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Measure Guideline: Implementing a Plenum Truss for a Compact Air Distribution System

Arlan Burdick
IBACOS, Inc.

October 2013

Building America
U.S. Department of Energy

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Implementing a Plenum Truss for a Compact Air Distribution System

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

Golden, CO 80401

NREL Contract No. DE-AC36-08GO28308

Prepared by:

Arlan Burdick

IBACOS, Inc.

2214 Liberty Avenue

Pittsburgh, PA 15222

NREL Technical Monitor: Michael Gestwick

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

October 2013

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Definitions

ACCA	Air Conditioning Contractors of America
ADC	Air Distribution Council
ANSI	American National Standards Institute
BEopt™	Building Energy Optimization software
HERS	Home Energy Rating System
HVAC	Heating, ventilation, and air conditioning
IECC	International Energy Conservation Code

Executive Summary

This Measure Guideline offers guidance on how to implement a compact duct system inside a plenum truss bulkhead of a one-story, slab-on-grade home. A one-story slab-on-grade house does not have the benefit of a floor system to run ductwork in conditioned space. In a compact duct design, ductwork runs are reduced in length to yield a smaller and more compact duct system. Less energy will be lost through ductwork if the ducts are contained within the thermal enclosure of the house.

These measures are intended for the production builder working to meet the 2012 International Energy Conservation Code option for keeping the ductwork within the thermal enclosure of the house (IECC 2012, Section R403.2). This measure of bringing the heating, ventilation, and air conditioning equipment and ductwork within the thermal enclosure of the house is appropriate for the builder wishing to avoid cathedralizing the insulation in the attic space (i.e., locating it at the underside of the roof deck rather than along the attic floor) or adding dropped soffits.

The results of monitoring system performance where this measure was implemented at a test house in Roseville, California, show the measured temperatures within the bulkhead remained closely aligned with the thermostat temperatures during the cooling season (Figure 1). The plenum truss bulkhead is isolating the ductwork from the extreme attic temperatures.

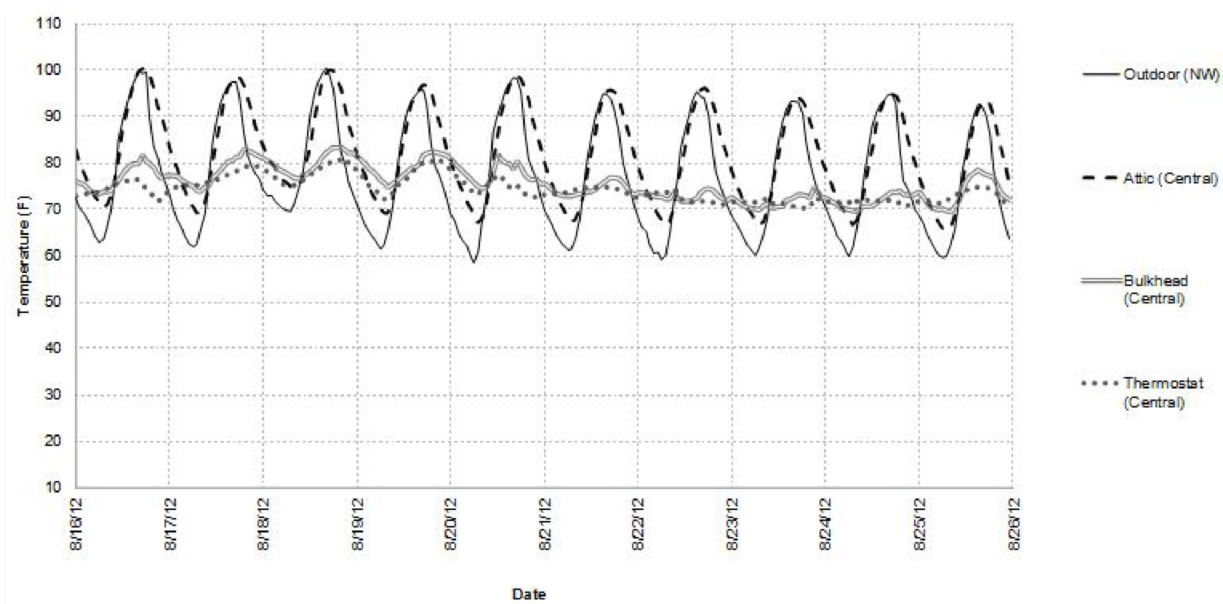

Figure 1. Bulkhead and thermostat temperature variation in extreme hot, August 2012

1 Introduction

Figure 2. Typical one-story, slab-on-grade home

This Measure Guideline presents the steps to implement a compact duct system inside a plenum truss bulkhead of a one-story slab-on-grade home such as the one shown in Figure 2. This measure was developed and implemented in an energy efficient, one-story, slab-on-grade house located in a hot and dry climate zone, although it could be implemented in any climate, with careful consideration of the risks outlined here. Short-term testing results of this type of house have been described in the IBACOS report by Stecher et al. (2012). The long-term monitoring results will be published in the near future.

For the purposes of this Measure Guideline, an energy efficient house is defined as one that is designed and built to meet the 2012 International Energy Conservation Code (IECC) (IEEC 2012). An energy efficient house could have load densities as high as 1,000 ft^2/ton or greater. (For reference, a house built to the 2006 IECC might have a load density of 600 ft^2/ton.) Consequently, less air volume is needed to condition the space. This presents both challenges and opportunities when designing the air distribution system. With less air required to condition the space, the delivery method for the air becomes more critical to creating comfort in the room. Ductwork and air outlets sized by "rule of thumb" might not have the throw needed to provide air mixing in the rooms to achieve the desired comfort results. The use of a compact duct system design can reduce the potential for insufficient airflow to the house.

In a compact duct design, ductwork runs are reduced in length to yield a smaller and more compact duct system compared to traditional systems. Less energy will be lost through ductwork if the ducts are contained within the thermal enclosure of the house. One-story slab-on-grade construction presents a challenge in creating space to bring the ductwork and heating, ventilation, and air conditioning (HVAC) equipment into the conditioned space. The plenum truss bulkhead adds only the amount of "inside conditioned space" required to house the ductwork by modifying the roof framing to create a boxed-in area in the otherwise unconditioned attic. The use of a compact duct system and the plenum truss bulkhead described here can simplify some of the issues commonly encountered with the loss of room volume, change of architectural character, or addition of unusable conditioned space.

"Rule of thumb." Ductwork and air outlets sized by "rule of thumb" usually means 1 ton of cooling per 400 ft^2 of floor space.

Throw. Throw is the effective distance that air leaving a supply outlet can reach.

2 Decision-Making Criteria

The following shows a high-level summary of factors to consider when deciding to use a plenum truss for a compact air distribution system.

PLENUM TRUSS

The plenum truss option. This option to bring ducts inside conditioned space is an early design consideration with implications for the space planning in the entire house.

The plenum truss solution works best if:

- The house is a slab-on-grade single story
- The ceiling height is an important architectural consideration
- The HVAC equipment is centrally located inside conditioned space
- The duct layout is a compact central design

SPACE PLANNING

Locate the HVAC equipment. Centrally locate the HVAC equipment in a mechanical closet inside the conditioned space.

HVAC DESIGN

Lay out the ductwork. Lay out shorter duct runs of similar length running to the interior walls of the rooms, with registers selected to throw the air toward the exterior walls.

STRUCTURAL DESIGN

Evaluate the structural bearing locations. The redesigned truss should not affect the bearing location at the footing level. If structural bearing supports must be relocated, the entire structural package for the home would need to be reevaluated.

A plenum truss bulkhead with compact duct air distribution and the HVAC equipment inside the thermal boundary is an early design consideration, with many benefits for the performance of an HVAC system and implications for the space planning in the house. Bringing ductwork out of the attic and inside the thermal boundary of the house can result in significant energy, material, and cost savings. However, simply covering the ducts under insulation can lead to building durability issues in hot, humid climates (CARB 2009).

The HVAC system design must be considered early in the design process to accommodate locating the equipment and ducts in the optimized placement. Other decision-making criteria include the configuration of the home, the level of energy efficiency desired, compatibility of the floor plan with this type of HVAC system, and the feasibility of redesigning the roof trusses to accommodate a bulkhead without relocating structural bearing supports. The following paragraphs offer additional considerations if a plenum truss bulkhead with compact duct air distribution is to be used.

2.1 Tradeoffs

One important step early in the design of the HVAC system is determining how to bring the ductwork out of the attic and into conditioned space. The three primary methods for bringing ductwork inside the thermal boundary are as follows: (1) sealing and insulating the roof plane; (2) dropping a soffit below the finished ceiling plane; and (3) modifying the truss design and creating the plenum truss bulkhead (Beal et al. 2011). *The Home Builders Guide to Ducts in Conditioned Space*, created by the California Energy Commission, is another resource for the methods (Hedrick 2003). The plenum truss bulkhead with a compact air distribution design can simplify bringing all HVAC equipment and ductwork within the conditioned space while preserving the ceiling height, as shown in Figure 3.

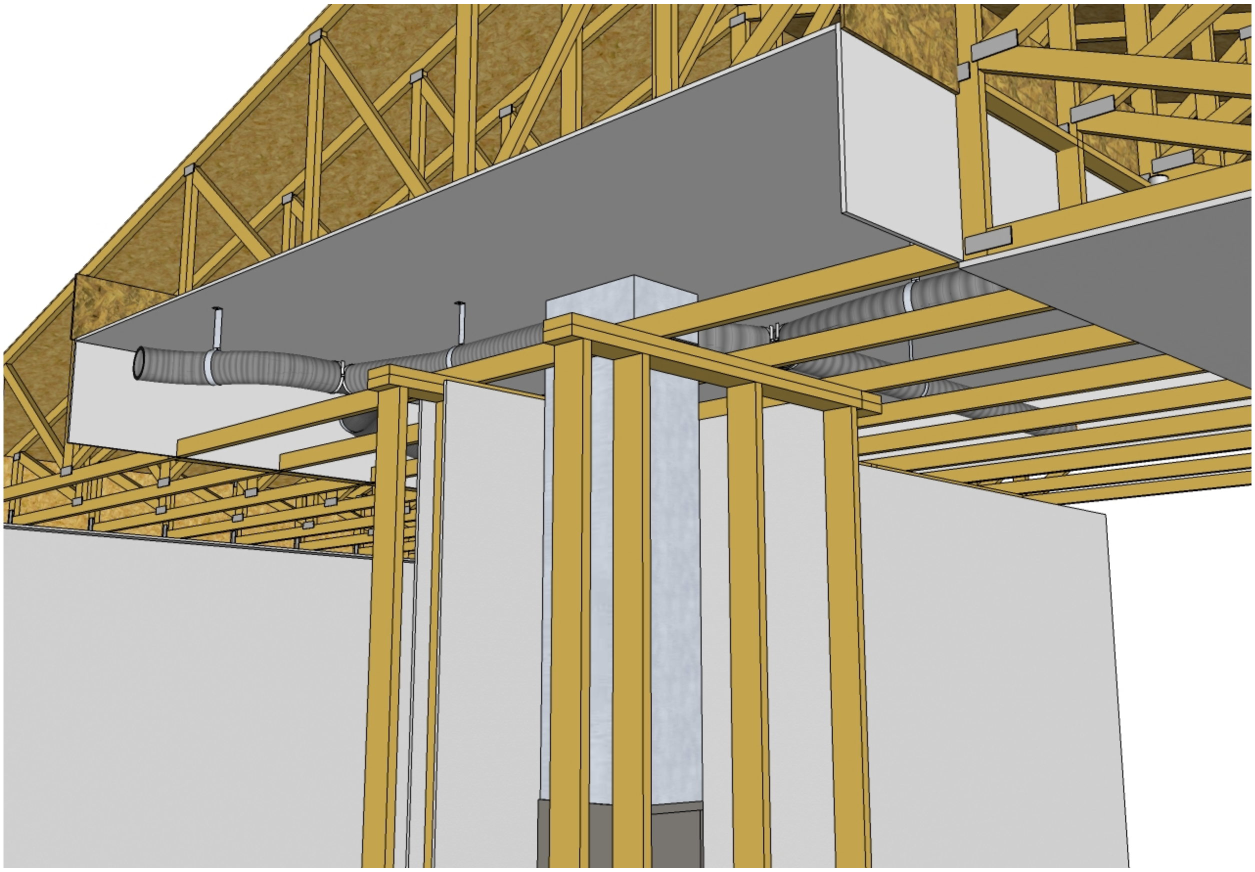

Figure 3. Plenum truss bulkhead

The plenum truss bulkhead is a particularly useful alternative measure for bringing mechanical systems and ductwork inside conditioned space where the use of either cathedralized attic spaces or dropping bulkheads below the insulated ceiling plane is not acceptable. Cathedralizing the insulation in the attic space (i.e., locating it at the underside of the roof deck rather than along the attic floor) will increase the total amount of insulation needed due to the increased surface area that would have to be covered, ultimately resulting in higher material costs. Additionally, changing the location of the insulation to the roof deck would increase the volume of conditioned space for the house but would not add usable square footage for the homeowner. The alternative of bringing the equipment and ductwork inside the conditioned space through dropped soffits or bulkheads below the ceiling plane also can be deemed unacceptable by a builder trying to maintain the architectural integrity of the ceiling plane.

2.2 Risk Identification

The area separated by the reverse attic bulkhead must be inside both the thermal air and pressure barriers to be considered "inside conditioned space." Care must be taken to fully seal all penetrations through the bulkhead walls to avoid air from the unconditioned attic entering and defeating the purpose of the bulkhead. The risk is increased in humid climate zones where, during the cooling season, moist air could condense on cooled duct surfaces.

Furthermore, the integrity of the bulkhead must be maintained for the life of the product. This will require awareness on the parts of any trades entering the attic after installation is completed; that is, they must exercise more care than typical when moving through the attic space.

2.3 Cost and Performance

The opportunities when implementing a smaller and more compact duct system include lower material and installation costs from smaller equipment, smaller duct runs, and fewer outlets. A smaller and more compact duct system also can be easier to fit into the conditioned space, further reducing the load on the HVAC system.

Cost considerations include the additional cost of the spray foam to adequately air seal the bulkhead. The redesign of the trusses and any related material may also increase costs. In the house where this measure was developed, truss-related costs were inconsequential due to the volume of production the builder has with the truss manufacturer. However, in a low volume production environment, the truss costs could increase.

Savings on the HVAC side are dependent on the base house. The reduction in load due to moving the ducts inside conditioned space may be enough to reduce the cooling equipment size, depending on the climate. For the house where this measure was developed, the previous system size was reduced by more careful estimation of the loads. Some savings in reduced ductwork and registers in the compact duct design also may be realized.

IBACOS used a combination of REMRate and EnergyGauge USA modeling to evaluate the whole-house energy consumption of the prototype. Energy modeling using Building Energy Optimization (BEopt™) software Version 1.3 also was performed. Table 1 provides a sample of the modeling work performed using EnergyGauge USA that IBACOS completed to represent the source energy and operational cost savings associated with bringing ductwork inside conditioned space. The results show an anticipated source energy savings of 11 MMBtu/yr and approximately $116 savings in annual operating costs.

Table 1. Sample Modeling Results

	Mechanical Equipment and Ductwork in the Vented Attic	Mechanical Equipment and Ductwork Inside Conditioned Space
Source Energy Use (MMBtu/yr)	123	112
HERS* Index	54	52
Estimated Annual Operating Costs	$1,274	$1,158

*Home Energy Rating System.

3 Technical Description

A standard slab-on-grade design may locate the HVAC system in the vented attic, exposing it to temperature extremes that lead to heat loss or gain and increased loads on the system (Roberts and Winkler 2010). Figure 4 illustrates this concept. Historically, due to poorly performing windows and lower levels of wall insulation, supply outlets were located at the perimeter to "wash" the thermal enclosure with conditioned air.

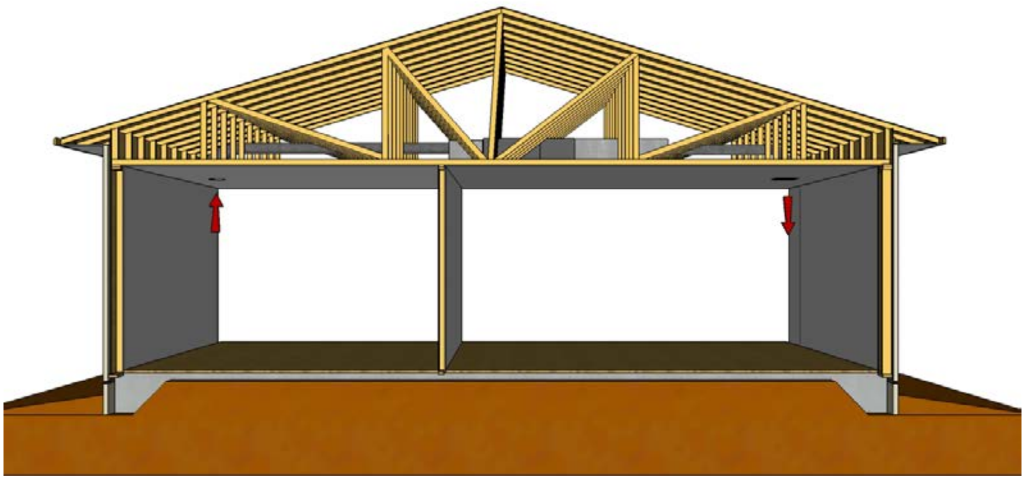

Figure 4. HVAC system outside the thermal barrier

The measure described here includes locating the HVAC equipment in a mechanical closet inside the conditioned space of the house and creating an air-sealed reverse bulkhead in the attic to enclose most or all of the ductwork, as shown in Figure 5. In addition to the energy savings and performance improvements, moving the HVAC equipment out of the attic makes it easier to service the equipment. With the lower loads of an energy efficient house, it is possible to use a compact duct air distribution design with fewer outlets and smaller ducts.

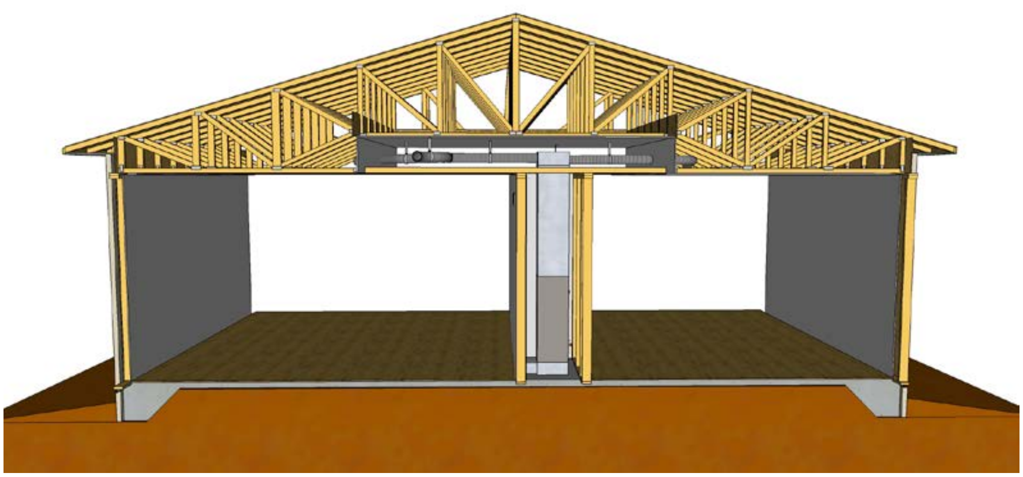

Figure 5. HVAC system inside the thermal barrier

3.1 System Interaction

Figure 6 shows a traditional supply air duct layout, with HVAC equipment located in the attic and several long runs to the exterior walls. By comparison, Figure 7 shows a compact air distribution design that locates the HVAC equipment centrally within the house and has shorter duct runs of similar length running to the interior walls of the rooms. A compact air distribution strategy also uses more efficient outlets that throw the air toward the exterior walls. Shorter duct runs of similar length can lead to a better balanced system and improved performance.

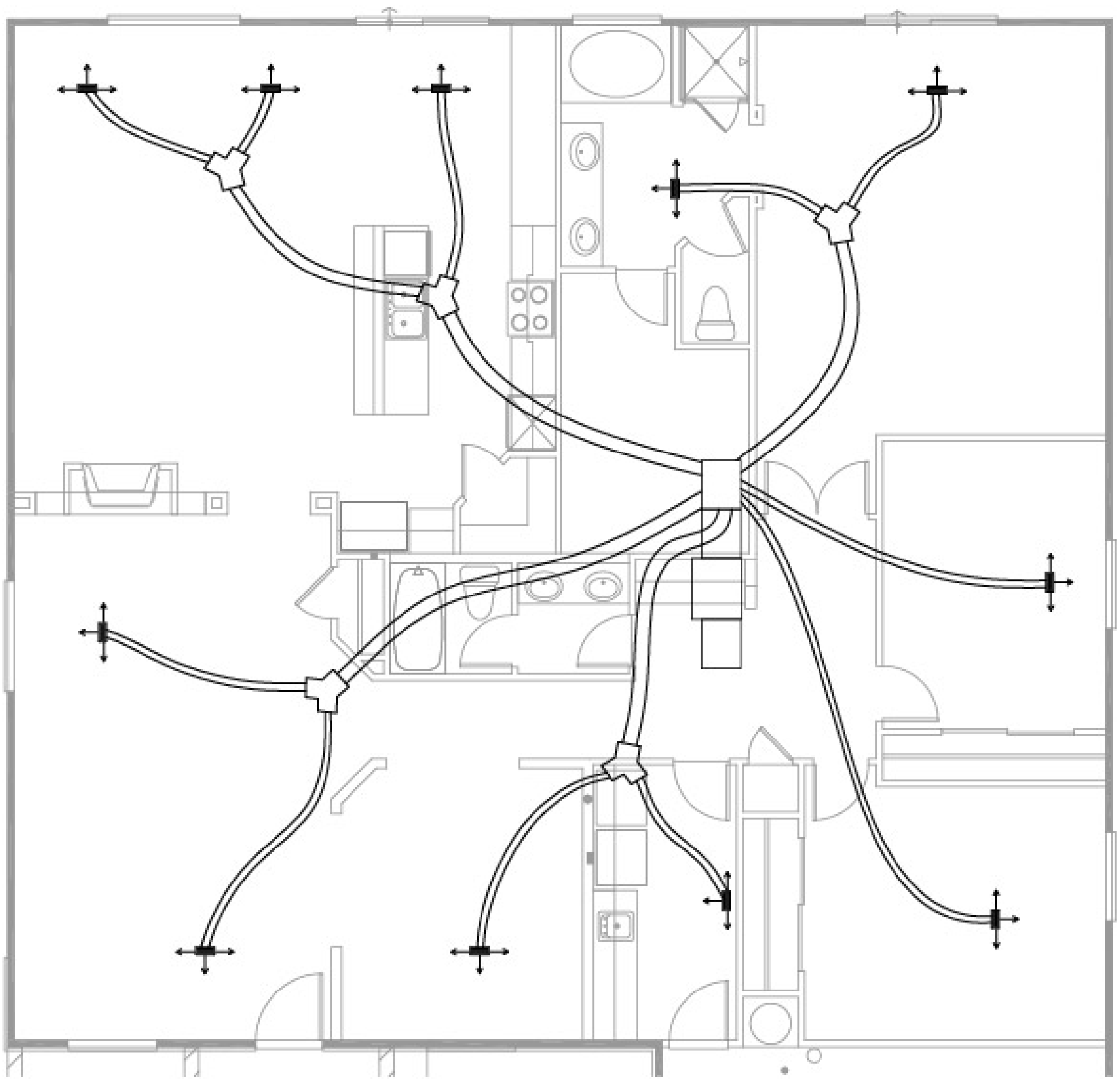

Figure 6. Traditional supply air duct layout

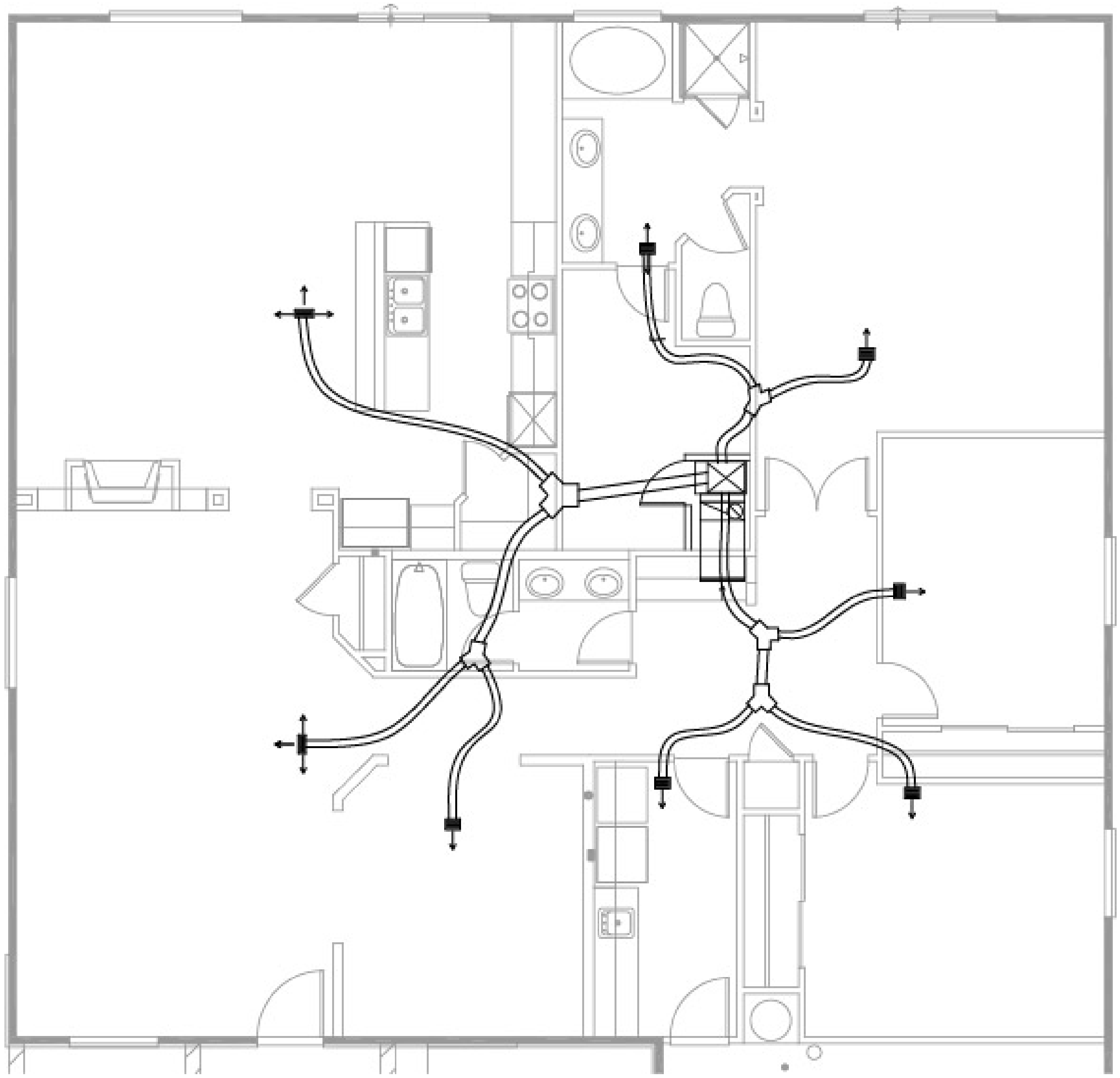

Figure 7. Compact supply air duct layout

In Figure 8 and Figure 9, the more traditional return air strategy of a ducted ceiling return with door undercuts is compared to a short wall return in the hall with over-the-door transfer grilles from each bedroom. The compact duct design for the return helps achieve a low-resistance return path.

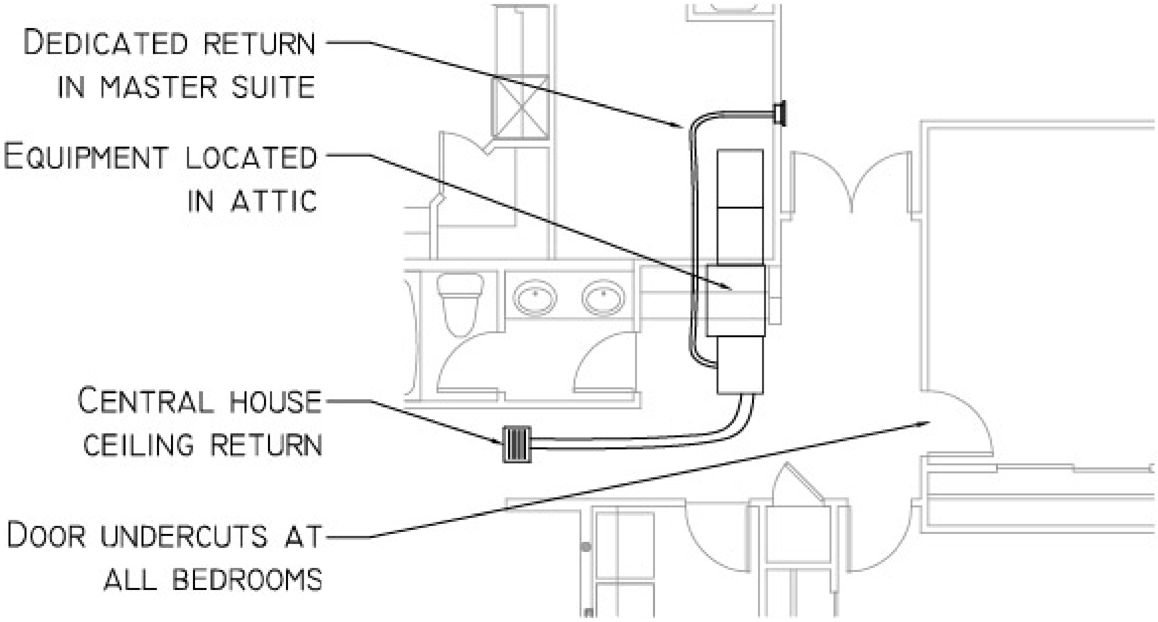

Figure 8. Traditional return air duct layout

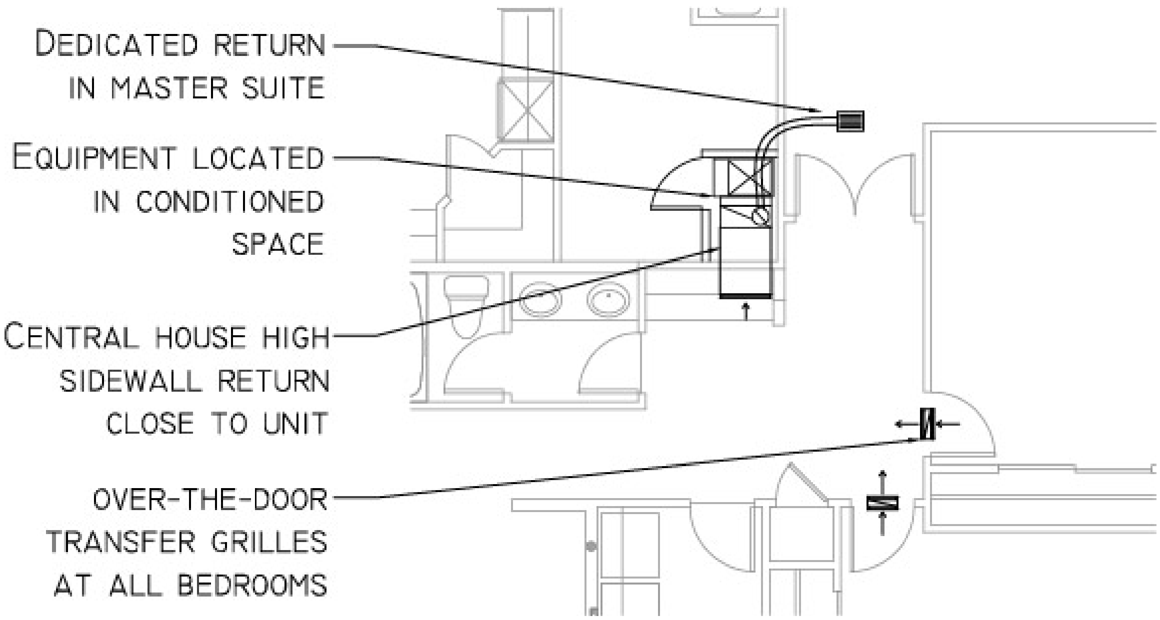

Figure 9. Compact return air duct layout

4 Implementation

To effectively implement the plenum truss bulkhead approach, several design parameters must be met. One important factor is that the redesigned truss must not affect the bearing location at the footing level. Involving the roof truss manufacturer early in the design discussions will help to provide a proposed redesign of the roof truss. If structural bearing supports must be relocated, the entire structural package for the home would need to be reevaluated, and the plans would need to be resubmitted to the permitting jurisdiction for additional review.

For example, by modifying the original design, which is shown in Figure 10, the proposed design, as shown in Figure 11, can provide a centrally located chase along the floor of the attic. In this example, to provide a central bearing location that is consistent with the existing structural design for the home, a framing member had to be dropped from the truss web to bear on the interior load-bearing partition wall.

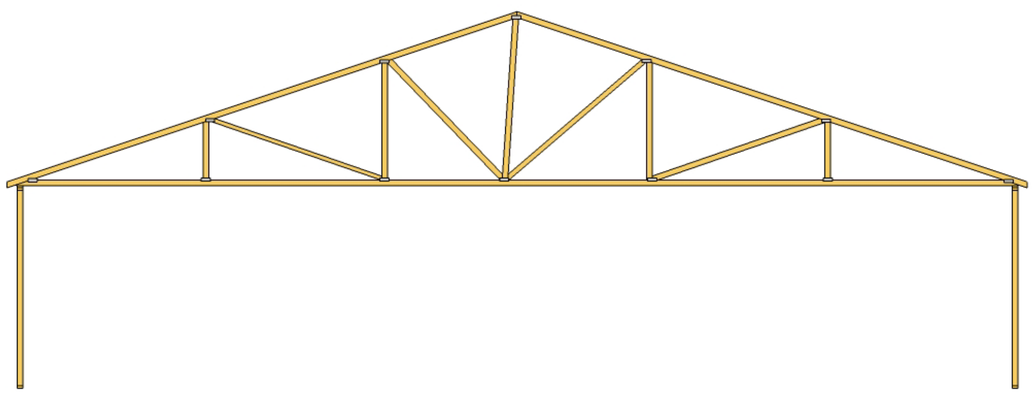

Figure 10. Standard truss

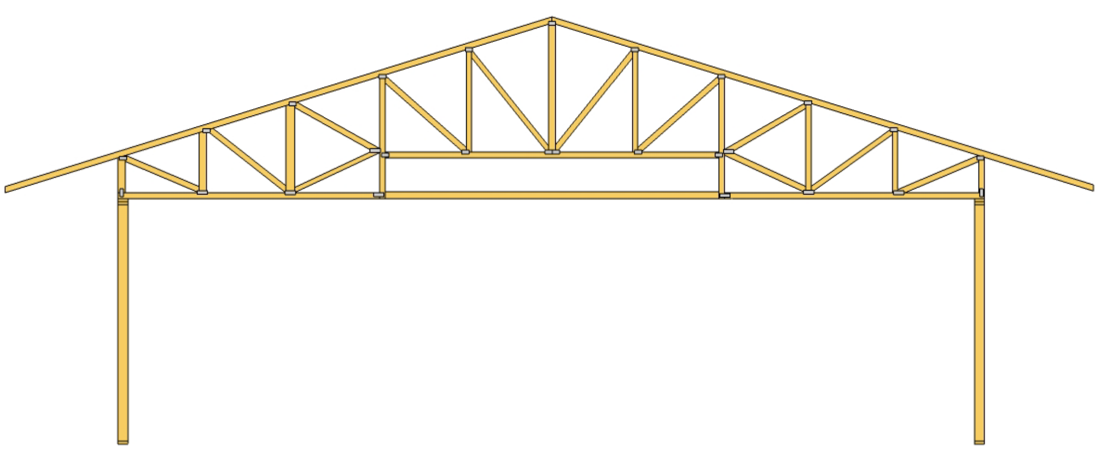

Figure 11. Modified truss

The HVAC equipment is brought down into the conditioned space by creating a centrally located space (see Figure 12) within the floor plan and an air-sealed plenum truss bulkhead in the attic to enclose most of the ductwork.

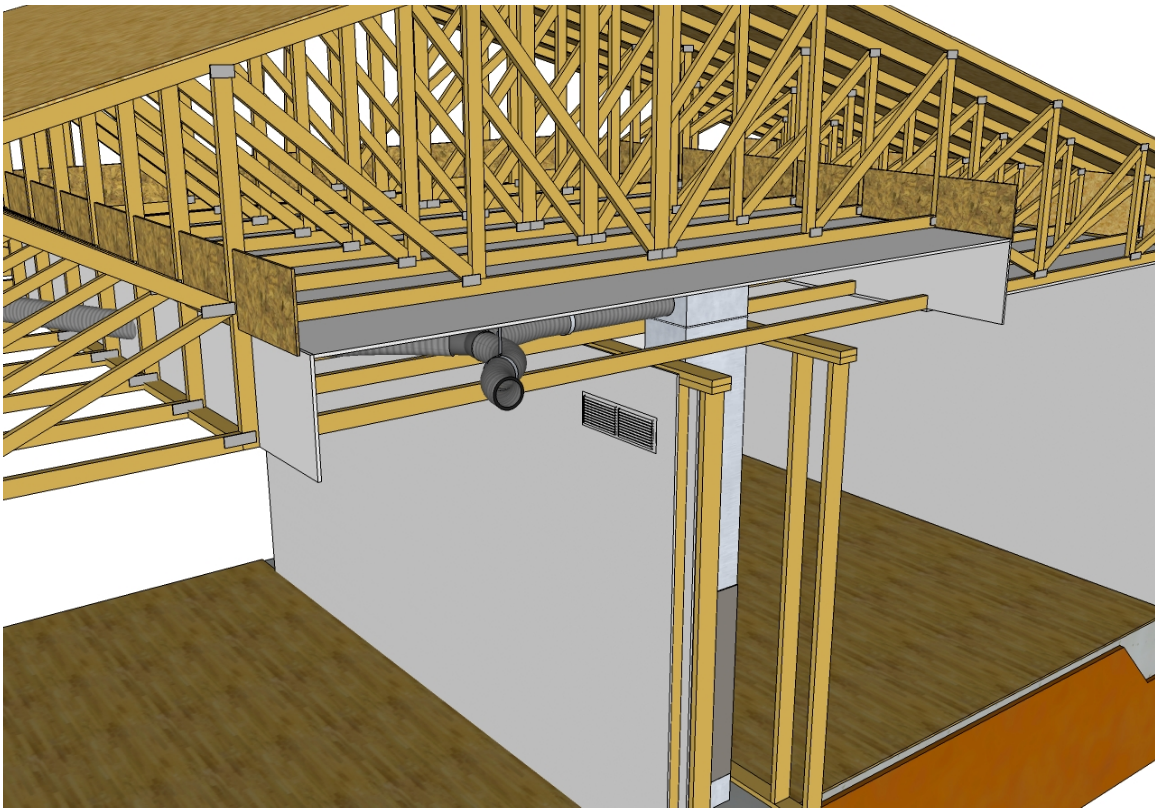

Figure 12. HVAC equipment closet in conditioned space

An end dam at the perimeter of the bulkhead will contain loose-fill insulation and will ensure that levels are consistent across the bulkhead. Figure 13 shows how the addition of an end dam at the edges of the bulkhead will hold the blown-in insulation at the proper height on top of the bulkhead without having to add excessive amounts of insulation. The remainder of the attic ceiling plane can then be insulated to the proper depth.

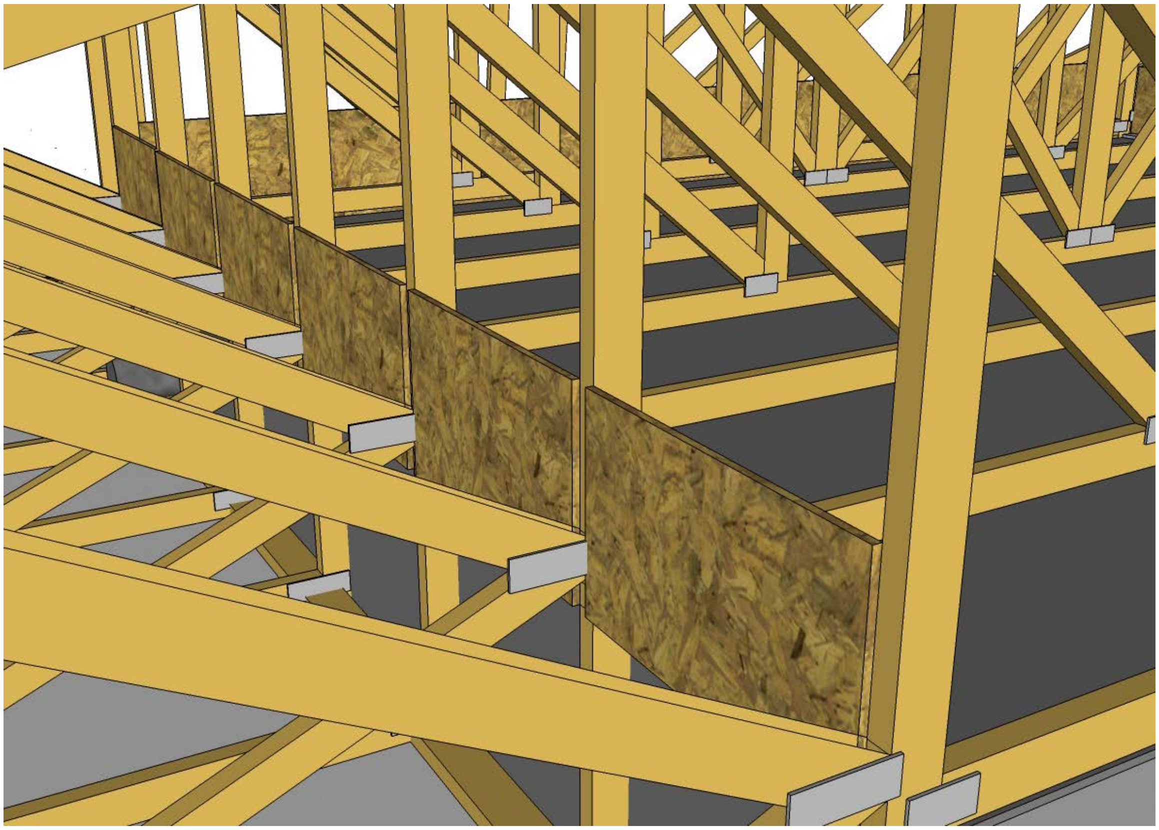

Figure 13. Insulation end dam at the edges of the bulkhead

The plenum truss bulkhead is placed over the HVAC equipment closet. Figure 14 shows a plan view of the approximate area of the cavity created by the new truss design. The height of the modified area in the trusses, as shown in Figure 15, must create an unobstructed space to accommodate the largest-diameter ductwork that is anticipated for use, based on the duct size determined from the Air Conditioning Contractors of America (ACCA) Manual D protocols (Rutkowski 2009) and the ACCA Manual J (Rutkowski 2006) room-by-room heating and cooling load calculations for the house.

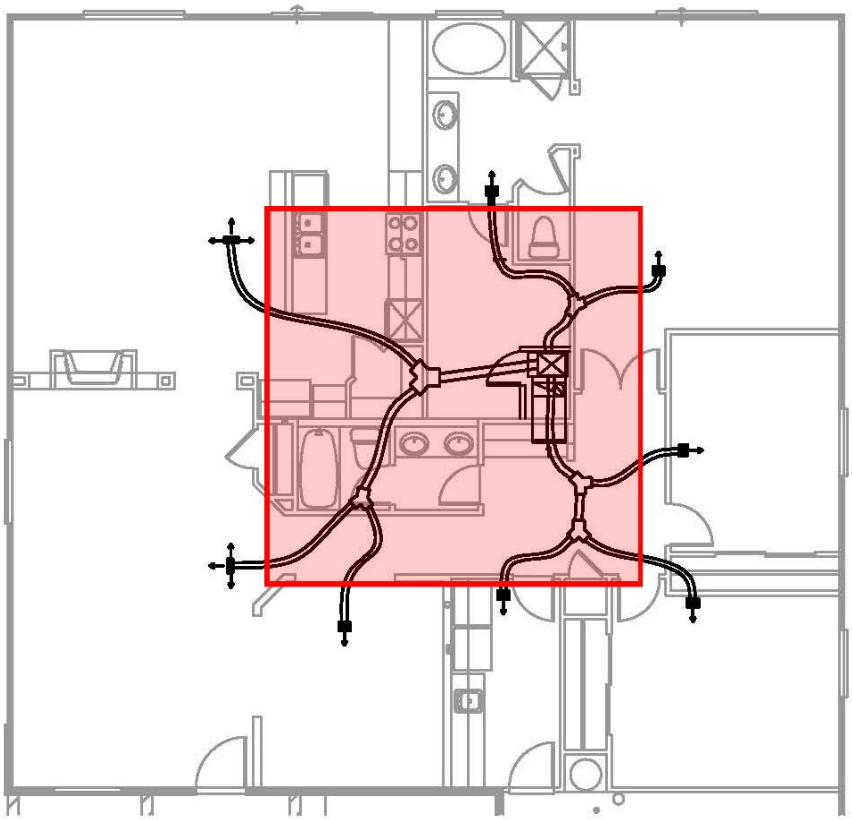

Figure 14. Approximate area of the reverse attic bulkhead

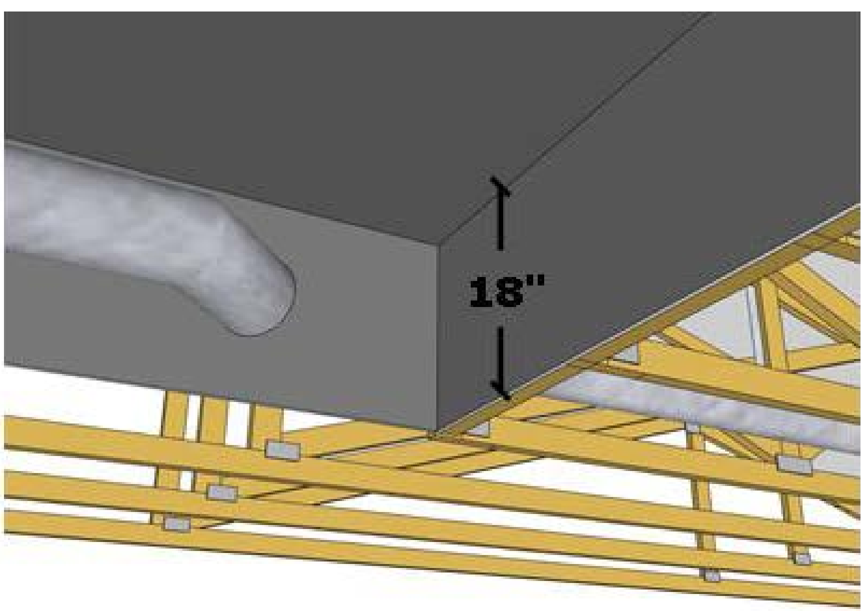

Figure 15. Inside the reverse attic bulkhead

The success of a design in either flexible duct or rigid duct depends on the faithful execution of the design during duct installation. The ACCA Standard 5 HVAC Quality Installation Specification (ACCA 2010) was introduced in 2010 as an American National Standards Institute (ANSI) standard to improve the core competencies of contractors and to ensure that quality installations occur. Duct tightness must be tested per the program or regulatory code mandates. For flexible duct material, installation details must follow the guidance of the Air Distribution Council (ADC) Flexible Duct Performance and Installation Standards (ADC 2010).

Although not all the ductwork fits into the area of the cavity, care is taken during installation to ensure that any ductwork passing out of the cavity is well sealed with closed-cell foam at the penetration (see Figure 16). Furthermore, creating an air-sealed bulkhead in the attic to enclose most of the ductwork requires careful attention to the air-sealing details at all intersections of the ceiling and bulkhead wall planes (see Figure 17).

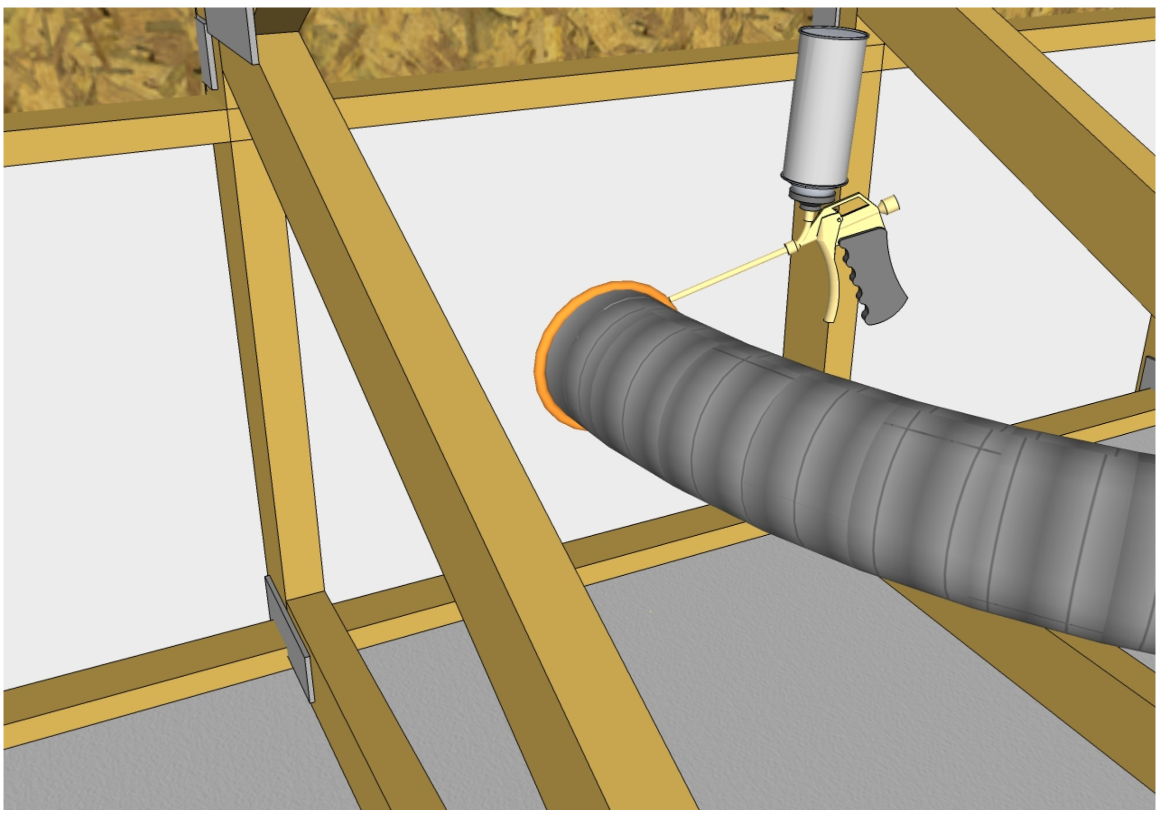

Figure 16. Seal penetrations of ducts exiting the cavity

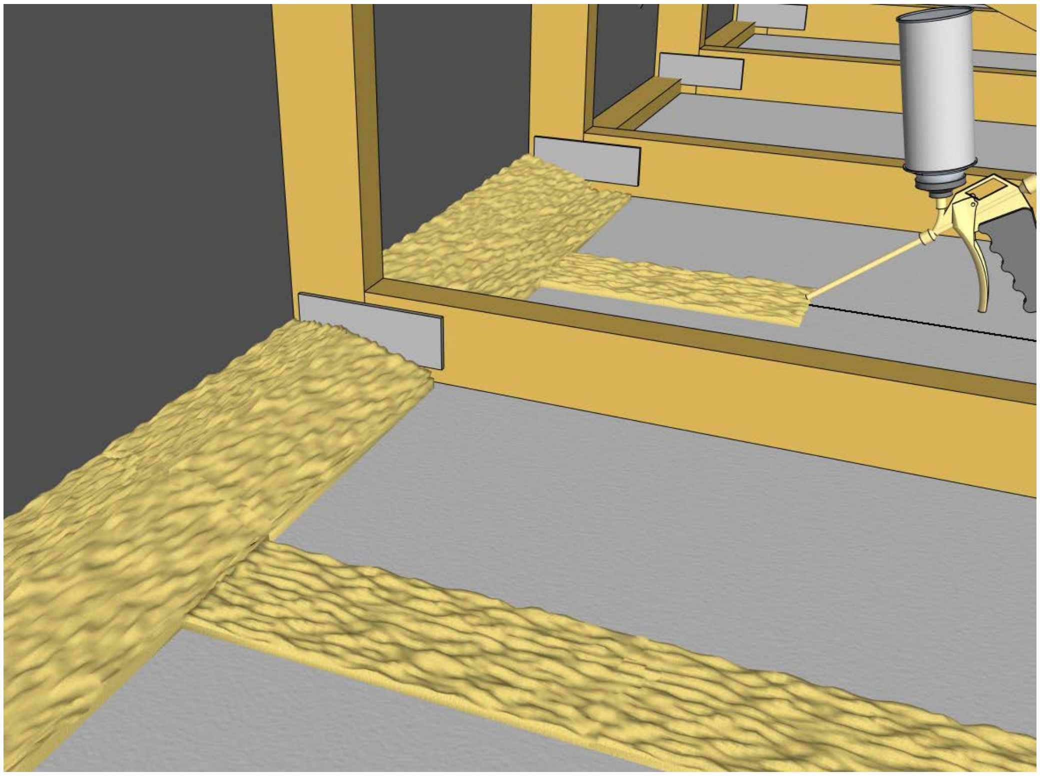

Figure 17. Seal all ceiling and bulkhead wall intersections

4.1 Sequencing

The following gives an overview of the sequence of steps required to implement a successful system:

1. Design phase.
    a. Allot space in the floor plan for a mechanical room.
    b. Ensure all structural bearing points are addressed in the new truss design.
2. Manufacture the trusses and framing.
3. Install the bulkhead wall, lid, and loose-fill insulation dams in the attic.
4. Install the ductwork within the bulkhead.
5. Install the ceiling plane.
6. Seal all penetrations and seams and all ceiling and bulkhead wall intersections.
7. Test for airtightness of the bulkhead while conducting a blower door test.
8. Install loose-fill insulation in the attic.

5 Verification Procedures and Tests

The following should be verified to ensure that the compact duct distribution system is properly designed and implemented:

- Ensure that any truss modifications meet all engineering requirements for load bearing and structural support.
- Ensure the attic bulkhead is adequately sized to accommodate the ductwork.
- Ensure the end dam at the perimeter of the bulkhead will contain the proper amount of loose-fill insulation, and ensure the levels of insulation are consistent across the bulkhead.
- Ensure that all ductwork is installed per the HVAC design and the ACCA Standard 5 HVAC Quality Installation Specification (ACCA 2010).
- Ensure room-to-room airflows are within design conditions and duct tightness meets program or code compliance.
- Ensure all penetrations and intersections in the bulkhead are carefully sealed by conducting a blower door test prior to installation of the loose-fill insulation.

6 Summary

Bringing ductwork out of the unconditioned attic and inside the thermal boundary of the house can result in significant energy savings. Implementation of a plenum truss bulkhead for a compact duct air distribution system is one method to accomplish this without impacting the ceiling planes or architectural features of the rooms in the home. This measure to bring ductwork inside conditioned space is especially useful in single-story, slab-on-grade houses where dropped soffits in the ceiling would be the only other option.

Early design consideration is necessary. Allowing space for the HVAC equipment to be placed inside the conditioned space and the use of a simplified duct layout will reduce the area the bulkhead must cover. In addition, the truss design will need to be modified to accommodate the bulkhead space while meeting all structural engineering requirements for load bearing and support.

Ductwork installation within the bulkhead must follow the guidance of the ACCA Standard 5 HVAC Quality Installation Specification (ACCA 2010) and the ADC Flexible Duct Performance and Installation Standards (ADC 2010).

All penetrations and seams in the ductwork and bulkhead must be thoroughly air sealed. End dams also must be installed to hold loose-fill insulation in place at the specified levels.

Proper implementation of a plenum truss bulkhead for a compact duct distribution system can result in reduced material and installation costs from smaller equipment, smaller duct runs, and fewer outlets. Furthermore, the load on the HVAC system can be reduced because the compact duct system fits readily into the conditioned space without changing the architectural character of the home.

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DOE/GO-102013-4017 ▪ October 2013

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