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CONSTRUCTION**

HVAC DESIGN GUIDE



DESIGN GUIDELINE

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to \$62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

What follows is an attachment to the final report for the Profitability, Quality, and Risk Reduction through Energy Efficiency program, contract number 400-00-037, conducted by the Buildings Industry Institute. This project contributes to the PIER Building End-Use Energy Efficiency program. This attachment, "California Residential New Construction HVAC Design Guide" (Attachment 2), provides supplemental information to the program final report.

For more information on the PIER Program, please visit the Commission's Web site at: <http://www.energy.ca.gov/research/index.html> or contact the Commission's Publications Unit at 916-654-5200.

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Abstract

Adequate tools and methods now exist to design energy-efficient HVAC systems. Failure to correctly apply them in production homes costs California homeowners. This major missed opportunity is a function of both a faulty design process and inaccessibility of the design methods. The cost-centric design-build process commonly employed by production builders rarely includes a skilled HVAC designer early in the development phase where they can most effectively integrate HVAC requirements with the house design. Currently available HVAC design tools and methods require time and high levels of skill, which negatively affects the cost/profit agenda. A more integrated design process and simplified design methods are essential to improve usage, increase HVAC design quality, and reduce HVAC energy consumption.

This design guide is not intended to be a step-by-step instruction book on how to design an HVAC system because adequate methodologies already exist for that. Rather, it is intended to be a step-by-step guide for clarifying those methodologies and integrating them into the overall design process for an entire house. It also addresses important topics particularly important to California, and specific to new-construction production homes.

1.0 Introduction

1.1 Purpose

The purpose of this Design Guide is:

1. To be a useful tool for the planning and implementation of a good residential HVAC design *process* and to assist during that process.
2. To encourage coordination between key players such as the architect, builder, structural engineer, framer, HVAC designer, HVAC installer, energy consultant, electrical designer, and plumber to minimize conflicts during the installation of a properly designed system.
3. To help identify how all of the designers, consultants, and trades people are impacted by the process and how they need to communicate in order to further minimize conflicts.
4. To explain and simplify current HVAC design methodologies so that they are more applicable to California production homes, more useful, and more widely used.
5. To address topics not well covered by existing HVAC design methodologies and provide guidance on issues that have been of particular concern in production homes.

1.2 Target Audience

The target audience for this design guide is:

1. HVAC designers, whether they work for the design-build contractor who will eventually be installing an HVAC system or a consulting engineering firm hired to provide a detailed design for others to follow.
2. Architects desiring to better incorporate the HVAC system into their house designs.
3. Builders desiring to better coordinate the installation of the HVAC system into their houses.
4. Related trades or consultants interested in better coordinating their work with that of the HVAC designer and installer.

1.3 Limitations

This design guide is not intended to walk you through all of the steps necessary to design an HVAC system. There are some very sophisticated design methodologies currently available which are well-supported by trade and professional organizations (e.g., ACCA's Manuals J, S, and D). Unfortunately, they tend to be complex and overly precise. Also, the time necessary to properly use them (not to mention the time needed to learn them) does not fit well within the current design process. They tend to be slanted toward issues related to custom houses and retrofitting older houses. They also devote much time and text to building practices atypical of California residential new construction, such as basements and sheet metal ducting. This Design guide is intended to supplement those methodologies and encourage wider use by making them more consistent with current practices in the construction of California production homes.

2.0 The Design Process

2.1 Designing houses around the HVAC system

Wouldn't it be nice houses were designed around the HVAC system? If special consideration was given to the architectural design for making the HVAC system easy to design and install? If adequate space was provided for the furnace and all of the duct work? If the house was designed with thermodynamics in mind, to minimize stratification, cross-zone interference and other problems that are difficult and/or expensive to remedy with standard HVAC practices?

This is unlikely to happen without the input of a qualified HVAC designer, and the designer's involvement needs to happen early in the design process. More typically, a house is almost completely designed before an HVAC designer ever sees it, and the HVAC system designed with an emphasis on fitting into the house rather than efficiently conditioning the house. Unfortunately, HVAC installers have become quite proficient at getting systems to fit into houses (whether they will work or not!). The result has been undersized and inefficient ducts that are difficult to balance and create unnecessary operating pressure on the fan motor. To compensate for the shortcomings of such duct systems, many installers have increased the size of the furnace, coil and condenser. This is the same logic as putting a larger engine in your car because the tires are too small. The car might go faster, but it sure wouldn't perform well or get very good gas mileage.



Often the reason given for a particular size duct being installed is, "that's the largest that would fit." If adequate space is a critical impediment to the installation of a properly designed system, then adequate space and clearance must be designed into the home by the architect and built into the home by the framer. No matter how well an HVAC system is designed on paper, the design efforts are wasted if the system cannot be installed in the field.

Typically a house goes through the following design process:

- **Conceptual Development:** Determines price range, square footage, number of stories, lot sizes, general features and styles.
- **Preliminary Design:** Develops floor plan sketches, number of bedrooms, major options, basic circulation and function locations, as well as some elevation concepts. Some early Value Engineering (VE) meetings.
- **Design Development:** Preliminary structural, mechanical, electrical, plumbing and Title 24 energy compliance. Some VE meetings.

- Construction Documents: final working drawings ready for bidding, submittal. Back checking and coordination by consultants. Some late VE meetings.

The HVAC designers need to provide input as early as possible. They need to tell the architect which architectural features cause comfort issues and are difficult or impossible to overcome with typical HVAC practices. They also need to make sure the architect allows adequate space to run ducts. Many architects have had to re-design plans enough times due to HVAC issues that they know fairly well how to accommodate HVAC items. Still, many problems commonly arise that could be avoided through earlier input and better coordination.

2.2 Coordination with other trades

The following matrix shows the main trades and consultants who are affected by the HVAC system. The first column lists the item or issue and each subsequent column how each trade is affected by it.

Matrix of Trades

Item	Architect	Builder/Framer /Structural Engineer	HVAC Installer	Energy Consultant	Electrical	Plumber	Drywall or insulation
FAU location	Roof pitch, furnace closets, clearance in garage	Truss design, platform, clearance, closets, bollards, attic access framing	Type of FAU (upflow, horizontal), clearance, timing of installation	Modeling correct location of ducts for computer model	Power, service light, control wiring, etc.	Condensate lines, gas piping	Insulation under platform may be different
Equipment size, load calculations	Clearances, # of systems, building features	Structural impacts (weight)	Materials, labor, costs	Energy features impact sizing	Electrical loads		
Supply register locations	Aesthetics, clearances	Register boot support	Materials, labor				Sealing around registers
Return grille locations	Aesthetics, noise issues	Framed openings	Materials, labor				Sealing around grilles
Condenser locations and line set	Aesthetics, noise issues	Clearance, accessibility to yard (set-back issues), 2x6 walls, chases	Materials, labor, serviceability		Power, service disconnect		
Attic access	Aesthetics	Framed opening, truss issues	Access, serviceability				
Routing B-vent	Chases, clearances, aesthetics (on roof)	Framed chases, roof cap	Materials, labor, installation			No conflicts with vent	
Chases, soffits, and drops	Aesthetics, feasibility	Framing, clearances for ducts, conflicts	Materials, labor, installation			No conflicts with ducts	
Thermostat location	Aesthetics		Materials, labor, installation		Wiring		Seal hole for wires
Equipment efficiency			Materials	Efficiency determined by energy consultant			
Combustion air	Attic vent calcs, routing for CA ducts	Adequate attic vents (roofer)	Ducting, if any				

Table 1: Matrix of Trades

3.0 Design Methodology

3.1 Code issues related to HVAC design

3.1.1 ACCA Manual D required by 2000 UMC

It is not widely known that the 2000 Uniform Mechanical Code (2001 California Mechanical Code) requires that all residential duct systems be sized according to ACCA's Manual D, which itself requires Manual J as a prerequisite design step. The exact language is:

Chapter 6, Duct Systems, Section 601.1 Sizing Requirements. Duct system used with blower-type equipment which are portions of a heating, cooling, absorption, evaporative cooling or outdoor air ventilation system shall be sized in accordance with Chapter 16, Part II Referenced Standards or by other approved methods.

Chapter 16, Part II Referenced Standards. Residential duct systems, ACCA Manual D.

Very few jurisdictions are enforcing this, most of them because they are not aware of it. This of course doesn't mean that it isn't required. It is unclear what exactly needs to be submitted in order to verify that a home has been designed to the ACCA method. One would assume that a clearly drawn mechanical plan along with supporting calculations and/or worksheets would be required.

The ACCA manuals were not written with the intent of being used as specific code language, therefore it will be up to the local jurisdiction to decide exactly how to enforce adherence to them. The Uniform Mechanical Code states that ducts must be "sized" according to Manual D. There are many suggestions and requirements in Manual D that do not relate duct sizing, some of which are impractical or simply inappropriate to California new construction. Flexibility in design is important and since little of Manual D is related to health and safety, much of Manual D outside of the sizing methodology should be considered discretionary.

Note: The next revision of the CMC may alter the Manual D requirement to be only for homes that require outdoor air. It has been suggested that this was the original intent and why it is in the UMC.

3.1.2 Title 24 load calculations

Chapter 2.5.2 of the 2001 Residential Manual expands on Section 150(h) of the Energy Efficiency Standards, which establishes the criteria for sizing residential HVAC systems in California. It provides for three different methods for calculating the building's design heat loss and heat gain rates (loads). It also establishes the design temperatures to be used for sizing equipment.

For the purpose of sizing the space conditioning (HVAC) system, the indoor design temperatures shall be 70 degrees Fahrenheit for heating and 78 degrees for cooling.[note: effective 10/1/05, the indoor design temperature will change to 75 degrees Fahrenheit for cooling] The outdoor design temperatures for heating shall be no lower than the Winter Median of Extremes column. The outdoor design temperatures for cooling shall be from the 0.5 percent Summer Design Dry Bulb and the 0.5percent Wet Bulb columns for cooling, based on percent-of-year in ASHRAE publication SPCDX: Climate Data for Region X, Arizona, California, Hawaii, and Nevada, 1982.[note: effective 10/1/05, the outdoor design temperatures for cooling changes to 1.0 percent Summer Design Dry Bulb and the 1.0 percent Wet Bulb columns for cooling]

The three approved load calculation methods are written and supported by three different trade organizations ASHRAE, SMACNA, and ACCA. Micropas and Energy Pro, the two most common Title 24 compliance software programs, both use the ASHRAE method. They generate whole house heat loss and gain calculations in order to meet the requirement of submitting approved load calculations as part of the energy compliance package. Whole house loads are useful for sizing the equipment but are of little use for designing a duct system, which requires room-by-room loads. However, it is very useful to have a whole-house load calculation to compare to the total of the room-by-room loads. This ensures consistent and accurate calculations and helps catch errors.

The Residential Manual also reminds us that the Uniform Building Code addresses the sizing of the heating system, though not the cooling system. It states:

The sizing of residential heating systems is regulated by the Uniform Building Code (UBC) and the Standards. The UBC requires that the heating system be capable of maintaining a temperature of 70 °F at a distance three feet above the floor throughout the conditioned space of the building.

None of the calculations approved by Title 24 address the temperature at any distance above the floor. They all assume that the temperature is the same everywhere in the house, that temperature being whatever the inside design temperature is. The specification of 3 feet above the ground simply provides a reference for testing an actual system. It is generally assumed that if the heater has a capacity equal to or greater than the heating load calculations and a reasonable distribution system, it will meet this requirement.

The residential manual reiterates that the load calculations are only part of the information used to size and select the equipment and who can prepare those calculations (presumably based on the Business and Professions Code), but does not go into much more detail about what else goes into the sizing and selection process.

The calculated heat gain and heat loss rates (load calculations) are just two of the criteria for sizing and selecting equipment. The load calculations may be prepared by: (1) the [Title 24] documentation author and submitted to the mechanical contractor for signature, (2) a mechanical engineer, or (3) the mechanical contractor who is installing the equipment.

Title 24 does not specifically state how cooling loads should be considered when sizing an air conditioner. It doesn't even state that an air conditioner has to be installed at all. Most jurisdictions treat the Title 24 cooling loads as a minimum sizing criteria. In other words, a system must be installed that has a cooling capacity that at least meets the Title 24 cooling load. In some climate zones, it is common practice to offer air conditioning as an option. So, apparently the sizing criteria only apply *if* air conditioning is to be installed. [note: 2005 amendments to Title-24 will offer an alternate sizing method.]

The following link will direct you to an on-line copy of the Title 24 Residential Energy Manual, Appendix C – California Design Location Data. A map of the California climate zones can be found in this appendix along with information on California climate zone requirements. http://www.energy.ca.gov/title24/residential_manual/res_manual_appendix_c.PDF. Or, if you are connected to the internet, you can click on the link below:

[Title 24 Residential Manual, Appendix C -- California Design Location Data](http://www.energy.ca.gov/title24/residential_manual/res_manual_appendix_c.PDF)

3.2 ACCA Manuals J/S/D

3.2.1 The Overall Design Method

The overall design steps for the ACCA J/S/D methodology, as it should be used in typical California new construction production homes, is described in the following list. Throughout the execution of this list, certain decisions are made that may affect other trades. It is important that this coordination be made in a continuous and consistent manner. The [Matrix of Trades](#) (page 10) is provided to help guide you in this coordination.

[Step 1.](#) Determine Zones

[Step 2.](#) Calculate Room by Room Loads

[Step 3.](#) Select/size Equipment

[Step 4.](#) Layout duct system

- Locate FAU(s)
- Locate grilles and registers
- Route ducts
- Sub zones (trunks)

[Step 5.](#) Determine operating conditions

- Static pressure
- Total CFM
- Equivalent lengths
- Friction rates

[Step 6.](#) Size ducts

- Room air flow is proportional to room load
- Friction rate and room air flow determine duct size

[Step 7.](#) Final touches

- Locate thermostat
- Locate condenser

Step 1. Determine Zones

Zones, as discussed here, are defined as areas of the house that are to be independently controlled, typically by their own thermostat. Smaller houses typically only have one zone. If the main criterion for zoning a house is whether it can be served by a single system or not, the designer may want to wait until after doing the load calculations. The new load calculation software products allow you to easily assign and reassign rooms to different zones and this step can be integrated into the next step of performing the actual room-by-room load calculations. However, evaluating a house for possible zone considerations is still a useful first step.

There are a variety of ways to zone a house and there are several factors to take into account. These include use patterns such as “living” areas and “sleeping” areas. Thermodynamic zones play an important role as well. These are areas of a house that will behave substantially different because of their relative position or isolation from each other such as upstairs and downstairs, east wing and west wing, etc. Sometimes use patterns and thermodynamic zones do not coincide and you may have to prioritize one over the other. Usually thermodynamic considerations take precedence.

Zoning a house for living/sleeping can generate an energy efficiency credit toward Title 24¹ compliance. This energy efficiency credit is based on the ability to program the thermostat schedule differently for these two zones thereby saving energy. The real energy savings of this strategy is highly dependent on the occupant’s proper programming and operation of the thermostats. It can either be accomplished by a single system with zonal control (single system with dual zone components) or by separate systems. See [Section 4.4. Zonal Control](#) for more discussion on zonal control. If the dual zone strategy is used for Title 24 compliance, the HVAC design must ensure that it does not have an adverse affect on comfort.

If all of the spaces defined as either living areas or sleeping areas are not located in thermodynamically similar zones, special steps may be required to ensure consistent comfort throughout each zone. For example, if a two-story house large enough to require two systems has all of the bedrooms upstairs except the master bedroom, it may be difficult to zone the house for living/sleeping. Because it is a two-story house, it wants to be zoned up/down for thermodynamic reasons. The sleeping zone is split between two floors and may require further zonal control to achieve satisfactory comfort, resulting in a total of 3 thermostats.

Usually the first question asked from a cost perspective is “Can the entire house be served by a single HVAC system?” In other words, can the total cooling loads, regardless of other considerations, be met by a single 5-ton air conditioner (the largest system typically used in residential construction)? This is not known until the loads are calculated. A preliminary estimate can be made based on square footage and window area and then later revised if the results of the load calculations change the assumptions.

¹ Energy Efficiency Standards for Residential and Nonresidential Buildings Publication Number: 400-01-024, August 2001

As homes get more and more efficient, especially in regard to window technologies, larger and larger homes can be served by a single 5-ton system. At some point, other considerations need to be taken into consideration. Things such as adequate airflow (air changes) need to be considered. Does a single 5-ton system at approximately 2000 cfm have enough air moving capability to adequately distribute air throughout a very large house, even if it can meet the steady state cooling load? Also, how susceptible is the house to non-steady state conditions? In other words, what happens if in cooling mode the temperature is inadvertently allowed to substantially exceed the comfort temperature? Will the system be able to catch up in a reasonable amount of time? This can be a critical customer service issue in production homes and is a topic that needs further research.

If the house can be served by a large single system (i.e., 5-tons) but has distinct zones (e.g., upstairs downstairs) it is recommended that those zones be controlled independently (separate thermostats). This can be accomplished by multiple systems or by a single system with zonal controls. See [Section 4.4](#) for more on zonal control

Step 2. Calculate room by room loads

For room-by-room loads, ACCA's Manual J is the most widely used and most widely supported standardized methodology. There are at least two software versions of it (See [Appendix A for resource information](#)). Even though it was originally intended to use hand written forms and worksheets, it is now virtually mandatory to use a computer method (unless you are extremely accurate and patient – the type of person who can fill out complicated tax forms by hand.). Because ACCA Manual J is all based on published tables and worksheets, some people have written their own load calculation spreadsheets based on Manual J.

The two available software packages (Right-Suite² and Elite³) have very sophisticated features allowing Computer Aided Design (CAD)-based take-offs for window and wall areas. This makes very easy and quick work of entering physical building data if you have access to an architect's CAD files. The software packages allow you to import a CAD floor plan of the home and essentially trace over it to create the rooms and zones. Windows and doors are drag-and-drop components. If you do not have access to the architect's CAD files, you can use the software to do a pretty reasonable job of recreating the floor plan of a house. These software packages also have useful duct layout drawing features.

The underlying concept of room-by-room loads is that each room, or area served by a supply register, is treated as an individual load. This provides for a very accurate determination of how to distribute the air. If air is distributed proportionally to each room's load, then each room will be conditioned appropriately; resulting is even temperature distribution across a home. This is the basis for ACCA Manual D. It's not perfect in reality. However, it is the best method we have right now and works quite well for most production homes. The more complex and "broken up" the house layout is architecturally, the less this assumption is applicable.

² Wrightsoft Software,

³ Elite Software

Step 3. Select and Size Equipment

Use total of room-by-room loads for each zone

1. Once the house has been zoned and the loads for each of the zones are finalized, the system can be sized and selected. ACCA's Manual S provides detailed information for determining heating and cooling capacities of various types of equipment. In California residential new construction, the most common HVAC system type is split-system Direct-Expansion (DX) cooling with a gas furnace. The heating capacity is easy to determine based on the rated heating output of the furnace, which changes very little based on actual conditions. Some adjustment may need to be made for high altitudes. Determining the cooling capacity at actual conditions is more complex. It depends on several conditions: a) the outdoor temperature, b) the indoor entering wet bulb⁴ and dry bulb⁵ temperatures, and c) the airflow (cfm) across the coil. In order to properly account for these conditions it is necessary to use detailed capacity tables provided by the manufacturer. Again, ACCA's Manual S goes into good detail on this process.

In California residential new construction the following conditions are typical:

1. Outdoor temperature: This is the temperature of the air that is blowing through the condenser to cool the refrigerant and is usually the same outdoor temperature that is used for the cooling load calculations unless it is known that the condenser will be located in a hotter location such as on a roof.
2. Indoor entering wet bulb and dry bulb: These describe the condition of the air blowing across the coil and are usually assumed to be the same as the indoor conditions used in the load calculations. Title 24 cooling loads are calculated using an indoor temperature (dry bulb) of 78 deg F. Some designers use a lower temperature, such as 75 degrees to be safe. (Note: lower indoor temperatures drive up the cooling load and decrease the calculated capacity, potentially requiring a larger system.) Except for some coastal areas, California is considered a dry climate. A safe indoor wet bulb temperature is 65 degrees F. This corresponds to 78 degrees F and 50% relative humidity on the psychometric table. (Note: The higher the humidity, the higher the wet bulb temperature, and the lower the cooling capacity will be.)

⁴ The wet bulb temperature (WBT) relates relative humidity to the ambient air or dry bulb temperature. When moisture evaporates, it absorbs heat energy from its environment in order to change phase (via latent heat of vaporization), thus reducing the temperature slightly. The WBT will vary with relative humidity. If the relative humidity is low and the temperature is high, moisture will evaporate very quickly so its cooling effect will be more significant than if the relative humidity were already high, in which case the evaporation rate would be much lower. The difference between the wet bulb and dry bulb temperature therefore gives a measure of atmospheric humidity.

⁵ Dry bulb temperature refers basically to the ambient air temperature. It is called dry bulb because it is measured with a standard thermometer whose bulb is not wet - if it were wet, the evaporation of moisture from its surface would affect the reading and give something closer to the wet bulb temperature. In weather data terms, dry bulb temperature refers to the outdoor air temperature.

3. Airflow across the coil: This is typically the same as the design airflow for the system. It comes from the furnace airflow tables at the design static pressure (usually between 0.5 and 0.7 inches water column, 0.6 is a reasonable number to use but it depends on the specific design criteria) and ranges from 350-425 cfm per “ton” of the furnace.

The following basic concepts are good things to keep in mind when designing (or evaluating the performance of) a system:

1. As the outdoor design temperature goes **up**, the cooling capacity of the AC unit goes **down** (and the load on the house goes up). This is because the outdoor air is the heat sink used by the air conditioner to dump the heat into that is extracted from the indoor air. As the outside air gets warmer, it is harder for the air conditioner to dump heat into it.
2. As the indoor dry bulb temperature goes **down**, the cooling capacity goes **down**. This is because it is harder to extract heat from colder air.
3. As the indoor wet bulb temperature goes **down**, the cooling capacity goes **down**. This is because the air has more moisture in it and cooling capacity is used up when this moisture is condensed out of the air.
4. As the airflow across the coil goes **down**, the cooling capacity goes **down**. This is because with less air passing across the coil, there is less opportunity for the coil to extract heat from the air stream.

Step 4. Lay Out Duct System

- Locate Forced Air Unit(s) (FAU) – The location of the FAU (furnace) depends on a variety of factors. These include such things as clearance, accessibility, duct routing, and venting. Personal preference even comes into play. An analysis was done on the impacts of energy consumption and furnace location (See [Section 4.1](#) for details of this study) as part of the research project that included the writing of this design guide. It found that furnace location had little impact on energy consumption and effectiveness of the system. The only notable difference between a furnace in the attic and a furnace in a garage, for example, was that the furnace in the garage tended to have somewhat longer ducts, which resulted in more conductive losses/gains and more resistance to air flows. It also showed a bit more fan power consumption due to the longer duct runs, but this can be compensated for by using larger ducts, if they can be accommodated.

First cost (due to labor) tends to be the biggest consideration in deciding where to put the furnace. The general trend today is to put furnaces in attics even though they are less accessible. Floor area, even in a garage, is at a premium. Also, since an attic location is more centrally located, it tends to have duct runs of more equal length. In other words, there are less likely to be very long duct runs. Also, venting a furnace is more straightforward from an attic than from a garage, especially in a two-story building. Furnace location (see [Section 5.2](#)) is a good discussion topic for value engineering meetings.

- Selecting and locating grilles and registers - ACCA also publishes a Manual T “Terminal Selection”, which contains some good information on the selection criteria for supply registers and return grilles. It covers such topics as register type (2-way,

3-way, etc.), pressure drop, face velocity, noise criteria, and throw distance. In residential new construction grilles are often sized based on the size of the duct serving them, which is altogether inadequate. Similarly, grille types are often selected based on personal preference and sometimes faulty reasoning. Much more thought should go into this process.

In a typical, “square-ish” room such as a secondary bedroom, there are four basic locations for a supply registers, five if you count floor registers, which are almost always located under a window. The four main locations are shown **Figure1**.

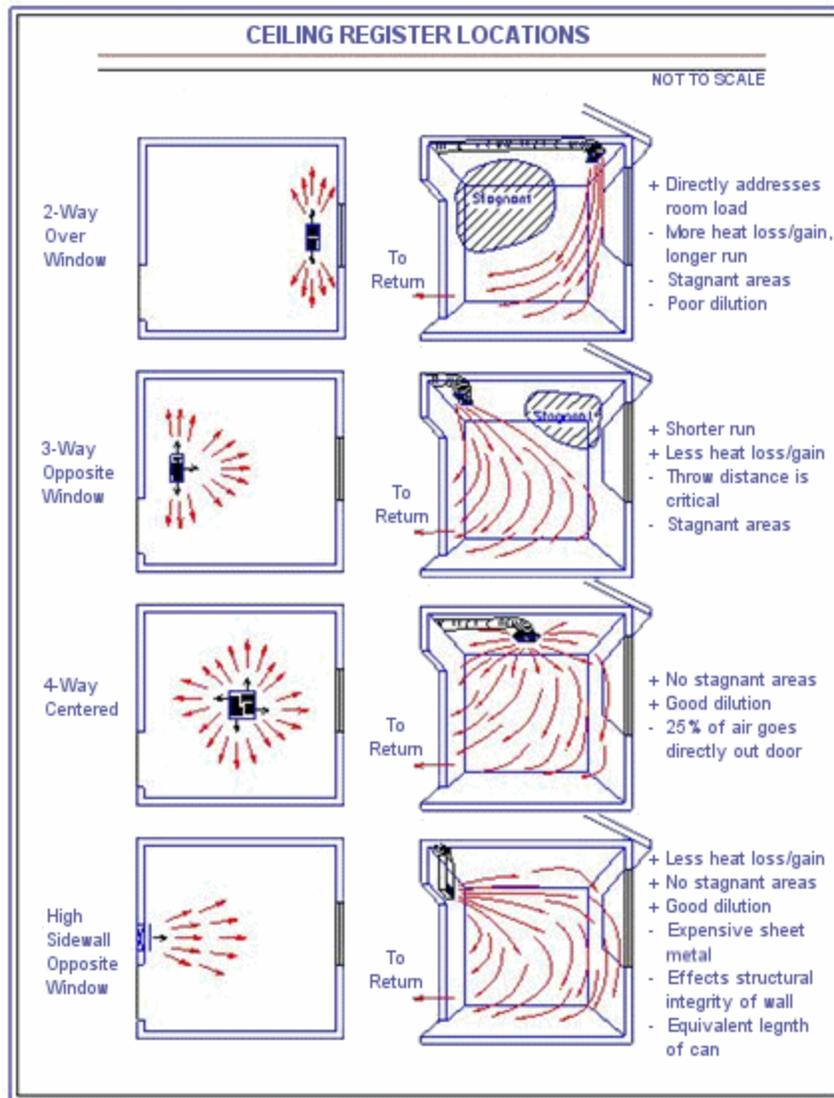


Figure 1: Ceiling Register Locations

A study on the impacts of energy consumption, comfort and supply register location was performed as part of the research project that included the writing of this design guide. This study evaluated and compared the most common of these locations: 2-way over a window, 3-way near an interior wall, and high sidewall opposite a window. See [Section 4.2](#) for details on this study.

Given a choice, the results of this study provide important considerations. Sometimes, however, the geometry of the room dictates where you must place registers. For example, in a long narrow room where the exterior wall is on the narrow dimension, you may be forced to put a register over the window because the interior wall is too far away. Also, structural and architectural constraints such as locations of chases, floor joist directions and beams may dictate register locations. Any of the locations mentioned above can be made to work adequately well if certain considerations are made. Whatever the register location, the following considerations should be emphasized:

1. **Register over window or on exterior wall.** Use a 2-way register oriented parallel to the window/exterior wall. This will create a curtain or sheet of supply air parallel to the exterior wall and the air will naturally move away from the wall and mix with the air in the room. Using a 3-way register pointed away from the window/exterior wall will throw the back into the room too quickly and may not adequately condition the area directly in front of the window. It may also “short circuit” the airflow by throwing it back into the natural return path before it has a chance to mix with the return air. A 3-way register located near a window but pointed directly at it will blow air directly on the window. This will heat and cool the window, which serves little benefit when the purpose is to heat and cool the air inside the room. In fact, this most likely wastes substantial energy.
2. **Register near an interior wall.** Use a 1-way or 3-way register with the primary direction toward the window/exterior wall. It is important to ensure that the register’s throw distance is adequate to reach near the window/exterior wall.
3. **Register centered in a room.** Use a 4-way register. 4-way registers deliver the air equally in all four directions. Consideration must be given for interference with light fixtures or ceiling fans. If this is the case, then locate the register an aesthetically appropriate distance away from the fixture, but toward the exterior wall.
4. **High sidewall registers.** Use a bar-type register that throws air perpendicular to the face of the register. Point the register toward the window/exterior wall. As with a register near an interior wall, it is important to ensure that the register’s throw distance is adequate to reach near the window/exterior wall. Bar-type registers located in a vertical wall typically have much, much greater horizontal throw distances than 3-way or 1-way ceiling registers, and better overall air flow characteristics in general (more cfm per square inch, quieter, etc.).

The basic things to keep in mind when selecting and locating a register are:

1. Good air mixing: you want the supply air to mix in with the room air as much as possible. This is aided by directing the air in the opposite direction of the natural path back to the return (e.g., out the door).
 2. Good air distribution and no stagnant areas: you want the supply air to reach all of the occupied areas of a room, especially areas close to a load (e.g., window). Throw distance is an important consideration for this.
- Determining sub-zones (trunks) and the use of balancing dampers – In production building, a designer is typically designing the system for a home that may be built in several different orientations. (See [Section 4.3](#) for discussion on designing for multiple orientations.) The system is typically designed for the worst-case orientation with consideration for airflows needed in other orientations. The system must at least be able to be easily balanced to work in all orientations. A strategy that helps accomplish this is to divide the main zones of the house into sub-zones. These sub-zones are areas in the main zone that will be affected similarly when the house is in an orientation other than worst case. For example, **Figure 2** shows a basic single-story, single-zone house in its worst-case orientation.

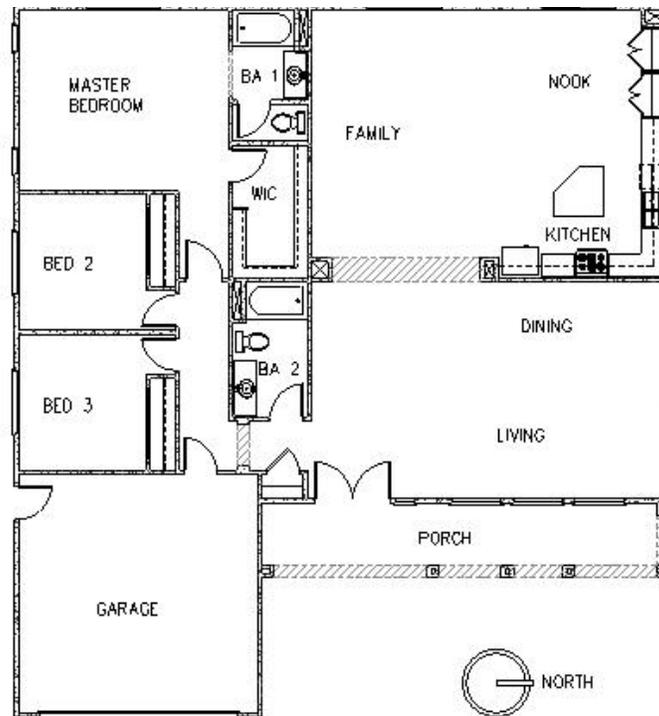


Figure 2: Example House Plan

If the house is rotated 180 degrees, bedrooms 2 and 3 will go from the south side of the house to the north side of the house and probably need much less air. If these two rooms are on the same trunk, this can be accomplished easily by using a manual balancing damper located right at the supply plenum. The family/kitchen area, living/dining area master bedroom may be treated similarly.

Figure 3 shows a reasonable layout and approach to accomplish orientation-dependent balancing using manual balancing dampers that are easily accessible.

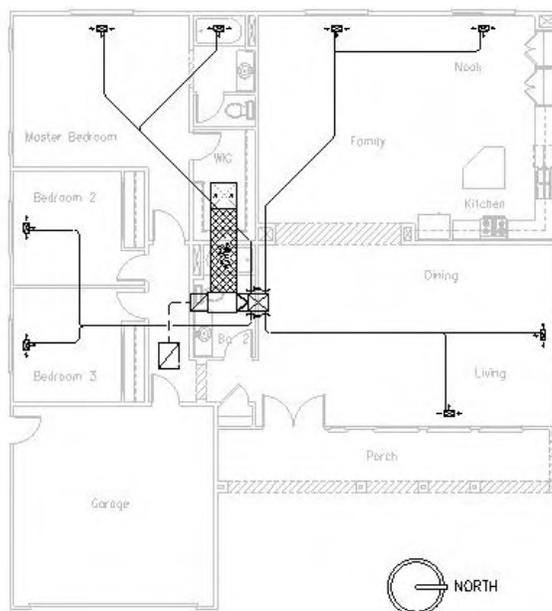


Figure 3: Example HVAC Design

- Routing ducts – The actual routing of ducts is a function of the number and location of supply registers (and to a lesser extent return grilles), architectural and structural constraints, duct size, duct length, and other practical issues such as preferred types of fittings (t-wyes vs. duct-board transition boxes). In a single-story house with ample attic space this is pretty straightforward. You can locate the registers first and then simply sketch the ducts in. In a multiple-story house, this is a much greater challenge, at least for all but the top floor. Assuming the system serving the first floor is located in the attic (a typical scenario), the ducts serving the first floor must pass vertically through the upper floor(s), and then horizontally (unless you are lucky) to the ceiling registers on the first floor. There is usually a great deal of framing (such as trusses, blocks, joists, beams, headers, and top/bottom plates) between the furnace and the register. In fact, very often the framing is the deciding factor in determining where registers are ultimately placed.

The following are some ideas for getting ducts from one point to another.

Vertical Duct Runs

Chases and voids – These are shafts between walls, either created intentionally (chases) or incidentally (voids) that can be used to run ducts from the attic, through the upper floor(s), to the lower floor(s).

Samples of Incidental Voids

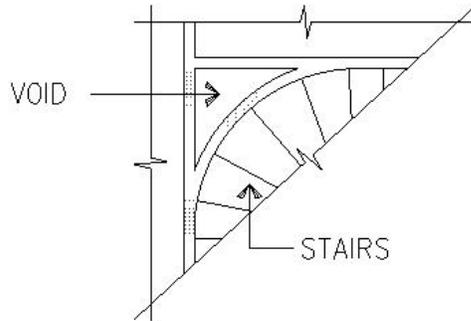


Figure 4: Example Void in Interior Stair Chase which often occurs adjacent to round room or stairways

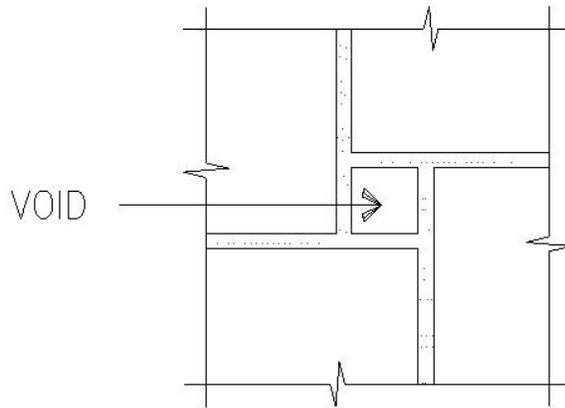


Figure 5: Example Void in Dead Space (where spaces of unequal size or shape are adjacent to each other)

Samples of Chases

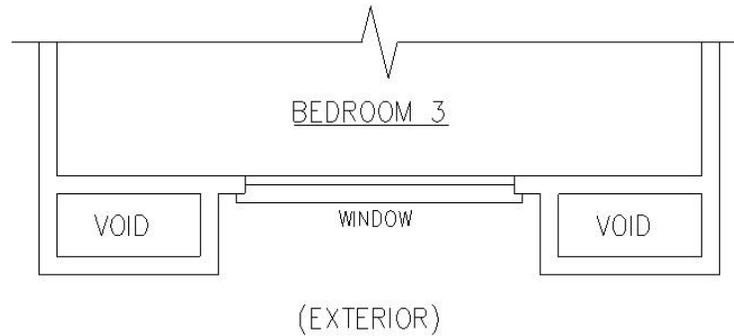


Figure 6: Example Exterior Chase
 Voids can be found in the “bump outs” of exterior architectural details, but care must be taken to ensure that that particular architectural detail occurs in all elevation styles

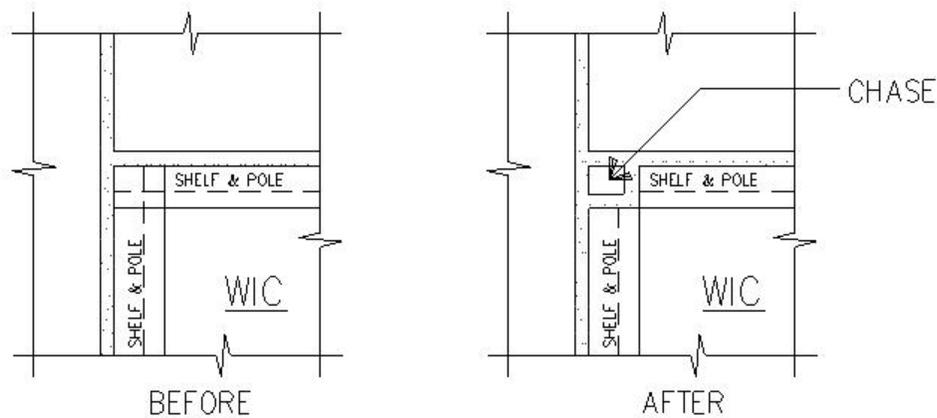


Figure 7: Walk-In Closet with Interior Chase
 Chases can be created in corners of closets. The “dead corner” of a walk-in closet is an ideal place because it has minimal impact or hanging space and it provides a convenient way for the shelf and pole to be supported.

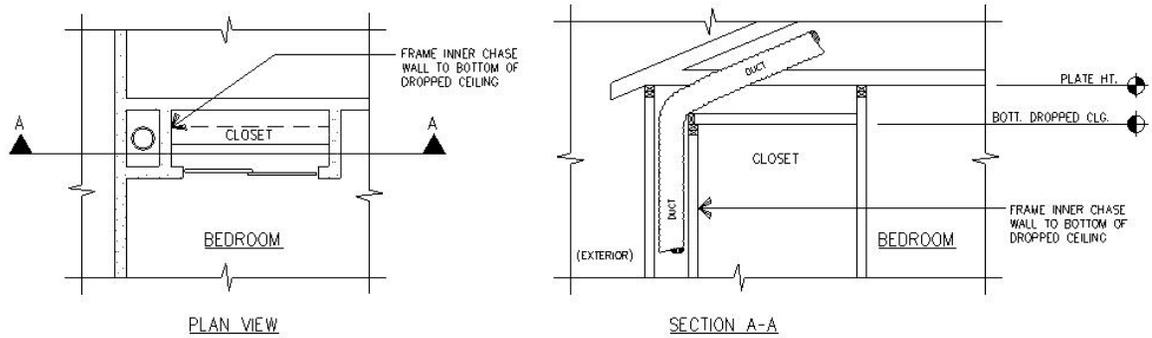


Figure 8: Closet Chase Example

Chases may also be added to either end of a “flat” closet. If given the choice, it is preferable not to have a chase adjacent to an exterior wall when the roof slopes down to that wall (i.e., hip roof), because the roof can interfere with the duct getting down through the top of the chase. If this cannot be avoided there are various ways to drop the ceiling in the closet to better accommodate the duct.

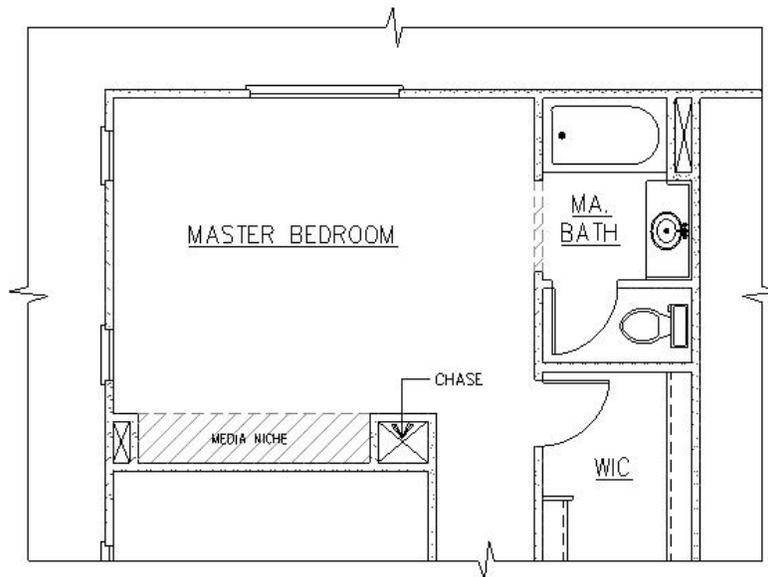


Figure 9: Media Chase

A good location for creating chases is in a media niche

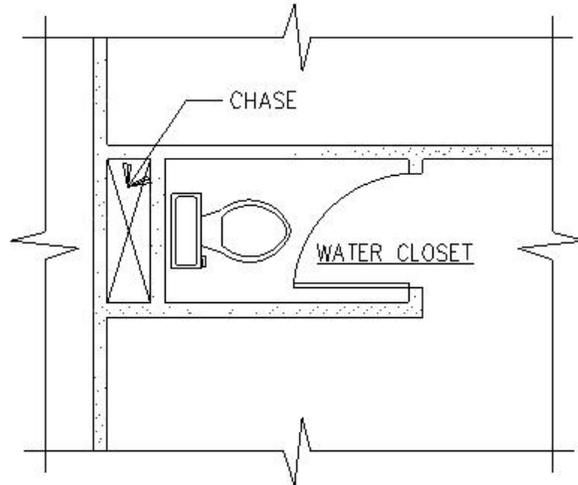


Figure 10: Water Closet Chase
 Another good location for creating chases is in a water closet

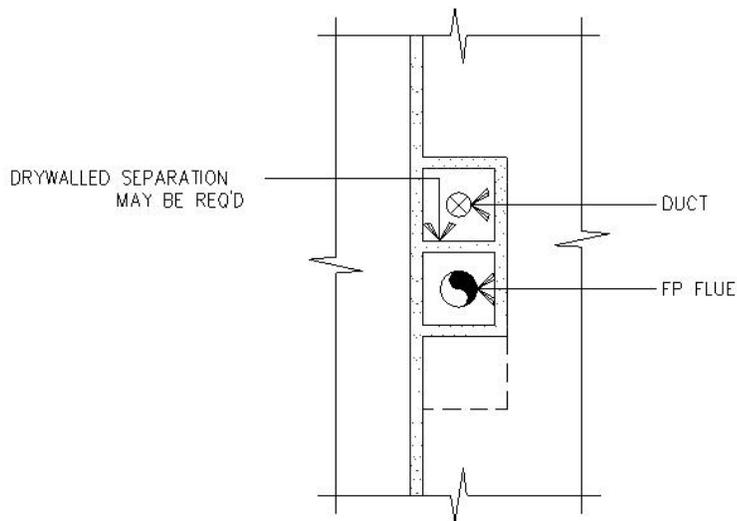


Figure 11: Chimney Chase
 Chases can also be in chimneys, even as false chimneys

Riser cans – These are rectangular ducts, usually sheet metal, which fit in a wall cavity between the studs. They are relatively common, but due to potential noise problems, high resistance to airflow (high equivalent length), structural constraints, and installation costs, they are typically used only as a last resort. If care is taken in their design and construction, they can however be a viable solution to many routing problems. You should keep the following things in mind if considering riser cans:

1. **Noise** – Thermal expansion and contraction can cause sheet metal riser cans to make substantial amounts of noise. This is called “oil canning” and can manifest itself in clicking, popping, clanking, squeaking and other annoying noises. Many contractors have had to tear out riser cans due to customer service complaints. This is a very expensive and messy retrofit. Some contractors will flat-out refuse to install them. Avoid putting riser cans in bedroom walls if at all possible. Some precautions to preventing noise are using heavier gauge metal, caulking *between* all metal-to-metal seams, and using lead tape as a sound dampener. You might also consider using duct board rather than sheet metal. It requires a larger cross sectional area than sheet metal but is virtually silent and has much better insulation properties.
2. **High Resistance to air flow** – The available space in a typical (16" on center) 2x4 and 2x6 stud wall is 3½"x14" and 5½"x14". The typical size riser cans used in these walls are 3"x14" and 5"x14", which correlate to round flex duct equivalent sizes of 8" and 9", respectively. The high resistance to air flow comes not so much from the riser can itself, but from the round-to-rectangular and rectangular-to-round transitions. It is highly recommended that smooth, rounded transitions be used where possible. It is highly discouraged to simply cut a round hole in the side face of the riser can.

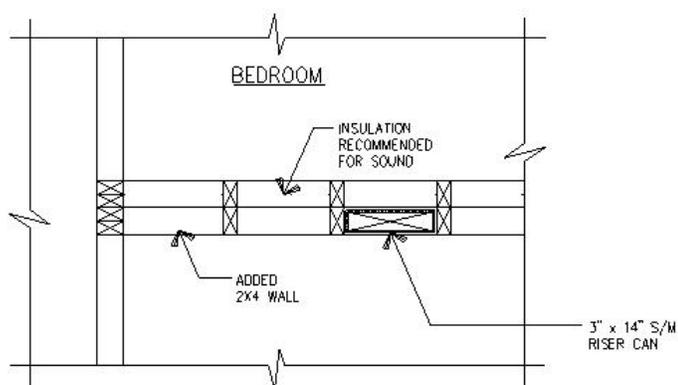


Figure 12: Riser Can Installation

3. *Structural Constraints* – Because the riser can takes up the entire stud bay in a wall it is necessary to cut out a 3½”x14” and 5½”x14” piece of the top and bottom plates. This is never allowed in a structural shear wall and rarely allowed on an exterior wall (not to mention the requirement for at least R-13 insulation in the wall and R-4.2 insulation on the riser can itself, if not located within the conditioned shell). One solution is to double the wall, install the riser can in one side, and leave the other intact.

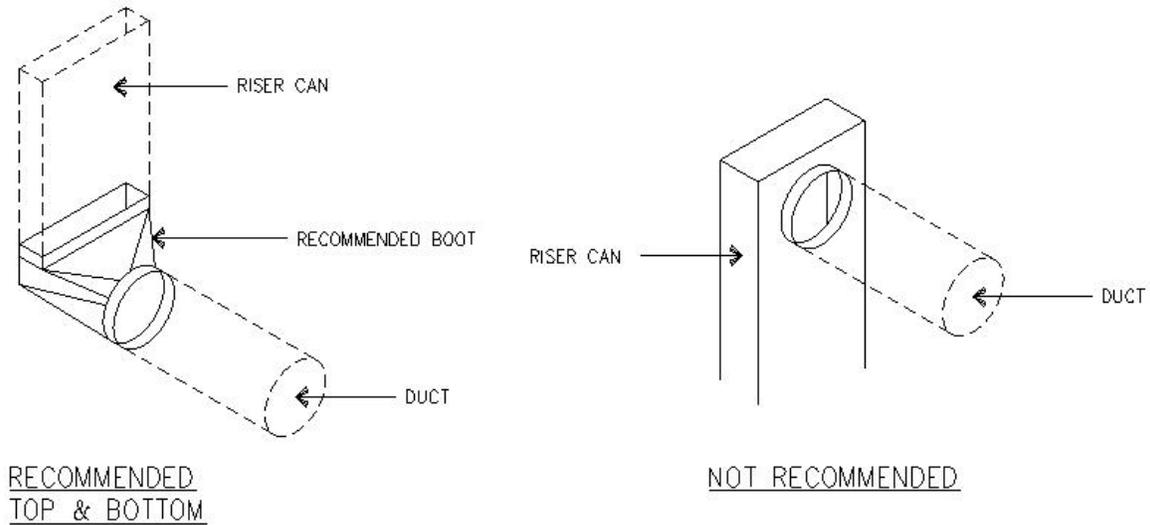


Figure 13: Riser Can Detail

Care must be taken to ensure that no truss sits on top of the stud bay that you intend to use and the stud bay must line up with the floor joists below. The use of riser cans requires careful coordination between the HVAC subcontractor, the architect, the structural engineer, and the framer.

Horizontal Duct Runs

Floor Joist Bays – These are the spaces between the parallel floor joists. California builders often use wooden “I-beam” type floor joists.

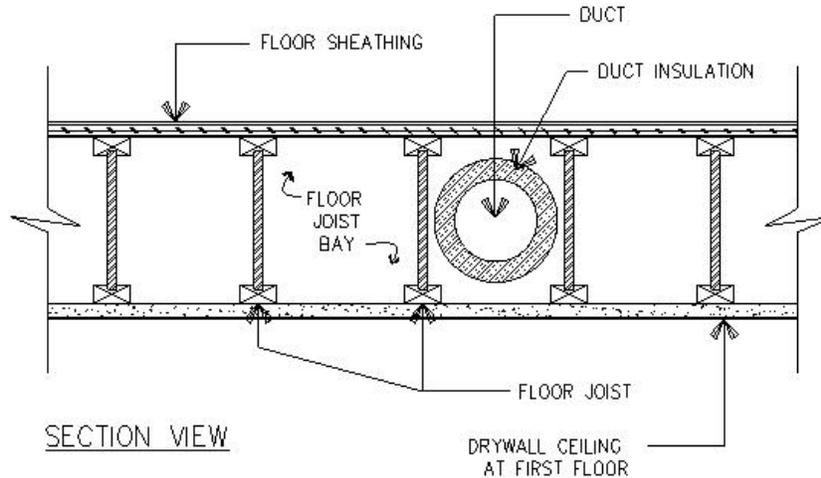


Figure 14: Floor Joist Detail

Common sizes (heights) are 12", 14", and sometimes 16". While it is possible to cut holes in floor joists as big as the height of the web, there are strict limitations on this and joist penetrations must always be approved by the structural engineer. Even if you do cut the I-joists it can be difficult to pull flex duct through these holes. The other coordination that must take place is with the trades that will be sharing this space, especially plumbers. Gas piping, sanitary drains and water piping can all be run either perpendicular to or parallel with the I-joists, and can interfere with ducts.

Some builders use floor trusses rather than I-joists. These consist of diagonal framing members similar to a roof truss rather than solid webbing.

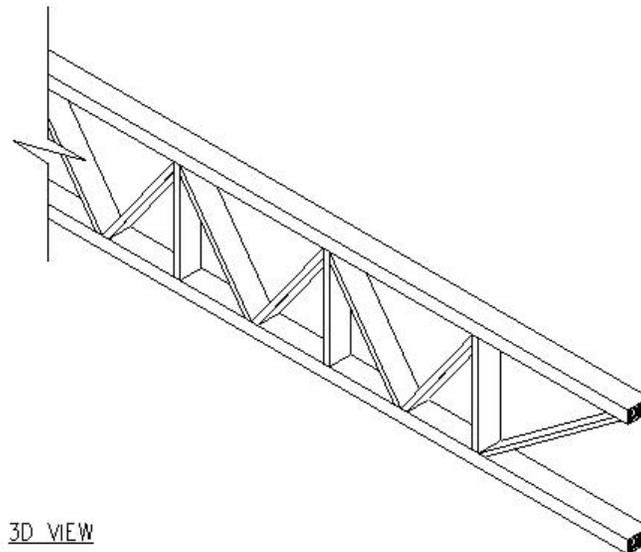


Figure 15: Floor Truss

These are much more accommodating of ducts without cutting holes but similar coordination must be made with the plumbers.

One important thing to keep in mind when running ducts in floor joist bays is that the best practice for connecting to a ceiling register may require a special transition fitting rather than simply making a 90-degree bend in the duct.

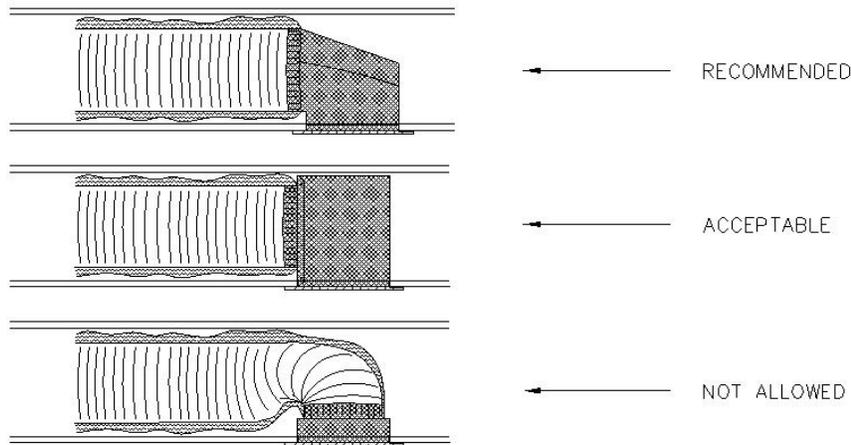


Figure 16: Duct-to-Register Connections

Dropped ceilings and Soffits – Sometimes the only way to get past a beam, wall or floor joists is to create a dropped or “false” ceiling below the obstruction that provides room to run a duct. When considering these as an option one must realize that they can be relatively expensive to build and often have aesthetic disadvantages because they lower the ceiling height. Usually lowering the ceiling in a small room such as a bathroom, laundry room, or hallway is not a big problem. The total drop required to run ducts is the outer diameter of the duct plus 3 ½” for the framing. In smaller rooms the dropped ceiling can be “flat studded” (with the 2x4’s turned sideways) and then you only need to add 1 ½” to the outer diameter of the duct. Most builders and architects do not like to go with less than an 8” ceiling height, but may sometimes allow a 7’ 6” ceiling height if absolutely necessary.

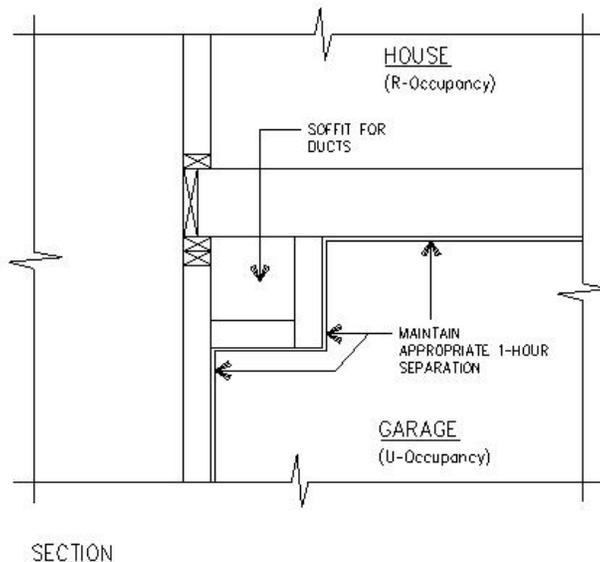


Figure 17: Soffit Chase

Soffits are similar to dropped ceilings except that they are localized and resemble a horizontal chase. Soffits provide a boxed-in area where a wall meets a ceiling as an alternative to dropping the entire ceiling. They are common in garages. When building a soffit in a garage care must be taken to maintain the integrity of the 1-hour fire separation between the garage (Group U occupancy) and the house (Group R occupancy).

Step 5. Determine Operating Conditions

- Static pressure

Static pressure is the pressure at which the fan (in the furnace, FAU, or fan coil) must operate. It is the absolute sum of the supply pressure (positive) and the return pressure (negative). The higher this pressure, the lower the airflow will be. The ACCA method allows you to size your ducts around a specified static pressure, ensuring that the fan will operate at conditions suitable to proper air flow and fan performance.

Most furnaces are rated at a nominal 400 cfm per ton. This usually corresponds to a static pressure of 0.5 inches of water columns (iwc). Because of this, many subcontractors assume that they are operating at 0.5 iwc and 400 cfm/ton just because they install a certain size piece of equipment. Many don't realize just how dependent static pressure and airflow are on how they size the ducts. If the duct sizing methodology does not properly account for pressure losses in the distribution system (e.g., coils, fittings, filters, bends, and registers), the static pressure will be too high and possibly outside the furnace manufacturer's

recommended range, resulting in poor performance and premature equipment failure. In addition, the airflow will be too low, decreasing the performance of the system and possibly reducing cooling capacity to below the cooling load (in effect making the air conditioner too small).

A design static pressure that gives good airflow and results in reasonably sized ducts is 0.6 iwc. ACCA utilizes a value called “Available Static Pressure” in its important equations. It is the operating static pressure across the furnace less the static pressure drops of various items such as, the coil, filters, heat exchangers (external to furnace), registers, grilles, etc. The values for all of these pressure losses are given in Manual D.

- Total CFM

Total Cubic Feet per Minute (CFM) can be determined by picking the design static pressure and referring to the furnace manufacturer’s airflow table for the airflow at that static pressure. Use high speed for cooling. The total CFM is used to determine actual design cooling capacity. This number is distributed to each room proportional that each rooms load. As long as the ducts are sized properly, this total airflow will be met or exceeded in the field.

- Equivalent lengths

The pressure drop of duct and duct fittings are accounted for using equivalent lengths. They are expressed in units of feet, which make sense for a length of duct but is a bit unusual for a fitting such as a t-wye or elbow. It is simply a way of accounting for pressure drop of a fitting by equating it to an equivalent length of duct. Equivalent lengths are used in the calculation for friction rate.

- Friction rates

The friction rate is the critical factor for determining what size duct is needed to provide a certain amount of CFM. The units are inches of water per 100 feet. It describes the pressure loss for every 100 feet of duct. The equation for friction rate is fairly simple:

$$\text{FrictionRate} = (\text{AvailableStatic Pressure} * 100) / (\text{TotalEquivalentLength})$$

It is used in the friction charts in Appendix A of Manual D. It is also used in duct slide rules, which are essentially the friction charts put into a slide rule or wheel format. Note that there is a different friction chart for different duct types. Chart 7 is for “Flexible, Spiral Wire Helix Core Ducts”, a.k.a. “flex duct” or “vinyl flex”. For a common friction rate of 0.1 and 200 cfm, the chart shows that you would need between an 8” and a 9” duct, so a 9” duct must be installed to ensure that at least 200 cfm is delivered.

In typical California residential new construction, friction rates between 0.9 and 1.2 are most common. Looking on chart 7, this is a very small area on the chart. Also, when you consider that the typical 5-ton system only goes up to about 2000

cfm, the area of chart 7 that is commonly used is very small and the accuracy is questionable. It is recommended that a designer not using the software use a good quality duct slide rule such as the wheel-type duct-sizing calculator published by ACCA.

Several duct slide rule manufacturers recommend that you use a friction rate of 0.1. This only works if you can design the system to ensure the correct available static pressure and total equivalent length. However, simply using a friction rate of 0.1 and the room-by-room air flows generated by Manual J for a residential new construction home would be better than most rules of thumbs currently being used.

Here are some examples using the friction rate equation and friction chart:

Example 1. The available static pressure (ASP) is calculated to be about 0.25 iwc. The total equivalent lengths (TEL) are estimated to be about 250 feet. The equation for friction rate (FR) yields a value of 0.1. If 130 cfm are required, the duct calculator shows that a 7" flex duct is not adequate so an 8" must be used. In the field, it is determined that the duct cannot be run as expected and a new route is determined, which adds 30 of extra length to the duct. Will this affect the duct sizing? In this case, no, it would not. Adding 30 feet changes the friction rate to 0.09. Using the duct calculator, an 8" duct is still adequate. In fact, an 8" duct would work as long as the friction rate was 0.065 or higher. This means that up to 130 feet of extra length (actual or equivalent) could be added and the duct would still supply at least 130 cfm.

This is not always the case, however. Each duct diameter can handle a range of airflows. It depends on how close you are to the upper limit of that range. Theoretically, adding just one foot of extra length could require increasing the duct size.

Example 2: Using the same starting point as Example 1 (ASP=0.25, TEL = 250 and FR = 0.1), the builder wants to offer electronic filters and needs to know if they would affect the duct sizing. The filter manufacturer lists a static pressure drop of 0.10 iwc.

This changes the friction rate from 0.1 to $(0.25 - 0.10) * 100/250 = 0.06$, which would require that a 9" duct be used to deliver 130 cfm and because the filter affects the entire system, many other ducts may be affected as well.

This scenario assumes that the designer intends to maintain the operating static pressure of 0.6 iwc in order to maintain a certain total airflow. A different approach would be to keep the ducts the same size and let the static pressure change. For the ducts to stay the same size, the friction rate must not change. For this to be true the available static pressure needs to stay the same (assuming that the equivalent lengths are not going to change, in other words the basic duct layout does not change), which means that the starting static pressure

across the fan has to go up by the same amount that the electronic filter will “use up”. If we assume an operating static pressure across the fan of 0.7 iwc (0.6 originally + 0.10 for the filter), the most obvious impact will be that the airflow will go down. This can be quantified using the furnace fan flow table. What needs to be confirmed is that the airflow is still adequate to meet the sensible cooling capacity (remember that as air flow goes down, so does cooling capacity). Also, maximum air velocities must be confirmed as does the furnace manufacturer’s recommended operating range for static pressure.

Step 6. Size Ducts

Room airflow should be proportional to room load. Once the room-by-room loads have been completed and the equipment has been selected, it is a simple matter to determine how much air each room or space needs. The airflow required in each room is proportional to each room’s load. In other words, if the room accounts for 10% of the load it must get 10% of the airflow.

Friction rate and room airflow determine duct size. Once airflow is determined, a duct calculator (duct slide rule) can be used to determine duct size using the [friction rate](#).

Step 7. Final Touches

Locate thermostat (refer to [Section 5.8 Thermostat Location](#).)

Locate condenser (refer to [Section 5.1 Condenser Locations and Refrigerant Lines](#).)

4.0 Special Design Topics

4.1 Furnace Location

As part of the task of developing this design guide, a case study was conducted to evaluate the impact of furnace and register placement on energy, comfort, and quality. The results of that study, as related to furnace location are:

- Furnace location has little impact on energy consumption and effectiveness of the HVAC system;
- One difference between an attic and a garage location is that the furnace in the garage tends to have somewhat longer ducts, resulting in more conductive losses/gains and more resistance to air flow; and
- More fan power consumption is required due to the longer duct runs, but this can be compensated for by using larger ducts, if they can be accommodated.

Detailed information on this study is available from the California Energy Commission as Attachment 2 to the [Final Report for the Profitability, Quality, and Risk Reduction through Energy Efficiency program](#). The report is also available through the Building Industry Institute (BII) or ConSol.

4.2 Register Location

As part of the task of developing this design guide, a study was conducted to evaluate the impact of furnace and register placement on energy, comfort, and quality.

Three supply register configurations were evaluated using a computational fluid dynamics model (CFD) for both heating and cooling. These three configurations represent the most common practice in California production homebuilding: register centered in the ceiling, register over window, and high sidewall. Two return locations, ceiling and low-wall, were also evaluated.

This study used a computer simulation and is not a perfect model of reality. For example, interior furnishings were not included in the model. However, the results do provide a reasonable picture that matches well with real-world experience. Detailed information on this study is available from the California Energy Commission as Attachment 2 to the [Final Report for the Profitability, Quality, and Risk Reduction through Energy Efficiency program](#). The report is also available through the Building Industry Institute (BII) or ConSol.

The studies indicate that the most energy efficient location, with no negative impact on comfort, is to place the supply register on a high sidewall. The study results show that this location provides the best mixing and is the preferred location. In general, high wall registers are a good idea since they allow the air stream to mix with room air above the heads of the occupants and minimize air velocity and temperature non-uniformities in the occupied part of the room. There are other considerations in selecting the supply register location and these are covered in [Step 4](#) of the Overall Design Method.

The figure below is an example of the information generated by this study. This example shows the duty cycle for the three supply configurations with a ceiling return under cooling conditions. The duration of the HVAC ON time is notably shorter for the in-wall supply. Also note that the total duty cycle time for the in-wall configuration is nearly 25% longer than the other cases.

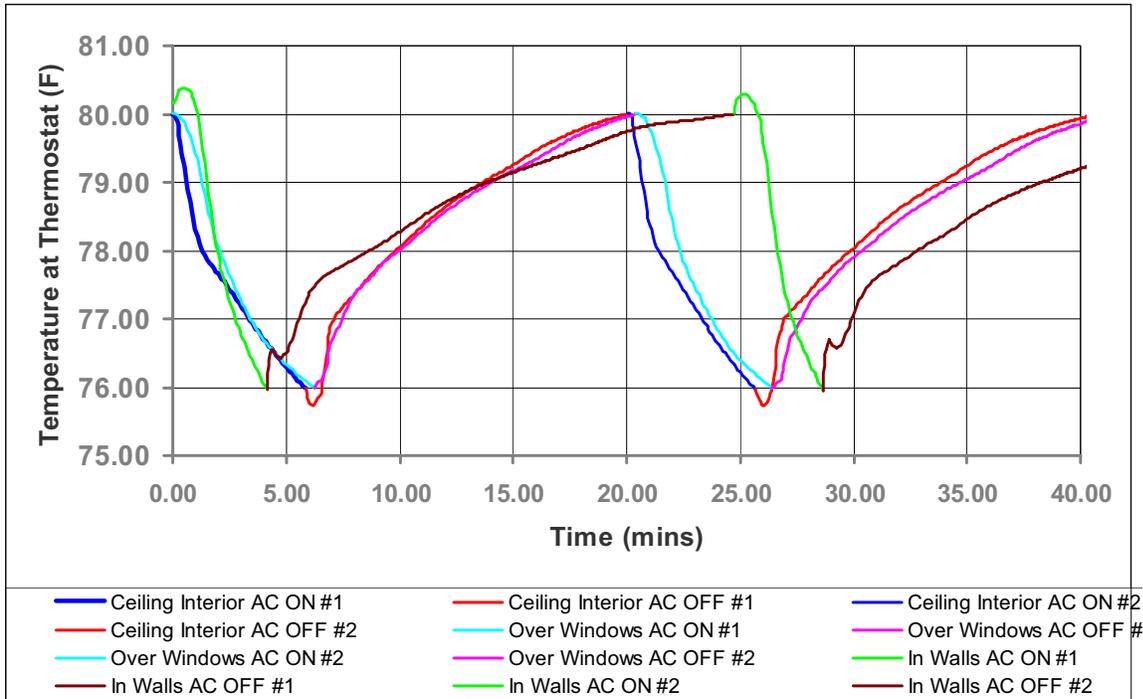


Figure 18: ON/OFF run times for three cooling configurations with ceiling returns: supply register interior ceiling; ceiling over windows; and in-wall

4.3 Multiple Orientation Designs

In a cooling dominated climate, which includes most of California, orientation has a dramatic impact on equipment sizing because most homes, especially new production homes, have the largest concentration of glazing on the back of the home. The required cooling equipment of a typical 2300 square foot home can change from 3.5-ton to 5-tons, a 30% increase in capacity, just by rotating the house from south-facing to east-facing. The orientation of a home, or more precisely its windows, is what determines the majority of its heat gain. East- and west-facing windows have the greatest heat gain because the sun is lower in the sky and shines through the window at an angle more perpendicular to the windows, increasing the amount of radiation entering the home.

Sun angle and window orientation are accounted for in the heat transfer multipliers used in the load calculation methods. Heat transfer multipliers (HTM) are values that when multiplied by the area of the window produces the heat gain of that window including conductive as well as radiative heat gains. The units are Btuh/sf. The following HTMs for a dual-pane, low-e, aluminum-framed window illustrate the impact of orientation on heat gain.

North	East/West	South	SE/SW	NE/NW
21.4	61.0	32.8	53.1	44.3

Table 2: Orientation Effect on Heat Transfer Multiplier

As this shows, each square foot of east- or west-facing glass has nearly twice the heat gain of south facing glass and nearly triples that of north facing glass. Most typical homes tend to have the majority of the glass on the back of the house. This is where most of the sliding glass doors and large family room/great room windows are typically located. When so much of the glass is loaded on one side of the house, the variation in total cooling load is much greater between orientations. Conversely, if the glazing area of a house were exactly evenly distributed on all four sides of the home, the total cooling load would be equal in all orientations. This is rarely, if ever, the case in typical production home design.

Because the majority of homes built in California are production homes using the master plan concept (several plan types used over and over, and built multiple times in various orientations), the variation between best and worst case orientation must be considered. Standard practice is to design for worst-case orientation. This is an acceptable practice for the vast majority of plans. The risk of this approach is that the equipment in the best-case orientation is oversized to a degree that can negatively impact effectiveness and efficiency.

Not only does orientation impact the total cooling load of a home, it has an even greater impact on an individual room's load. The key to a good duct design is even distribution of air in amounts proportional to the load from each room. If a house is built in multiple orientations, then each of its rooms can and will face any orientation. This means that an individual room's calculated cooling load can change by a factor of nearly three times (recall the difference between the North HTM and East/West HTM.) This, in turn means that a room's air flow requirement can nearly triple. The net result is that duct sizing requirements for a given room can change as the orientation changes, but it is extremely impractical to require different duct layouts for a single master plan depending on what orientation it is to be built in. Thus, the worst-case orientation is used even though it may not provide the best layout for all orientations.

Best Practices

The best practice for evaluating and implementing orientation dependent features in a residential HVAC design is to assess the potential equipment and duct-sizing impacts for all of the eight cardinal and semi-cardinal orientations that may be built for a given plan. To do this the designer should obtain a site/plot map of the subdivision and create a list of all possible orientations (to the nearest 45 degrees) for the project. It is possible that even in a large project the worst-case orientation may not even be plotted for one or more plan types.

Once this information has been determined, the loads can be calculated for just the orientations to be built. If the loads result a very high variation in equipment sizing (1 ton or more per system) then the designer should confer with the builder developer to see if it would be cost-effective to vary the equipment size by orientation. It is recommended that only the condenser tonnage be varied and not the furnace or coil. Leaving the furnace and coil the same for all orientations will allow the system air flow to remain essentially the same and reduces the potential need for varying duct sizes

Most manufacturers allow a 1-ton or more variation between condenser and furnace/coil. In other words, it is not uncommon to match a 4-ton condenser with a 5-ton furnace and coil, or a 3-ton condenser with a 4-ton furnace and coil. This allows the designer to have up to three levels of cooling capacity for a given duct layout. For example a single plan could utilize a 3/4/4, a 3.5/4/4 or a 4/4/4 system (condenser/coil/furnace) with sensible cooling capacities of around 26,000 Btuh, 30,000 Btuh and 34,000 Btuh. All of these systems would deliver approximately 1600 cfm.

Once the system airflow is determined the duct sizes can be determined and evaluated for all orientations. Currently it is a very tedious exercise to do this because it must be done manually. Eight duct tables must be printed out and each trunk and branch evaluated for the maximum size.

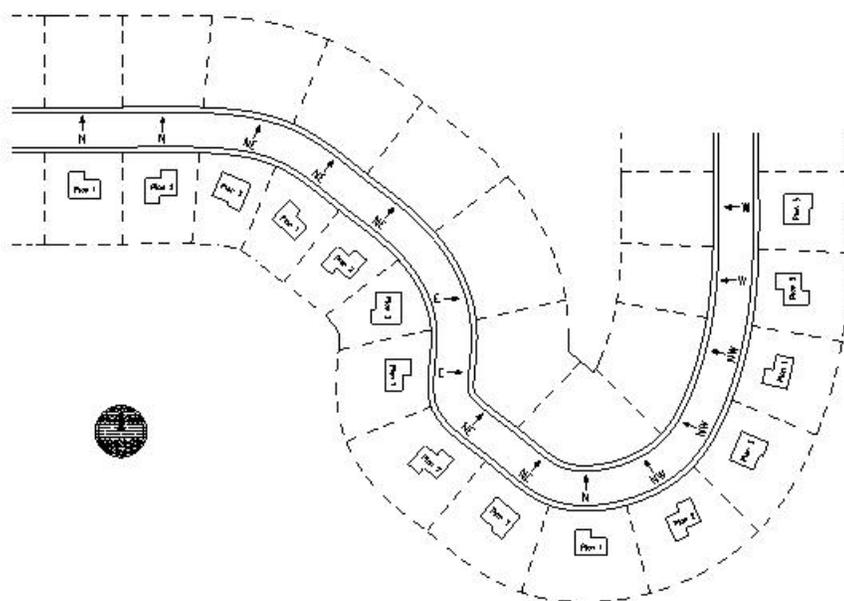


Figure 19: Sample Site Plan with Varying Orientation

Example:

The following example is for a 30-lot subdivision with three plan types. Plan 1 is a 2000 square foot single-story home. Plan 2 is a 2400 square foot two-story home. Plan 3 is a 2850 square foot two-story home. Each plan is to be built 10 times as shown below.

Table 3: Subdivision Site Plan Orientation

Lot	Plan	Front Orientation	Lot	Plan	Front Orientation
1	1	N	16	1	SW
2	2	N	17	2	SW
3	3	NE	18	3	SW
4	1	NE	19	1	S
5	2	NE	20	2	S
6	3	E	21	3	S
7	1	E	22	1	SE
8	2	NE	23	2	SE
9	3	NE	24	3	SE
10	1	N	25	1	E
11	2	NW	26	2	NE
12	3	NW	27	3	NE
13	1	NW	28	1	N
14	2	W	29	2	N
15	3	W	30	3	E

The loads and equipment sizing can be tabulated as shown below.

Table 4: Plan 1 Loads and Equipment Sizing

Plan1			
Orientation	Lots	Sensible Load (Btuh)	Cond/coil/furnace (tons)
N	1, 10, 28	29067	3.5/4/4
NE	4	33201	4/4/4
E	7, 25	33071	4/4/4
SE	22	26871	3.5/4/4
S	19	25067	3/4/4
SW	16	26721	3.5/4/4
W	-	33972	4/4/4
NW	13	32871	4/4/4

Table 5: Plan 2 Loads and Equipment Sizing

Plan 3			
Orientation	Lots	Sensible Load (Btuh)	Cond/coil/furnace (tons)
N	2, 29	34999	5/5/5
NE	5, 8, 26	38071	5/5/5
E	-	37088	5/5/5
SE	23	33281	4/5/5
S	20	33018	4/5/5
SW	17	33697	4/5/5
W	14	40021	5/5/5
NW	11	35881	5/5/5

Table 6: Plan 3 Loads and Equipment Sizing

Plan 3					
		Downstairs System		Upstairs System	
Orientation	Lots	Sensible Load (Btuh)	Cond/coil/furnace (tons)	Sensible Load (Btuh)	Cond/coil/furnace (tons)
N	-	22555	3/3/3	28900	3.5/4/4
NE	3, 9, 27	24082	3/3/3	30721	2.5/4/4
E	6, 30	23621	3/3/3	30020	3.5/4/4
SE	24	21921	3/3/3	27222	3.5/4/4
S	21	21002	2.5/3/3	26199	3.5/4/4
SW	18	20822	2.5/3/3	26789	3.5/4/4
W	15	25017	3/3/3	31110	3.5/4/4
NW	12	23221	3/3/3	29181	3.5/4/4

Plan 1: Since only lot 19 had a load low enough to make it a 3/4/4, it would be recommended that a 3.5/4/4 be used here and on the other lots where appropriate. The other lots would get 4/4/4 systems.

Plan 2: The sizing shown is a reasonable breakdown. Note that there is no such thing as 4.5-ton system. If there were, there would be three sizes of systems.

Plan 3: The sizing shown is a reasonable breakdown. Note that all of the lots had the same equipment sizing upstairs. This is because the second floor typically has a more even window distribution.

Note that this approach would result in the opportunity to downsize 10 out of 40 condensers by at least one-half ton at a substantial cost savings.

An example of how the front orientation of the house affects the duct layout for an example house is tabulated below. The numbers are the diameter of the branch duct serving the rooms shown. The numbers vary because as the house turns the orientation of each room changes, which changes each room’s load and subsequently, its air flow.

Trunk ducts are not shown but are affected similarly.

Table 7: Branch duct diameters under multiple orientations

Room	N	NE	E	SE	S	SW	W	NW	Max
Living	7	6	6	7	7	7	6	7	7
Dining	7	6	6	7	7	7	6	7	7
Living	7	6	6	7	7	7	6	7	7
Family	7	7	7	7	7	7	7	7	7
Family	7	7	7	7	7	7	7	7	7
Kitchen	7	7	7	7	7	7	7	7	7
Nook	7	7	7	7	7	7	7	7	7
Den	6	6	6	6	5	6	6	6	6
Bath3	4	4	4	4	4	4	4	4	4
Laundry	5	5	5	5	5	5	5	5	5
Mbed	8	8	8	8	7	8	8	8	8
Mbath	6	6	6	6	6	6	6	6	6
Mwic	4	4	4	4	4	4	4	4	4
Bed2	6	6	6	6	6	6	5	6	6
Bath2	4	4	4	4	4	4	4	4	4
Bed3	6	6	6	6	6	6	6	6	6
Bed4	6	6	6	6	6	6	6	6	6

As one can see, the required duct sizes never vary more than one size for any particular room. Also, many rooms are unaffected by orientation. This particular house had a fairly good fenestration distribution. As glazing gets more loaded on any single side, the variation in duct sizes gets greater.

Designing to the maximum size for each room does not result in a large amount of change for most homes but it does insure that all rooms will have ducting large enough to provide its fair share in all orientations.

Balancing

Once the home is built according to the mechanical plans, the next challenge is to properly balance the system. Because the system is designed to accommodate any and all orientations, there will be some adjustment necessary for each and every home by means of in-line manual balancing dampers. In most cases, these adjustments will be very small.

The number of manual balancing dampers can be reduced and the locations can be more accessible if the duct system is laid out carefully. A simple four-trunk system can work adequately for most homes. The house is divided into four sub-zones. Sub-zones are one or more adjacent rooms whose loads are impacted in a similar fashion as the house rotates and are otherwise thermodynamically similar. Each sub-zone is served by a supply trunk that is controlled by a single balancing damper. The more complex that a home's floor plan is, the more sub-zones it will need.

It is common practice to leave the entire manual balancing dampers fully open until the homeowner has lived in the home for a while. If areas of excess air flow (over conditioning) occur the dampers controlling those areas can be closed down. It is usually not necessary to precisely balance a home to the exact design flows because individual homeowner preferences and use pattern sometimes outweigh the design assumptions.

4.4 Zonal Control

Zonal control typically refers to a single HVAC system with 2 or more independent zones. This independence is accomplished through a control panel and motorized dampers that send air to the zones that require it and limit or stop altogether the air going to zones that do not require it. Each zone has its own thermostat.

As homes get more and more efficient, the size of a home served by a single system gets larger and larger. The larger a house is, the more difficult it can be to adequately control the indoor temperature with a single thermostat. Zonal control is an effective way to add zones without the expense of multiple systems. Zonal control should be used for comfort only. It will not reduce the load of the envelope nor will it increase the total capacity of the system at peak conditions.

In deciding whether zonal control is needed or not, the designer must consider the diversity of the home. For example a 3000 square foot 1 story house that is sprawling and spread out with many wings and “appendages” would be more likely to need zonal control than a house with the exact same cooling load but that is larger but more compact.

The designer must also consider the relative airflow requirements between the two zones as they change between heating and cooling modes. For example a two-story house may require more air downstairs than upstairs in heating mode but that may reverse in cooling mode. Because the ducts are sized for cooling air flow (due to the higher fan speed) the home may need to be balanced seasonally by closing dampers and/or registers in order to get adequate comfort distribution between the upstairs and downstairs in heating mode. This is not an unreasonable expectation but a zonal control system would help alleviate this effort. If a zonal control is not installed in this situation, the occupants should be informed of the seasonal balancing requirement and educated on how to perform it.

For more discussion on zonal control, see [Section 3.2.1 The Overall Design Method, Step 1.](#)

4.5 Window Loads

Windows account for a very large fraction of cooling and heating loads in a building. The glazing type, the amount of glazing, insulation and shading devices used all contribute to a significant portion of the overall cooling loads (mainly solar gains) and heating loads (conductive heat losses) in a building.

As an example, a 1940 square foot home with an 18.6% window-to-wall ratio was analyzed in 4 climate zones (zones 7, 10, 12, and 14) and four orientations using Micropas⁶. Heating loads attributed to glazed surfaces remained approximately equal (16.5% - 18.0%, depending on climate zone). Cooling loads varied between 32.0 % and 41.3% depending on both orientation and climate zone. Because windows represent such a high percentage of heating and cooling loads, it is important that their impact be accurately quantified.

4.5.1 Heating loads from windows

In calculating heating load, only conductive heat loss is calculated because solar gains reduce the net heat loss and actually assist the heater. Heat loss calculations are therefore based on nighttime conditions when there are no solar gains. A simple $UA\Delta T$ calculation is used:

$$q = UA\Delta T = \frac{A}{R} \Delta T$$

In this equation, “U” is the overall window u-value including glass and frame; “A” is the rough opening of the window; and “ ΔT ” is simply the difference between the indoor and outdoor winter design temperatures.

The ability of the $UA\Delta T$ formula to predict actual heat losses is limited by the accuracy of the input parameters. Area is not a problem since it is a fixed value. U-value is limited by the accuracy of generic window descriptions to accurately reflect the actual U-values of all the different brands of windows that may meet the generic definition. If the make and model of the window to be installed is known and it is a window that has been tested to National Fenestration Rating Council (NFRC) standards there will be a reasonably accurate U-value that can be used for that window. Even tested values have their limitations. U-value within a particular make and model of window will vary by window size because the frame-to-glass ratio changes. As a reasonable simplification and to keep the cost of testing windows down, only a single “common” size window is tested and that tested U-value is used for all windows in that product line.

The actual ΔT (difference between the indoor and outdoor winter design temperatures) value can vary somewhat from the number used in the calculations. Of course, outdoor temperature varies with season and time of day, but the ΔT used in the calculation can be wrong even at the time when they are *supposed* to be correct. To understand this, it is important to understand how these temperatures are selected.

The indoor design temperature is the desired indoor temperature. It can be thought of as the thermostat set point. However, even when a thermostat reads a certain temperature, 70 degrees for example, it will not be 70 degrees everywhere in a house. There can be places in the house where the temperature is substantially higher or lower than 70 degrees. For example, supply air registers are commonly placed directly above or below windows. When the heater is operating, hot air of up to 150 degrees is blowing on or near the window. With an

⁶ Enercomp, Inc

outdoor temperature of 30 degrees, this yields a real ΔT of 120 degrees. If the design temperatures were assumed to be 70 degrees indoors and 30 degrees outdoors, the real ΔT is three times the design ΔT of 40 degrees, tripling the heat loss.

The outdoor design temperature is a statistically derived temperature based on historical temperature data collected at a nearby data collection point. There are hundreds of these throughout the state. Because it is a statistically derived value, rather than the coldest temperature on record, for example, it is understood that this temperature will, by definition, be exceeded a certain number of hours per year. The statistical number that is used is determined to be one that makes these excessive temperatures (i.e., temperatures colder than the assumed outdoor design temperature) an acceptable occurrence. Variations from this data can be caused by microclimates or normal (or abnormal) macro climatic changes and will throw off the *statistical* accuracy load calculations, but problems with the indoor temperature as described above will have an even greater impact in the statistical accuracy of the loads. In other words, the actual number of hours that the real heat load exceeds the calculated heat load may be dangerously high; the heater may be unable maintain a comfortable indoor temperature during long periods of extreme cold when reality exceeds the design margin.

4.5.2 Cooling loads from windows

Cooling loads largely consist of the incoming solar radiation through the windows and conductive heat gain. Heat gain calculations are made up of a conductive component, very similar to heat loss calculations, but the heat is traveling into the house rather than out of the house. Heat gain calculations are susceptible to the same factors that make heat loss calculations inaccurate. They are also made up of a much larger radiant component. This is the heat gain associated with sunlight passing through the windows and is effected by a very large number of factors, only a few of which are accounted for in the load calculations, for simplicity reasons. Also, for simplicity reasons, the load associated with sunlight is averaged throughout the day. This is called “diversity” and has to do with the fact that the sun travels across the sky and the actual load on rooms in a house will not match this averaged value. Some calculation methods allow a “peak load” to be calculated when appropriate. This is the highest cooling load that will occur at any time during a given day.

Factors that effect window heat gain and loss, calculated and actual, are summarized below:

- Window area – total and for each orientation. Because windows are a less efficient part of the building shell than walls, floors or ceilings, the more windows you have, the higher the heating and cooling loads will be. Some windows have a higher heat gain per square foot because of their orientation. See the orientation discussion in the next section.
- Location – The geographic location of the house can impact the cooling loads associated with windows other than simply affecting the outdoor design temperatures. The latitude of house determines the angle of sun and sun’s path across the horizon. Local factors can affect the intensity of sun. These include cloud cover, pollution, and humidity.
- Window solar heat gain coefficient (SHGC). This is a property of the particular window and is defined as the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then radiated, conducted, or convected into the space. The SHGC of a window is affected by the number of panes, thickness and clarity of the glass panes, any tinting or other special coatings,

thickness of the frame, mullions and other details. SHGC can be dramatically improved through the use of special coatings that block certain wavelengths of light, particularly those responsible for heat gain.

- U-value. The U-value describes a window assembly's ability to transmit heat conductively and is a function of the properties of both the frame and glass panes. Like the SHGC, it can either be a generic number based on the general description of the window or it can be a National Fenestration Rating Council (NFRC) tested value.
 - Emissivity of window. This number describes the amount of heat that is emitted from a window due to its being warmer than the surroundings. The lower the level of emissivity, the more efficient the window. Emissivity levels generally range from 0 to 1 and can be dramatically improved through the use of special coatings. Emissivity is usually accounted for in load calculations by adjusting the window U-value.
-
- ◇ Shading. Shading devices are either interior or exterior. They can be further subdivided into removable (or otherwise controllable) and fixed. This controllability is important because they can assist in reducing heat gain in cooling mode but they can also reduce heat gain in heating mode when heat gain may be desired (i.e., on a cold but sunny day). An additional type of exterior shading includes those that are not necessarily integral to the building and are categorized as "adjacent structures".
 - ◇ Interior shading devices. Curtains, blinds, roller shades and other such interior window treatments, though often aesthetic in purpose, can have a substantial impact on heat gains when used correctly. The more opaque and reflective the material, the more it will reduce solar heat gain. For example, a white, opaque roller shade will reduce solar gains better than a dark drape. One disadvantage of interior shading devices is that solar gains have already entered the space by the time they are intercepted by the interior shade device. This heat is trapped between the shading device and the window. Some of the heat is reflected or radiated back out of the window, but much of it remains inside.
 - ◇ Exterior shading devices. These are devices that are part of the building or window assembly and include overhangs, bug screens, solar screens, and awnings. Overhangs are often overlooked as very efficient devices for reducing loads and energy consumption. Architectural fashion typically outweighs their practicality. Though a permanent component of the building they can be designed to maximize the benefit in the summer and minimize their impact in the winter. Bug screens are not considered an energy device but can have a noticeable impact on the SHGC of a window assembly. Sun-screens (a.k.a. solar screens) can be a very cost effective means of reducing heat gain. Also, because they are removable, their impact in the heating season can be minimized. Awnings behave as an overhang and are also seasonally removable.
 - ◇ Adjacent structures. These can include buildings, trees, fences, and terrain such as hills. They may have a substantial impact on actual loads but are rarely accounted for in the calculations. They most commonly shade a window but can have the opposite impact of reflecting light into a window. In this regard, the ground adjacent to a building is considered an adjacent structure because it can reflect additional light into a window. Imagine the difference in solar gains between a house surrounded by lush lawn and a house surrounded by a bright white concrete surface.

Best Practices

Best practice for new construction loads would be to model no internal or external shades in the load calculations, but to model overhangs because they are fixed architectural features of the building that are unlikely to be removed. Internal and external shades are frequently left open, left off or otherwise removed. To assume that they are in place when calculating cooling loads is risky. Some designers believe that interior shades should be assumed closed. This results in dramatically lower solar gains and cooling loads. However, if the cooling equipment is sized under these assumptions, the home will not cool properly on hot days if the homeowner does not close the drapes. While closing drapes on a hot day is a praiseworthy behavior, this design philosophy is not consistent with the expectations of most homebuyers.

The approach used for modeling features in Title 24 compliance is usually appropriate for load calculations in new construction. In Manual J, Version 8, the designer should always assume NFRC rated windows will be used in new construction. If non-rated windows are used default performance values can be used that are consistent with Title 24 calculations but entered in the load calculations as though they are rated windows. Assume the same minimum features necessary for compliance, if slightly better features get installed, fine. If, however, better features get installed than were assumed in the load calculations, there is a small risk of oversizing the equipment to a point of reduced energy efficiency and conditioning performance. However, the potential expense to a builder of undersizing equipment is far greater than that of oversizing.

Performance values used in the load calculations (U-value, SHGC, and shading coefficient of screens and other shading devices) should be consistent with those used in the Title 24 calculations. The current computerized versions of Manual J, Version 8, for room-by-room loads and the current methodology used by Micropas for whole-house loads do a very adequate job accounting for loads associated with windows. It is a useful exercise to compare the Micropas load to the total of the room-by-room manual. This provides a trustworthy check to help ensure that no calculation errors have been made. This is another reason why it is important to use the same window performance values in both calculations.

For duct sizing it is appropriate to assume worst-case window conditions. For example a home may have a window that could be replaced by an optional sliding-glass door, which substantially increases the glazing area and the subsequent load on that room. Sizing the duct for the worst case (with the sliding-glass door) ensures that the duct serving the room will accommodate the amount of air required for the higher load. When the higher load does not occur, it is a simple matter to damper down the airflow if it is excessive. Again, the potential cost of underestimating the load is far greater than overestimating it.

4.6 Duct Loads

Duct leakage rates of up to 45% were not uncommon in *new* homes built and tested prior to the late 90's. This is a direct loss of concentrated energy; the heated or cooled air is dumped directly into unconditioned spaces (e.g., supply leaks into attics), or conditioned air is displaced by unconditioned air (return leaks in attics or garages).

Manual J does a reasonable job of accounting for duct leakage loads, given a known leakage. The problem lies not in quantifying a known leakage rate but in estimating the actual leakage amount. Prior to construction and/or without actually testing the system leakage, it is very difficult to predict. Field-testing has shown that using very similar installation protocols on two similar houses can still result in leakage rates that are vastly different. Even the brand of furnace can affect the leakage rate by one-third or more.

Title 24 software assumes that the system is “tight” if it is known that the home will be tested, and repaired if the leakage is greater than 6%. If the home is subsequently tested and the leakage is indeed less than 6% then the designer can rest assured that the load calculations are valid. However if the system is not tested and the leakage is significantly more than 6%, the equipment may be undersized. Commonly, if the system is not going to be tested, current practice is to assume that the system is “guilty until proven innocent” – i.e. it leaks more than 6%. The system is assumed to be “typical,” with a leakage of 22%. If the designer assumes this higher leakage and the installer does an excellent job of installing the system, the system may potentially be oversized.

Even testing a system using common procedures such as a duct blaster test does not guarantee that the actual load of the duct leakage will be accurately estimated. Limitations of current duct leakage tests result in substantial variances between tested leakage and actual leakage. These limitations include the inability of the test, using common practices, to distinguish between supply and return leaks and the inability to identify the location of a leak, which may be located in a very high pressure part of the system (near the fan) or in a very low pressure part of the system (near a register or grille). Note: The duct blaster test pressurizes the entire system to the same pressure level and thereby treats all leaks equally.

Best Practices

The best way to minimize variances between estimated and actual leakage is to assume that the leakage is attainably low and then make the appropriate effort to ensure that it is installed that way. More sophisticated test methods may improve the accuracy of measuring leakage, but the tighter the systems become, the law of diminishing returns makes more testing expensive and unnecessary.

4.7 Two-story Considerations

As homes become more and more efficient, their heating and cooling loads decrease. The result of this is that larger and larger homes are being served by single HVAC systems. In a typical California subdivision that offers four floor plans, three will be two-story homes. Many of those are served by a single system, a very common design in California new construction and one that tends to have many customer service complaints related to temperature variations (stratification) in the home.

Many HVAC subcontractors believe that a two-story home with a single system must have a substantial amount of the return air taken from the first floor. While there is no evidence to support this, HVAC subcontractors will insist that architects and builders go to great effort and expense to accommodate a relatively large return duct and grill to the first floor. Some designers believe that a return in the ceiling of the second floor is adequate as long as the downstairs supply ducts are properly sized.

There is also much debate and disagreement over the proper location of a thermostat in a two-story home served by a single system. Some designers locate it upstairs because heat rises and that is where the most cooling is needed (cooling emphasized). Others locate it downstairs because in the winter the first floor tends to be colder and that is where the most heating is needed (heating emphasized).

As part of the task of developing this design guide, a study was conducted to evaluate the impact of the number and locations of returns and the placement of the thermostat in a two-story home served by a single HVAC system.

Three return configurations were evaluated for cooling using a computational fluid dynamics model (CFD). These three configurations were designed to address the common practices in California production homebuilding:

- Case 1: split returns upstairs and downstairs; thermostat upstairs
- Case 2: return upstairs; thermostat upstairs
- Case 3: return downstairs; thermostat downstairs

The figure below is an example of the information generated by this study showing the temperatures and duty cycles for the three configurations. Case 2 (return upstairs/thermostat upstairs) and Case 3 (return upstairs/thermostat downstairs) cycle twice as often as Case 1 (returns upstairs and downstairs/thermostat upstairs). Case 1, with split return upstairs and downstairs, provides a better mixing of air, delaying the return to ambient temperature.

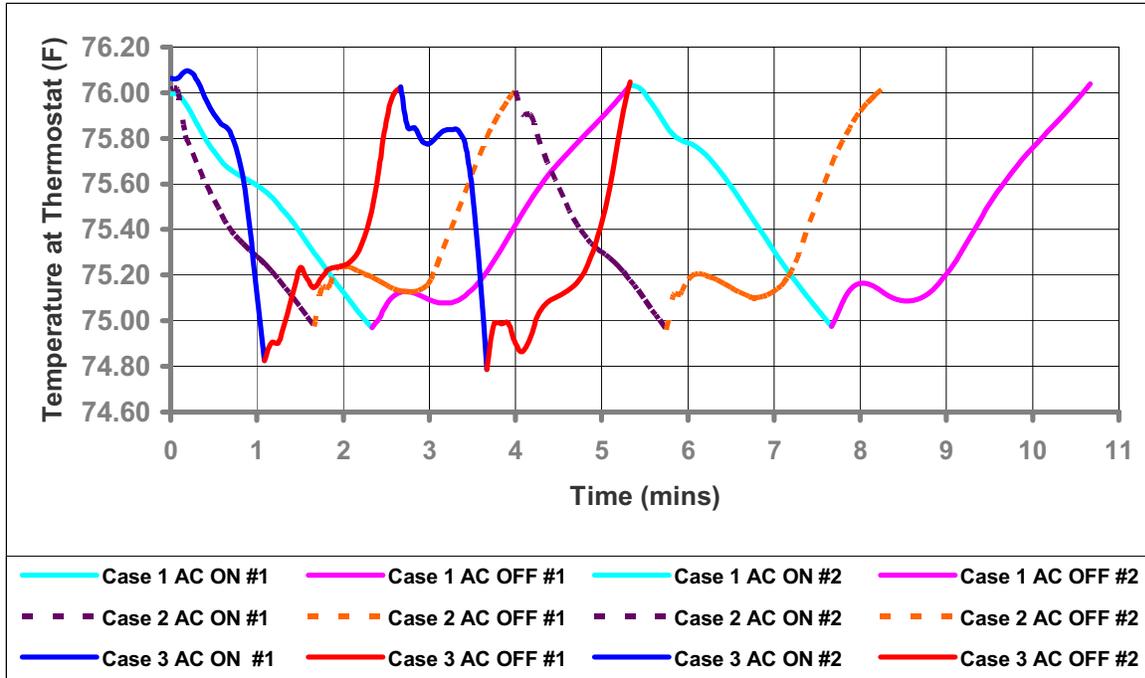


Figure 20: Comparison of HVAC Cycle Time for Case 1, 2 and 3

Recommendations

For the two-story application, installing returns both upstairs and downstairs provides longest duty cycles with good comfort and air quality. While the total On-Times are nearly equal for all cases, the two-return design causes the least system cycling, less startup demand, and less wear on the HVAC equipment.

The thermostat located downstairs, farthest from the return, has the most negative effect on duty cycle. Not only does it generate more startup demand for each cycle, this configuration requires frequent system cycling, causing additional equipment wear, and should be avoided.

5.0 Other Mechanical Design Related Issues

Many HVAC-related items should be coordinated in a meeting between stakeholders early in the design process, such as at a value-engineering meeting. The following checklist is provided for use at such a meeting. A detailed discussion of each item follows.

A value engineering meeting checklist

- Condenser locations and refrigerant lines
- Furnace location and clearance
- Attic access locations
- Flue (b-vent) locations and routing
- Duct sizes and locations (soffits, joist bays, chases and drops)
- Supply register locations
- Return air locations
- Dryer vent routing
- Combustion air supply
- Thermostat location

5.1 Condenser Locations and Refrigerant Lines

From a design/performance standpoint, condensers and refrigerant lines are a simple concept: obey the minimum clearances and the maximum line lengths and the design should work fine. From an installation/practical standpoint, they can be a real headache. The noise they generate can be a real problem. Bedroom walls should be avoided when running lines and locating condensers. Some manufacturers make special noise reduction kits that can help avoid or resolve noise problems. Vibrations transferred from the compressor through the refrigerant lines can be transferred and magnified by walls. Care should be taken not to let the lines come in direct contact with framing. Always use some sort of gasket or cushion. With the higher insulation requirements for refrigerant lines (Title 24 requires R-3 minimum insulation on the suction line, see section 2.5.5 of the Residential Manual) it is recommended that a 2x6 wall or some sort of a chase be provided to run the lines. Some builders have been known to run a 6"x6" framed chase down the exterior of the house.

Minimum clearances for condensers may vary by manufacturer but they are typically 6" on one side, 30" on the service access side, 12" on the other two sides, and 48" above. (Consult specific manufacturer's specifications.) They should also be 24" apart if more than one is used. These clearances can sometimes cause problems in narrow side yards. Minimum access requirements must be verified with the builder and can sometimes vary by lot. A condenser works best in a cool, shady spot with good air circulation, but this is usually an impractical request in production homes.

Typically, most manufacturers do not recommend that you exceed refrigerant line lengths of 75', some even say 50'. Some allow lengths up to 175' using a special kit. The impact on capacity and efficiency must be taken into account. Always refer to specific manufacturer's requirements.

The electrical contractor also needs to know exactly where the condensers are located so the power and disconnect can be properly located.

5.2 Furnace Locations (also see previous discussion)

Most single-family detached homes in California are designed with the furnace(s) located in the attic. This is because the attic provides a good central location with good clearance and good direct access to get ducts to most rooms, which reduces overall duct length. Furnaces in garages are the next most common location. Furnaces in closets are rare because of the restrictive clearances and service access to the unit, plus the valuable floor area it takes up. Even if a furnace has a minimum clearance of 0", code requires at least 3" for removal and service. Occasionally, homes with very low-pitched roofs or floors that are difficult to access will have furnaces in a closet. They are most common in attached and multi-family projects.

The popularity of low-pitched roofs in current architecture has made it more of a challenge to locate furnaces in attics. Clearance must be verified if it appears that it will be a tight fit. There are always unexpected items that will use up whatever clearance you thought you had. Careful coordination in the field is critical. <UBC/UMC access and clearance>

Provide permanent electrical outlet and lighting fixture controlled by a switch at or near FAU (2001 CMC Sect. 309)

Provide continuous 24" wide (min) floor from attic access to service platform.

Refer to 2001 CMC Sect. 908 for access and service space code requirements

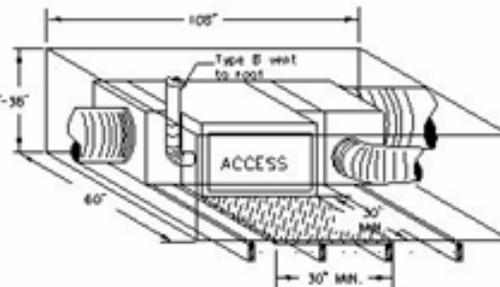


Figure 21: FAU Clearance

The truss designer and structural engineer need to know where the furnace platform will be located and how big it needs to be (how many units, up flow or horizontal, etc.) so the trusses can be properly designed and the weight of the furnaces can be accounted for. The electrical contractor will need to provide electricity, a disconnect, a light and a light switch per the Uniform Building Code.

5.3 Attic Access Locations

The location of the attic access is especially important if the furnace is located in the attic. Section 908.0 of the UMC requires a minimum 30"x30" opening and passageway but allows for an opening as small as 22"x30" as long as the largest piece of equipment can be removed through the opening. Sometimes this is not very easy to determine because more than just the dimension of the opening and dimension of the furnace needs to be considered. Notice that it does not say, "as long as the larger piece of equipment can *fit* through the opening". Remember that just because a furnace has a dimension of 21"x29" does not mean that it can be *removed* through a 22"x30" opening. You have to consider the length of the furnace, the attic access' proximity to trusses and the roof decking, and the angle that the furnace must take to be removed.

In case of a hip roof, the attic access must also be located far enough away from the exterior of the building so that there is a full 30" clearance above it. There should be a 30"x30" passageway all the way to the furnace and then there should be a 30"x30" work area in front of the furnace. The way it is sometimes described is that you need to be able to push a 30"x30"x30" cardboard box from directly above the access all the way to the furnace (but not more than 20 feet) and park it right in front of the furnace.

It is allowed to locate the furnace immediately next to the attic access as long as the 30" cube is provided and the unit can be served from the access (e.g., standing on a ladder).

<UBC attic access locations, UMC 908.0 and 304.1 (clearances)>

5.4 Flue (b-vent) locations and routing

Furnaces located in an attic can usually be easily vented straight up through the roof unless the aesthetics of the vent termination is an issue. B-vents can angle 60 degrees from vertical one time or 45 degrees from vertical more than one time, and must run in a generally vertical direction. Clearance from framing is very important. <UMC chapter 8>

The vent termination must also be at least 8 feet from any vertical wall, including a turret, tower, upper floor, etc. If not, it must extend above that wall.

A 90% or condensing furnace may provide a suitable alternative to a B-vent. Condensing furnaces and boilers are the most energy efficient units on the market today, potentially 10-15% more efficient than conventional units. The combustion process produces gas by-products that include water vapor and carbon dioxide. In a conventional heating system, these by-products are vented out of the house. Condensing systems cool the combustion gases to the point that water condenses and the process releases additional heat that is captured and distributed to the home. The extracted heat lowers the temperature of the combustion products to a point that any of the approved types of pipe can also be used for venting combustion products outside the structure. The combustion-air and vent pipes can terminate through a sidewall or through the roof when using one an approved vent termination kit, consistent with local codes.

5.5 Duct sizes and locations (soffits, joist bays, chases and drops)

Two-story homes with the furnaces in the attic pose a special challenge: how do you get ducts from the upper attic down past the second floor rooms to rooms on the first floor? Sometimes it is easy and sometimes it is impossible. Typically, in a two-story house the upstairs is predominantly bedrooms. Bedrooms have closets. Despite the protests from the architect, closets are a good place to locate a vertical chase that cuts through the second floor. The “dead” corners of walk-in-closets work very well because they don’t use up too much hanging space and they provide a nice wall for the shelves and poles to die into. Care must be taken when using vertical chases adjacent to an exterior wall. The slope of the room can severely restrict access to the top of the chase in the attic. It may be necessary to drop the ceiling adjacent to the chase and “low-frame” the interior wall(s) of the chase. See [Section 4, Chases and voids](#), for more discussion on chases.

It is recommended that chase locations be conveyed to the architect so they can be put on the official floor plans and coordinated with the framer. Nothing ruins a good chase faster than dissecting it with a roof truss or floor joist. It may be useful to explain to the framer that two 6” ducts are not the same as one 12” duct!

Soffits and dropped ceilings are often necessary evils for getting ducts to a particular location if it cannot be accomplished using floor joist bays alone. The total depth of a drop (reduction in ceiling height) is typically the diameter of the duct to be run, plus 4-6 inches to allow for framing and duct insulation. Sometimes this can be reduced if “flat framing” is allowed and the insulation can be compressed, which is allowed if the drop is between conditioned spaces. Generally speaking, the amount of clear space required for a duct of a given diameter is the nominal diameter plus two inches. Less is feasible if the insulation can be compressed 5 but it can make it much harder to install.

5.6 Duct Installation, Insulation, and Location

Ducts carry air from the central heater or air conditioner to each part of the home and back again. Unfortunately, ducts can waste a significant amount of energy and money due to improper installation and poor materials. A number of factors can affect the functioning of ducts, including:

5.6.1 Duct Sealing

Typically, ducts are so leaky that more than 35% of the conditioned air is lost before it arrives at the target room the duct is trying to reach. This means that more than 20% of the energy used to condition the air is wasted. Improved duct performance depends on sealing the seams between the ducts. Duct tape, which is commonly used, does not adequately seal the joints nor does it last very long. UL listed tapes or duct mastic should be used to seal all joints and seams in the ductwork.

The following link, "[Procedures for HVAC System Design and Installation](http://www.thebii.org/hvac.pdf)" (<http://www.thebii.org/hvac.pdf>) lays out the criteria and procedure for designing and installing a quality HVAC system. It provides the "Details for an HVAC System: Material, Fabrication, Design, and Installation, and Performance Testing" that will help to insure a lasting, tight installation (aka "tight duct protocol").

5.6.2 Duct Location and Insulation

Builders often place ducts in spaces that homeowners do not heat or cool, such as attics, crawlspaces, garages, or unfinished basements. The extreme temperatures that can occur in these spaces (attic air in the summer can reach above 150°F) will affect the temperature of the air moving through the ducts into the home.

As air moves through the ducts, the temperature of the duct location, either hot or cold, affects the air temperature. To reduce these temperature variations, ducts need to be insulated. The R-value of ducts in unconditioned space is R-4.2. There is a compliance credit for higher R-values.

If the ducts are located in the living area of the home, which tends to remain at a reasonable temperature, then the need for insulation is reduced. However, some insulation is still needed to ensure that the conditioned air is delivered at the desired temperature and to prevent condensation on the duct walls

Installing ducts within the conditioned area of a home will substantially reduce duct air losses "Ducts in Conditioned Space" minimizes conduction and radiation losses. In addition, air that leaks out of the ducts goes into conditioned spaces. There are a number of publications available on this topic. For example: [Locating Ducts in Conditioned Space](#), from the EnergyStar Program.

5.7 Combustion air supply

Furnaces (and any gas burning appliances) need to be provided with combustion air. This is air that provides the oxygen for the combustion of the gas. If a typical furnace is located in a closet, that combustion air should be ducted. Chapter 7 provides some options for providing these ducts and openings. This can be quite a challenge if the furnace closet is deep within the building because two ducts are required and they can be 6 or even 8 inches in diameter and made of sheet metal. Some higher efficiency condensing furnaces can solve a lot of combustion air problems because they provide their own combustion air through PVC piping as small as 2" and as long as 70-80 feet. They also vent through a similar pipe and the termination of the vent and combustion air can be through the same concentric terminal.

Furnaces located in a garage may not need special combustion air vents if the volume of the garage is adequate to meet the definition of an unconfined space. Be sure to count all gas burning appliances when making this determination.

Furnaces located in attics are typically assumed to have adequate combustion air as long as the attic is adequately ventilated based on the attic ventilation requirements of section 1505.3 of the UBC. This is because the venting area required for attic venting is much greater than that for combustion air. However, despite the logic that if combustion air can be ducted from an attic to a closet (section 703.1.2 of the UMC) then you should be able to locate the furnace in that attic, some building departments require that the attic meet the high/low requirements for combustion air. Some building departments go even farther and require that combustion air venting be installed *in addition to* the normal attic venting. They do not understand that the air that serves to vent the attic can do double duty and also be combustion air.

5.8 Thermostat location

Properly locating a thermostat can be as much a Zen art as a science. There are 10,000 bad places to put a thermostat in a house. Your job is to choose the “least bad” of those places. Some places to definitely avoid are exterior walls, locations that get direct sun, locations that a supply register will blow on, locations near an exterior door or window, walls adjacent to or near a fire place, etc.

Remember that a thermostat does two basic things: It turns the system ON and it turns the system OFF. The best location for turning the system on may not be the best location for turning the system off. The best place for turning the system off is usually under or near the main return grill. This is because when the system is running, the return is pulling air from all over the house and it is a good sampling of the average temperature in the house. When the system shuts off this may not be a very good place to sense the average temperature in the house.

As part of the task of developing this design guide, a study was conducted that included evaluating the locations of the thermostat in a two-story home served by a single HVAC system. Reference [Section 4.7 Two-story Considerations](#) for recommendations on thermostat placement. Detailed information on this study is available from the California Energy Commission as Appendix C of Attachment 2 to the [Final Report for the Profitability, Quality, and Risk Reduction through Energy Efficiency](#) program. The report is also available through the Building Industry Institute (BII) or ConSol.

5.9 Ventilation and Indoor Air Quality

In the old days, the wind and other uncontrolled forms of air leakage ventilated buildings. Today, people no longer accept such cold, drafty houses. Houses are now expected to be cozy, draft free and energy efficient and a tight home is fine, as long as it comes with good ventilation and indoor air quality. Modern building materials tend to make newly constructed homes much tighter than old ones. Plywood, house wrap, better windows, caulk and expanding foam are a few examples of common products that tighten a house. Research has shown that some builders inadvertently build houses much tighter than intended.

If too little outdoor air enters a home, pollutants can accumulate to levels that can pose health and comfort problems. Unless they are built with special mechanical means of ventilation, homes that are designed and constructed to minimize the amount of outdoor air that can "leak" into and out of the home may have higher pollutant levels than other homes. However, because some weather conditions can drastically reduce the amount of outdoor air that enters a home, pollutants can build up even in homes that are normally considered "leaky."

In any home, uncontrolled air leakage is an unreliable ventilator. The best way to ensure adequate ventilation is to install some type of automatically controlled ventilation system and there are several choices for the builder to consider, depending on local codes and costs.

5.9.1 Indoor Air Quality

Indoor air quality (IAQ) refers to the physical, chemical, and biological characteristics of air in the indoor environment within a building or an institution or commercial facility. These characteristics can be influenced by many factors, even though these buildings or facilities do not have industrial processes and operations found in factories and plants.

Factors that influence indoor air quality include:

- Inadequate supply of outside air.
- Contamination arising from sources within the building (e.g., combustion products including carbon monoxide and environmental tobacco smoke; volatile organic compounds from building materials, fabric furnishings, carpet, adhesives, fresh paint, new paneling, and cleaning products; ozone from office equipment).
- Contamination from outside the building (e.g., ozone, carbon monoxide, and particulate matter) through air intakes, infiltration, open doors, and windows.
- Microbial contamination of ventilation systems or building interiors.

Here are a few important actions that can make a difference in indoor air quality:

- Provide proper drainage and seal foundations in new construction. Air that enters the home through the foundation can contain more moisture than is generated from all occupant activities.
- Become familiar with mechanical ventilation systems and consider installing one. Advanced designs of new homes are starting to feature mechanical systems that bring outdoor air into the home. Some of these designs include energy-efficient heat recovery ventilators (for example, air-to-air heat exchangers).

- Ensure that combustion appliances, including furnaces, fireplaces, woodstoves, and heaters, are properly vented and receive enough supply air. Combustion gases, including carbon monoxide, and particles can be back-drafted from the chimney or flue into the living space if the combustion appliance is not properly vented or does not receive enough supply air. Back-drafting can be a particular problem in weatherized or tightly constructed homes. Installing a dedicated outdoor air supply for the combustion appliance can help prevent backdrafting.

5.9.2 Ventilation Systems

Ventilation systems serve three important functions:

- Expelling stale air containing water vapor, carbon dioxide, airborne chemicals and other pollutants.
- Drawing in outside air, which presumably contains fewer pollutants and less water vapor.
- Distributing the outside air throughout the house.
- Controlling system operation automatically.

The basic ventilation system has two elements. First, there's a fan to pull stale air out. Pickup points for stale air are generally in high moisture areas, such as the kitchen, utility and bathrooms. Second, there should be a makeup air supply. Outside air is delivered around the house, with one supply point in each bedroom and at least one in the living area. The suction, also called negative pressure, created by the exhaust fan pulls air through the house from supply points to the pickup points. By properly locating the pickup and supply points, you make outside air travel through the entire house.

Mechanical ventilation systems are designed and operated not only to heat and cool the air, but also to draw in and circulate outdoor air. If they are poorly designed, operated, or maintained, however, ventilation systems can contribute to indoor air problems in several ways.

Advanced designs of new homes are starting to feature mechanical systems that bring outdoor air into the home. Some of these designs include energy-efficient heat recovery ventilators (also known as air-to-air heat exchangers).

5.9.3 Ventilation and Indoor Air Quality Standard

The ASHRAE Standard 62-1999 — Ventilation for Acceptable Indoor Air Quality, specifies the minimum ventilation rates and indoor air quality that will be acceptable to human occupants. It is intended to minimize the potential for adverse health effects and applies to all indoor or enclosed spaces that people may occupy except where other applicable standards and requirements dictate larger amounts of ventilation. Release of moisture in residential kitchens and bathrooms, locker rooms and swimming pools is included in the scope of this standard. The standard also includes Addenda A.

A copy of this standard can be found on-line using the following link:

[ASHRAE Standard 62-1999 — Ventilation for Acceptable Indoor Air Quality:](#)

ASHRAE recommends a ventilation rate of 0.35 ach (air changes per hour) for new homes, and some new homes are built to even tighter specifications. Particular care should be given in such homes to prevent the build-up of indoor air pollutants to high levels. An alternate measure of controlled ventilation rate is to use 15 cubic feet per minute (cfm) per person. A household of four would require 60 cfm. (You can quickly estimate the airflow in cfm needed to meet the 0.35-ach requirements by dividing the floor area in square feet by 20.)

Appendix A: References & Resources

ACCA Manual D ACCA Manual J ACCA Manual S	Residential Load Calculations See: http://www.acca.org/tech/manualj/ (this page contains links for Manual D and S)
Title 24	Energy Efficiency Standards for Residential and Nonresidential Buildings Publication Number: 400-01-024, August 2001, available online at: http://www.energy.ca.gov/title24/2001standards/index.html
Right-Suite	Wrightsoft, http://www.wrightsoft.com/
Elite	Elite Software, http://www.elitesoft.com/ 2700 Arrington Road, College Station, Texas 77845
Micropas	Enercomp, Inc http://www.micropas.com/

Appendix B: Glossary

ACCA Trade Association	Air Conditioning Contractors of America see < http://www.acca.org >
ASHRAE Trade Association	American Society of Heating, Refrigerating and Air-Conditioning Engineers see < http://www.ashrae.org >
ASP	Available Static Pressure
BII	Building Industry Institute
Btuh	British Thermal Units per Hour
CAD	Computer Aided Design
Cardinal Orientations	North - South - East - West
CEC	California Energy Commission
CFD	Computational Fluid Dynamics
CFM	Cubic Feet per Minute
CMC	California Mechanical Code
DBT	Dry Bulb Temperature – relates to ambient air temperature
DX	Direct Expansion
Elite	Elite Software - software package featuring CAD-based take-offs for windows and wall areas
Energy Pro	Common Title-24 compliance software using ASHRAE method
F	Fahrenheit
FAU	Forced Air Unit
FR	Friction Rate
HTM	Heat Transfer Multiplier
IAQ	Indoor Air Quality
iwc	Inches of Water Column
Load Calculations	Building's design calculated heat loss and heat gain
Manual D	ACCA Manual which includes duct sizing
Manual J	ACCA Manual with room-by-room loads
Manual S	ACCA Manual with detailed information for determining heating and cooling capacities of various types of equipment
Manual T	ACCA Manual with selection criteria for supply registers and grilles
Micropas	Common Title-24 compliance software using ASHRAE method
NFRC	National Fenestration Rating Council
Right-Suite	Wrightsoft - software package featuring CAD-based take-offs for windows and wall areas
SHGC	Solar Heat Gain Coefficient
SMACNA Trade Association	Sheet Metal and Air Conditioning Contractors' National Association see < http://www.smacna.org >
SPCDX	ASHRAE Publication
TEL	Total Equivalent Length
UAΔT	U = Window U value, A = Rough opening of window, ΔT = Difference between indoor & outdoor winter design temperature
UBC	Uniform Building Code
UMC	Uniform Mechanical Code
WBT	Wet Bulb Temperature – relates relative humidity to ambient air temperature