

# Strategy Guideline: Compact Air Distribution Systems

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June 2013

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## **Strategy Guideline: Compact Air Distribution Systems**

Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

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NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-40341-03

June 2013

## **Acknowledgments**

This report was prepared for the U.S. Department of Energy Building America program. Funding for this work was provided by the National Renewable Energy Laboratory under Subcontract No. KNDJ-0-40341-03.

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## Definitions

ACCA	Air Conditioning Contractors of America
HVAC	Heating, ventilation, and air-conditioning
IECC	International Energy Conservation Code
NC	Noise criteria

## Executive Summary

This Strategy Guideline covers the pros and cons of compact air distribution systems and the decision criteria that must be considered early in the whole-house design process.

An energy-efficient house has a lower load; consequently, less air volume is needed to condition the space. This presents both challenges and opportunities when designing the air distribution system. The use of a compact duct system—a compact air distribution system that locates the heating, ventilation, and air-conditioning (HVAC) equipment centrally within the house and uses similar-length, shorter duct runs to the interior walls of the rooms—can maximize the opportunities and reduce the challenges.

Challenges arise when “rules of thumb” are used in selecting equipment, sizing ductwork, and selecting the types and locations of air outlets for an energy-efficient house. The protocols of the Air Conditioning Contractors of America (ACCA) Manual S for equipment selection (Rutkowski 1995), Manual D for duct design (Rutkowski 2009a), and Manual T for air distribution basics (Rutkowski 2009b) are especially critical when dealing with lower loads calculated from the Manual J protocol (Rutkowski 2006). Three recent Building America Strategy Guidelines—Accurate Heating and Cooling Load Calculations (Burdick 2011b), HVAC Equipment Sizing (Burdick 2012), and Air Distribution Basics and Duct Design (Burdick 2011a)—help interpret the ACCA guidance for low-load homes.

Opportunities with compact duct systems include lower material and installation costs, smaller equipment, shorter ducts, and fewer outlets. The smaller system also can be easier to fit into the conditioned space, further reducing the load on the HVAC system and increasing the energy efficiency of the house.

# 1 Introduction

An energy-efficient house with higher levels of insulation, high performance windows, reduced air infiltration, and controlled mechanical ventilation has lower heating and cooling loads; consequently, less air volume is needed to condition the space. This presents both challenges and opportunities when designing an air distribution system for an energy-efficient house.

Challenges arise when using ductwork and air outlets sized by rule of thumb (i.e., 1 ton of cooling per 400 ft<sup>2</sup> of floor space). Such systems often do not have the level of performance needed to provide moisture removal or air mixing in the room to achieve the desired comfort results. With less air required to condition the space in a low-load home, the delivery method for the air becomes more critical to creating comfort in the room. A high performance thermal enclosure enables the use of a compact duct system that further improves performance.

For the purposes of this Strategy Guideline, an energy-efficient house is defined as one that is designed and built for decreased energy use and improved comfort through higher levels of insulation, more energy-efficient windows, high efficiency space conditioning and water heating equipment, energy-efficient lighting and appliances, reduced air infiltration, and controlled mechanical ventilation. Specification levels for energy-efficient houses have historically been prescribed by beyond-code programs that set a percentage better than code for energy use, such as ENERGY STAR<sup>®</sup>, which requires houses to be 15% more energy efficient than code.

Beyond-code programs continue to set a percentage better than the improved codes for energy use, raising the bar for whole-house energy efficiency. A comparison of the 2006, 2009, and 2012 editions of the International Energy Conservation Codes (IECC) revealed the 2009 and 2012 editions of code yielded positive benefits for U.S. homeowners and significant energy savings for the nation (DOE 2012). Moving from a baseline of the 2006 IECC to the 2009 IECC reduces average annual energy costs by 10%, whereas moving from the same baseline to the 2012 IECC reduces them by 30%. As new codes are adopted and implemented, a house that was built to a beyond-code program in 2010 will likely be the code-mandated house in 2015. As the energy efficiency of the house is increased under code or beyond-code programs, the peak heating and cooling loads are significantly reduced.

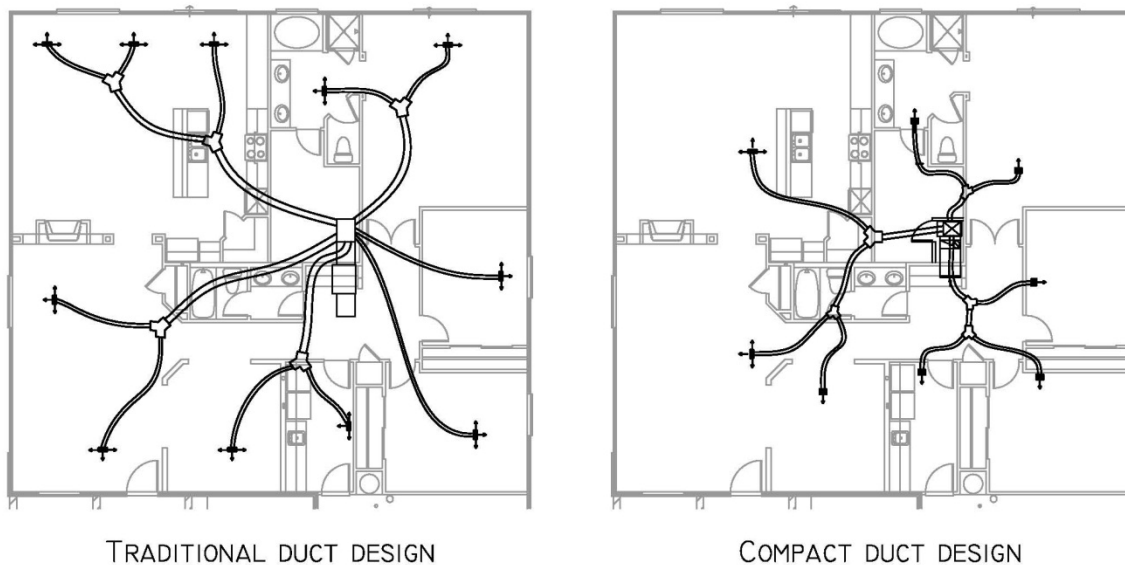
Historically, due to poorly performing windows and lower levels of wall insulation, supply outlets were located at the perimeter of a room to “wash” the thermal enclosure with conditioned air. With the improved thermal enclosure of an energy-efficient house, it is possible to use a compact duct air distribution design. Compact duct air distribution is an early design consideration that offers many benefits for the performance of an HVAC system and implications for the space planning in the house.

Although the advantages of well-designed interior duct systems are recognized, the implementation of this approach has not gained significant market acceptance. However, an extensive body of literature exists to support the implementation of interior ducts in energy-efficient housing (Fonorow et al. 2010).

As shown in Figure 1, a compact air distribution system locates the HVAC equipment centrally within the house and uses similar-length, shorter duct runs to the interior walls of the rooms. In a



compact air distribution system strategy, supply outlets are selected to throw the air toward the exterior walls along the ceiling plane. Shorter duct runs with similar lengths can lead to a better balanced system, reduced static pressure, lower fan energy, and overall improved performance. Furthermore, a compact air distribution system design can simplify bringing all HVAC equipment and ductwork within the conditioned space, further improving efficiency and performance. Another strategy is to use shorter ducts running to interior walls with high sidewall supply outlets in combination with ceiling outlets. Note that floor supply outlets are not recommended with compact duct strategies because they can frequently be blocked by furniture and typically cannot accomplish the same throw and mixing that properly selected high sidewall or ceiling outlets can achieve.



**Figure 1. Traditional versus compact duct design**

Rittelmann (2008) concluded that high sidewall supply air outlets provide slightly better thermal comfort performance than a system incorporating floor diffusers for both heating and cooling operation. The better performance was quantified by the reduced head-to-toe temperature stratification and more uniform room-to-room temperatures achieved by the high sidewall system. Although thermal comfort criteria of ASHRAE were met more than 98% of the time for all stages of both heating systems, the performance of the floor diffuser system was noticeably worse at extremely cold outdoor temperatures (ASHRAE 2004). Head-to-toe temperature stratification was noticeably better (lower) in the high sidewall system, but stratification for both systems was well within the acceptable ASHRAE limit of 3.0°C.

## 2 Planning and Decision-Making Criteria

The compact duct strategy must consider the supply and return air systems as well as the location of the equipment within the house. For this reason, the compact duct strategy must be considered in the schematic design phase of the whole-house design process to optimize the location of the equipment and supply outlets.

### 2.1 Pros and Cons

When making a decision whether to implement a compact duct system design, the pros and cons of the decision must be considered.

#### 2.1.1 Pros

The following are positive aspects of using a compact air distribution design:

- Shorter ducts require less material.
- Less material leads to less labor and faster installation.
- Shorter ducts will have less equivalent length and therefore less pressure loss.
- Selection of better performing outlets leads to fewer outlets being required.
- Shorter duct runs will have lower heat losses and gains, which will facilitate further reduction of system loads.
- A compact duct system can be easier to integrate with the structure and bring inside conditioned space.
- Outlet placement on high sidewalls or ceilings in lieu of the floor can eliminate furniture register conflicts and can permit more flexibility in the use of the rooms.

A compact duct system can be achieved with any typically used duct materials (e.g., sheet metal, duct board, flex duct), and the obvious benefit of “less material equals less cost” applies, especially with metal ductwork. When working with flex duct, short run-outs have the added benefit of being easier to install straight and stretched for proper flow. By combining the shorter runs with better performing outlets, fewer runs can be installed, further reducing cost and installation time. Although a shorter duct will inherently have lower losses and gains than a longer run, there is an added benefit when attempting to bring ductwork inside conditioned space to further reduce the duct loads. A compact system simplifies the structural issues.

#### 2.1.2 Cons

The following are negative aspects of using a compact air distribution design:

- Architects and production builders seem reluctant to incorporate compact air distribution system design into building architecture.
- Early coordination with designers is required to locate ducts in conditioned space.
- Resistance may be encountered from the installing contractor to try something different.

- Potential conflicts could arise with plan reviewers or code officials who are unfamiliar with compact air distribution systems.
- The higher performing thermal enclosure of recent code-driven or voluntary programs is required.
- Careful installation and adherence to the design are critical.

In a broad sense, the HVAC industry often seems to be resistant to trying new methods, instead resorting to rules of thumb that have worked for years on houses with lower performing thermal enclosures and higher loads. However, these traditional rules can lead to comfort issues in a high performance house. Furthermore, in areas of the country where locating floor registers at the perimeter of the home is the norm, the compact design with registers sized to throw the air across the room has resulted in objections from plan reviewers and code inspectors simply because it is different from what is typically done. Although any installation of a high performing HVAC system with lower loads requires care and attention to the design intent, the compact air distribution system with fewer outlets requires even more care to ensure that air is delivered in a manner that will provide the desired comfort in the space, without creating excessive drafts on the occupant.

## **2.2 Supply Air Design**

At the heart of the compact duct system design is selection of the shortest and most direct path for air to travel to the space that is to be conditioned. A trunk-and-branch layout generally is the best way to lay out a compact system; however, this can vary, depending on the floor plan of the house.

Careful consideration of the air outlet strategy and a full duct design are critical to the HVAC system delivering comfort in a high performance house, whether it is new construction or an energy upgrade retrofit. Ducts and supply outlets should be sized for the following purposes:

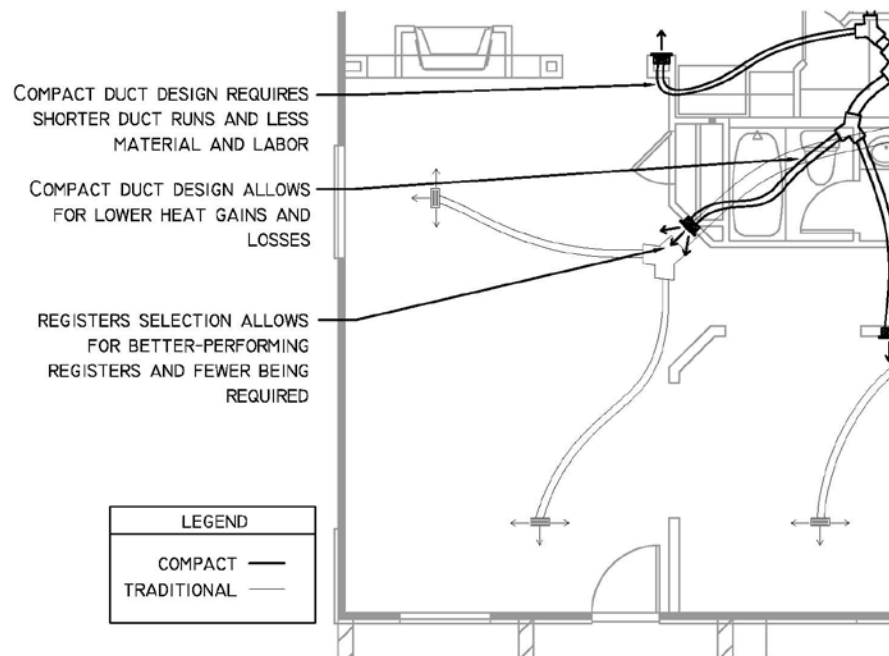
- Select outlets based on the design airflow and velocities to provide the optimal throw without creating noise problems.
- Promote mixing of the air in the room without creating drafts in the occupied zone of the room.
- Limit head-to-toe temperature stratification.

### **2.2.1 Supply Outlet Selection and Placement**

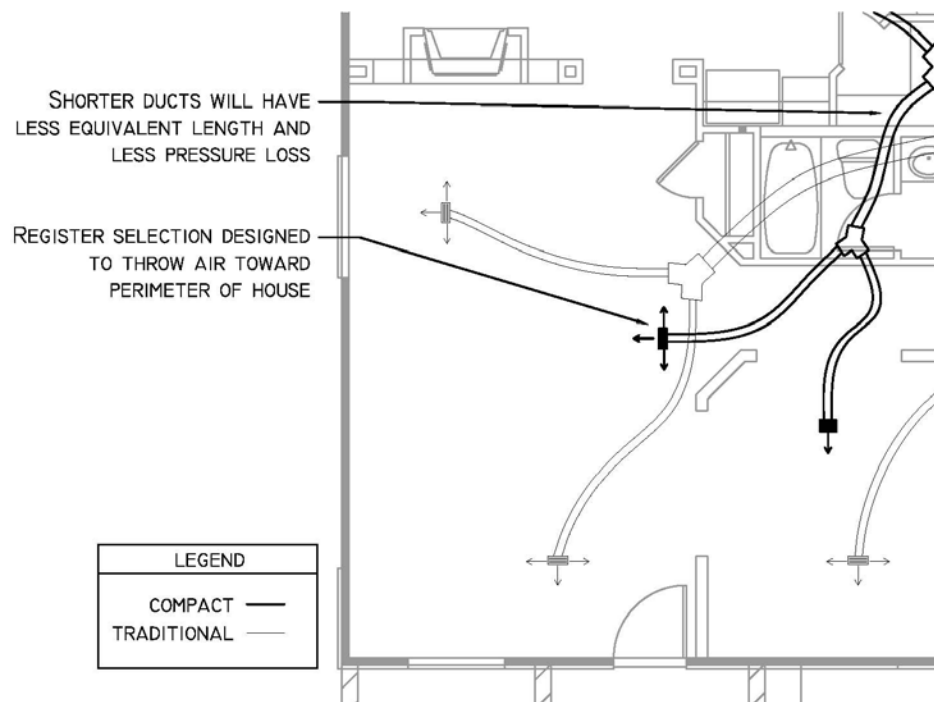
In high performance homes, the lower volume of air required must be delivered to the space in a manner that will result in good mixing with the space air to provide comfort without introducing unacceptable noise or causing the sensation of a draft on the occupant. The selection and placement of the supply air outlets are critical to the comfort provided by the compact air distribution system.

Figure 2 shows a comparison of compact ducts with high sidewall outlets versus a traditional ceiling outlet strategy. Rooms that require low volumes of air can be adequately conditioned from high sidewall or ceiling registers that are located toward the interior of the house. In such a situation, the airflow is directed toward the exterior walls.

Figure 3 shows a comparison of outlet placements for a compact duct system versus a traditional layout. Fewer outlets are used along with the shorter ducts.



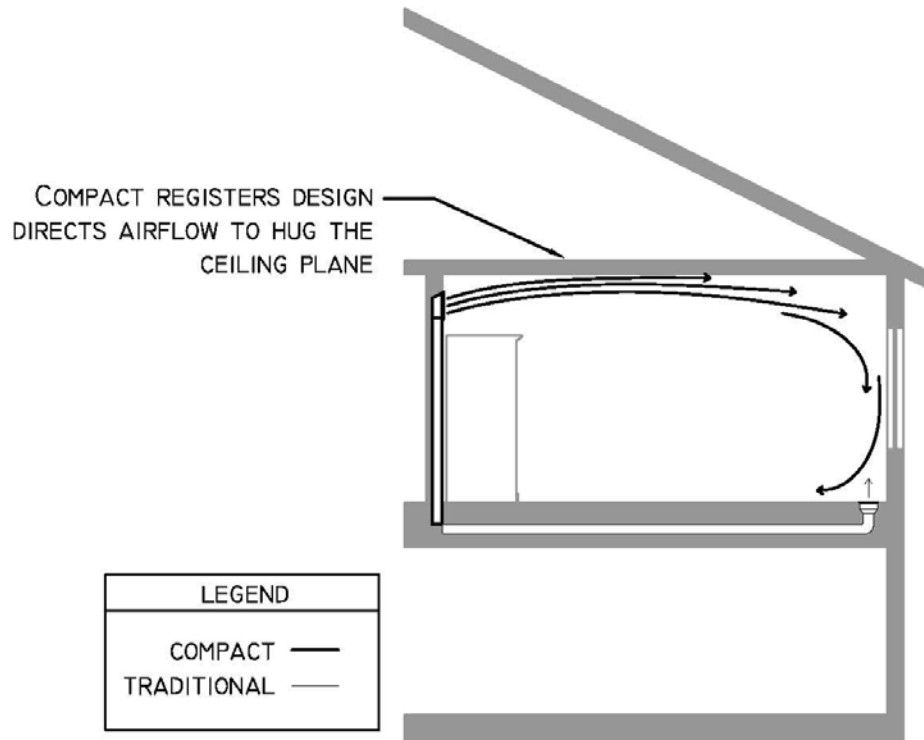
**Figure 2. High sidewall versus traditional—plan view**



**Figure 3. Compact ceiling register placement versus traditional—plan view**

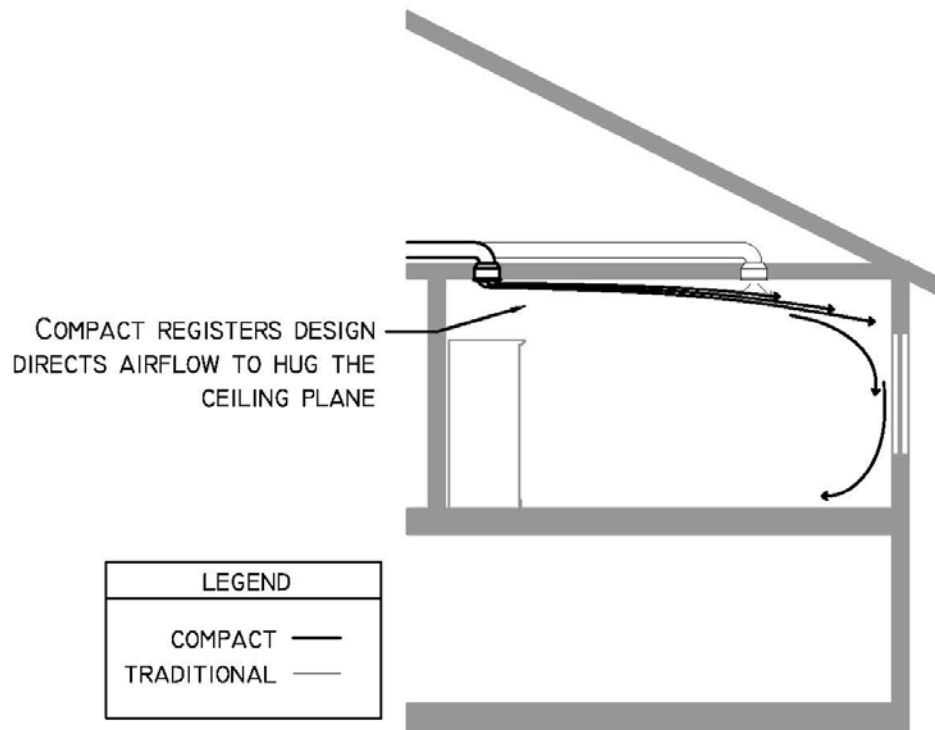
Floor registers are not a good choice for compact duct systems because they are susceptible to being covered or blocked by furniture or draperies, making them ineffective at throwing and mixing air. If the floor plan will allow for floor outlets, they must be sized for the lower airflows of a high performance house. Typical floor registers may not have the desired throw or spread to provide comfort to the occupant.

A floor plan that previously was served by floor outlets should be converted to wall stacks and high sidewall outlets served from the floor, as shown in Figure 4.



**Figure 4. High sidewall versus floor register—section view**

A house with a high performing thermal enclosure and a floor plan that previously was served from above through ceiling outlets should be examined for shorter runs and possibly fewer multidirectional outlets, as shown in Figure 5.



**Figure 5. Compact ceiling register placement versus traditional—section view**

### **2.2.2 Register Performance**

Consideration of the floor plan for the room size and shape, with the register selection based on the manufacturer's performance data, is critical. Performance data for registers are published by manufacturers using data tables similar to that shown in Figure 6.

Face Velocity		400	500	600	700	800	900	1000	1100
Pressure Loss		.010	.016	.022	.031	.040	.050	.062	.075
8 x 4	cfm	65	80	100	110	130	145	160	175
Ak .160	Throw	6.5	8.0	10.0	11.0	13.0	15.0	16.0	18.0
10 x 4	cfm	80	100	120	140	160	180	200	220
Ak .202	Throw	7.0	9.0	11.0	13.0	14.0	16.0	18.0	20.0
12 x 4	cfm	100	120	145	170	195	220	245	270
Ak .244	Throw	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0
14 x 4	cfm	115	145	170	200	230	255	285	315
Ak .286	Throw	8.5	11.0	13.0	15.0	17.0	19.0	22.0	24.0
12 x 5	cfm	125	155	190	220	250	280	310	345
Ak .312	Throw	9.0	11.0	14.0	16.0	18.0	20.0	22.0	25.0
10 x 6	cfm	125	155	190	220	250	285	315	345
Ak .314	Throw	9.0	11.0	14.0	16.0	18.0	21.0	23.0	25.0

Ak= net area in square feet

\*NC 30

NC 35

\*less than or equal to

**Figure 6. Example of register performance data**

The required cubic feet per minute for the room being serviced by the supply outlet is a critical input to the selection process, as well as the face velocity, throw, spread, pressure loss, mounting location, and noise criteria (NC).

The target face velocity for the high performance strategy is 700–900 ft/min. For the high performance strategy with a high interior sidewall outlet, the ideal scenario would be a throw that just reaches the opposing exterior wall at a terminal velocity of 75 ft/min or has a throw that is 2 ft greater than the distance to the wall at a terminal velocity of 50 ft/min.

The performance data are often published at a terminal velocity value of 75–100 ft/min. If the listed throw at the 75-ft/min terminal velocity is the throw necessary for the room, these data are acceptable; however, it is likely that it will be necessary to interpolate the throw distance at 50 ft/min. The procedures for doing these calculations are best handled using the calculations for nonisothermal jets, as described in ASHRAE (2009).

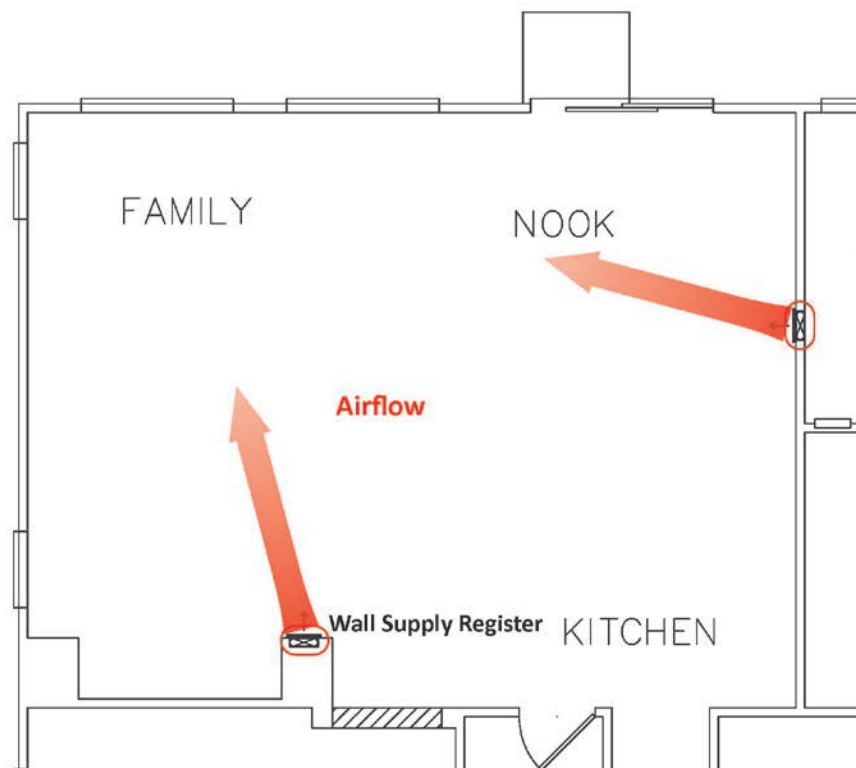
Noise at the air outlets is an important comfort consideration in any air distribution system design. Air distribution system noise comes from the velocity of air in the ducts and the air handling equipment. The NC rating of the registers must be appropriate for the residential environment: NC35 or lower.

### 2.2.3 Drafts

An air distribution system should be designed to deliver air without inducing drafts. ACCA Manual T provides a discussion on the basic factors that affect room air distribution (Rutkowski 2009b). The compact duct design should avoid installing supply registers that blow air directly onto occupants. The occupied zone of a room, which generally is 2 ft away from the walls and 2 ft off the ceiling, is the area where the perception of a draft must be avoided. Selecting an

outlet register with adjustable blades will allow air to be directed into the room, avoiding a collision of air in the middle of the room, where the occupants may experience the sensation of a draft.

Higher performing registers may carry a higher cost than the simple stamped register of a traditional design; however, the additional costs of higher performing registers often can be offset by a reduction in the number of outlets. The family room and the kitchen and nook area, as shown in Figure 7, may require three or four typical residential supply outlets running to the exterior walls in a traditional design; however, in this example, two adjustable-blade outlets directing air into the room supply the necessary airflow.



**Figure 7. Directed airflow**

#### **2.2.4 Cost and Availability**

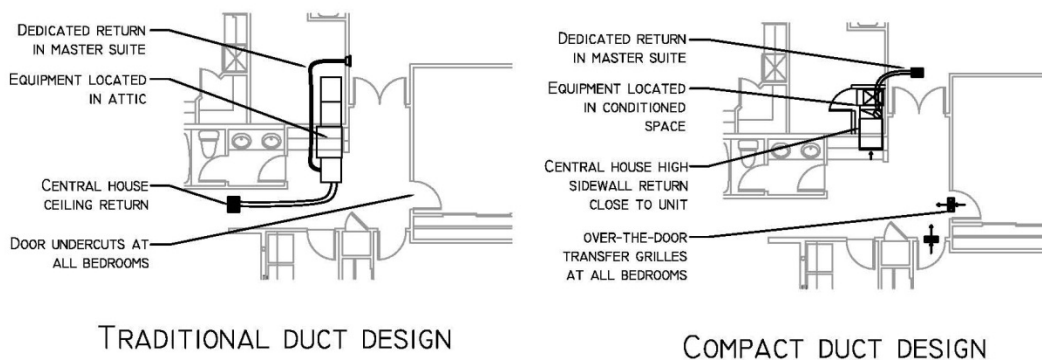
Other considerations that are not directly related to performance—but should be considered—are the availability, price, material, and appearance of the outlets. The lack of availability of low-cost high sidewall or ceiling supply outlets to satisfactorily meet the low air volumes of an energy-efficient house while providing good throw characteristics can present a design challenge. More options are becoming available in manufacturers' residential lines, but it may be necessary to search light commercial options to find appropriate outlets with the desired performance characteristics. The additional costs of a higher performing curved blade ceiling outlet or high sidewall outlet can often be offset by a reduction in the number of outlets and the associated ductwork.



## 2.3 Return Air Design

The return air system to bring air back to the air handling equipment is also critical in maintaining comfort levels within the house. Rooms without adequate return airflow can impede the supply airflow due to overpressurization in the room, which can lead to comfort issues and airflow imbalances that can increase infiltration. Every room with a supply outlet (with the exception of bathrooms or kitchens due to the potential for spreading odors through the house) must have a clear return air pathway. Utilizing a central return strategy of a single-return grille in a central space is a simple and effective way to move air back to the air handler.

An over-the-door transfer grille with a noise and light attenuation baffle or an attic transfer duct with adequate net free area would be an appropriate solution to provide a return air path without compromising privacy in the room. As shown in Figure 8, a central return is located in a central hallway, adjacent to the main living space of the house. Each room that has a door to close off the respective room from the central space (with the exception of the laundry and the hall bath) utilizes an over-the-door transfer grille as a clear path from that room back to the central return. ACCA Manual D provides guidance in Section 4-9 for a low-resistance return path because air velocities through the return grille should be less than 350 cfm (Rutkowski 2009a).



**Figure 8. Traditional versus compact return**

### 3 Integrated Design

The HVAC system must be considered in the early schematic design phase to achieve the optimal performance that results in an energy-efficient and comfortable house. Trying to fit a system late in the design process may result in undesirable consequences. A compact air distribution system can further simplify integration of the HVAC system into the house.

During the schematic phase, the design team needs to allocate adequate space for the equipment and ducts while identifying principal potential conflicts between the structure of the building and the HVAC system. Decisions made during the early design phase will be critical to the successful performance of the HVAC system.

#### 3.1 HVAC System in Conditioned Space

An energy-efficient house should use strategies to keep all ductwork inside the thermal enclosure of the house, which helps to minimize heating and cooling losses and improves HVAC system performance. One strategy that can accomplish this is to use soffits or dropped ceilings in secondary spaces of the house. These must be designed with the floor plan flow and can add visual and special differentiation to the room. Although locating ductwork within conditioned space is not a requirement of a compact air distribution system, the compact size makes it easier. A preliminary layout of the HVAC equipment location and the duct system can be made on the schematic floor plan, taking into consideration the performance criteria. By considering equipment sizing and air delivery requirements, early accommodations can be made in the framing plan as needed.

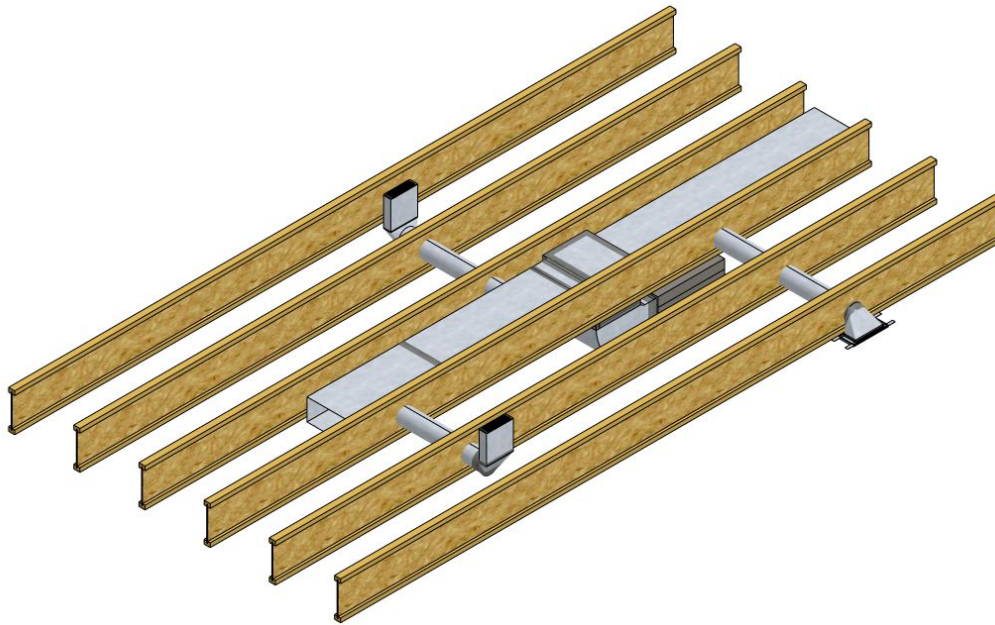
##### 3.1.1 HVAC Equipment in Conditioned Space

If the HVAC equipment is located in the basement or crawlspace, the space must be fully insulated and air sealed and must receive conditioned supply air. If the house is a slab-on-grade construction, space must be allocated within the floor plan to accommodate the HVAC equipment while considering the potential noise that might be emitted from the equipment, avoiding equipment placement near “quiet” rooms such as bedrooms.

##### 3.1.2 Ducts in Conditioned Space

Floor systems are a commonly used element to run duct systems within the thermal enclosure, particularly in multistory houses. A compact duct system will require less clear open framing area for ducts. Designing clearly delineated spaces for the HVAC system during the schematic design will allow the compact duct system to perform as desired. Considering the location of horizontal and vertical chases early in the design can enhance the simplicity in the duct runs by stacking the vertical chases and avoiding elbows, transitions, and offsets that increase both the friction losses in the system and the cost. These designated chases should be clearly identified and set aside on the construction prints as “reserved” for HVAC. Furthermore, HVAC routing is less flexible than plumbing and electrical, which is another reason that the HVAC space should be clearly set aside in the design and construction documents.

Although a compact air distribution system will reduce structural interference issues, beneficial choices in framing materials can be made early in the design stage. As shown in Figure 9, floor joists can be penetrated, following the joist manufacturer’s tolerances, to allow the HVAC contractor to route the ductwork both parallel and perpendicular to the floor framing.



**Figure 9. Framing and duct integration strategy**

Following the joist manufacturer's guidance on the hole sizing and spacing is critical to the structural performance of the joist. However, with advance planning and design for a compact system, these locations can be predetermined, thereby reducing the need for field modifications.

### **3.1.3 Register Selection**

The selection and placement of supply air outlets are critical to the comfort in the space. The air must be delivered in a manner that mixes the supply air with the room air without introducing unacceptable noise or causing the sensation of a draft on occupants. The manner in which the air is distributed in the room is a function of the shape and size of the air outlet. Placement of the air outlet is as important to the comfort in the room as is the type of air outlet selected.

Ducts and supply outlets should be sized for the following purposes:

- Maintain the air velocity as high as possible without creating noise problems.
- Promote mixing of the air in the room.
- Limit stratification.

## 4 Conclusions

A compact air distribution system provides a method of handling the lower loads and consequently the reduced air volume needed to condition the spaces of an energy-efficient house while lowering material costs and increasing installation efficiencies. Shorter duct runs with similar lengths can lead to a better balanced system and improved performance. A compact air distribution design can simplify bringing all HVAC equipment and ductwork within the conditioned space, further improving efficiency and performance. Considering a compact duct system early in the design phase will simplify the implementation, allowing for structural and floor plan issues to be resolved.

The compact duct system may seem different from traditional systems of the region, leading to questions or objections from those asked to implement or approve it. However, with careful attention to details in selecting and placing the system, the benefits can be realized.

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DOE/GO-102013-3846 • June 2013

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