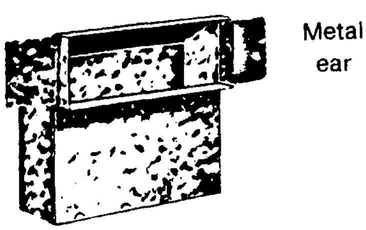


Fig. 29. Rectangular stackhead

Stack Boots

A transitional stack boot permits use of less expensive, more adaptable round ducts for horizontal branch runs, in conjunction with rectangular wall stack.

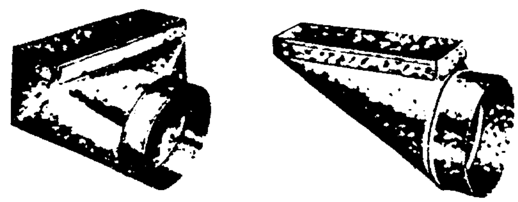


Fig. 30. Stack boots

Outlets and Returns

Grilles, registers and diffusers are louvered metal units used at supply outlets or return inlets. Grilles generally are used to cover return inlets, while registers or diffusers are usually used at supply outlets to control air delivery. A wide choice of grille and register configurations and sizes are available for residential use. Generally, they are constructed from lighter gauge materials and offer fewer adjustment features than more costly commercial units. Painted steel units are normally less costly than those made of aluminum.

Registers

A register is a grille with an operable damper or control valve attached. The air delivery pattern from a register can range from perpendicular to fan-shaped, depending on louver configuration. Two types of dampers are commonly used on registers—

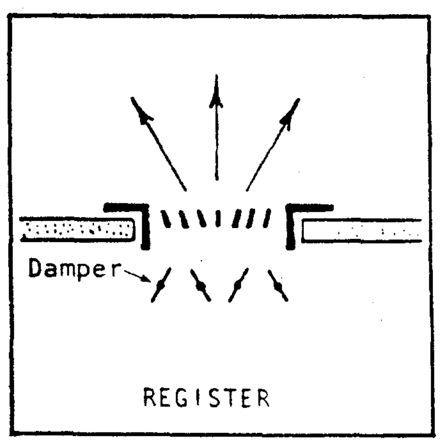
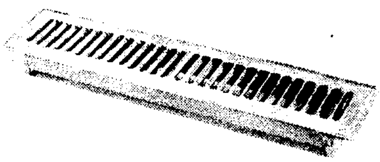


Fig. 31. Register schematic

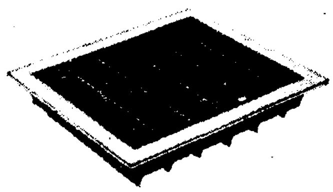
single-blade dampers and opposed blade dampers. The opposed-blade (see Fig. 31) generally provides more uniform air flow. Registers are available in three main variations for floor, baseboard or wall applications.

Floor Registers

Floor registers, used predominantly with perimeter distribution systems, provide good air delivery for both heating and cooling. A larger, heavy duty register is used with gravity systems.



Typical floor register adaptable to most forced air systems



Large heavy duty floor register used with gravity systems

Fig. 32. Floor registers

Baseboard Registers

Baseboard registers are fed from below, similar to floor registers. This allows for air delivery from the wall without cutting into the wall structure. They provide reasonably good air distribution patterns for both heating and cooling.

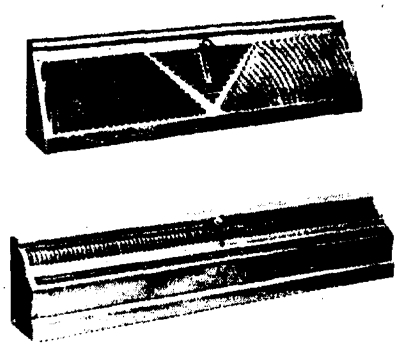
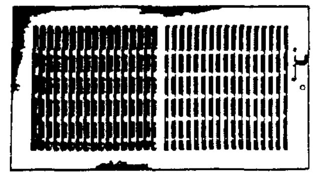


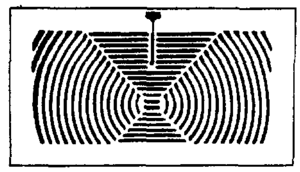
Fig. 33. Baseboard registers

Wall Registers

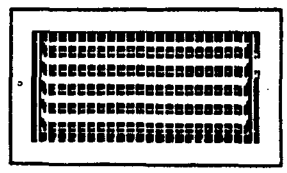
Wall registers can provide good air delivery patterns for heating, but are not always ideal for cooling. Standard wall registers can also be used as ceiling diffusers, but are not as effective generally as units designed for this purpose.



Standard residential wall register with fan shaped air delivery



Multidirectional register usable as a ceiling diffuser



More costly light commercial register with movable louvers which can be individually adjusted

Fig. 34. Wall registers

Diffusers

Diffusers are a special type of register which delivers air parallel to adjacent surfaces. Diffusers

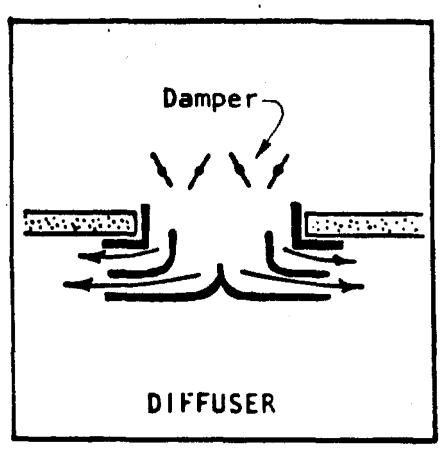


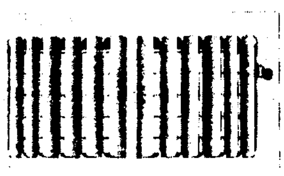
Fig. 35. Diffuser schematic

are commonly used in ceiling applications. Ceiling diffusers provide superior air distribution patterns for cooling. Adjustable models are also suitable for limited heating conditions. The terms register and diffuser are often interchanged

Standard Ceiling Diffusers

Available in both round and rectangular configurations, this type of ceiling diffuser is installed mainly in cooling installations where heating is less critical. The wide spacing of deflection louvers provides maximum free area for airflow, and directs air in a flat blanketing pattern.

Standard



Curved Blade

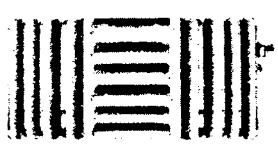


Fig. 36. Ceiling Diffusers

Curved Blade Ceiling Diffuser

With this type of diffuser the curved louvers can be individually adjusted. This style is excellent for cooling with the blades adjusted outward. With the blades adjusted downward, this style also provides satisfactory heating. Models are available with one-, two-, three-, or four-way air throw patterns.

Grilles

A grille is a covering with fixed louvers and no damper mechanism for any outlet or intake. Grilles are normally used at return air intakes for concealing the duct. Grilles also can be used at supply outlets, but provide no means of regulating air flow.

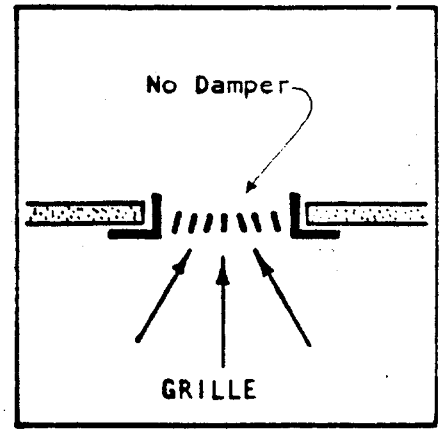
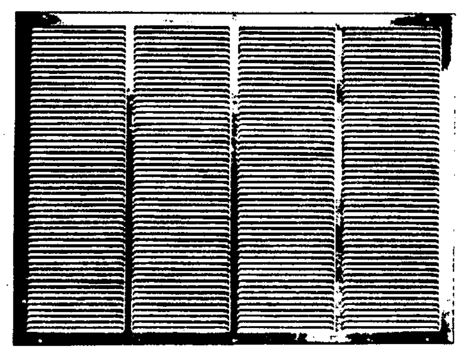


Fig. 37. Grille schematic

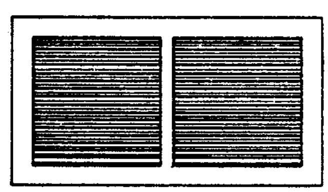
However, in a well-balanced system, they provide a method that is tamper-proof by occupants. Grilles are available in a wide variety of sizes, including typical register sizes.

Wall and Ceiling Grilles

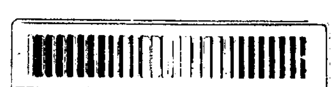
These grilles are adaptable to both wall and ceiling installations for central and individual returns.



Central return grille



Individual room return grille



Toe-space grille

Fig. 38. Wall and ceiling grilles

Floor Grilles

Heavy duty grilles also are available for use as floor returns. This location is generally associated with retrofit installations, and is typically used in conjuction with a panned joist space that serves as the central return air duct.

Fig. 39. Floor grille

Filter Grilles

These units combine a hinged return air face with a filter rack, and permit servicing the HVAC system filter at the return grille. They are ideal for installations where the mechanical equipment is in locations such as an attic or a crawl space.

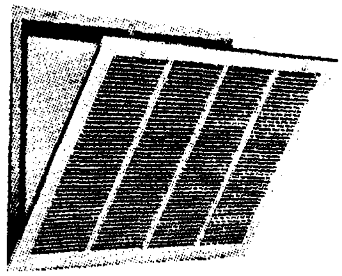


Fig. 40. Hinged filter grille

2. Selecting the Right System

This chapter deals with the basic types of duct systems, so that alternative systems may be intelligently weighed in selecting an appropriate system depending on house type and other design considerations. The final selection and design of the system should be worked out with a competent HVAC contractor.

The most common residential duct systems are the extended plenum and radial systems because of their versatility, performance, and economy. These systems and several other common systems are illustrated, showing adaptability to different house types. While supply-air systems are emphasized, return-air systems are also discussed. The examples used in this chapter show a broad variety of duct system possibilities, and do not necessarily represent the optimum solution for any particular case.

Extended Plenum Systems

The most commonly used residential duct system is the extended plenum system. A relatively large main supply duct (trunk duct) is connected to the furnace supply plenum and serves as an extension to the plenum. The smaller branch ducts which deliver air to the individual outlets are connected into the trunk duct at various points.

Characteristics of Extended Plenum Systems

Extended plenum systems have several advantages:

- Simplicity—relatively long runs of one size rectangular trunk duct permit ease of fabrication and installation with a minimum number of sizes or special fittings.
- Performance—balancing of air flow to rooms presents no major problem in the average-sized house, especially with centrally located equipment.
- Adaptability—the system readily adapts to most house types including one-story, two-story and multi-level designs. Ideally suited to basement constructions, it can also be installed in crawl spaces, attics and dropped ceilings.
- Concealment—rectangular trunk ducts can be readily concealed in finished areas by bulkheading and other means. Smaller branch ducts may be installed within joist and stud spaces.
- Cost—the extended plenum system is generally the lowest cost system for typical basement, bi-level and split-level construction. This system can also be cost effective with slab-on-grade construction where it may be installed in a dropped hall ceiling.

Design of Extended Plenum Systems

The principal design limitation of the extended plenum system is the length of single-size trunk duct. To maintain reasonably uniform air pressures in the air-distribution system, the length of a single-size trunk duct should be limited to about 24 feet. When this length is exceeded, pressure tends to build up toward the end of the duct, resulting in too much airflow in branches near the ends, and insufficient airflow in branches closer to the equipment. In extreme cases where unreduced duct length is excessive, reduced pressures at branch duct takeoffs close to the equipment can actually cause air to be drawn into supply registers rather than being forced out.

An efficient extended plenum system is shown in Figure 41. In this application, the equipment is centrally located, with a straight trunk duct serving one group of branch outlets and another straight trunk duct serving a similar group of branch outlets. Neither of the trunk ducts exceeds 24 feet.

Extended plenum systems with centrally located equipment can be used in homes up to approximately 50 feet long and still be within design limitations, depending on register locations in end rooms.

If this system were located in a finished basement area, the trunk duct typically would be installed close to the center girder where it could be concealed in a bulkhead along with the girder. The branch ductsfeeding perimeter floor outlets in this case, would be concealed within the joist spaces.

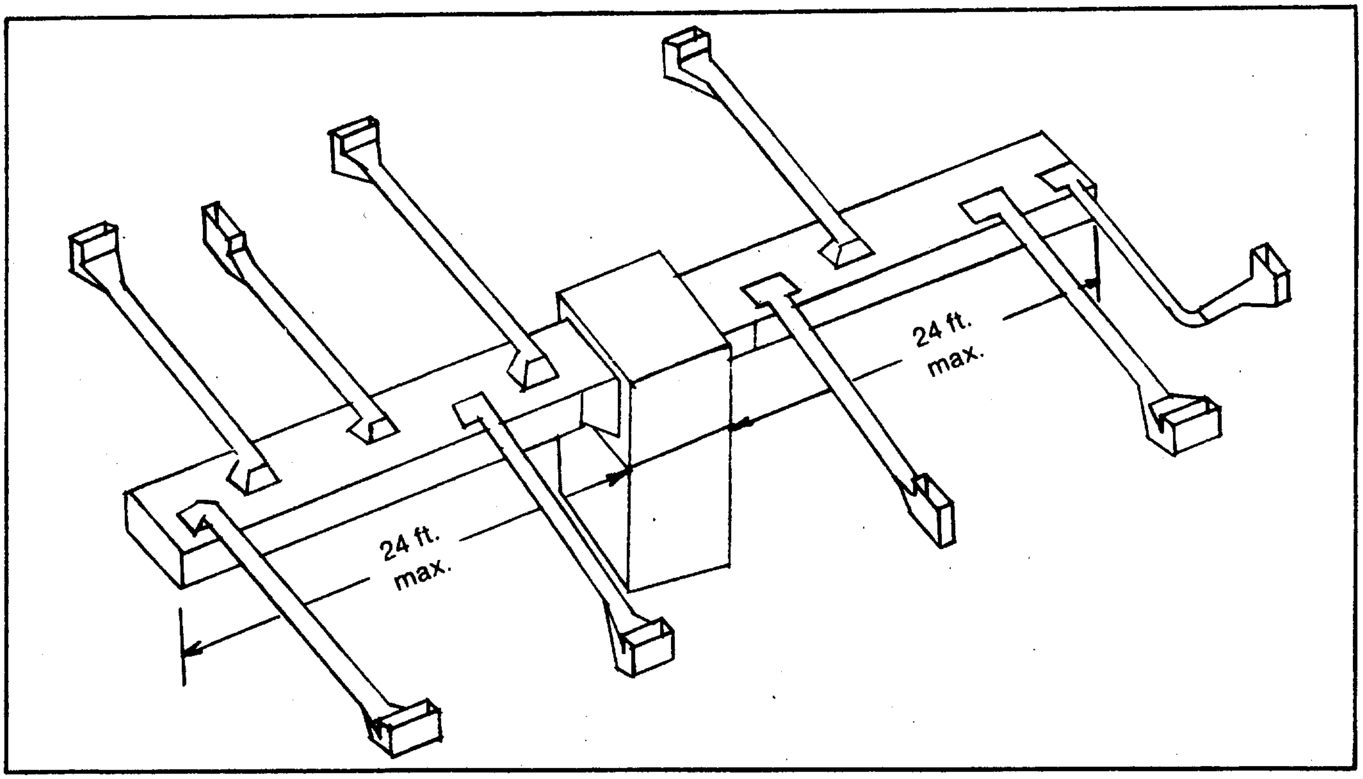


Fig. 41. Extended plenum duct system, equipment centrally located

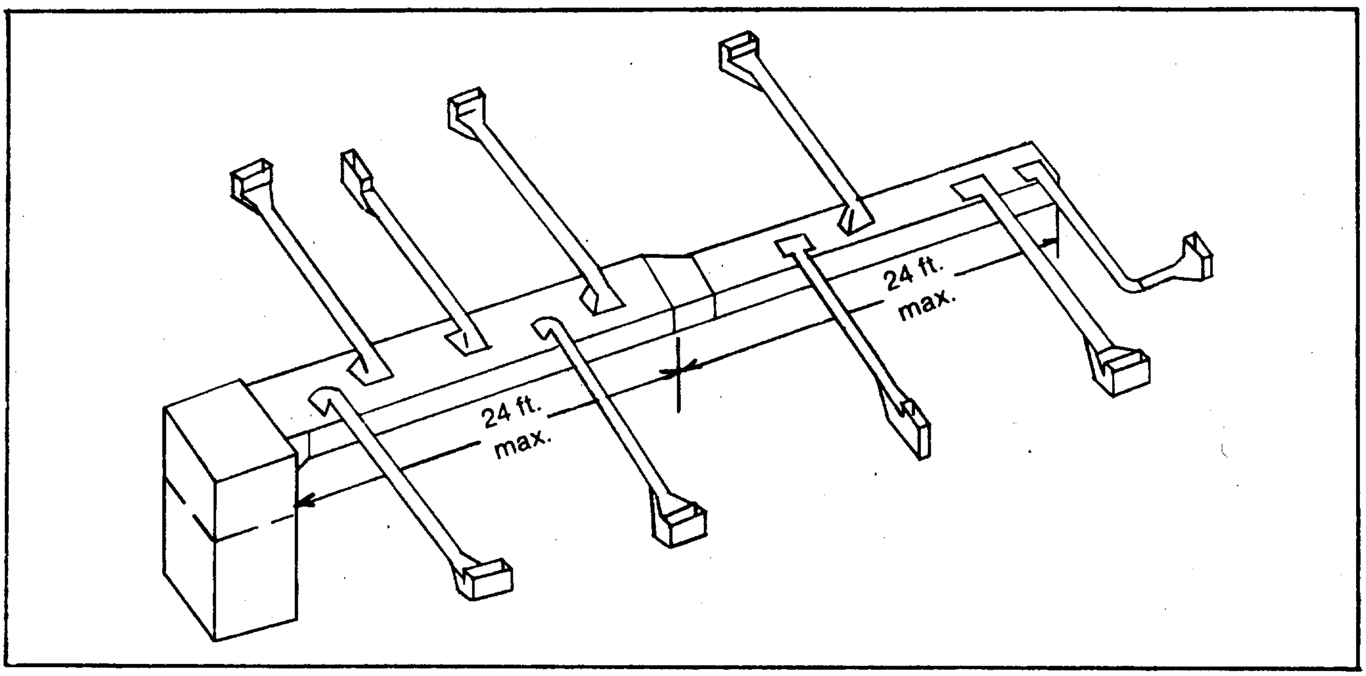


Fig. 42. Reduced extended plenum duct system, equipment at one end of structure

Sometimes it is not practical to locate the equipment centrally. Proximity to a flue on an end wall or other floor-plan considerations may require that equipment be located at one end of the building. This could require trunk ducts in excess of 24 feet. Under these conditions a reduced extended plenum system would be required. Figure 42 illustrates this application. Note that the trunk duct has been reduced after the first group of branch outlets to maintain sufficient air pressure to the branches closer to the equipment. Also note that trunk ducts of a given size do not exceed 24 feet.

Examples of Extended Plenum Systems

The following examples illustrate the use of extended plenum systems in different house types and constructions.

One-Story

- Furnace centrally located in basement (Fig. 43)
- Furnace located at one end with ducts in crawl space (Fig. 44)
- Rooftop unit with attic duct system (Fig. 45)
- Duct system located in dropped hall ceiling (Fig. 46)

Two-Story

- Furnace centrally located in basement (Fig. 47)
- Furnace located at one end of basement (Fig. 48)
- Slab-on-grade with ducts in first-floor ceiling (Fig. 49)

Split-Level

- Three levels with furnace on grade level and first floor over crawl space (Fig. 50)
- Four levels with furnace in basement and grade level over crawl space (Fig. 51)

Bilevel

- Central furnace located in partially finished lower level (Fig. 52)

Note standard air symbols used:

 supply duct

 return duct

 supply outlet

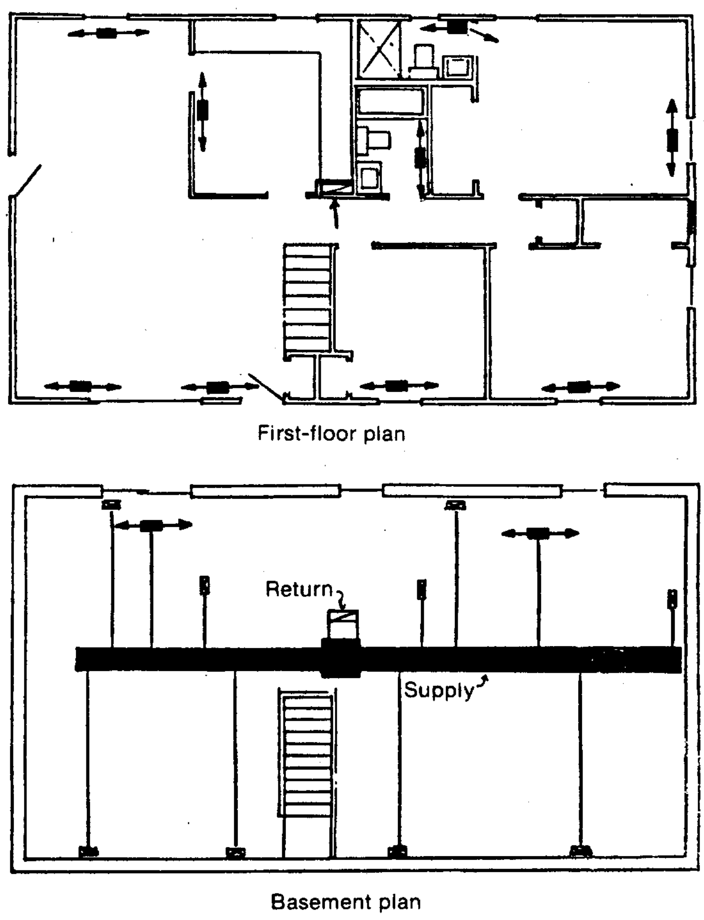
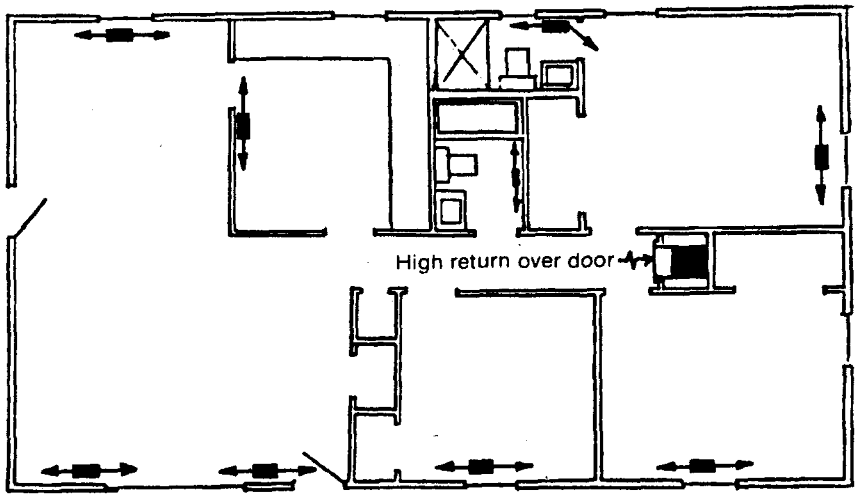
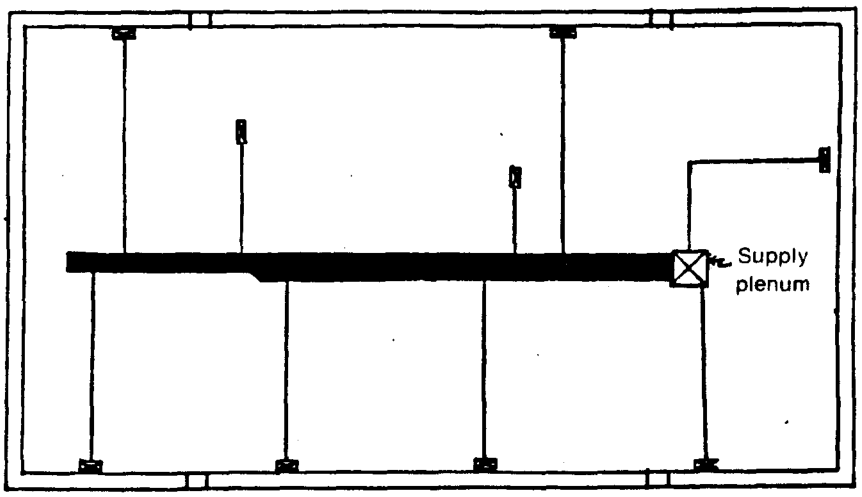


Fig. 43. Extended plenum system, one-story house, equipment centrally located in basement

- Single-sized unreduced trunk duct extends out on both sides
- Branch ducts feed perimeter floor outlets
- Note two ceiling outlets in basement to temper air
- Return air grille centrally located in first-floor hall



First-floor plan



Crawl-space plan

Fig. 44. Extended plenum system, one-story house over crawl space, equipment on first floor

- Counterflow unit in closet at end of hall directs supply air down
- Trunk duct in crawl space reduced because of length of run
- Trunk duct insulated, unless crawl space insulated and conditioned
- Branch ducts feed perimeter floor outlets
- Two bedroom outlets supplied directly from furnace plenum
- Central return located high over closet door
- Note this type of system is discouraged in crawl spaces with uninsulated foundation walls because of energy conservation considerations

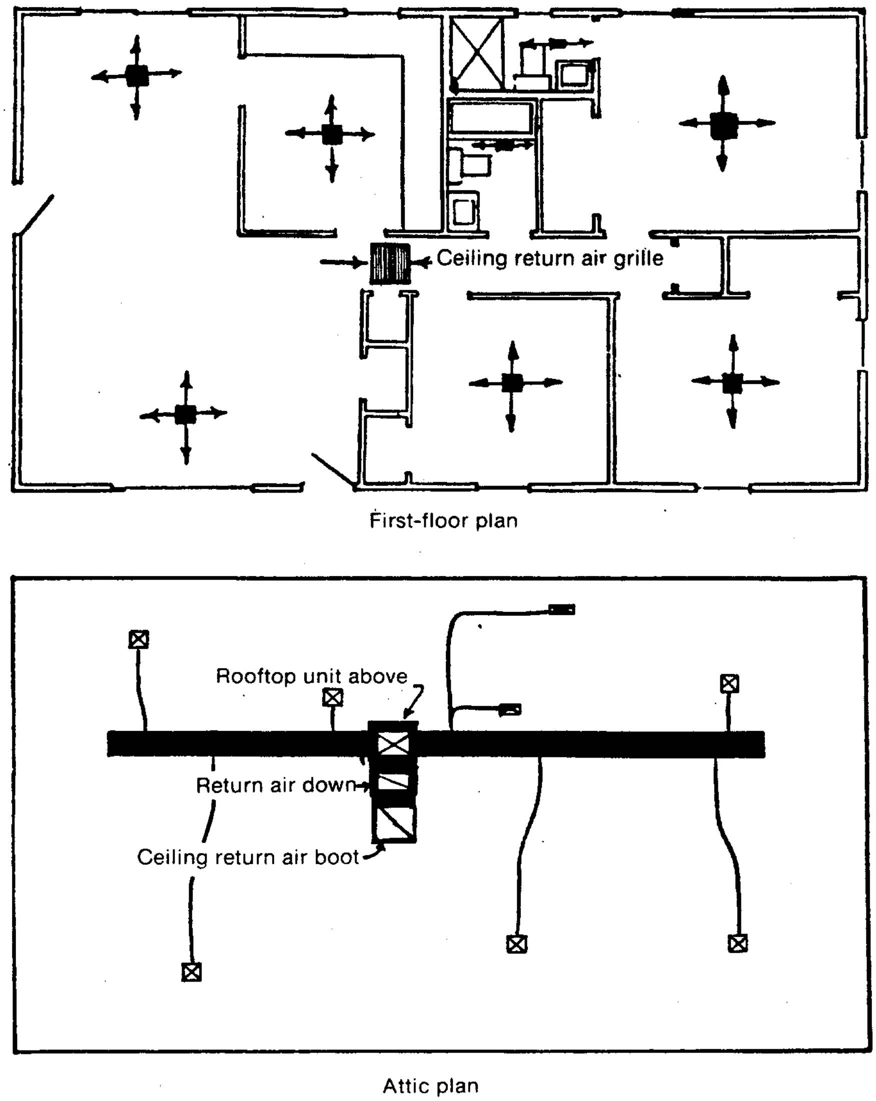


Fig. 45. Extended plenum system, one-story, slab-on-grade house, roof-top equipment

- Rooftop unit located centrally, behind ridge
- Unreduced trunk duct extends out on both sides in attic
- Rigid fiberglass or insulated metal duct used for trunk
- Ceiling diffusers located centrally in each room
- Flexible, insulated round duct used for branch ducts
- Return air grille located centrally in hall ceiling close to equipment
- Filter-type grille could be used at return air for ease of filter changing
- This system most appropriate where cooling predominates; can also be used for heating with proper register selection
- To avoid excessive heat losses and gains, high levels of insulation are required in ductwork and rooftop equipment

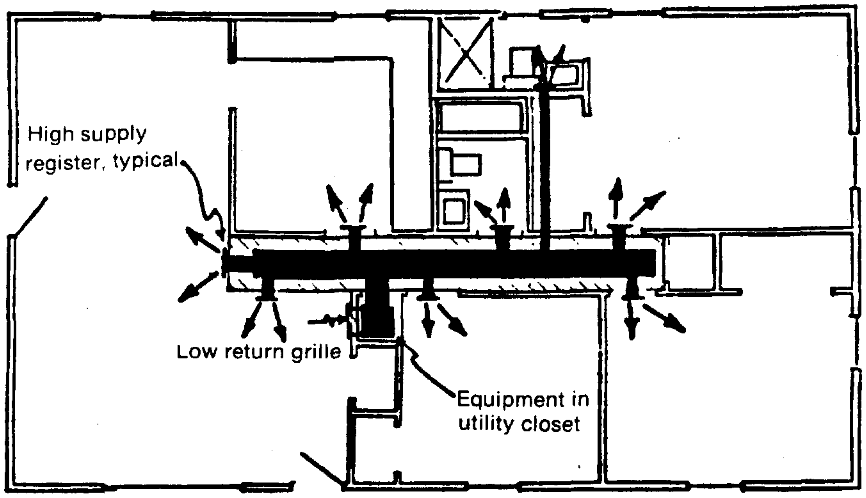


Fig. 46. Extended plenum system, one-story, slab-on-grade house, ducts in dropped hall ceiling

- Standard upflow unit located centrally in utility closet
- Simplified trunk duct enclosed in dropped hall ceiling provides economical system and eliminates energy losses and gains from ductwork by locating equipment within the conditioned space
- Stub ducts feed supply registers high on inside walls of each room
- Register typically centered above door opening to room, but could be elsewhere
- Rear bath supplied by small duct through closet; concealment optional
- Low central return enters directly into unit
- Registers with adjustable louvers and opposed blade dampers preferred for air pattern control (see Fig. 35)
- System works well for cooling; can also be used for heating with proper register selection
- High outlets well-adapted to heat pump systems since relatively low-temperature heated supply air does not blow directly on occupants
- One of the most economical ducted HVAC systems for moderate climates and in well-insulated homes in moderately cold climates

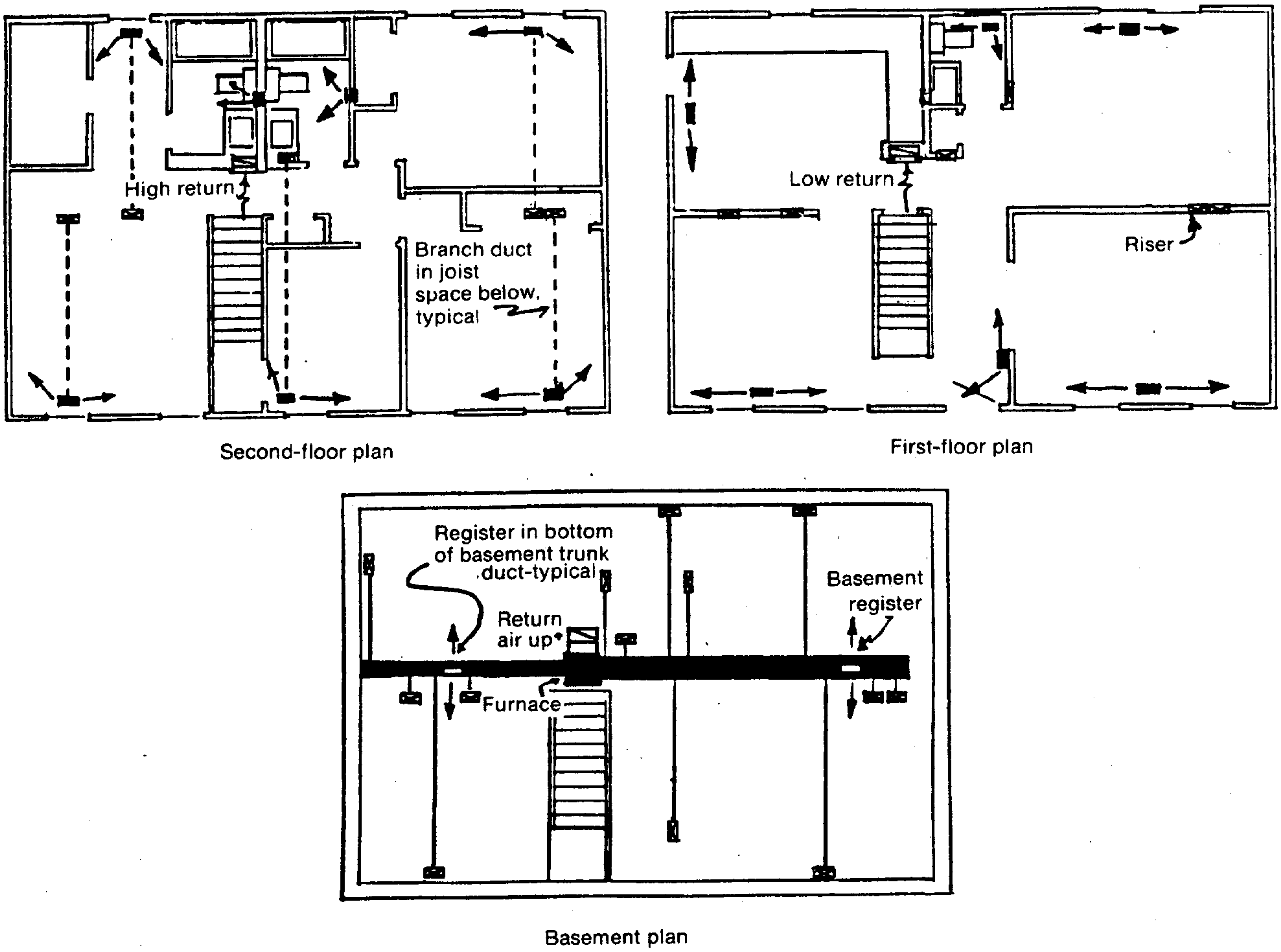


Fig. 47. Extended plenum system, two-story house, equipment centrally located in basement

- Central location of equipment allows trunk ducts to be run with no reductions
- Perimeter floor outlets fed by branch ducts concealed within joist spaces
- Individual risers from basement to second floor located in partition walls. Outside walls should not be used for risers because of energy inefficiencies and loss of structural integrity in building.
- Second floor baths have wall registers (often preferred); alignment of partitions on the first floor simplifies installation of wall registers
- Central return at each level run in common chase; location high on second floor, low on first floor
- Basement temperatures moderated by two registers cut into bottom of trunk duct

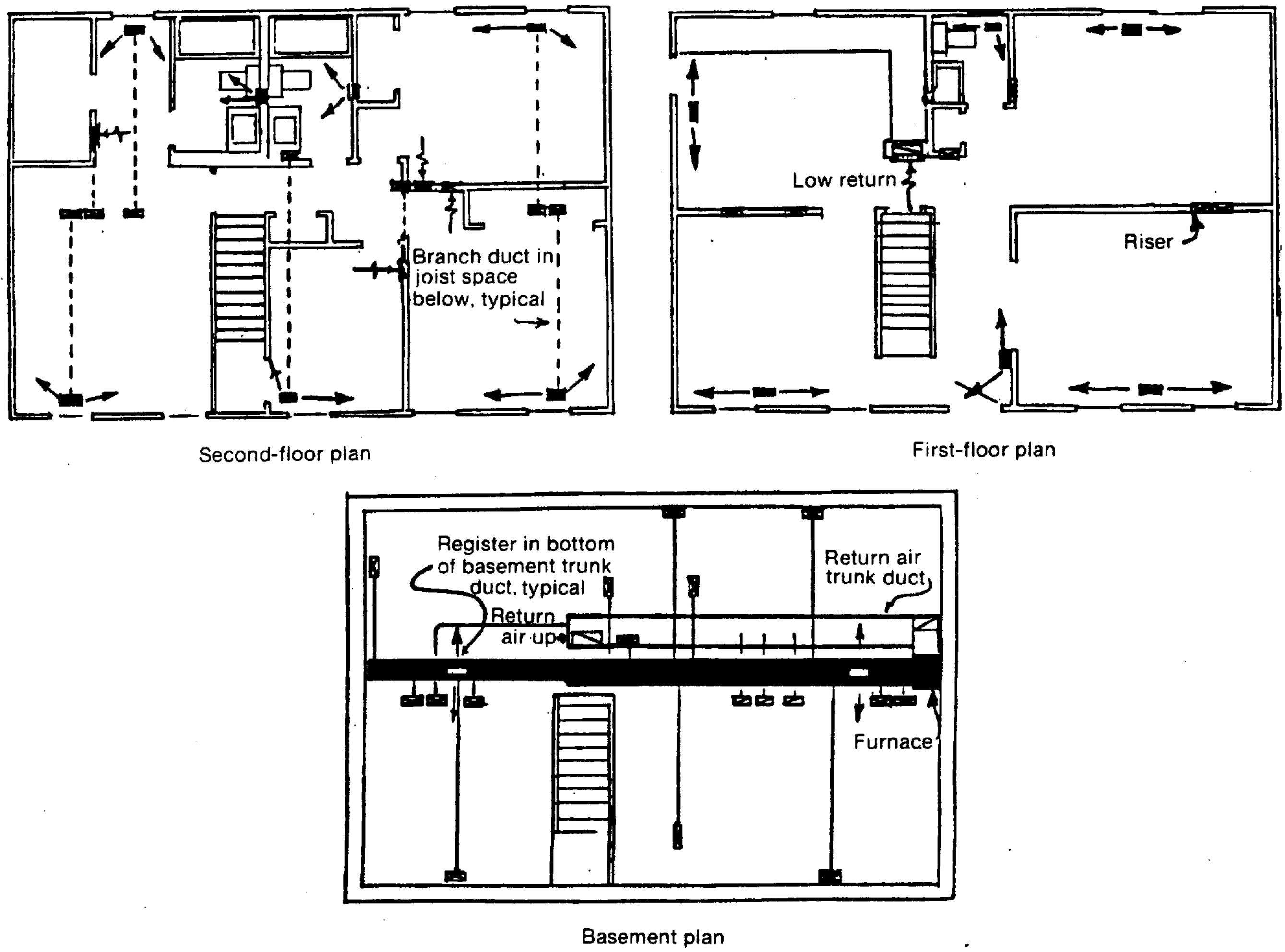


Fig. 48. Extended plenum system, two-story house, equipment located at one end of basement, individual room returns on second floor

- Equipment located at end of basement requires that supply duct be reduced midway to maintain static pressure in larger duct
- Wall stacks for second-floor supplies and individual returns located in interior partitions
- Individual room air returns on second floor allow for proper air circulation without need to undercut doors; system is quieter and privacy is better in bedroom areas than in with central return
- Individual return grilles located on interior wall for good cross-flow of air
- Central return used for first floor; open planning allows for free flow of air

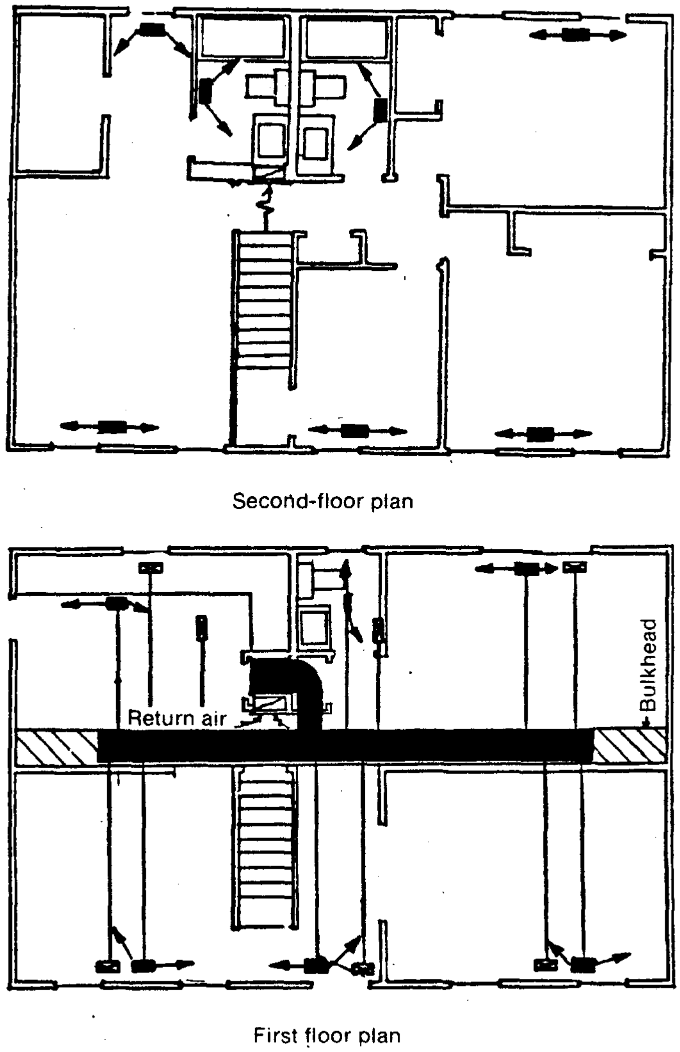


Fig. 49. Extended plenum system, two-story, slab-on-grade house, equipment centrally located

- Furnace located centrally in utility closet
- Unreduced trunk line located below ceiling adjacent to bearing wall, concealed in bulkhead
- Perimeter floor outlets on second floor and perimeter ceiling outlets on first floor fed by branch ducts concealed within joist spaces
- Ceiling outlets are adjustable type to direct air down for heating, or flat against ceiling for cooling
- Return air central for both levels via chase provided in house design
- Main feeder supply to extended plenum trunk duct is run through guest closet ceiling; concealment optional
- No energy losses and gains from ductwork with this type of system since all ductwork is located within the conditioned space

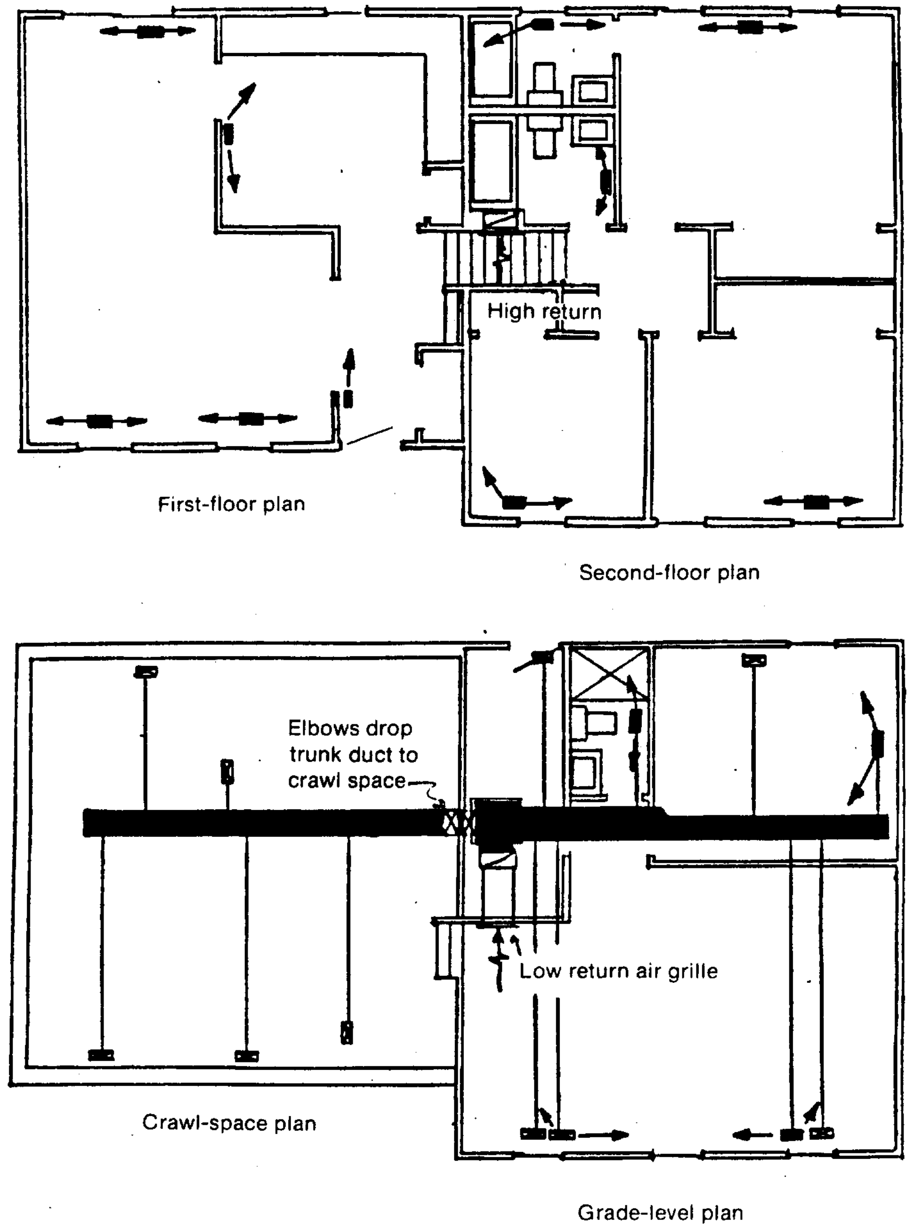


Fig. 50. Extended plenum system, split-level house, grade level on a slab, first floor over crawl space

- Upflow equipment located centrally at slab level
- First floor trunk duct located in crawl space below floor joists feeds perimeter floor diffusers
- Trunk duct for two-story portion of house located in bulkhead below second floor joists, feeds perimeter floor outlets on second floor, perimeter ceiling outlets at grade level
- Economical system for this type split-level; heating for grade level compromised somewhat with ceiling outlets but is satisfactory
- With chase provided and open planning, central returns used to economic advantage Doors on second-floor rooms undercut to permit air flow
- Trunk duct for two-story wing reduced to maintain static pressure in ducts closest to equipment

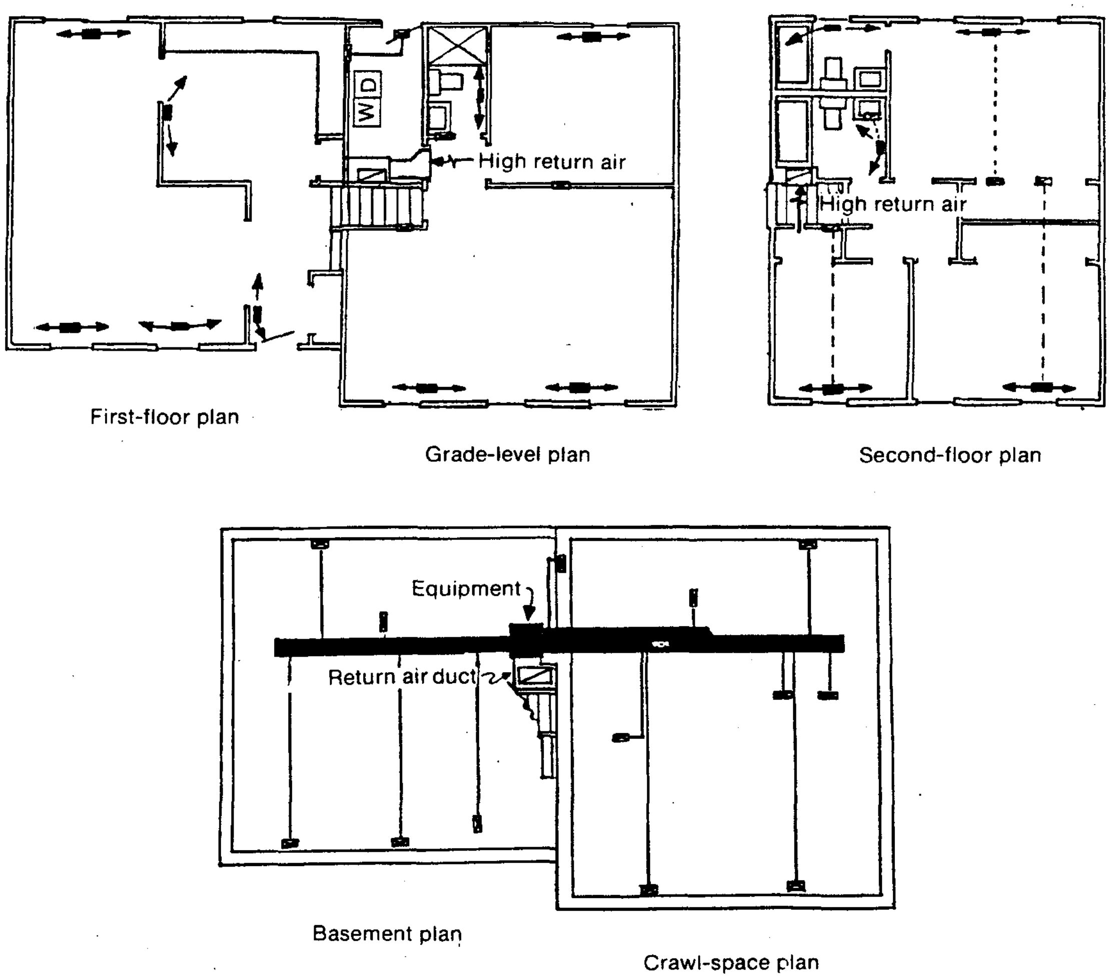
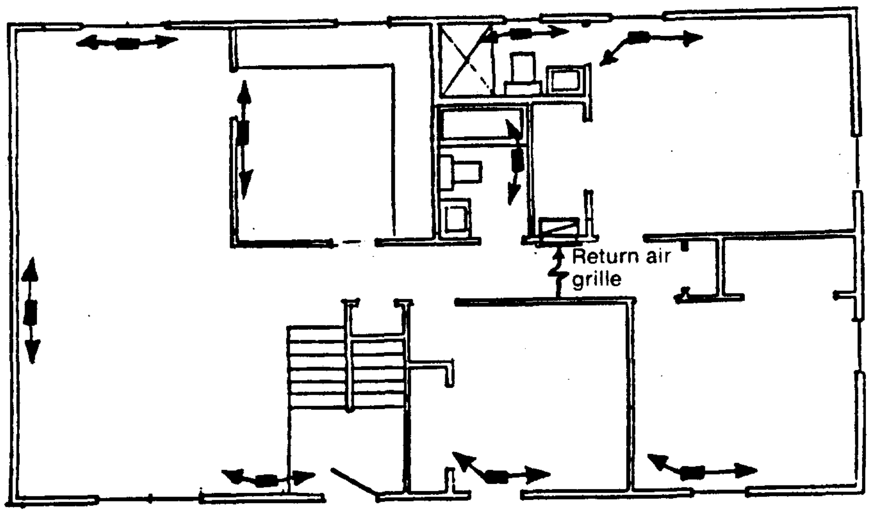
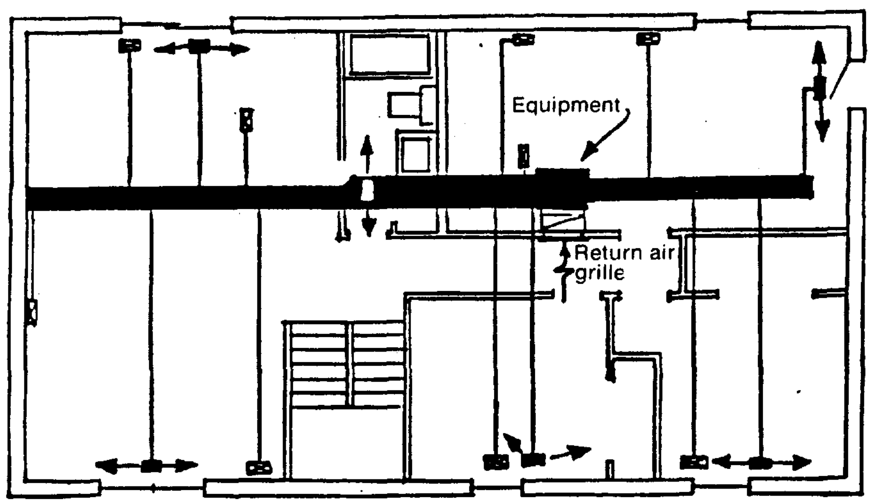


Fig. 51. Extended plenum system, split-level house, grade level over crawl space, first floor over basement

- Upflow equipment located in basement area adjacent to crawl space
- Trunk duct in basement serves first-floor perimeter floor registers
- Trunk duct in crawl space serves perimeter floor outlets at grade level as well as feeders to wall stack for second-floor perimeter outlets, similar to two-story examples
- System is superior for both heating and cooling
- Central returns used at both major levels
- Trunk duct in crawl space reduced to maintain pressure in outlets closer to equipment
- If crawl space not insulated, truck duct should be insulated. Branch ducts can be located above insulation in joist spaces, to isolate them from unconditioned crawl space
- Return air at grade level ideally would be low. Two economical options could be a floor return, or a return entering directly into the side of the main return duct located in the laundry room with a louvered door leading into the room.



Upper-level plan



Lower-level plan

Fig. 52. Extended plenum system, bi-level house, equipment located off-center

- Similar to one-story with basement, except finished lower level requires more outlets
- Location of equipment allows trunk duct to be run same size on short run but reduced on longer run
- Central hall permits effective use of central returns
- Upper-level floor outlet location provides superior heating and cooling
- Lower-level ceiling registers provide superior cooling; heating satisfactory. Low supplies would be ideal, but cumbersome and expensive to install.

Radial Systems

Radial duct systems are the second most commonly used in single-family homes. With radial duct systems there is no trunk duct. Branch ducts which deliver conditioned air to individual outlets connect directly to the equipment plenum. Radial systems typically are used where it is not necessary to conceal ductwork, and where the equipment may be centrally located.

Characteristics of Radial Systems

Typical characteristics of radial systems are—

- Simplicity—This system is probably the simplest duct system to install. Branch ducts are run in the most direct route from the furnance plenum to the outlet; finished appearence of ductwork is not considered.
- Performance—Air flow in the branch ducts is fairly uniform since all branch ducts originate at a central plenum. If balancing dampers are installed in the branch ducts near the plenum, they can be serviced from a central location.
- Concealment—Radial systems are typically installed in unused crawl spaces and attics, and below concrete slabs, where concealment is not a design cosideration.
- Adaptability—The system is most adaptable to single-story structures with centrally located equipment. Application to other structures is limited.
- Cost—This is the lowest cost system for many single-story structures. The basic simplicity of the system provides cost savings through reduced materials inventory and the use of less specialized labor.

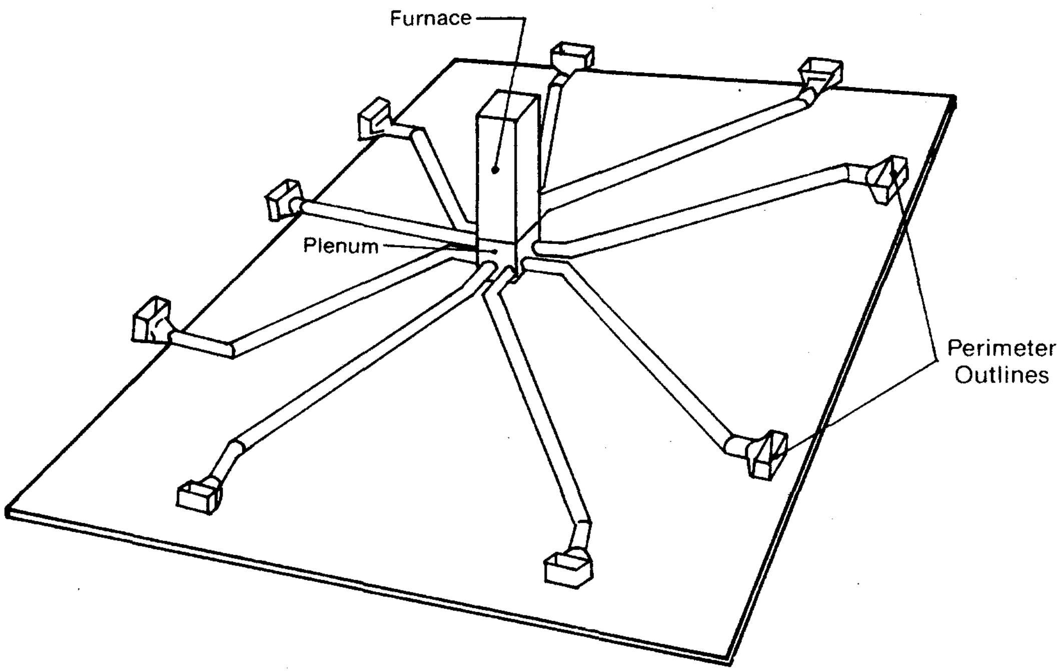


Fig. 53. Typical radial duct system

Design of Radial Systems

Several basic design considerations affect radial duct systems:

- Equipment must be centrally located to take best advantage of the system.
- The system is most economical when applied to single-story rectangular homes.
- The system can provide economies when applied to single level elements of two-story and split-level homes.

A typical radial system is shown in Fig. 53. Ductwork shown in this system could be located in a crawl space or basement, or embedded in a concrete slab. Return air ducts for radial systems are typically central and are located close to the heating equipment.

Examples of Radial Systems

The following examples of radial duct systems illustrate their application to several different house types and constructions.

One-Story

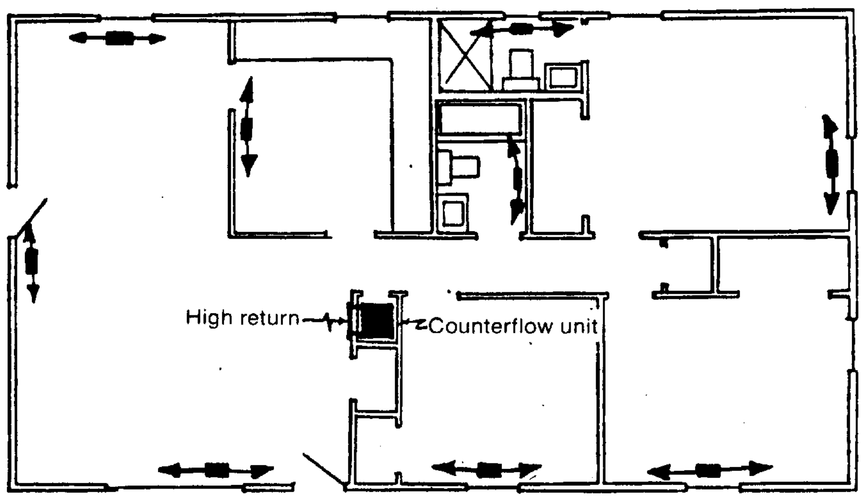
- Crawl space or slab construction (Fig. 54)
- Slab perimeter loop system (Fig 55)
- Attic duct system (Fig. 56)

Two-Story

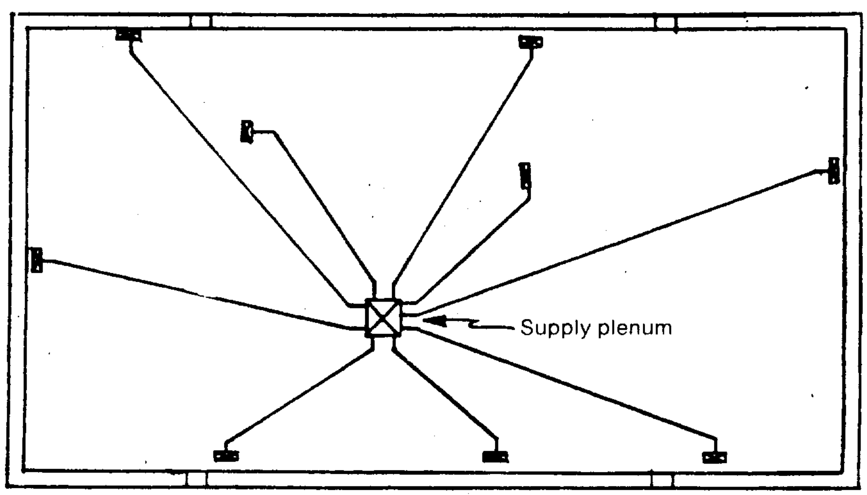
- Crawl space radial system combined with attic radial system (Fig. 57)
- Extended plenum in basement combined with attic radial system (Fig. 58)

Split-Level

- First floor crawl, grade-level slab, second-floor attic radial system (Fig. 59)



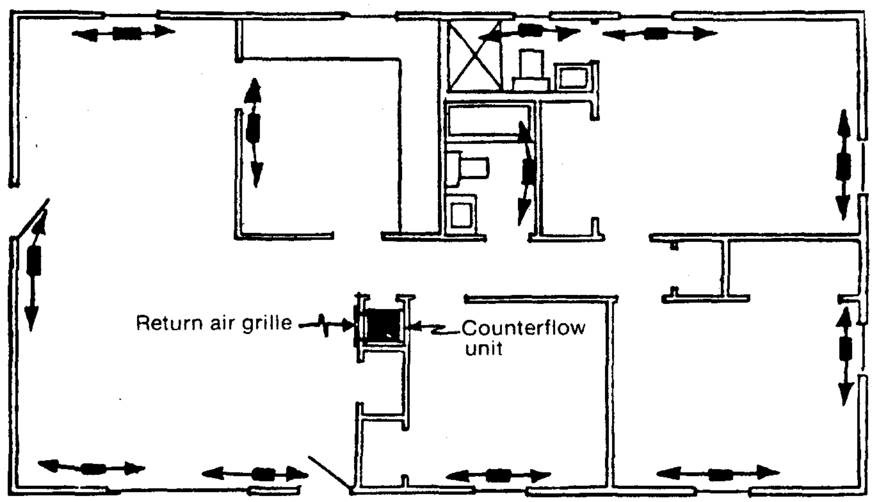
First-floor plan



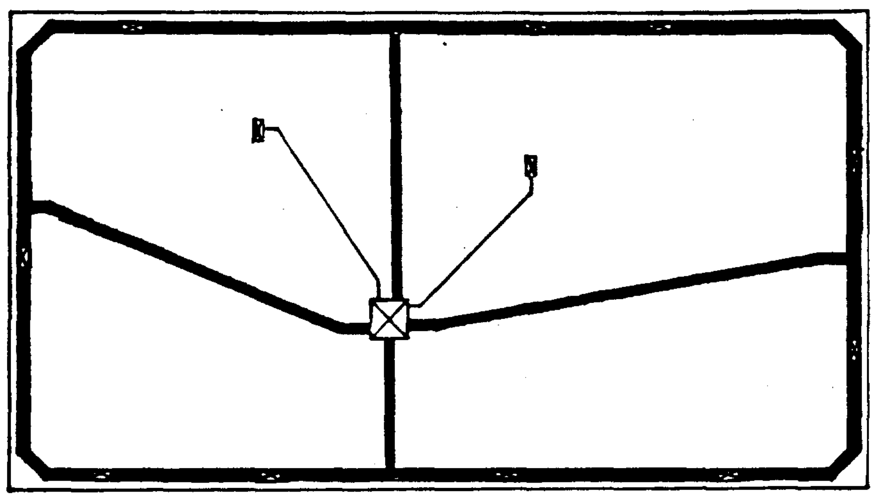
Crawl-space plan
(slab similar)

Fig. 54. Radial duct system, one-story house over crawl space

- Counterflow unit located centrally in utility closet directs supply air down
- Metal supply plenum located directly beneath equipment
- Branch ducts connect directly into plenum, feed perimeter registers located in floor
- Relatively equal branch-duct runs provide well-balanced air flow
- Central return high on wall adjacent to unit
- Basic radial system shown is one of the most economical duct systems
- To avoid excessive duct heat losses or gains, ducts should be properly insulated; or crawl space foundation walls, and ground as necessary, should be insulated



First-floor plan



Slab plan

Fig. 55. Radial duct system with perimeter loop, one-story house on slab

- Counterflow unit located centrally directs air downward
- Loop supply duct in slab runs around entire perimeter of structure
- Radial branch ducts feed supply loop at intervals to maintain uniform supply-air pressure
- Supply collars spaced around perimeter to blanket exterior walls with conditioned air
- Supply ducts waterproofed to prevent infiltration of ground water
- System provides good comfort conditions in colder climates when properly insulated slabs are used, comfort is enhanced by perimeter warming effect
- One of the more costly duct systems to install
- Because of modern insulation techniques used to reduce perimeter heat losses, perimeter loop system is not used as frequently as it was in the past.

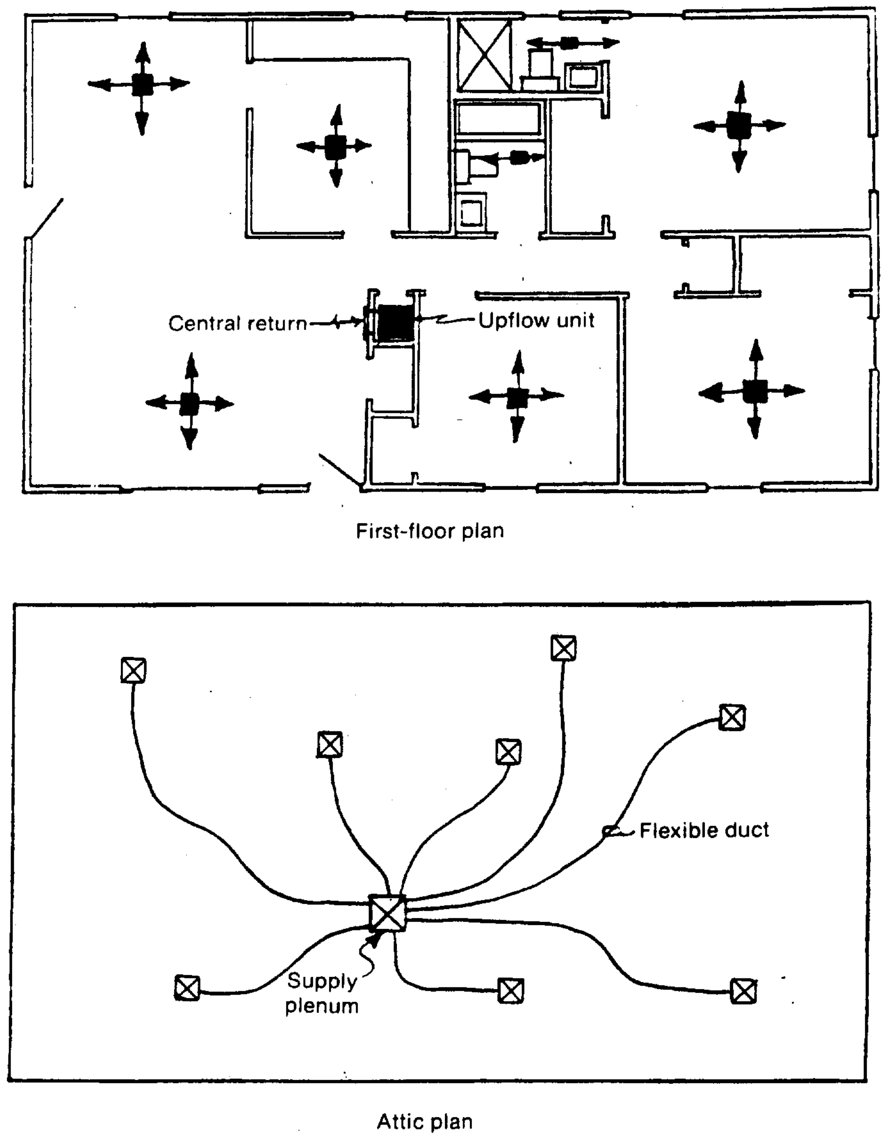


Fig. 56. Attic radial duct system, one-story house on slab

- Upflow unit located in utility closet feeds plenum in attic; rooftop unit or horizontal unit in attic could also be used
- Insulated flexible duct feeds ceiling diffusers in rooms
- System adapts best where cooling predominates
- Heating performance can be satisfactory with adjustable-blade registers that direct air downwards
- Low return shown in example; return would be in ceiling with an attic or rooftop unit
- Ducts must be well sealed and insulated to avoid excessive energy losses or gains because duct system is located outside of conditioned space.

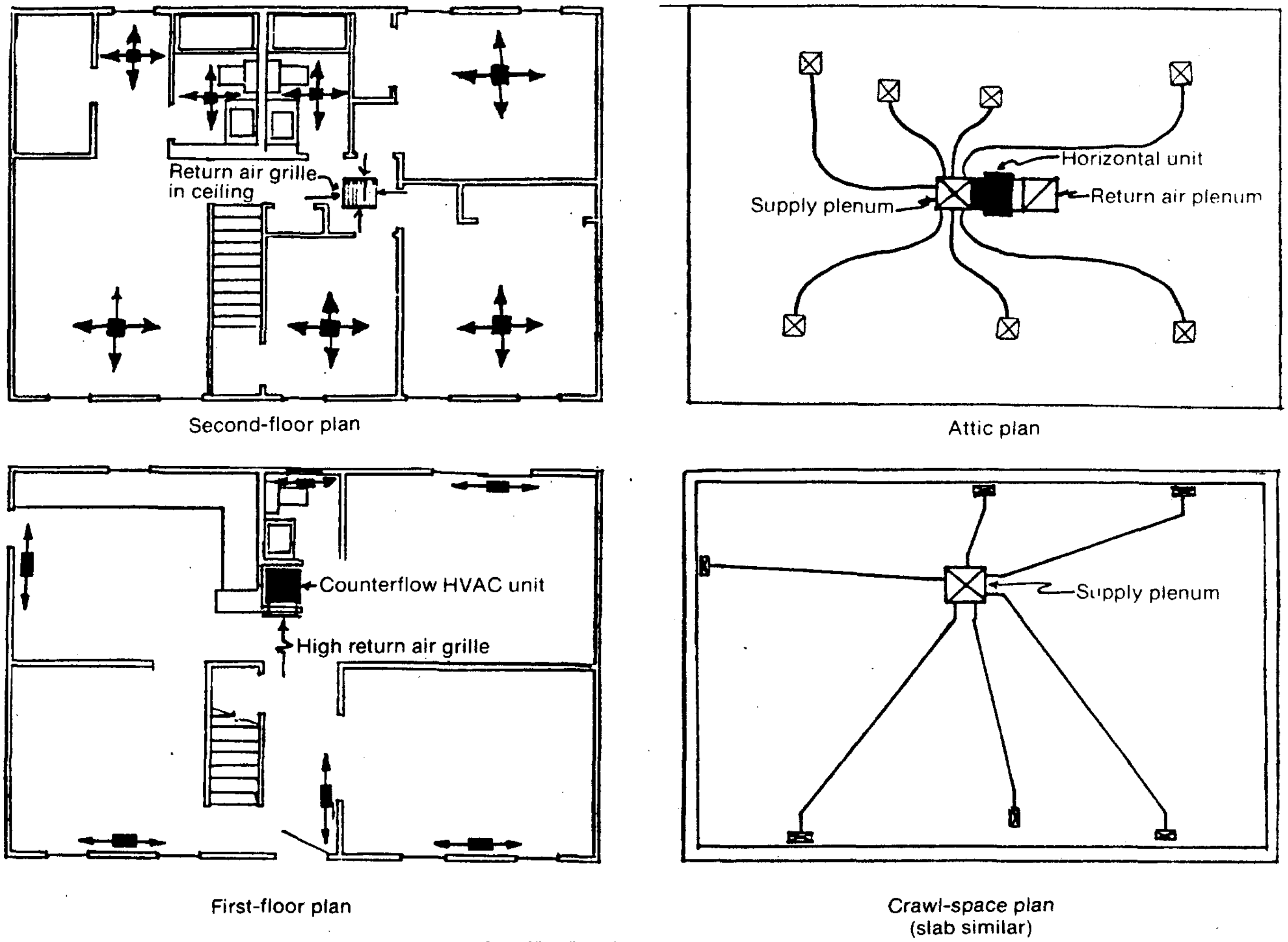


Fig. 57. Radial duct system, two-story house on crawl space

- Two heating units used—counterflow unit in utility closet for first floor, horizontal unit in attic for second floor
- Plenum on counterflow unit extends into crawl space. Metal or fiberglass branch ducts radiate out to perimeter floor registers
- If first floor is slab construction, duct layout would be similar
- High return-air grille for first floor connects into top of unit
- Supply plenum for second floor connects to horizontal unit in attic
- Insulated flexible duct used for branch ducts to feed ceiling diffusers on second floor
- Return-air grille for second floor located in hall ceiling. A filter-grille could be used for ease in replacing filter
- Combined systems of this type provide two zones with separate controls for each floor
- The combination shown provides good comfort conditions; first floor heats well, second floor cools well
- System is generally more costly because of double equipment

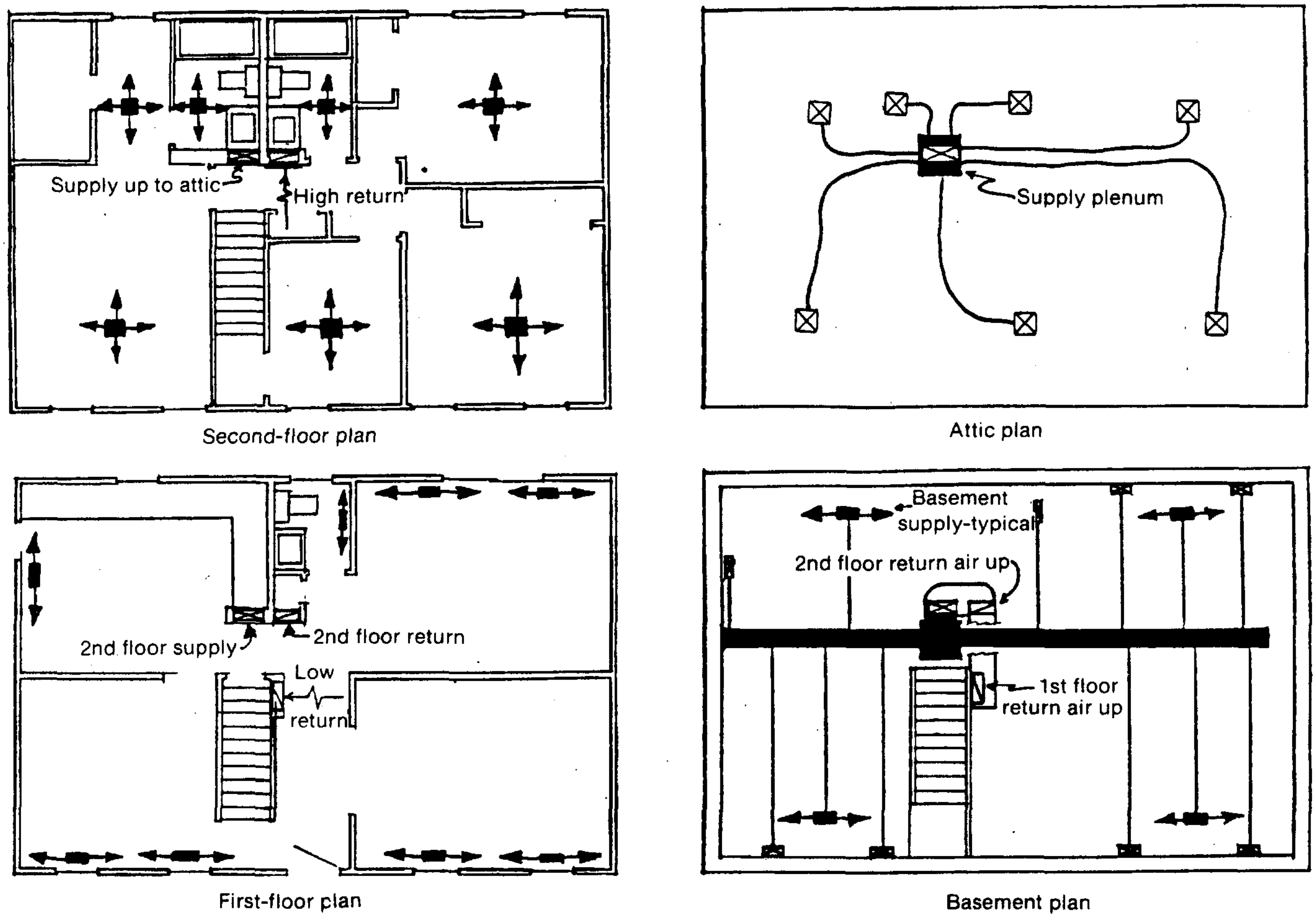


Fig. 58. Radial duct system combined with extended plenum system, two-story house with basement

- Equipment is centrally located in basement
- Extended plenum system located in basement with perimeter outlets on first floor
- Main feeder duct routed to attic through chase terminates in attic supply plenum
- Flexible ducts radiate from attic plenum to ceiling outlets on second floor
- Central returns for each level located in chases
- This system provides a good compromise between heating and cooling requirements
- Attic ducts must be well sealed and insulated to avoid excessive heat losses and gains

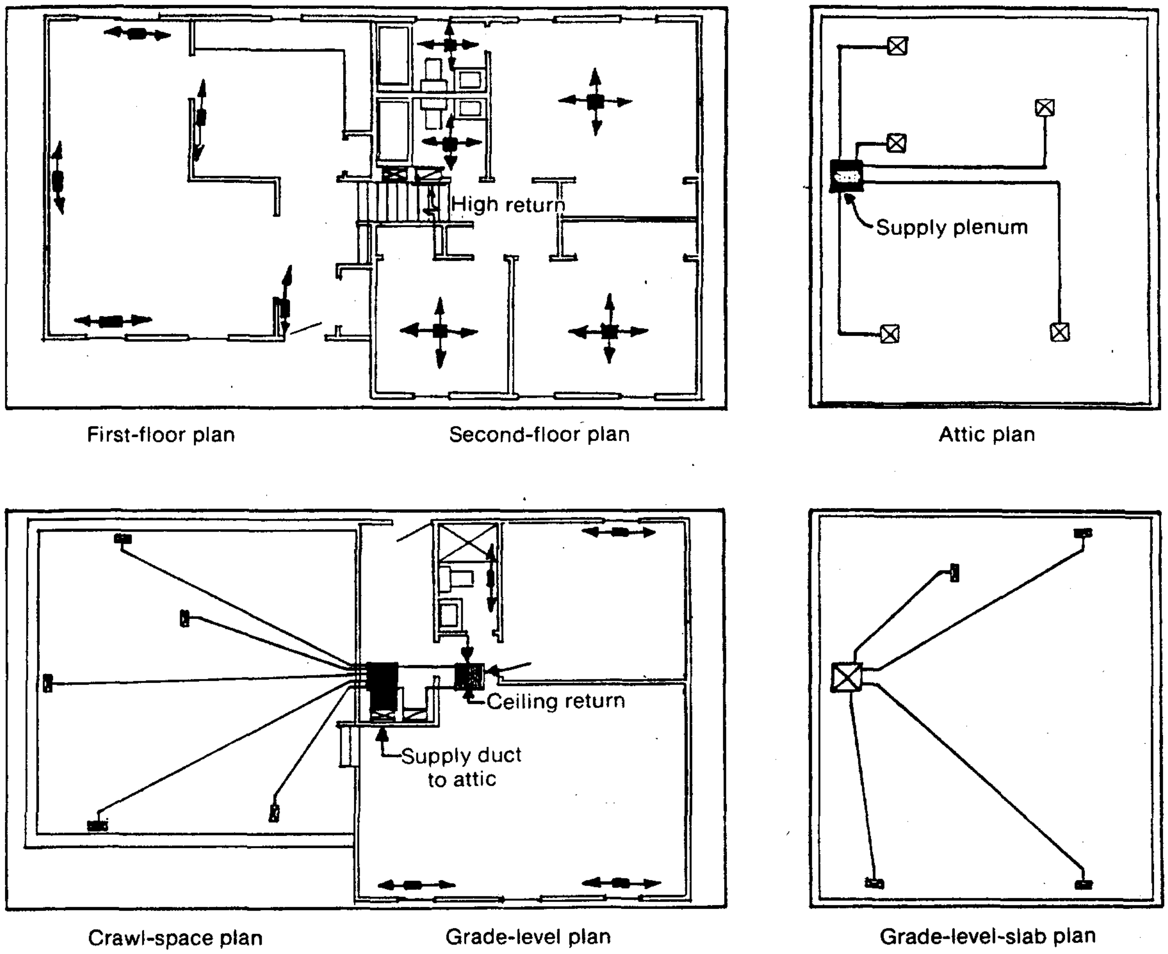


Fig. 59. Radial duct system, split-level, first floor over crawl space, grade level on slab

- Counterflow unit located centrally at grade level
- Branch ducts radiate from plenum through crawl space to supply air to first-floor perimeter outlets, and below slab to supply grade level outlets
- Main feeder duct for second floor terminates in attic supply plenum
- Rigid round fiberglass ducts feed ceiling registers on second floor
- Central returns provided on second floor and grade level
- This system provides a good compromise between heating and cooling performance.

Reducing Trunk System

A properly designed reducing trunk system represents the ultimate in an engineered duct system, with each portion of trunk duct specially sized so that the trunk is proportionately reduced after each branch takeoff. This is not to be confused with the reduced extended-plenum system described in the first section.

Although not commonly installed in competitively priced homes, the reducing trunk system may be used in custom homes, and light commercial buildings, etc., where performance is of greater concern relative to initial cost.

Characteristics of Reducing Trunk Systems

For comparison, the same characteristics considered previously for extended-plenum systems are discussed here—

- Simplicity—A reducing trunk system is the most difficult to design and fabricate. Each system is engineered for a specific application, precluding the extensive use of standardized duct and fittings.
- Performance—Properly designed, it is the ultimate system for exacting performance and function. Streamlined fittings and method of takeoff minimize air turbulence and noise. The system is well-balanced, since each branch is specifically engineered.
- Adaptability—The system readily adapts to most house types, and is generally suitable for the same applications as extended-plenum systems. It is particularly well-suited where equipment must be located at one end of the building.
- Concealment—Duckwork is easily concealed within framing and by bulkheading, similar to extended-plenum systems.
- Cost—More costly than other standard duct systems because of custom nature of design, ductwork and installation.

Design of Reducing Trunk Systems

Effective design of reducing trunk systems requires precise Btu and cubic feet per minute (cfm) determinations for each outlet by a qualified HVAC contractor or engineer. The outlet, branch duct and portion of trunk duct to which each branch connects must be accurately sized and designed for the required air flow.

Fig. 60 represents a section of reducing trunk showing branch takeoff fittings used with such a system. Note that the main trunk duct becomes smaller after each takeoff, ultimately reducing to a single branch duct at the last takeoff.

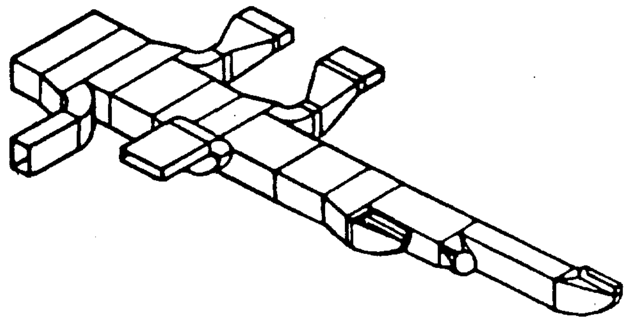


Fig. 60 Typical section of reducing trunk system

Since air delivery requirements in a reducing trunk system are predetermined by design, grilles are sometimes used in place of registers to avoid tampering at individual outlets. Proper design of a reducing trunk system requires a well-qualified HVAC contractor or engineer.

Gravity Systems

Most gravity systems are essentially a radial system. They are typically associated with coal- and wood-burning furnaces, and are used in areas where wood and coal are available and economical, and where cooling is of minimal concern. Gravity systems circulate heated air through duckwork by natural convection, requiring no blower or other mechanical assist.

Characteristics of Gravity Systems

Typical characteristics of gravity systems are—

- Simplicity—Short supply ducts, connected to the furnace plenum, terminate at floor registers at inside walls. Extensive use of joist-panning minimizes return air ductwork while providing the large return air ducts required for satisfactory performance.
- Performance—Operation is extremely quiet since no blower is used. Because of limited combustion control on gravity coal and wood furnaces, this system often results in substantial fluctuation in room temperatures. This can be alleviated somewhat by firing more frequently with small amounts of fuel. However, larger furnaces are often preferred because they do not have to be fired as often.
- Adaptability—Gravity systems adapt best to simple one-story houses with a basement. The furnace should be centrally located in the basement to minimize supply-run lengths and to provide a balanced system. The large central furnace, sloping

ducts and fuel storage area reduce the usefulness of the basement. The second floor of two-story structures can be heated by ducting or through openings cut in the second floor, covered with special floor-and-ceiling grilles, which permit warm air to rise into upstairs rooms, but at the expense of acoustical privacy between floors.

• Concealment—Gravity systems are almost impossible to conceal because of large sloping ducts associated with gravity air flow.

• Cost—Gravity duct systems are somewhat more costly than standard radial systems because of larger duct sizes, larger register boots and larger heavy-duty registers and grilles. Other considerations include more expensive equipment, larger flue requirement, and basement floor-space lost to equipment and fuel storage. These added costs may be offset in some cases by saving on fuel tanks or other utility connections that are not required or by lower operating costs with relatively cheap fuels and savings on electricity, since no power is required for equipment operation. However, operating efficiently tends to be lower than comparable forced air equipment.

Design of Gravity System

The following provisions should be made when planning a gravity installation—

• Adequate basement floor space; central furnace location essential

• Locate a relatively large masonry or insulated stainless steel flue, typically 8 to 12-inch size, close to furnace

• Provide for fuel storage, ash removal and disposal

• Provide adequate combustion air.

A typical gravity system layout is shown in Fig. 61. Certain considerations unique to gravity warm-air systems should be noted—

• Furnace—Coal-burning units are considerably larger than most other types of furnaces. Wood can also be burned in a coal furnace. However, coal should not be burned in a wood furnace unless special coal-type grates are provided. Coal furnaces are usually sized by the inside diameter of the firebox, with 22, 24 and 27-inch the most common residential sizes. Combustion efficiency at optimal loading (not seasonal efficiency) ranges between 50 and 60 percent for gravity units.

• Output—For the residential sizes noted, outputs generally range from 90,000 to 150,000 Btuh. Outputs in this range are several times higher than required for most homes built today. Smaller units are not produced because they would require too frequent firing.

• Control—Control is somewhat limited since the coal or wood must continue burning even when there is no demand for heat. Although combustion can be manually controlled on gravity furnaces, most systems are equipped with a standard low voltage wall thermostat which actuates a small electric damper control. This regulates combustion rates by simultaneously opening and closing combustion air and flue draft dampers on the furnace.

• Fuels—Approximate heat content for coal and wood—

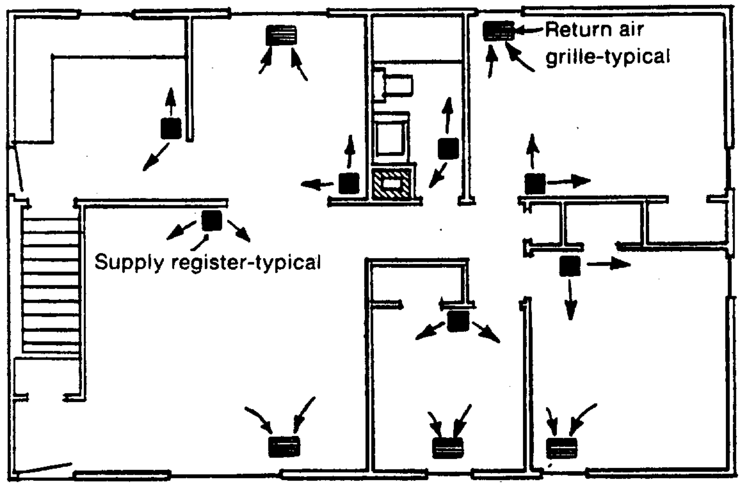
Fuel	Btu per pound
Eastern hard coal	13,500
Eastern soft coal	10,500
Western coal	8,500
Dense hardwood	8,600

• Stokers—A stoker is a large auger mechanism that automatically feeds coal into the furnace. It is controlled on demand by a room thermostat. On bin-feed stokers, the auger extends into a hopper-shaped coal bin. On hopper-feed stokers, a metal hopper is manually filled periodically and provides automatic operation until the hopper is again empty. Stokers are not commonly installed today, because of their limited availability and high initial cost, and because of limited availability of the special nugget-size stoker coal.

• Furnace location—The furnace (see Fig. 61) should be located centrally below the area being heated to minimize the length of radial supply ducts, and it should be located close to a proper flue. The basement should be provided with adequate ventilation for combustion air.

• Supply air—Round galvanized-metal duct is used to supply register boxes which are usually floor mounted. Although various size branch ducts are used, 8 inch diameter is a popular size, as opposed to 6 inch round which would be typical in a forced-air system. Supply ducts must be pitched upward from the furnace to allow warmed air to rise toward the register. Accordingly, registers are located near inside walls as close as possible to the furnace.

• Return air—Return air intakes are located near outside walls, preferably adjacent to a window, to enhance the natural convection of air across the room and down the outside wall. A cold-air return should be located in each major area being heated. Since return-air ducts must be large and not interfere with supply ducts, it is common to use panned-joist spaces in conjuction with convential rectangular metal ductwork for the cold-air return system.



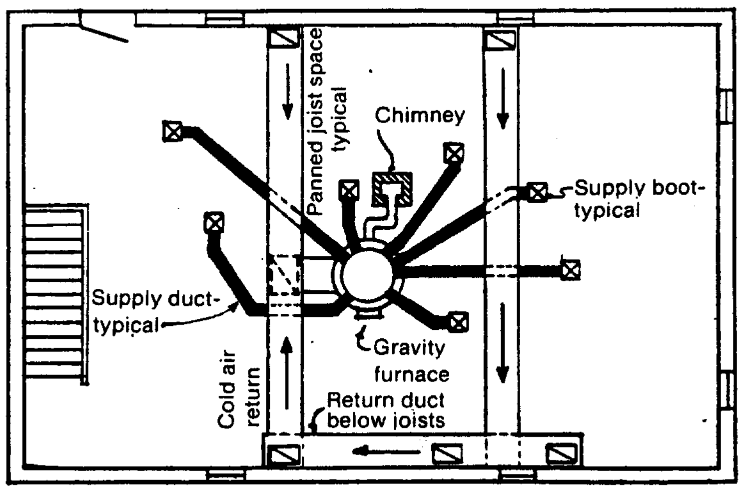


Fig. 61. Duct layout for gravity coal/wood fired system

(This is discussed in the next section.) In a simpler version of the system, return-air ductwork is eliminated and the return air flows through the basement from outside wall return-air intakes cut through the floor.

• Registers and grilles—Since they often are located in traffic areas, registers and grilles are designed as a special heavy duty floor grate. Typical sizes range from 10 by 8 inches to 14 by 12 inches. When used to provide heat to a second floor level without ducting, floor grates are sold in pairs with an interconnecting metal sleeve and are referred to as floor-and-ceiling grilles.

Return Air Systems

While emphasis is placed on supply air duct systems in this manual, proper design of the return air system is also essential to ensure total system performance. Its design is particularly important because the return air system is frequently designed as an afterthought, which can result in higher operating noise levels or reduced performance. Although the return air system is not highly critical to the air-flow pattern within individual rooms, it must be sized to handle the volume of air supplied to the rooms being conditioned.

Central Versus Multiple Returns

Return air systems fall into two major categories—

• Central (whole house return)
• Multiple (individual room returns).

Typically, a central return consists of one large grille located in a common-use area relatively close to the equipment which draws all of the house air back through the equipment. Doors to individual rooms are undercut to allow return air to get back

Central Return

Advantages	Disadvantages
• Ductwork minimal; usually one large duct with a relatively short run	• Generally noisier unless special acoustical provisions are made
• Allows for sufficient air flow with a minimum of air friction loss, thus minimizing blower requirements	• Doors to individual rooms must be undercut to permit proper air flow
• Easy to install	• Large duct may require a special chase
• Often preferred with an open plan	• Large grille can be unattractive
• Permits convenient air-filter servicing if a filter-grille is used, especially if equipment is in an attic or crawl space	
• Generally less costly	

Individual Returns

Advantages	Disadvantages
• Good sound attenuation inherent to system of branch ductwork; quieter operation	• Requires a second duct system, usually trunk and branch similar to supply system
• Facilitates good air flow within individual rooms, even with doors closed	• Installation more complex usually requiring a separate layout
• Provides better privacy, especially in bedrooms, since doors need not be undercut	• Usually more costly to install
• Small branch ductwork easily concealed within joist and stud spaces	
• Small grilles less conspicuous	

to the central return. In multistory homes one central return may be located on each level. Multiple returns are smaller and are designed and located to handle the air requirements of each room. Each system has its advantages and disadvantages.

The choice of return air system depends on performance criteria, construction limitations and cost. Sometimes the best solution is a combination of the two systems employing a central return for large adjoining open areas and individual returns for smaller rooms such as bedrooms or dens. Multilevel or two-story homes with a central return system typically would have a return air grille at each living level.

Sizing of Return Air Systems

Adequate sizing of the return air ducts and grilles is essential for optimum efficiency of the system. Unlike the supply ductwork in which oversizing (or undersizing) can result in poor performance, oversizing the return ductwork from a performance standpoint is almost impossible within reasonable limits. As a general rule, return ducts should be at least as large as the supply ducts, and preferably at least one size larger. The larger size promotes efficiency by reducing internal air friction, air velocity, and blower horsepower requirements. This tends to improve operating characteristics and reduces noise generated by air turbulence. The placement of returns and some additional insight regarding both supply and return duct sizing are discussed in Chapter 3, "Designing the Total HVAC System." Ducts and fittings used for return air systems are, for the most part, identical to the supply ducts and fittings discussed in Chapter 1.

Panning

The technique of enclosing a structural joist or stud space for use as a duct is referred to as panning. Traditionally, sheet metal has been used for panning. However, drywall, hardboard, or other suitable materials also can be used. Panning is particularly well suited to the return air system as opposed to the supply air system for several reasons—

- It is presently allowed by most residential codes

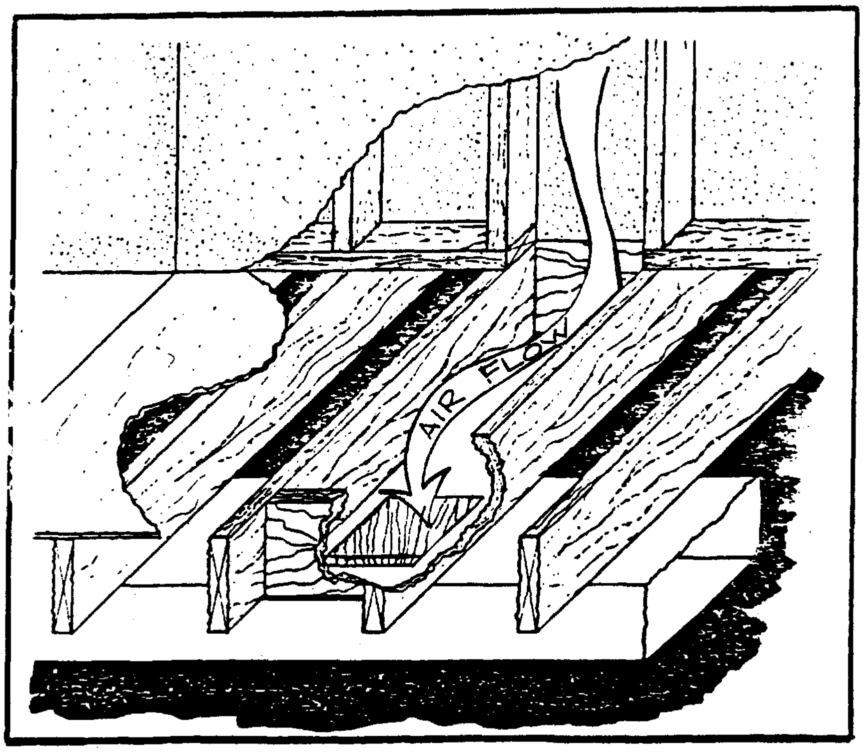


Fig. 62. Combination metal duct, panned joist space, and finished stud space for return air

- Low-temperature return air presents no fire hazard with framing members
- Relatively large joist and stud spaces can provide ample air flow with minimal friction losses
- Small air leaks resulting from normal construction tolerances are not critical to overall performance
- Panning minimizes metal duct and fittings needed; work may be done by carpenters and other trades.

Figure 62 shows combined use of a metal duct, a panned-joist space, and a finished-stud space for an air return. Any combination of these can be used. Other examples of non-ducted air passageways include boxed-in chases, dropped ceilings (especially in hallways), and raised-platform equipment closets utilizing the enclosed space as a return air plenum.

Sound Attenuation

Sound attenuation is of particular concern in return air systems. The source of noise in a duct system usually can be traced to the return air ductwork, especially on systems with short central returns. These operating noises come from two sources—

- Mechanical equipment
- Air turbulence

Mechanical Equipment

Noises generated by mechanical equipment include those from the blower, burner, and related mechanical vibrations. These are usually the major noise sources. These sounds can be transmitted to the living space through the return duckwork. The more direct the sound path, the greater the noise level. Therefore, an individual return-duct network will provide quieter operation. The less costly central return tends to transmit more noise.

Several techniques can alleviate noise associated with central returns—

- Locate mechanical equipment and returns away from heavily used rooms or rooms where lower noise levels are desired.
- Set equipment on vibration pads, install flexible connections to ductwork, or use other similar techniques to isolate the system from the structure.
- Line the blower compartment and return duct with acoustical duct insulation.
- Provide one or more 90 degree turns in return duct to create an indirect path back to equipment.

Air Turbulence

Many of the techniques used to reduce mechanical noises can also be used to reduce air flow noises. These include acoustical linings and turns in the ductwork.

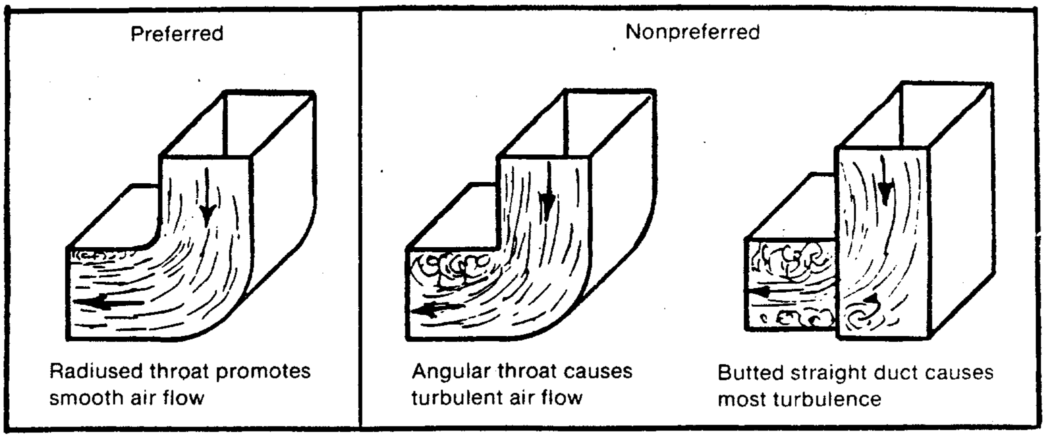


Fig. 63. Effect of fitting design on air flow

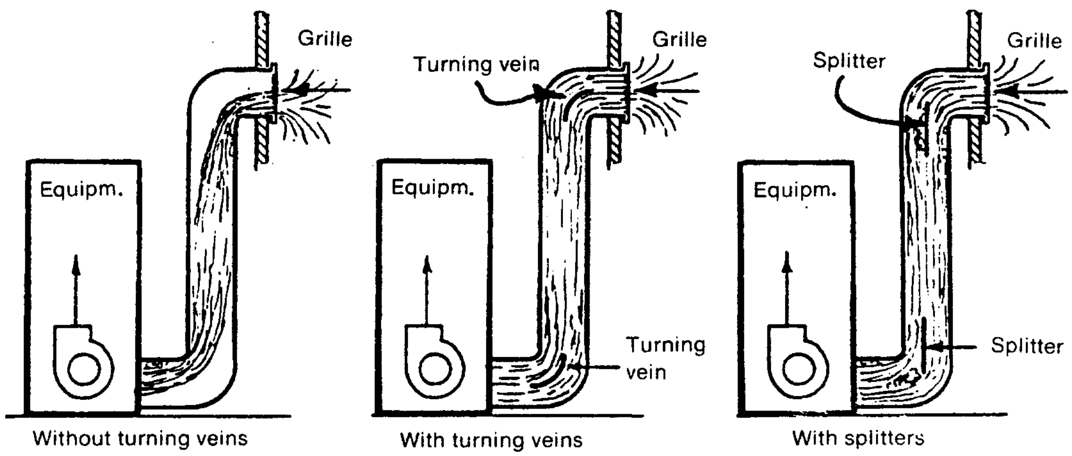


Fig. 64. Air flow in central returns

However, the most common sources of air turbulence noises are sharp changes in the direction of air flow in ductwork and uneven air flow through grilles. The following techniques can be used to alleviate these problems—

• Size return ductwork and grilles adequately. Undersized ducts or grilles will result in increased noise levels because of higher air velocity and trubulence.

• Install fittings with a curved rather than an angular throat to provide smoother flow of air with a minimum of turbulence and related noise (see fig. 63).

• Install turning veins or less costly (and less effective) splitters in the major elbows to promote uniform flow of air through fittings and across grilles (see fig. 64). Air being drawn at high velocity through only part of the grille is a frequent noise source. Although turning veins usually are associated with commercial installations, they also are effective in residential work.

3. Designing the Total HVAC System

This chapter brings together the elements that make up a complete HVAC design and provides general guidelines for determining heating and cooling requirements, selecting HVAC equipment, and designing the distribution system. A section on special considerations for energy conserving homes is included. The information is intended only as a guide to aid builders in understanding alternative systems so that they may deal more effectively with their subcontractors in obtaining a system that meets their requirements at the least cost. For precise system design, the services of a competent HVAC contractor or a mechanical engineer are still needed.

Determining Heating and Cooling Requirements

Heating and cooling loads must be calculated before the HVAC contractor or builder can select appropriate equipment and design the distribution system. This is done on a room-by-room basis to determine the amount of air that must be delivered to each room in order to maintain a well balanced temperature level throughout the house.

Heating Requirements

Loads calculated for the heating season are referred to as heat loss calculations since heat is being lost from the building. Heat losses must be calculated for all portions of the building envelope including walls, windows, doors, ceilings, floors and foundations. Losses also are calculated for ductwork passing through unconditioned spaces and for air infiltration (building leakage). The total of these losses is expressed in thousands of Btu per hour (Btuh) at an indoor temperature of at least 68° F when the outdoor temperature is at the winter design condition specified for a given location. Note the design temperature is not the coldest outdoor temperature that may be expected. Actual temperatures may be below design temperatures 2½ percent of the time based on recorded averages. Outdoor design temperatures for heating and cooling are listed in the *Insulation Manual—Homes/Apartments*, second edition.*

Cooling Requirements

Loads calculated for the cooling season are referred to as heat gain calculations. Heat gain is more complex than heat loss, since in addition to heat gains through the building envelope (similar to heat loss) there are other gains. They include internal gains from the heat given off by people, household appliances and lighting, and direct solar radiation through windows. The total of these gains can be sensed as heat by a thermometer or a thermostat, and are referred to as sensible heat gain.

In addition to the sensible heat gain, latent heat gain must also be calculated. Latent heat results from vaporization of the water or humidity that exists in the building. Latent heat cannot be sensed by the theromostat, yet some of it is removed by the cooling equipment through condensation on the cold evaporator coil. Latent heat can be significant; it is represented as one-third of the total cooling load in most calculations.

The sensible gain plus latent gain equals the total heat gain for the structure. Similar to heat loss, total heat gain is expressed in thousands of Btuh at an indoor design temperature of 78 to 80° F or less when the outdoor temperature is at the summer design condition. Heat gains are represented as tons of cooling, one ton equalling 12,000 Btuh.

Example: A house has a calculated heat gain of 29,430 Btuh:

$$\frac{29{,}430}{12{,}000} = 2.45 \text{ tons} = 2\tfrac{1}{2} \text{ tons (nominal)}$$

Estimating Heating/Cooling Loads

Several procedures are available to professional engineers and HVAC contractors for the calculation

*Available from NAHB Research Foundation, Inc., P.O. Box 1627, Rockville, Maryland 20850

Table 1. Heating and cooling load calculations

House Description		Heating		Cooling	
Builder's House Type or Model	Square Feet of Conditioned Space	Calculated Heat Loss (Btuh)	Btuh per Square Foot for Heating	Calculated Heat Gain (Tons)	Square Feet per Ton of Cooling
"A" Rambler	1440	34,143	23.7	21,048 (1¾)	821
"B" Rambler	1856	42,356	22.8	32,520 (2¾)	675
"C" Split Level	1971	48,664	24.7	33,126 (2¾)	714
"D" Two Story	2080	43,780	21.0	30,094 (2½)	832
"E" Bilevel	1716	35,803	20.9	27,550 (2⅓)	735
Average Values			23		750

of heat losses and gains. See the *Insulation Manual—Homes/Apartments*, second edition, for one developed by the NAHB Research Foundation and *Manual J, Load Calculation for Residential Winter and Summer Air Conditioning** for another. Whichever calculation procedure is used, the builder should insist that a detailed room-by-room heat loss-heat gain calculation be submitted for each house type (not a short-cut calculation or educated-guess method). If large unprotected glazing areas are incorporate in the architectural design and a standard house type is to be repeated on lots with different orientations, a separate calculation for each major orientation will be needed.

Traditional load calculation procedures sometimes result in overestimating heating and cooling requirements for heavily insulated energy efficient homes because of reduced air infiltration, passive solar gain and internal heat gain.

Load calculations prepared by the HVAC contractor or engineer can be checked by builders for basic takeoff or numerical errors, since builders are more familiar with the plans and specifications than the HVAC contractor, especially with more complex house configurations. If an error is found, it can be corrected before any decisions are made.

After some experience in reviewing heating/cooling loads, builders may wish to develop their own quick reference table summarizing Btuh-per-square-foot that applies to similar house types for the local climate. Table 1 is an example, which could be modified over a period of time.

While approximate loads of this type do not provide a basis for designing the HVAC system, they do help to develop a feeling for the heating and cooling loads and to evaluate the reasonableness of an HAVC proposal. By comparing approximate numbers of this type with calculations in a proposal, a major load calculation error can be easily identified. The builder may also use these approximate numbers to roughly assess energy requirements on proposed house designs.

*Available from Air Conditioning Contractors of America, 1228 17th Street, N.W., Washington, D.C. 20036

Example:

A builder decides to bring a new two-level house on line with 1,120 square feet on the upper level and 624 square feet finished on the lower level, for a total of 1,744 square feet. A bid for $3,400 is received from a heating contractor that includes a 120,000-Btu gas furnace, a 3-ton air conditioner, ductwork, and installation. Drawing on past experience and average per square foot loads in similar homes (23 Btuh per square foot heating, 750 square feet per ton cooling), the builder performed a quick estimate on this new house type to verify whether or not this proposal was in the right "ball-park," as follows—

Heating: 1,744 square feet × 23 = 40,112 Btuh
Cooling: 1,744 square feet ÷ 750 = 2.3 Tons

The HVAC contractor is asked to review his figures based on this evaluation. The HVAC contractor confesses that he has been installing the same system for another builder for years in a similar house type with no problems, and did not actually perform a load calculation.

A week later the HVAC contractor resubmits a bid (with calculations) showing a heat loss of 39,800 Btuh and a heat gain of 28,200 Btuh. The smallest gas furnace available locally is a 60,000-Btuh unit (48,000-Btuh output) with matching air conditioning equipment of 28,000 Btuh (2¼ tons). A determination is made that a smaller prefab flue and reduced ductwork could now be used. The revised bid price is $2,950. In addition to reducing direct construction costs by more than $450, this would provide a more efficient, comfortable, and economical HVAC system.

Selecting HVAC Equipment

This section describes different types and configurations of equipment, alternate fuels and comparative installation and operating costs. General equipment characteristics are then summarized to provide a basis for selecting the equipment.

The importance of proper size equipment and the related duct system should be emphasized. If undersized for cooling by more than 15 to 30 percent, a temporary temperature rise (temperature swing) of from 4.5 to 6°F can be expected above the indoor design temperature when outdoor design conditions are exceeded. This compares to a temperature swing of 3°F when the unit is exactly sized. If oversized by more than 10 percent for both heating and cooling, the equipment will cost more initially and will short cycle, resulting in lower comfort levels, higher operating costs, and a waste of energy. In addition, oversize cooling equipment may not provide adequate dehumidification because of reduced running time.

Designers have a tendency to oversize HVAC systems. Calculations are rounded to the high side, a percentage is added for safety, and the next larger size equipment is selected. Oversizing is not necessary because even a properly sized system is overcapacity except when operating at full design conditions. In addition, winter heat loss calculations do not take into account internal heat gains and passive solar heat gain—significant factors for homes having high levels of thermal protection.

Types of Blowers

At the heart of any forced-air system is the furnace or air-handler. It may include the blower, filter, controls, heat exchangers and coils housed in a cabinet. This equipment moves the air and adds or removes heat from the air as it passes through. The amount of air the blower is capable of moving is referred to as cubic feet per minute (cfm). Most residential equipment requires air volumes in the range of 500 cfm to 2,000 cfm.

Blowers generally are of two types—belt drive and direct drive (see Fig. 65). Belt drive blowers usually have a single speed motor, but offer a wide range of blower speeds through use of variable pulleys which transfer the power to the impeller by means of a belt. On direct drive blowers, the motor shaft is connected directly to the impeller. Blower speed can be changed by connecting one of several motor leads which yields a preset speed. Three or four

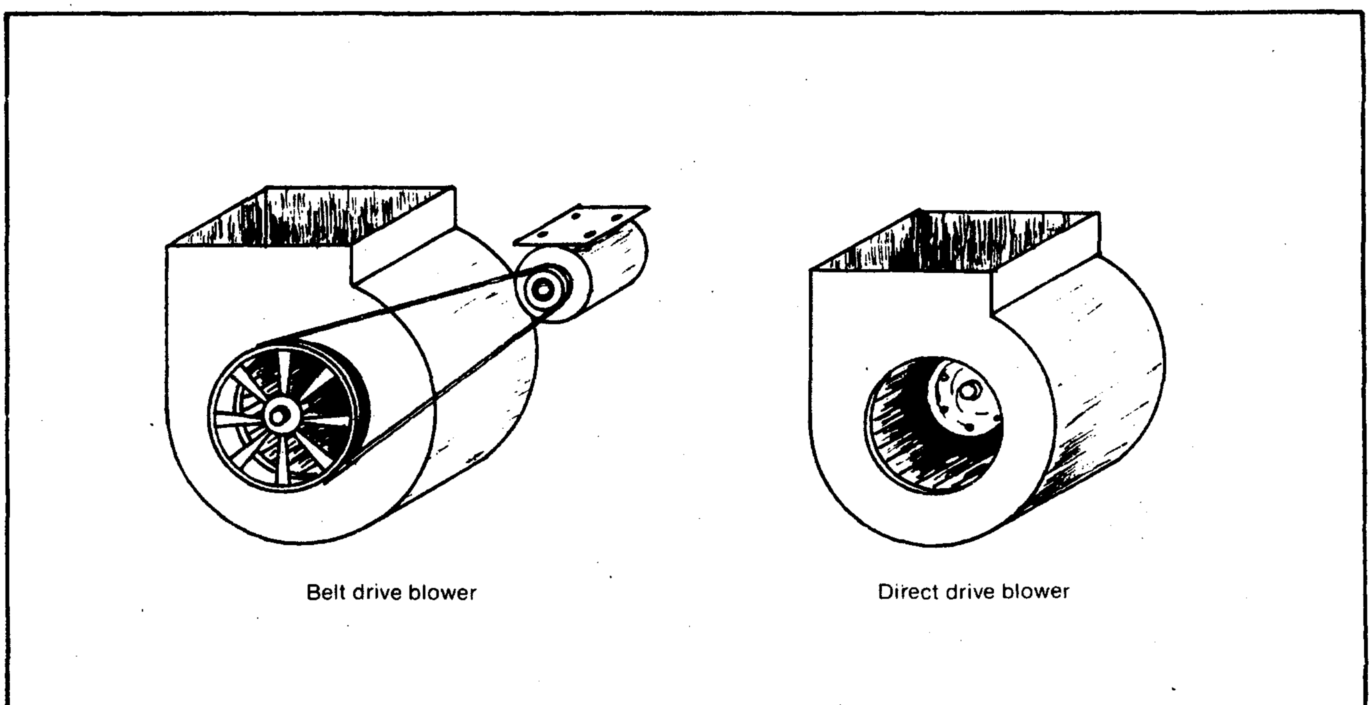


Fig. 65 Basic blowers types for residential equipment

speeds usually are available. Direct drive blowers usually are less costly, more compact and provide quieter operation.

Types of Heating and Cooling Equipment

There are several types and configurations of heating and cooling equipment. Their selection depends on available fuels, building design requirements and other factors. The most common types of HVAC equipment are illustrated and briefly described as follows:

- Upflow (Highboy) gas or oil furnace, Fig. 66
- Lowboy gas or oil furnace, Fig. 67
- Counterflow (downflow) gas or oil furnace, Fig. 68
- Horizontal gas or oil furnace, Fig. 69
- Coal furnace, Fig. 70
- Electric furnace, Fig. 71
- Split system cooling equipment, Fig. 72
- Refrigeration cycle, Fig. 73
- Heat pump, Fig. 74
- Self-contained unit, Fig. 75

Upflow (Highboy) Gas or Oil Furnace

Upflow furnaces are used where the ductwork will be installed above the unit. The furnace may be located in a basement with the distribution system just below the first floor joists, or in a first-floor utility room with the distribution overhead in an attic or dropped ceiling. Upflow furnaces usually are available in more sizes, and cost less than other types of units.

Lowboy Gas or Oil Furnace

Lowboy furnaces are similar to highboy upflow units but can be used where ceiling heights are restricted. Typically installed in basements of older homes as replacement units, they are generally more costly than highboy units. They are frequently equipped with a belt drive blower.

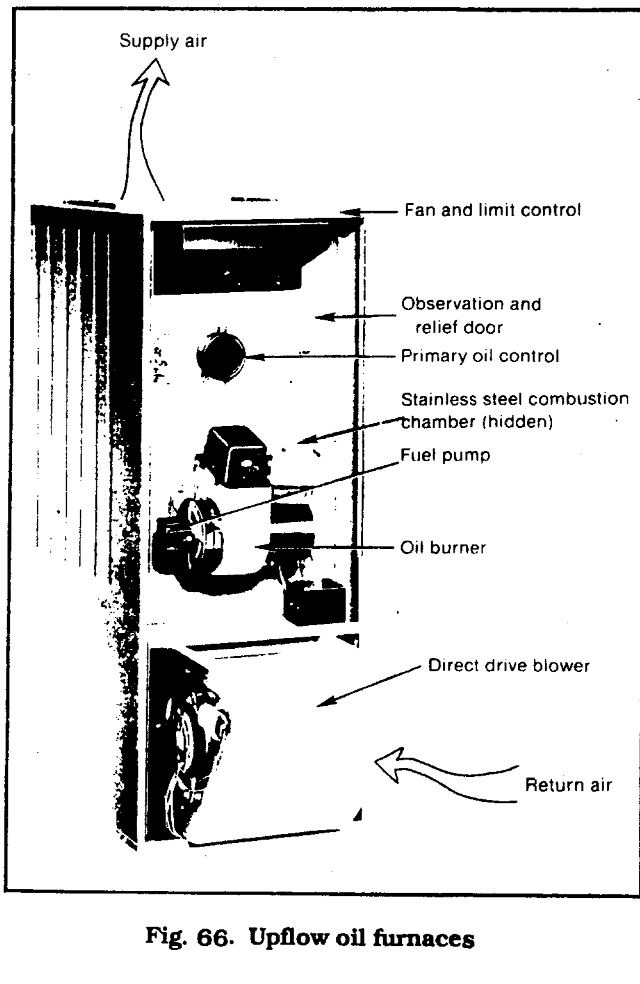


Fig. 66. Upflow oil furnaces

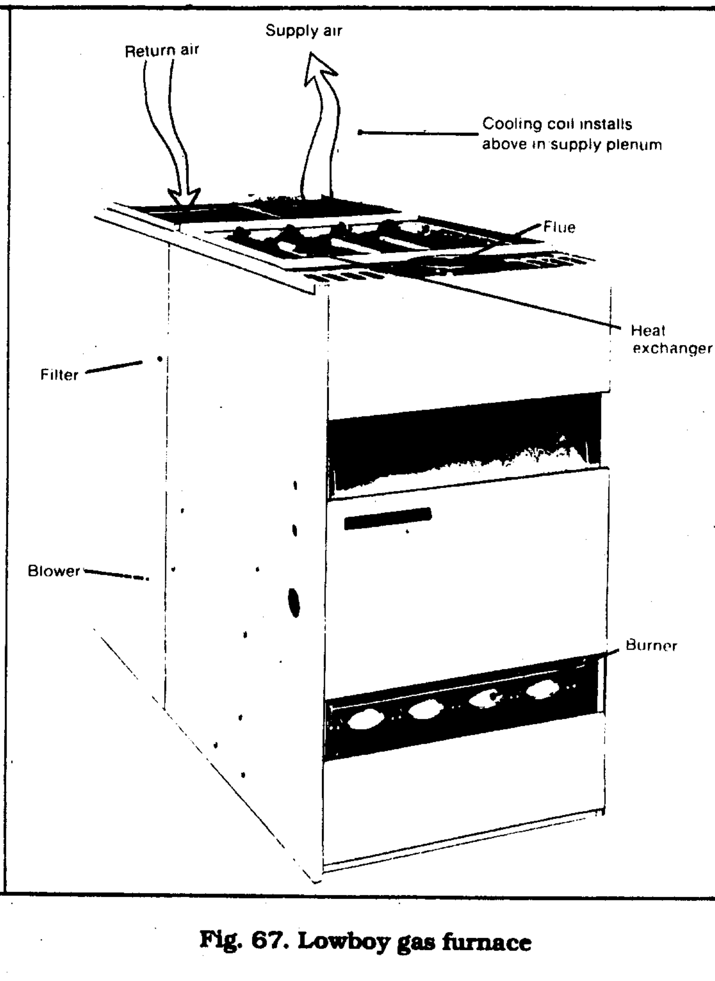


Fig. 67. Lowboy gas furnace

Counterflow (Downflow) Gas or Oil Furnace

Counterflow furnaces are frequently installed in single-story homes built on a slab or crawl space where the air distribution system is below the floor. The cooling coil typically is installed in the return plenum for draw-through operation. Counterflow furnaces usually are somewhat more costly than upflow units. When installed on wood-floor systems, most models require a noncombustible floor base which is purchased as a furnace accessory.

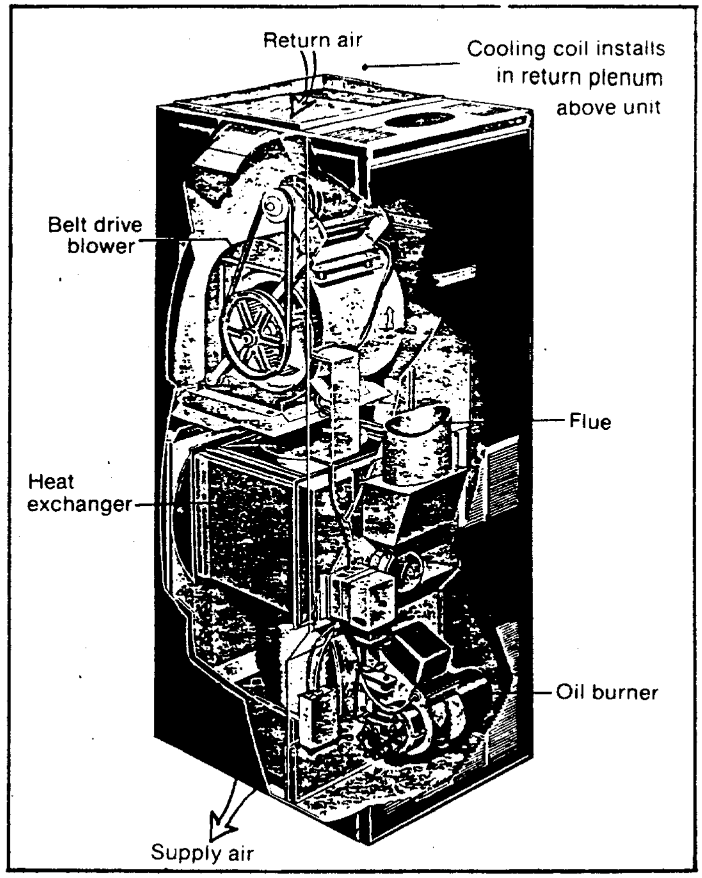


Fig. 68. Counterflow oil furnace

Horizontal Gas or Oil Furnace

Horizontal furnaces are designed primarily for installation in an attic or crawl space where both the unit and the distribution system will be located. Oil-fired units are customarily installed only in crawl spaces (or occasionally in basements) since an attic installation would require a two-stage oil pump to lift the heating oil, and because of potential damage and odors that could result from oil leaks. Horizontal furnaces are more costly than most upflow or downflow models.

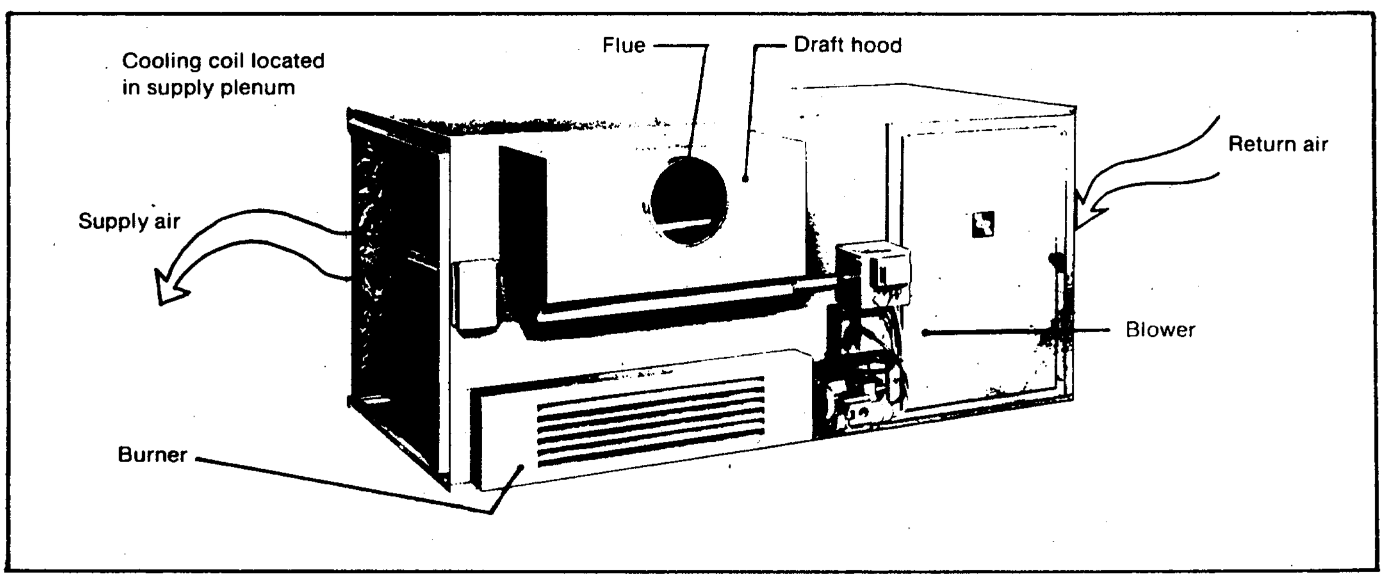


Fig. 69. Horizontal gas furnace

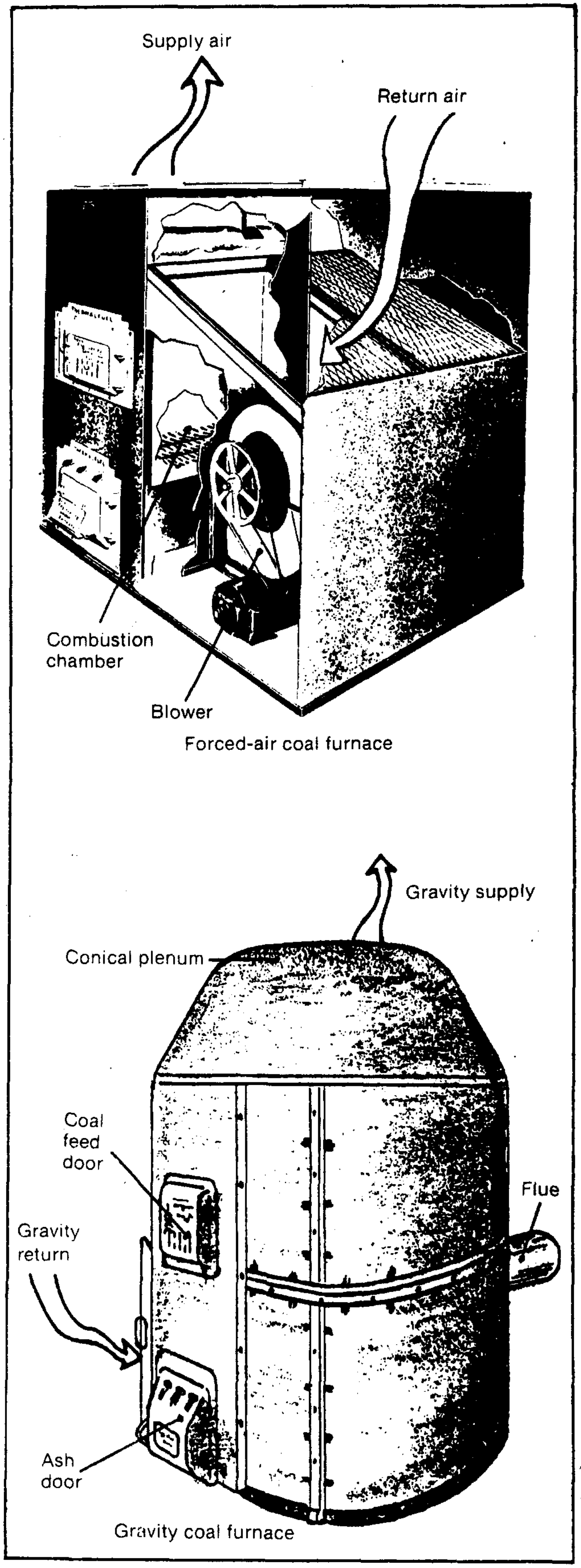


Fig. 70. Coal furnace

Coal Furnace

Coal furnaces are somewhat larger than other types and are generally designed for hand-firing into the upper door. Automatic stokers are available, but very costly. Most available units are an upflow design and are generally intended for basement installation, considering the dirty nature of coal handling and ash removal. In addition to coal, wood or even trash can be burned. Newer units are forced air with a large belt driver blower. Gravity models also are still available. Forced-air models are adaptable to air conditioning. Coal furnaces are more expensive than other types and tend to burn out sooner.

Electric Furnace

An electric furnace is simply an air-handler unit with electric resistance heating elements inside. Units are sized by either Btuh or kilowatts (Kw), one Kw equalling 3,413 Btu. Outputs typically are available in 5 Kw increments. Electric furnaces are compact and can be used in upflow, downflow and horizontal installations with little or no modification. They have a lower first cost, but operating costs are generally higher because of the high cost of electricity compared to other fuels.

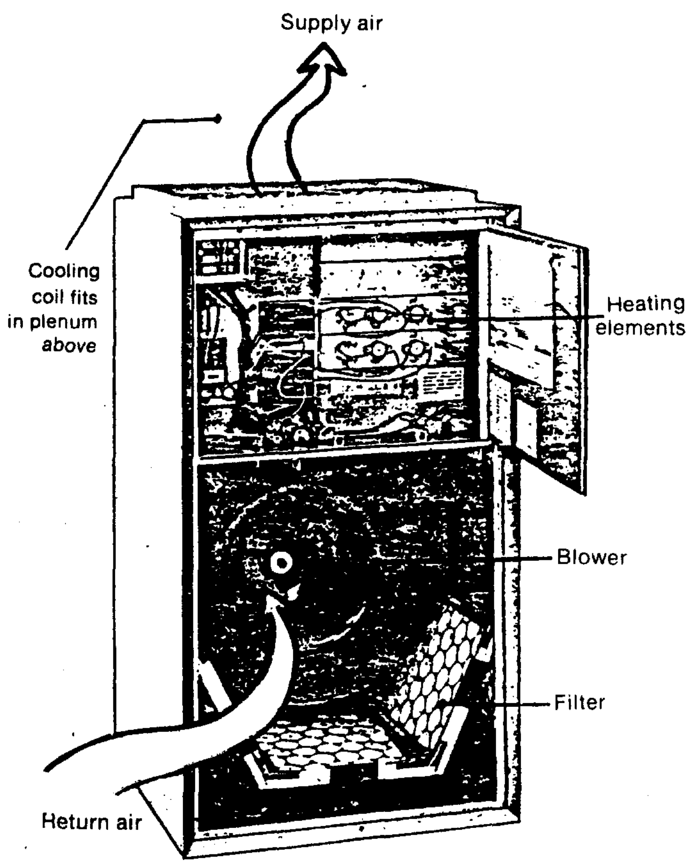


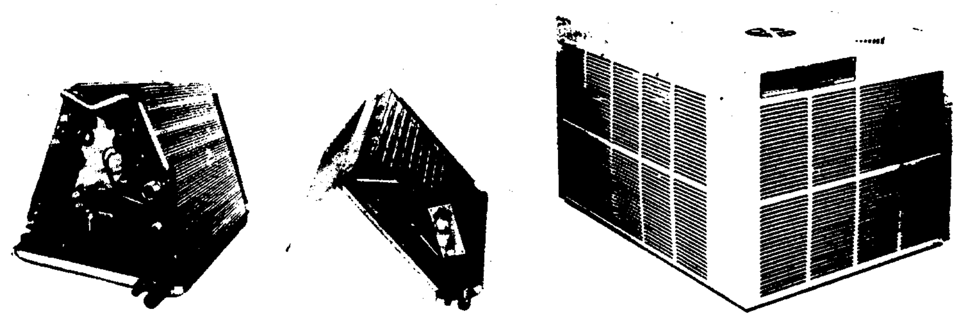
Fig. 71. Electric furnace

Split System Cooling Equipment

When cooling is incorporated with a standard furnace, a split system is generally used (see Figs. 72 and 73). A split system consists of the familiar outdoor condensing unit containing the condensing coil and compressor, the indoor evaporator coil (cooling coil), the interconnecting refrigerant tubing, and the blower which is part of the furnace. Cooling capacities of standard residential equipment range from 1½ to 5 tons normal. Performance efficiency of cooling equipment under test conditions is expressed in Btu output/watt input, called the energy efficient ratio (EER). Average cooling equipment has an EER in the range of 6.5 to 7.5, while some high efficiency equipment has an EER rating of 10 or more. Seasonal energy efficiency ratings (SEER) are being included now on some models. SEER ratings are generally lower than EER ratings and take into account minor reductions in installed efficiency that result from factors such as variable outdoor and indoor operating conditions, normal oversizing, and other installation variables.

A basic understanding of the refrigeration cycle is important when dealing with cooling equipment. Fig. 73 shows the refrigeration cycle for a standard air-cooled system. First, refrigerant vapor is compressed to a high-temperature, high pressure vapor at the compressor. The vapor passes through the coil cooled by a fan, and the vapor condenses into a liquid. The liquid refrigerant is transported in the high-pressure line to a metering device at the cooling coil where because of the release in pressure, it becomes a low-temperature vapor.

As warm, humid air from the return duct system passes over the coil, heat is removed and moisture condenses on the cold coil surface. It is important to provide adequate air flow across the cooling coil, as



Typical indoor cooling coils

Typical outdoor condensing unit
(contains compressor and condensing coil)

Fig. 72. Split system cooling equipment

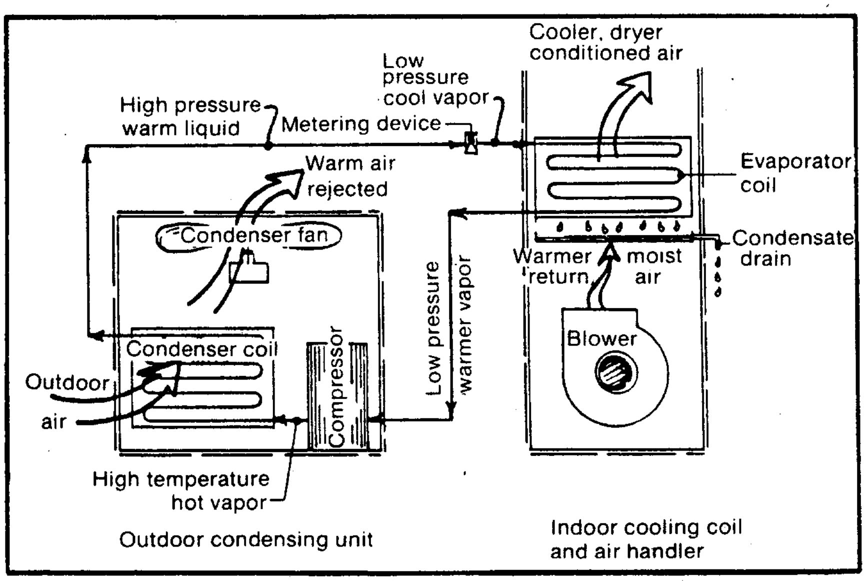


Fig. 73. Refrigeration cycle

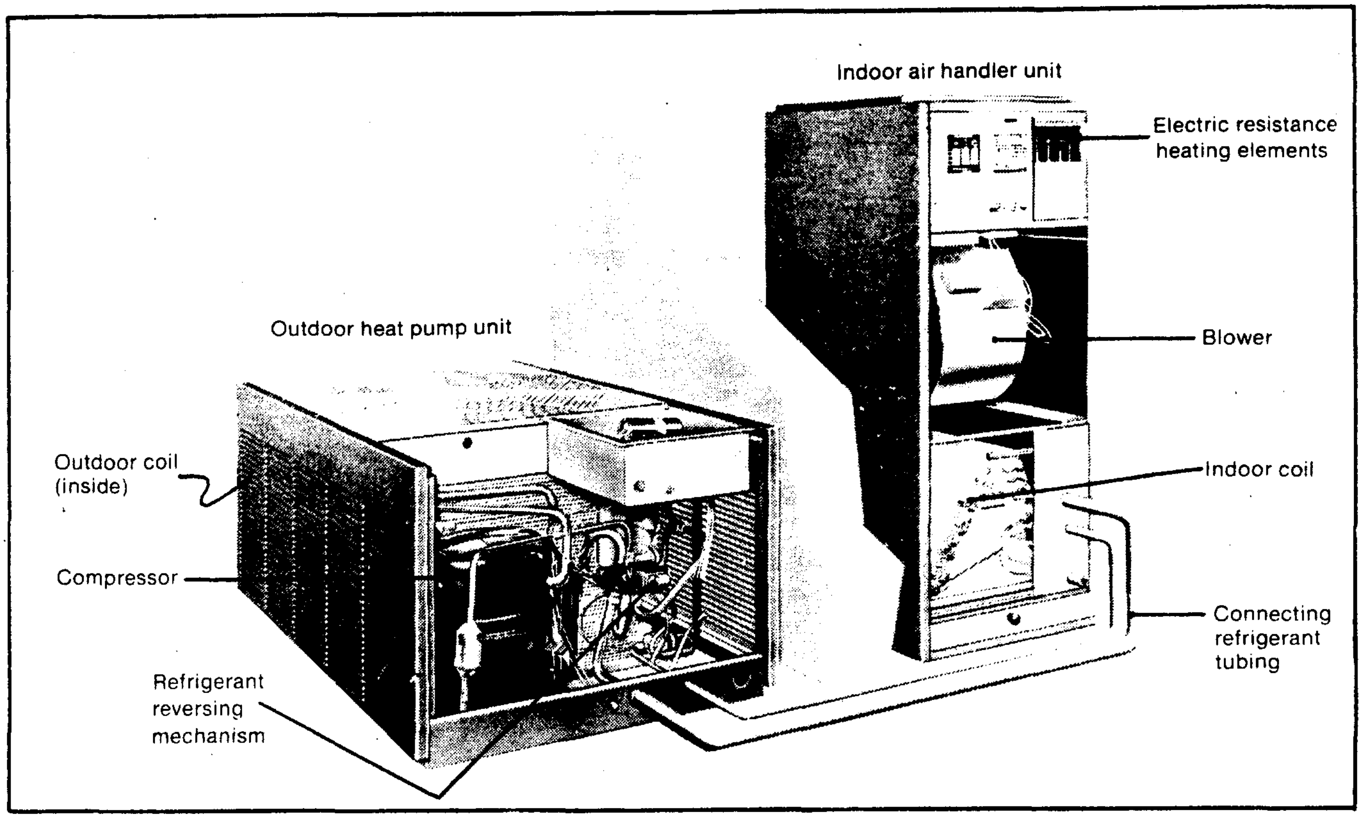


Fig. 74. Air-to-air heat pump system

recommended by the manufacturer, to avoid freezing and to maintain efficiency. The refrigerant in the coil then returns to the compressor in the low pressure line as a warm vapor to begin another cycle, and the cool, dehumidified air is distributed to the house through the supply ducts.

Heat Pumps

Two types of heat pumps are used in residential work: air source (air-to-air) and water source (water-to-air). The more common air-to-air heat pump resembles split system cooling equipment. An electric furnace is generally used to provide air handling and supplemental resistance heat. During the cooling cycle operation it is essentially the same as with split system cooling equipment. However, during the heating cycle, refrigerant flow is reserved with the outdoor coil functioning as the evaporating coil and the indoor coil functioning as the condensing coil. Heat from the outdoor air is absorbed by the refrigerant and is pumped to the indoor coil by the compressor where it is released into the duct system to warm the house.

The advantage of a heat pump is that space heating is generally provided more efficiently than with electric resistance heat. The efficiency of a heat pump is referred to as the coefficient of performance (COP) which equals the Btu output of the heat pump divided by the equivalent Btu input of electricity:

$$COP = \frac{\text{Btuh output}}{\begin{array}{c}\text{Kwh consumed}\\ \text{by equipment}\end{array} \times \begin{array}{c}\text{3,413 Btu}\\ \text{per Kwh}\end{array}}$$

The ability of an air-to-air heat pump to produce heat efficiently diminishes as the outdoor temperature drops. In most systems, when it can no longer meet the demand, output is supplemented by electric resistance heating elements. Heat pumps are best suited to areas with relatively moderate winter and summer weather, and least suited to areas with extremes of either cold or hot weather, since both heating and cooling are provided by the equipment. Most air-to-air heat pumps have a seasonal COP of about 1.5 to 2.0. The local power company is a good source of information on the use of heat pumps in a particular area.

Water-to-air heat pumps are similar to air-to-air heat pumps except that they extract heat from a water source such as a pond or shallow well rather than outdoor air. Their use is limited by the availability of a suitable water source. Ground water temperatures are generally higher than winter air temperatures and vary little over the season, usually ranging from 55 to 65° F. This results in a relatively high seasonal COP ranging from 2.0 to 3.0.

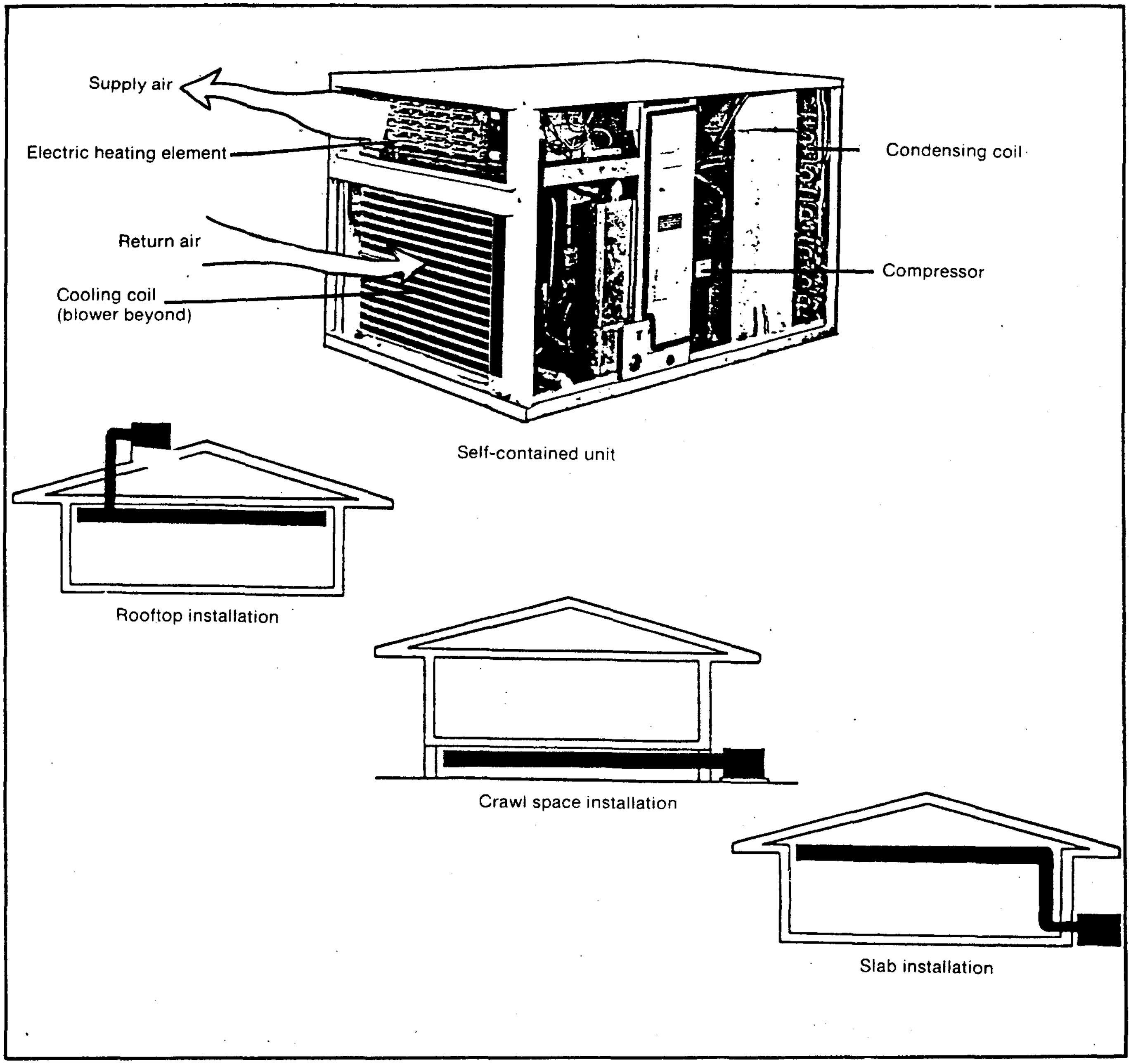


Fig. 75. Self-contained unit and alternate installations

Self-Contained Units

Cooling equipment is also available in a self-contained unit in which the condenser, blower, and coils are included in a single package. A heating option, usually gas or electric, generally is available on this type of equipment. Heat pumps also are available as self-contained units. This equipment can be either roof-mounted or located at ground level outside the house. No floor space and no interconnecting lines are required, and normally the cost is less than for a split system. Self-contained units are generally used in areas where cooling predominates. Typically, rooftop units are installed in conjuction with an insulated attic duct system. Units may also be set on a ground-level concrete pad to supply a crawl space or basement duct system. A disadvantage is that operating costs may be somewhat higher because the air handling equipment and some ductwork are located outside of the conditioned space.

Installation and Operating Costs

Initial installation cost and operating cost are important considerations in selecting equipment. Operating cost is dependent on the local availability and cost of fuel, and the seasonal efficiency of the equipment. The primary heating fuels are natural gas and electricity. Less common are #2 heating oil, propane, coal and wood. For cooling, electricity is used predominantly.

Table 2 summarizes relative installed costs by fuel type and relative operating costs for heating and cooling based on certain assumptions identified in the table. These comparisons may vary significantly depending on regional differences in fuel costs, heat content of fuel, climate and installation practices. Also, actual seasonal efficiency may be significantly lower than manufacturer ratings caused by such factors as design and installation deficiences, oversizing, normal cycling, standby losses, and inadequate maintenance and adjustment.

Heating Equipment Characteristics

In addition to installation and operating costs, a number of equipment characteristics should be analyzed for advantages and disadvantages. Table 3 outlines some typical characteristics of heating equipment by fuel type.

Designing the Distribution System

Once heating and cooling loads have been determined and the type of equipment selected, the distribution system itself can be designed. The primary design concern is proper sizing of the ductwork. For optimum performance, the ductwork must be sized to handle the airflow delivered by the HVAC equipment. The tables presented are rules-of-thumb to provide a working guide. Precise engineering of an air-distribution system is dependent on a room-by-room load calculation. Procedures for sizing ductwork are developed elsewhere. Two sources frequently used by HVAC contractors and engineers are *Manual D, Duct Design for Residential Heating and Cooling,** and *HVAC Duct System Design.***

*Available from Air Conditioning Contractors of America. 1228 17th Street, N.W., Washington, D.C. 20036

**Available from Sheet Metal and Air Conditioning National Association, 8224 Old Courthouse Road, Vienna, Virginia 22180

Determining Equipment Airflow

The total airflow (cfm) that a piece of equipment delivers to the distribution system essentially determines the sizes of the ductwork which must handle this airflow and direct it to the conditioned spaces. For precise airflow determination, manufacturer's literature for specific equipment must be consulted. Allowances for various system friction losses such as coils and filters and for operating at various static pressures usually are included in such literature. However, a few rule-of-thumb assuptions can be made concerning cfm, based on average conditions for the different equipment types. Table 4 summarizes typical airflow rates for the basic equipment types, with examples.

When heating and cooling are combined in the same system, the ductwork generally is sized for the operating mode requiring the *highest* cfm, usually cooling. Using the examples given in Table 4, in a home with a 64,000 Btuh gas furnace and 2½ tons cooling, the ductwork would be sized to handle 1,000 cfm based on cooling requirements, not 640 cfm, which would be the heating-only requirement.

Supply and Return Locations

The location of supply and return outlets can have a significant effect on the performance of an HVAC system. An understanding of air flow characteristics in combination with good judgment and common sense are necessary ingredients for effective placement of registers and grilles. Outlets and returns should be located to provide an acceptable level of comfort in the most critical operating mode, whether heating or cooling.

Supply and Return Air Patterns

A supply outlet is responsible for most of the air movement within a room. The distance it can deliver its airstream is referred to as throw. In addition to throw, supply air has the ability to induce motion in room air by entrainment into its main airstream.

Similar to the suction end of a vacuum cleaner hose, the return-air intake can only collect air in the immediate vicinity of the grille. This localized influence is in direct contrast to the airstream issuing from a supply outlet. To illustrate this comparison, Fig. 76 represents a room with a typical supply outlet and return intake grille, both with a face velocity of 600 feet per minute (fpm).

The supply air, as shown, still has a velocity of 50 fpm as far as 20 feet from the grille. The supply air outlet also entrains room air along its path, producing air movement throughout most of the room. The velocity of return air at the same time has

Table 2. Examples of relative efficiencies and operating costs for various equipment types ard fuels[1,2]

Type of Heating/Cooling Equipment	Typical Mfgr. Rating	Seasonal Efficiency COP/EER[3]	Typical Unit Fuel Cost as of 12/80[4]	Operating Cost Per Million Btu	Relative Installed Cost[5]
Heating					
Gas furnace, basic unit—natural gas	80%	60%	$0.375/Therm	$ 6.25	Medium Low
Gas furnace, IID + vent damper—nat. gas	80	70	0.375/Therm	5.36	Medium
Gas boiler, basic unit—natural gas	80	65	0.375/Therm	5.77	Medium High
Gas boiler, IID + vent damper—nat. gas	80	75	0.375/Therm	5.00	Medium High
Gas pulse combustion boiler[6]—nat. gas	95	90	0.375/Therm	4.17	Medium High
Gas furnace, basic unit—propane	80	60	.80/Gal.	14.65	Medium
Gas furnace, IID + vent damper—propane	80	70	.80/Gal.	12.56	Medium High
Oil furnace, flame retention	80	65	1.10/Gal.	12.26	Medium High
Oil boiler, flame retention	80	70	1.10/Gal.	11.39	High
Coal furnace, gravity	55[7]	35	75.00/Ton	8.92	High
Coal furnace, forced air	65	45	75.00/Ton	6.94	High
Coal boiler, forced circulation	65	45	75.00/Ton	6.94	Very High
Wood furance, forced air	65	45	80.00/Cord	6.17	Very High
Electric resistance heat	1.0	1.0[8]	0.05/Kwh	14.65	Low
Heat pump, air-to-air, average—heat	2.5	1.6	0.05/Kwh	9.16	Medium High
Heat pump, air-to-air, high eff.—heat	3.0	2.3	0.05/Kwh	6.37	High
Heat pump, water-to-air—heat	3.0	2.5[9]	0.05/Kwh	5.86	Medium High[10]
Cooling					
Split system, average—electric	7.5	6.8	0.05/Kwh	7.35	Low
Split system, high efficiency—electric	10.5	9.5	0.05/Kwh	5.26	Medium Low
Heat pump, air-to-air, average—cool.	7.5	6.7	0.05/Kwh	7.46	Medium
Heat pump, air-to-air, high eff.—cool.	9.0	8.1	0.05/Kwh	6.17	Medium High
Heat pump, water-to-air—cool.	11.0	10.0[9]	0.05/Kwh	5.00	Medium High[10]
Gas absorption unit—natural gas	.5	0.40[11]	0.375/Therm	9.38	High

1. Varies regionally with specific installation, climate, equipment sizing and type.
2. Electrical consumption is not reflected in efficiency values for fossil fueled equipment unless noted, but is included for heat pump and air conditioning equipment.
3. Assumes new equipment properly maintained.
4. Assumed average fuel values: natural gas 1000 Btu/cu. ft., propane 91,000 Btu/gal., #2 fuel oil 138,000 Btu/gal., electricity 3413 Btu/Kwh, coal 12,000 Btu/lb., seasoned hardwood 8,000 Btu/lb.—3,600 lb./cord.
5. Relative installed costs include all equipment and related tanks, flue, piping, wiring, etc.
6. Assumes complete condensation of water vapor in flue gases.
7. Units typically rated by gross output in Btuh for a specific grade of fuel, based on a formula which factors in grate area, pounds of fuel per square foot of grate, and an efficiency not to exceed 65% for forced circulation. Gravity units about 10% lower in rated output.
8. COP of 1.0 based on direct conversion of electricity into heat, such as an electric furnace. Zoning or individual room control as with electric baseboard may result in further operating economy because of localized control as opposed to central control.
9. Based on a constant ground water temperature of about 60°F.
10. Relative cost highly dependent on cost of obtaining a suitable ground water source.
11. Steady state COP for most absorption units equals about .50. Seasonal COP of 0.40 includes adjustment for blower operation, controls, and cycling.

Table 3. **Heating equipment characteristics**

Equipment Type	Typical Available Output Ranges	Advantages	Disadvantages
Gas furnace	40,000 to 150,000 Btuh	Burner relatively quiet Warm, comfortable heat delivered to spaces Clean burning, minimal service Available in upflow, downflow, and horizontal	Use limited to availability of natural gas Flue required Lower output units (15,000 to 30,000 Btuh) compatible with actual requirements not readily available Seasonal efficiency reduced by oversizing
Oil furnace	72,800 to 168,000 Btuh (.65 to 1.5 gph nozzle size)	Favorable alternative to electricity in colder climates Warm, comfortable heat delivered to spaces Available in upflow, downflow, and horizontal	Burner relatively noisy Flue and storage tank required Lower output units (15,000 to 30,000 Btuh) compatible with actual requirements not readily available Seasonal efficiency reduced by oversizing Occasional service required to assure clean combustion
Electric furnace	17,065 to 136,520 Btuh (5 Kw to 40 Kw)	Warm, comfortable heat delivered to spaces No flue required Small space requirement Same unit adaptable to upflow, downflow, and horizontal Many sizes available in small increments (5 Kw) allows close sizing to actual loads Minimal service	High operating cost in most areas
Heat pump (air-to-air)	18,000 to 60,000 Btuh (1½ to 5 tons)	No flue Space requirement similar to electrical furnace Same unit often adaptable to upflow, downflow, and horizontal Economical operation compared to electric resistance furnace Uses same equipment for both heating and cooling	Lower air temperature at registers Higher air volume requires more critical duct design Economical heating output limited to nominal tonnage of air conditioning size Least efficient when coldest outdoors Less efficient for cooling than available high efficiency, cooling only, condenser-coil combinations Servicing more sophisticated than furnace
Heat pump (water-to-air)	18,000 to 60,000 (1½ to 5 tons)	No flue Space requirements similar to electric furnace Same unit adaptable to upflow, downflow, horizontal Extremely efficient in both heating and cooling modes	Requires dependable ground water source within economical operating temperature range Requires means of returning water to ground or other drainage Potential freeze-up problems in cooler climates Installed cost highly dependent on cost of obtaining ground water
Coal/wood furnace	80,000 to 200,000	Provides abundance of warm heat utilizing economical fuels Ideal for retrofit in poorly insulated older homes Coal furnace can burn coal, wood, and even trash Operation not dependent on electric supply, hence not affected by outages	Economical use limited to availability of wood or coal Requires large space for coal/wood storage and larger furnace Requires frequent daily firing Coal handling and ash removal messy and inconvenient Grossly oversized for most new construction Difficult to accurately control temperature Tends to overheat home during moderate weather

Table 4. Approximate cfm for HVAC equipment

Equipment Type	Approximate Airflow Rate	Example
Gas/Oil Furnace	1 cfm per 100 Btuh output	64,000 Btuh output furnace $\frac{64,000}{100} = 640$ cfm
Electric Furnace	*50-70 cfm per Kw input	1. 10 Kw furnace 10x70 = 700 cfm 2. 30 Kw furnace 30x50 = 1500 cfm
Electric Air Conditioning	400 cfm per ton	30,000 Btuh cooling $\frac{30,000}{12,000} = 2\frac{1}{2}$ tons 2½x400 = 1000 cfm
Heat Pump	450 cfm per ton	30,000 Btuh heating/cooling $\frac{30,000}{12,000} = 2\frac{1}{2}$ tons 2½x450 = 1125 cfm

*Varies significantly with equipment. Cfm/Kw tends to be higher with smallest equipment (5-15 Kw), lower as equipment becomes larger.

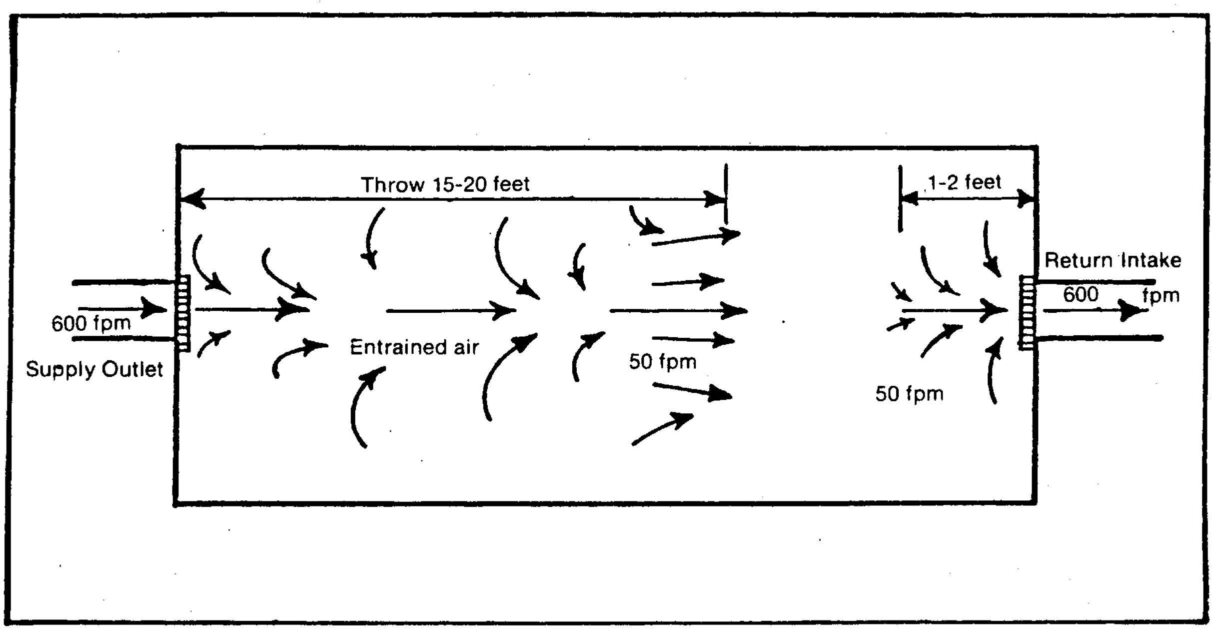


Fig. 76. Influence of supply outlet and return intake on room air movement

dropped to 50 fpm within 2 feet of the grille without significantly influencing air patterns in the room.

Several general observations on the location of supply outlets and returns follow—

- Air patterns within a room are primarily determined by placement and sizing of supply air registers.
- Low return air intakes draw cooler air from the floor to improve heating.
- High return air intakes draw warmer air from the ceiling to improve cooling.

Air patterns are also affected by drafts from air infiltration and thermal convection currents stemming from cold surfaces.

Air Stratification

Air stratification is another factor affecting register and grille placement. Stratification is the tendency of different layers of temperature to develop from floor to ceiling. In homes having low levels of thermal protection, the temperature difference between the floor and ceiling may be 5 to 10°F or more. The placement of registers and grilles in such homes was considered critical in reducing these differences. However, in most houses built with today's higher levels of thermal protection, temperature stratification is in a more acceptable range of 2 to 5°F, and register and grille placement is much less critical.

Continuous blower operation traditionally has been recommended to alleviate air stratification. In today's energy efficient homes, if the equipment is not oversized, the benefits of continuous blower operation are marginal compared to the added cost of operating the blower.

Supply Locations for Year-Round Operation

Supply outlets are traditionally located near the source of highest heat loss (heating) or highest heat gain (cooling). Supply outlets are generally placed to serve the more critical need since it is not usually practical to install two separate supply systems.

In cold climates where heating requirements prevail, perimeter floor outlets generally are preferred. In hot climates where cooling prevails, ceiling diffusers or high wall outlets that blanket the entire area often are used to provide good cooling distribution.

In more moderate climates, particularly in well insulated homes, comfort conditioning is not as critical and therefore outlet location is less critical. Floor outlets located along interior walls will be satisfactory in many cases with a significant reduction in ductwork. High inside wall outlets are another option, typically associated with distribution systems located in a dropped ceiling. An adjustable straight-blade register sized to throw the conditioned air across the room provides good cooling characteristics, as well as inducing sufficient room air movement to provide acceptable heating performance. See Table 5 for a guide to register selection for different climates.

Table 5. Guide for register selection and location by climate

Type of Climate	Principal Operating Mode	Supply Outlet Location	Preferred Register Type	Comfort Performance		Comments
				Heating	Cooling	
Cold	Heating, little or no cooling	Perimeter floor	Floor register Baseboard diffuser	Very good Very good	Good Good	Floor register provides minimal interference with draperies
Moderate	Heating predominant	Perimeter floor	Floor register Baseboard diffuser	Very good Very good	Good Good	Same as above
		Low inside wall	Baseboard or floor diffuser	Satisfactory	Satisfactory	Best suited to houses with a high level of thermal protection
		High inside wall	Adjustable straight blade	Satisfactory	Good	Same as above. Requires initial adjustment only
	Cooling predominant	Perimeter ceiling	Curved blade diffuser	Satisfactory	Very good	Requires blade adjustment between seasons for optimal performance
Hot	Cooling, little or no heating	Ceiling	Ceiling diffuser	Poor	Very good	Central room location provides uniform air distribution
			Curved blade diffuser	Satisfactory	Very good	More adjustability to meet special requirements

Return Locations for Year-Round Operation

While return air grilles have significantly less effect on room air motion than supply air registers, they can be located to enhance total system performance. For heating, since warm air rises, a low return helps the supply outlet perform by drawing off the cooler air near the floor. For cooling, since cool air falls, a high return draws off warmer air near the ceiling. For year-round operation, returns should be placed to serve the more critical need, as follows:

Operation	Return Location
Heating only	Low
Cooling only	High
Heating predominant, some cooling	Low
Cooling predominant, some heating	High

On multilevel and two-story homes with both heating and cooling, good judgment again applies. Since upper levels will tend to heat more readily by natural convection, cooling is more critical and the upper-level returns should be placed high. Conversely, lower levels will tend to cool by convection, and the returns should be placed low to improve heating.

Placing returns in some rooms or areas may be ill-advised for reasons of odor, safety, or comfort. These include—

- Bathrooms
- Kitchens
- Garages
- Mechanical equipment rooms (if fossil fuel)
- Areas where noise or drafts may be objectionable

Ductwork Sizing

Proper duct sizing allows for optimal performance within the limitations of the system for which it was designed. Undersizing can result in higher noise levels, higher operating costs, and reduced comfort and consequent customer complaints. Oversizing of supply ductwork can often result in system imbalance and higher installation costs.

Supply Duct Sizing

Total air-carrying capacity of a supply duct depends on the cross-sectional area, total length, friction losses in ducts and at fittings, type of duct material, and blower output. These factors would all be considered by a competent HVAC designer. For purposes of this guide, however, average values are used with examples of duct sizing.

Table 6 lists the nominal cfm capacity for several duct sizes that are generally considered standard in the HVAC industry. This table is referenced in text and examples that follow. In areas where fiberglass duct systems are common, or where other duct sizes are commonly used in local practice, this table can be used by equating cross-sectional areas and interpolating the cfm values. The cfm values shown are averaged to allow for a reasonable margin of error when approximating sizes for a system design. A nominal 20 percent increase in cfm capacity for a given duct size is allowable for estimating purposes.

Several explanations and rules-of-thumb helpful in sizing ducts follow—

- Standardized rectangular duct sizes—The rectangular sizes listed in Table 6 will cover most residential designs requiring rectangualr trunk duct. The 4-inch increment provides a reasonable spread between cfm capacities and duct cost. This provides the contractor sufficient design flexibility with a minimum inventory of stock duct sizes. Other sizes or special fittings can be custom fabricated.

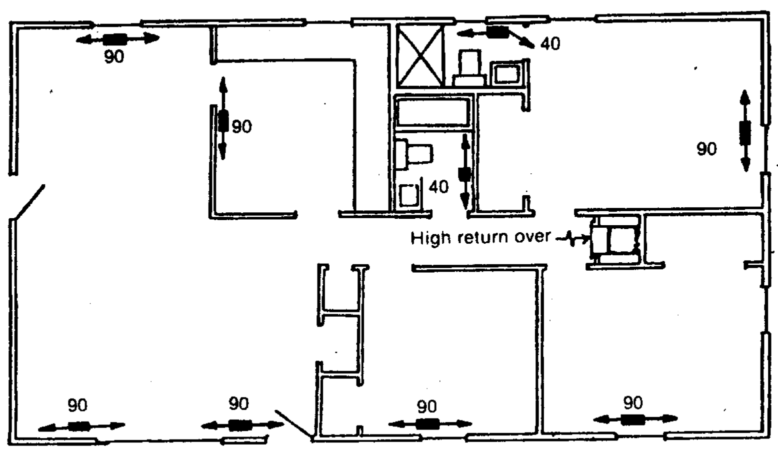
- Round duct sizes—The round duct sizes listed provide a wide range of air volumes for branch ducts in extended plenum and radial systems. Because 100 cfm $\pm$ per outlet works well for many system designs when left open or dampered, many contractors standardize on 6-inch round branch ducts to simplify design and installation, and to minimize costs. With these designs, a 6-inch round branch duct can be left open to its full capacity or be dampered for small rooms such as baths. Average size rooms such as bedrooms or kitchens can be designed by the rule-of-thumb of one outlet per room. Larger rooms such as master bedrooms, living rooms, or areas with large amounts of glass may require two or more outlets. An inexpensive damper installed at each branch takeoff provides for airflow adjustment if required. As a quick cross-check, the total number of outlets times 100 cfm should approximately equal the cfm capacity of the heating/cooling equipment.

- Lined ductwork—Metal ductwork which has been lined with fiberglass duct liner will have a smaller inside area, thereby reducing its cfm capacity. Suitable allowances should be made when estimating duct sizes. For example, a 12- by 8-inch duct with a ½-inch lining nets out as an 11- by 7-inch duct. The inside area has been effectively reduced from 96 to 77 square inches. Interpolating from Table 7, it could carry approximately 380 cfm (a little less than halfway between an 8- by 8-inch and a 12- by 8-inch duct). Technically, the fiberglass lining material increases friction losses, but in typical residential design this is not significant.

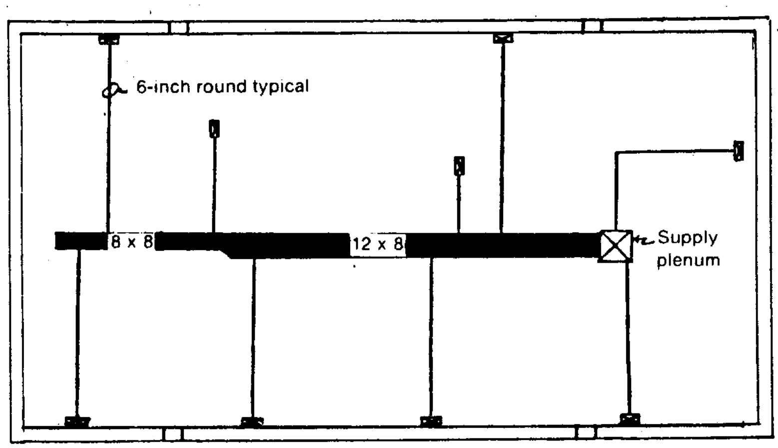
Table 6. Average cfm capacity for standard residential supply duct sizes*

Duct Type	Duct Size (Inches)	Nominal Cross-Section Area (Square Inches)	Nominal CFM Capacity
Round or oval branch duct or rectangular equivalent	4	13	40
	5 (3¼x8)	20	70
	6 (3¼x10)	28	120
	7 (3¼x14)	38	170
	8	50	250
Rectangular trunk duct	8x8	64	300
	12x8	96	500
	16x8	128	750
	20x8	160	1000
	24x8	192	1250
	28x8	224	1500

*For nonstandard duct sizes, compute cross-sectional areas and interpolate cfm.



First-floor plan



Crawl-space plan

Fig. 77. Preliminary HBAC system in one-story house

Return Duct Sizing

When return duct systems are undersized the system will operate less efficiently, run at higher noise levels, and provide less effective conditioning. Two rules-of-thumb based on static pressures and velocities normally used in determining return duct sizes are—

- The return main should be at least as large in total area as the supply main.
- Increasing the return duct one nominal size larger than the supply duct generally provides a quieter system with improved operating characteristics. For example, if the supply trunk duct is 20-by 8-inches at its largest point, then a 24- by 8-inch main return duct could be used.

The same rules-of-thumb apply to either branch or individual returns. For example, if a room is supplied by a properly sized 6-inch round branch duct, an individual return would be at least a 6-inch or perhaps a 7-inch round duct.

Example of a Preliminary HVAC System Design

A preliminary HVAC system can now be developed utilizing the general knowledge of HVAC systems presented in this chapter. Fig. 77 refers to a typical extended plenum system as shown in Chapter 2, Fig. 44. The example home is a 1,232 square foot single-story over a crawl space.

Referring to Table 1 on load estimating and the example with Table 1, determine the approximate heating and cooling loads.

Heating: 1,232 square feet × 23 Btuh/square feet = 28,336 Btuh

Cooling: 1,232 square feet ÷ 750 square feet /ton = 1.64 □ (1¾ tons, nominal)

Since gas is locally available, a gas furnace (40,000 Btuh output - smallest available size) with split-system cooling, is to be used. Table 4, equipment cfm, is used to determine approximate equipment cfm for duct sizing. Typically, cooling governs cfm for duct sizing.

Heating: 40,000 Btuh × 1 cfm/100 Btuh output = 400 cfm

Cooling. 1¾ tons × 400 cfm/ton = 700 cfm

By referring to Table 5, it is then determined that a perimeter distribution system with floor outlets would be a good choice in a moderately cold climate. Assuming that an extended plenum system with 6-inch round branch ducts is being installed, the outlets are distributed around the perimeter using the one outlet per average room rule-of-thumb. The living room is larger than average and has a large front window plus a door, so two outlets are used. The two bathroom outlets will be dampered to approximately one-half capacity. Total airflow at an assumed 100 cfm per outlet yeilds approximately 800 cfm. Considering that airflow is more critical for cooling, it is arbitrarily decided that 700 cfm is adequate.

Referring to cfm capacities for ducts, Table 6, the first 3 outlets from the end total 270 cfm and can be carried by an 8- by 8-inch duct. The next 4 outlets total 260 cfm for a new total of 530 cfm. A 12- by 8-inch duct size appears adequate considering that some tolerance is built into the tables. The last two outlets are tapped into the supply plenum. Had they tapped into the trunk duct, it would have been sized as a 16- by 8-inch duct. Knowing this, the short return duct is increased one size to 20-by-8-inches using the rule-of-thumb suggested in "Return Duct Sizing." "Return Locations" indicates that a low return is preferred. However, space limitations with the counterflow furnace might dictate a high location. Since the system load is reasonably split between heating and cooling, and return sizing is an overriding consideration compared to location, the high return is a compromise that can be accepted. The HVAC contractor may suggest an alternate solution.

While the preliminary design method described above is relatively unsophisticated, it is based on sound principles used by professionals. This same approach can be used to evaluate an existing or proposed system.

HVAC Systems in Energy Efficient Homes

The main purpose of this guide has been to acquaint builders with alternate types of HVAC systems as applied to a variety of typical house designs. However, some considerations relative to homes built with a high level of thermal protection deserve special attention. A comprehensive reference developed by the NAHB Research Foundation, Inc., *Designing, Building and Selling Energy Efficient Homes*,* discusses such homes in detail.

Lower Heating/Cooling Loads

The principle characteristic of energy-efficient homes concerning the HVAC system design is simply the reduced heating and cooling load. Experience shows that highly insulated, tightly built homes with superior window and door closures, and proper attention to design details such as summer shading, have significantly lower heating and cooling loads than common experience might

*Available from Publications orders, National Association of Home Builders, 15th and M Streets, N.W., Washington, D.C. 20005 indicate. Actual loads can be in the order of one-half to one-third that expected in a more typical home. For example, a typical 1,600 square foot home in a moderately cold climate might have a calculated heating load of 40,000 Btuh and a cooling load of 24,000 Btuh (2 tons) at design temperature. By comparison, a similar home built with special energy-conserving measures might have actual loads of 14,000 Btuh for heating and 12,000 for cooling.

When building an energy-efficient home of this type for the first time, builders may want to work more closely with their HVAC contractors, mechanical engineers or utility companies that calculate heating and cooling loads for their homes. Quite often, heating and cooling load values are simply taken from tables that may not reflect the higher level of insulation and low air-infiltration rates. In fact, many recognized calculation procedures have relatively high infiltration rates factored into their tables, .5 to 1.0 air changes per hour. A tightly built home, however, may have an infiltration rate of less than .2 air changes per hour. The builder of an energy-efficient home should request that load calculations be prepared representing the installed R-values of insulation, and that air infiltration loads be calculated separately to reflect the tighter construction.

Smaller Equipment Size

The lower heating and cooling requirements of energy efficient homes mean that smaller heating and cooling equipment can and should be used. Many such homes (and apartments) call for heating equipment with relatively low outputs ranging from 7,500 to 30,000 Btuh. Similarly, cooling equipment of 1 to 1½ tons capacity is adequate for many of these homes.

An increasing number of manufacturers are offering equipment in this range, particularly electric and heat pump equipment. However, much of the equipment on the market is still grossly oversized for energy-efficient homes. Fossil-fueled equipment, particularly, is generally unavailable in a lower output range. Oversized heating and cooling equipment is not only less efficient, but also produces less comfort as a result of short operating cycles; oversized cooling equipment provides inadequate dehumidification and air movement. Operating costs will also be higher.

The builder and HVAC subcontractor should strive to obtain properly sized equipment that accurately reflects the reduced heating/cooling loads of an energy-efficient home and should resist the temptation to install larger equipment "just to be sure."

Simplified Distribution System

The reduced level of heat loss/gain through the ceiling, walls and floor of an energy-efficient home make it easier to heat and cool. The design of the duct system, and location and number of outlets therefore becomes less critical in many respects. Smaller ducts accommodate the reduced air flow from the lower output equipment. Blanketing exterior walls and windows with warm air from perimeter outlets to overcome cold surfaces and drafts is less important. Similarly, ceiling or high outlets are not essential for acceptable summer cooling.

Abbreviated duct systems with outlets located at inside partitions—high or low in the wall or floor—which might have been considered unacceptable in the past, can perform quite satisfactorily in energy-efficient homes. A duct system located in a dropped hall ceiling, as shown in chapter 2, fig. 46, is well suited to such homes even in relatively cold climates. If tightly constructed, the dropped ceiling space can sometimes be used as an extended plenum, eliminating much of the duckwork. Most codes, however, limit this application to equipment with lower temperature outputs such as heat pumps.

Larger rooms which might have been provided with two or three outlets in a typical home, may require only one outlet in an energy efficient home. In some cases, small rooms such as interior baths or baths with no windows may have loads that are so small (e.g. 25-150 Btuh) that no outlet is required, since the room will gain adequate heat from adjacent conditioned spaces.

Reduced Cost, Increased Comfort

The reduced equipment size and simplified distribution system possible in an energy-efficient home can provide some savings in the cost of the total HVAC system, and this savings can contribute toward the extra cost of an energy-efficient home. Indeed, the energy-efficient home should be viewed as a package, including the HVAC system along with other energy-conserving features. The reduced operating cost of a well-built energy-efficient home is an increasingly important factor to home buyers as energy costs soar.

Another benefit of energy-efficient homes that is not always recognized is the increased comfort. The high degree of thermal protection moderates the surface temperatures of walls, ceilings, floors, windows, and doors. This increases the mean radiant temperature (the temperature that people feel) in winter and reduces it in summer. Together with the reduced drafts from infiltration, the comfort factor is enhanced to the point that thermostats can often be set back in winter and set up in summer without sacrificing comfort. In addition, an energy-efficient home tends to moderate the daily temperature swings from day to night, which contributes to comfort and also reduces the demand for heating or cooling.

One less desirable effect that some have experienced with tightly built homes is high levels of relative humidity. This condition generally results from over-zealous use of vapor barriers and is more likely to occur in smaller homes. Vapor barriers are encouraged in walls to avoid moisture condensation in the unvented wall cavity. However, it has been found that elimination of a ceiling vapor barrier in combination with ample attic ventilation will usually preclude excessive relative humidity and assure superior comfort in an energy-efficient home.