An Innovative Approach to Reducing Duct Heat Gains for a Production Builder in a Hot and Humid Climate—How We Got There

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ABSTRACT

The Consortium for Advanced Residential Buildings (CARB), one of five Building America industry teams, has been working with Mercedes Homes in Melbourne, Florida, to improve their product with energy-, material-, and labor-saving strategies. Typical construction for Mercedes, and other builders in the area, is a single-story on a slab foundation with all HVAC supply ductwork in the attic feeding ceiling supply registers. A key element of the systems engineering approach for most Building America projects has been to improve space conditioning system efficiency by reducing or eliminating duct losses or gains. To date CARB has worked with Mercedes through the design and construction of three different homes involving different innovations. A different strategy for addressing the attic duct heat gain has been applied in each of the three homes. The first strategy was to bury the ducts under blown attic insulation, and monitoring was performed to assess the potential for condensation problems on the surfaces of the ducts. The second strategy brought the ducts down out of the attic and hid them in dropped ceiling chases. The third strategy involves an innovative redesign of the roof trusses to provide a chase space for the duct system that can be isolated from the attic conditions. This paper further describes each of the three strategies and their field implementation.

Introduction

In hot climates, air conditioning loads dominate and HVAC design manuals dictate that cool air should be supplied from ceiling or high wall registers for best performance (ACCA 1995). Thus, ducts, and sometimes the air handler as well, are typically installed in the hot attic space and feed to ceiling supply registers. If the ducts are not properly sealed, conditioned air is lost to the vented attic. And, even with insulated ducts, the conductive and radiant heat gains to the conditioned air as it travels through the ducts in the hot attics during peak cooling periods can be significant.

The Building America program, funded by the Department of Energy, applies a systems engineering approach to residential construction. The ultimate goal is to improve energy and resource efficiency without increasing the builder's cost. A key element of the systems engineering approach for most Building America projects has been to improve space conditioning system efficiency by reducing or eliminating duct losses or gains. Several approaches have been taken and some have been more successful than others.

During the past two years, the Consortium for Advanced Residential Buildings (CARB), one of five Building America industry teams, has been working with Mercedes Homes in Melbourne, Florida, to improve their product with energy-, material-, and labor-saving strategies. Typical construction for Mercedes, and other builders in the area, is a single-story on a slab foundation with all HVAC supply ductwork in the attic feeding ceiling supply registers. To date CARB has worked with Mercedes through the design and construction of three different homes involving different innovations. A different strategy for addressing the attic duct heat gain has been applied in each of the three homes. This paper summarizes each of the strategies and field implementation issues.

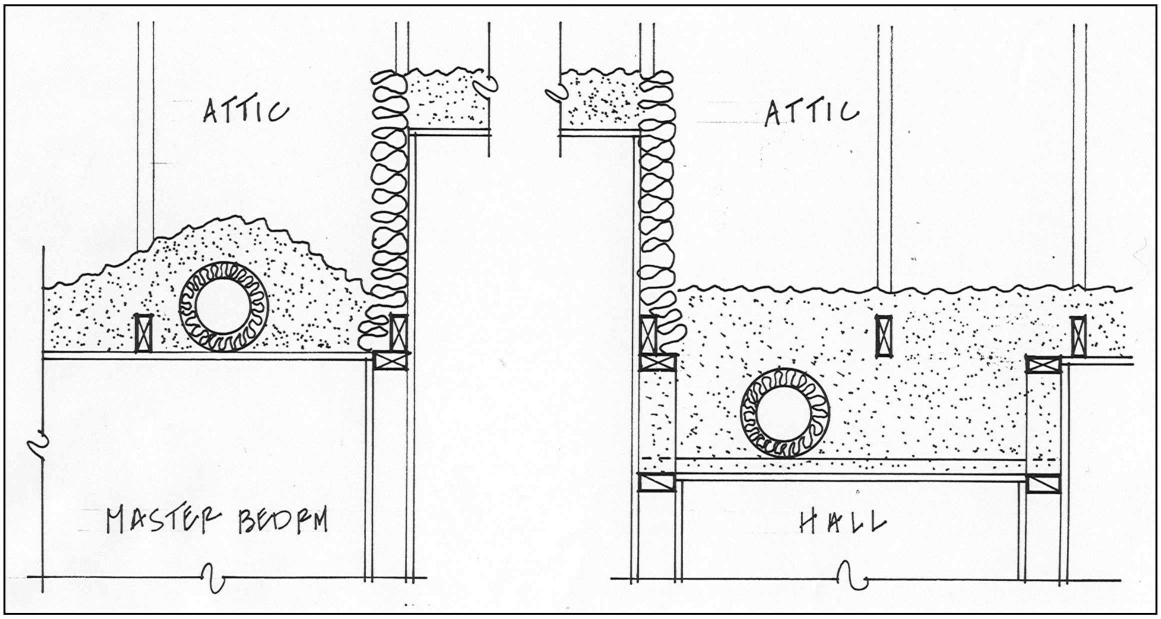
The First Approach—Bury the Ducts under the Blown Attic Insulation

A rather simple approach to reducing the energy penalty associated with ducts in attics is to bury them under the blown attic insulation. This approach does not address leakage problems, but conduction and radiation losses are reduced significantly. CARB successfully demonstrated this approach with another Building America builder in the hot and dry Phoenix climate. The concern with burying insulated ducts under the attic insulation in a humid climate such as Melbourne, Florida, is that the surface temperature of the ducts' vapor barrier jacket may, during certain conditions, be below the dewpoint of the surrounding air causing condensation.

Steady-state calculations based on psychometric theory suggest that condensation could occur. For typical duct sizes and insulation values, when attic temperatures are below 120 °F and the outdoor humidity is at the 80 °F dewpoint design level and 50 °F conditioned air is flowing through the ducts, the duct jacket temperature will be below the dewpoint of the attic air. In the humid Melbourne climate, this set of conditions could occur most mornings during the lengthy cooling season. However, the problem is transient in nature because the air conditioning system cycles on and off. The extent of the period when the air conditioning system is operating and the attic temperatures are still moderate is also not well defined. With these uncertainties, CARB and Mercedes Homes agreed to investigate further with the monitoring of an actual installation.

In the first Mercedes prototype home, the ducts were buried under blown attic insulation. A data logger was installed to record air temperature and humidity at several key locations in the attic. Two different installation conditions were evaluated. The master bedroom supply duct is 6-inch insulated flexible duct resting on the truss bottom chord. Additional blown fiberglass insulation, approximately 4 inches, is mounded over the duct. The north bedroom supply duct is a 6-inch insulated flexible duct installed below the trusses in a 12" deep dropped hall ceiling. Blown fiberglass insulation fills the dropped area with no air barrier isolation from the attic. The duct is covered by approximately 8 inches of insulation. These two configurations are shown in Figure 1.

Figure 1. Two Buried Duct Installation Configurations



At each duct location, thermocouples were taped onto the duct vapor barrier at the top, side, and bottom of the duct. Temperature/relative humidity (T/RH) sensors were mounted on the bottom and side of the master bedroom duct and the side of the north bedroom duct. Another T/RH sensor is hung in the attic to record attic conditions. Monitoring began in early June and continued into February of the following year. The home was occupied at the end of September.

Figure 2 shows the temperatures around the master bedroom duct for August 4. On this day, which was representative of many other days, the potential for condensation is high during the morning hours when the attic dewpoint is highest. This is represented by the closeness of the surface temperature and dewpoint temperature at the side of the duct. On the top of the duct, the surface temperature is higher because there is less insulation burying it.

Another observation is the consistent variation in the dew point measurements with the air conditioning system cycling. As the duct temperature drops with air conditioner operation, the dewpoint drops as well. A possible explanation is nearby leakage of dry air-conditioned air. The sensors are located within 10 inches of the register boot and a junction box connection. The duct blaster tests indicated leakage of 100 cfm at 25 Pascals for a 2.5-ton system. Half of the leakage was on the return side. The ducts were sealed with mastic, but pin holes were observed at some junctions.

Figure 2. Temperature and Dewpoint Data—Master Bedroom

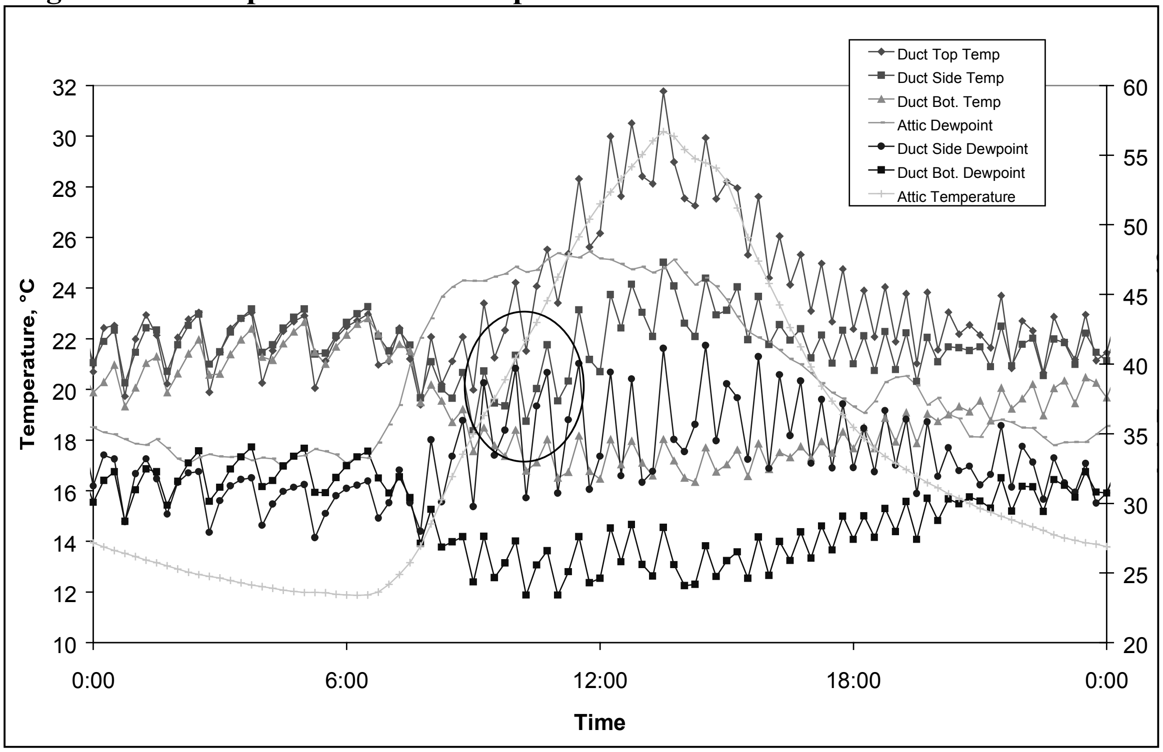
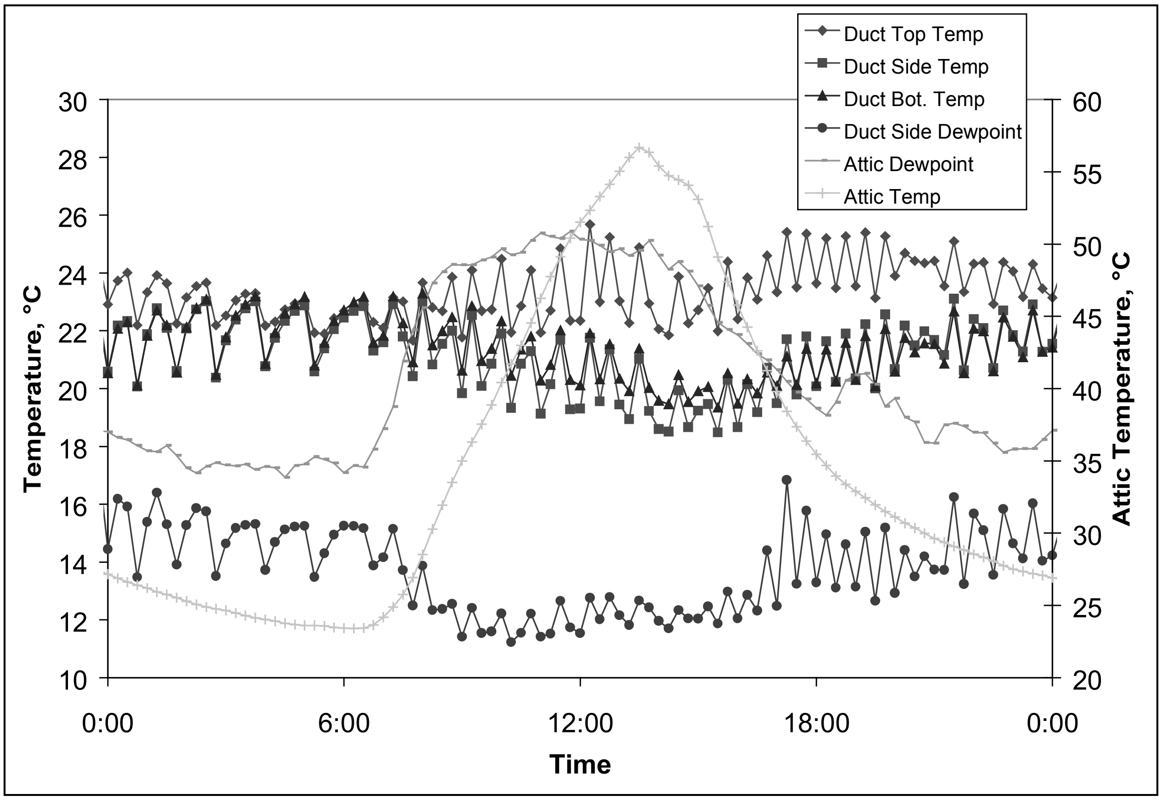


Figure 3 presents the data for the north bedroom duct location for the same day. The potential for condensation at this location is low. The dewpoint at the side of the duct is lower. This duct is buried under more insulation and is communicating less with the attic. Again, a possible explanation is that leakage of dry air-conditioned air from nearby register boots and the junction box is affecting the conditions around the duct. There is also a recessed light fixture in this dropped ceiling that may be allowing conditioned air into the dropped area.

A typical air conditioning system is controlled by a thermostat and will only dehumidify when the space temperature is higher than the thermostat setpoint causing the system to run. Thus during the summer, interior relative humidity would be expected to be lower during the day when there is a near constant demand for cooling, than during the night when the demand for cooling is sporadic. As such, the interior air has a greater potential to act as a sink for attic moisture during the day than during the night. This phenomenon is evident in the behavior of the dew point at the bottom of the duct in the master bedroom and the side of the duct in the north bedroom. The dew point here starts to decrease sharply at 6:00 A.M. when the air conditioning system first turns on. It remains low throughout the peak cooling period from approximately 10 A.M. to 6 P.M., then gradually increases after 6 P.M. as the cooling load tapers off. On the other hand, the attic air dew point starts to increase sharply at 6:00 A.M. when the sun heats up the attic air thereby increasing its moisture storage capacity. It remains high throughout the hottest part of the day from approximately 10 A.M. to 4 P.M., then gradually decreases after 4 P.M. as the outside air temperature slowly drops. The dew point and temperature behavior in the middle of the blown in attic insulation is affected by boundary conditions in both the attic air and the interior air.

Figure 3. Temperature and Dewpoint Data – North Bedroom Location



Periodic variations in temperature and dew point are evident in all of the measurement locations except the attic air. It is unlikely that these fluctuations are due to random measurement noise since the data logger was set up to sample every 10 seconds and record average values every 15 minutes. Instead, it may be that these periodic fluctuations result from air conditioner cycling. Supporting this hypothesis is the observation that the cycling is of a higher frequency after 6 A.M. when the air conditioner operates more frequently. In the early morning hours before sunrise, the cycling frequency is lower when the air conditioner operates sporadically. Also, no cycling due to air conditioner operation would be expected in the attic air since the temperature and RH in this location are primarily affected by ambient conditions.

The measurements made during this test do not indicate exactly why the dew point on the side of the duct behaved differently in the master bedroom than in the North bedroom. However it can be conclusively stated that in the master bedroom, the dew point on the side of the duct is most strongly influenced by the attic air dew point. While in the North bedroom, the dew point on the side of the duct is most strongly influenced by the interior air dew point. This observation leads to the hypothesis that air leakage either from the ducts or from conditioned space may have prevented condensation from occurring in the North bedroom.

Based upon over six months of observations in this one home, it was concluded that insulated ducts can be buried under attic insulation with little concern for condensation problems, but it is not an ideal solution. Condensation does occur for brief periods of time and water damage is unlikely. Leakage of conditioned air from the ducts or through ceiling penetrations appears to minimize the potential for problems, but leakage should not be relied upon.

The Second Approach—Enclose the Ducts in Dropped Chases

The most ideal approach to reducing duct heat losses and gains, from a performance standpoint, is to install the ducts within the conditioned space. This approach was applied in a second Mercedes home. The second "test" home is a larger, four-bedroom home, and one of Mercedes' best sellers.

An earlier builder decision to eliminate vaulted ceilings and use 9-foot tall exterior walls and flat ceilings throughout made the inside-the-envelope duct system a more viable option. One-foot deep dropped duct chases were designed into the plan (Figure 4). A soffit was placed between the kitchen and the great room. It not only provided a large enough chase for the main supply trunk, but also served aesthetically as a break in the ceiling plane between the two spaces. A coffered ceiling detail was used in the master bedroom to provide space for ducts that served the master bedroom and great room spaces. The other three bedrooms and the hall bath were served with high wall registers off from a duct above the dropped hall ceiling. All of the duct chases were air-sealed from the attic with 1/8" laminated fiber sheathing.

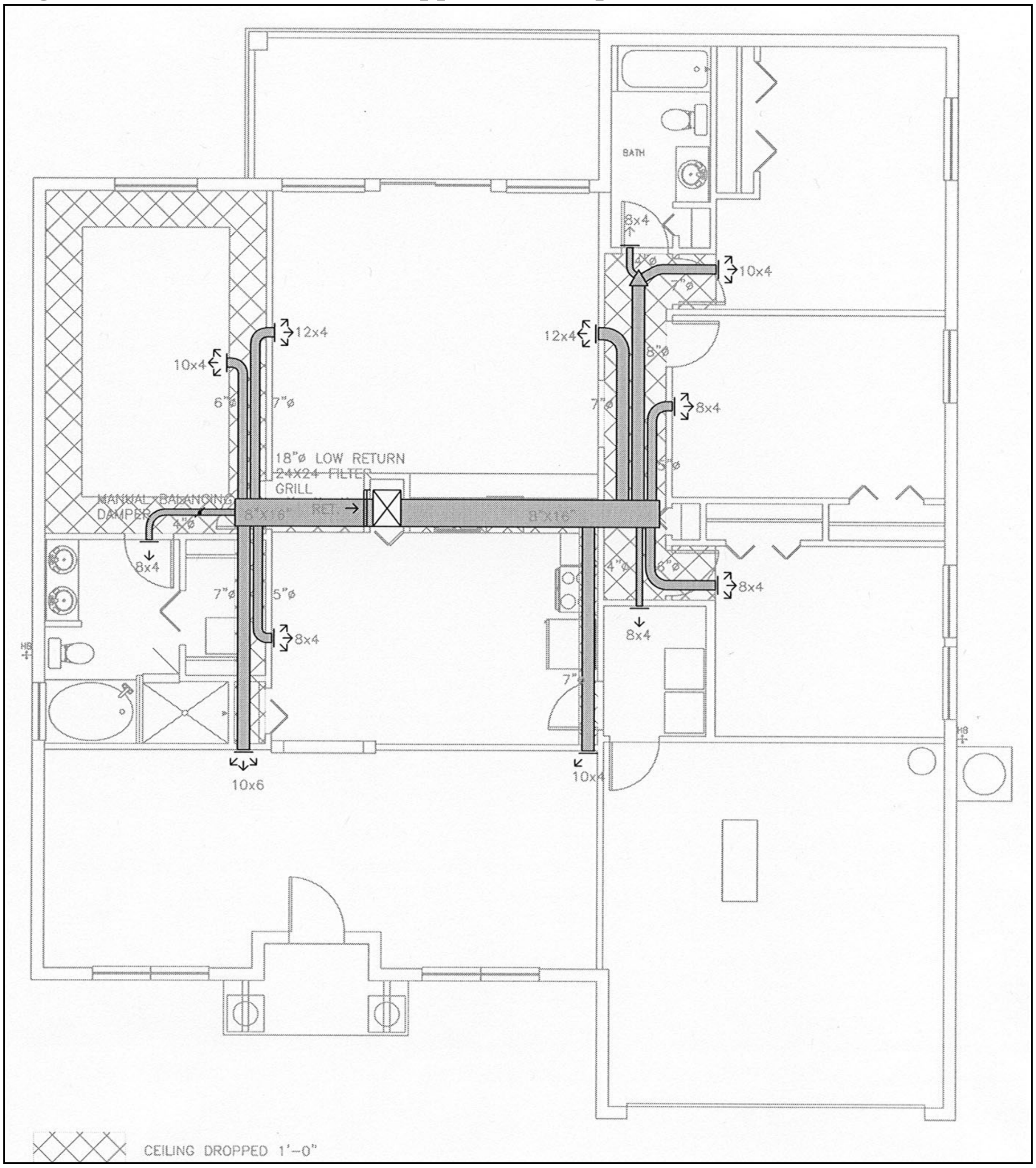
The most significant change to the existing house plan was moving the air handler from the garage to a utility closet between the kitchen and great room. In addition to its functional purpose, the closet acted as a space divider in an otherwise open plan.

This approach did require the extra step of installing a laminated fiber sheathing air barrier on the truss bottom chords at the drop locations, and the drops do increase the framing costs. However, moving the ducts from the attic to the conditioned space enables the downsizing of the air-conditioning system by a half ton according to a REMDesign computer simulation performed by CARB Mercedes.

A duct blaster test of the system indicated leakage to the outside of 107 cfm or 9 percent of the air handler's rated flow. This leakage is high given that the ducts are intended to be within the conditioned space. The first-time installation of the laminated fiber sheathing air barrier at the drop locations was not ideal.

While this approach, with some installation refinements, represented a good solution for this plan, it was not as easy to implement across the builder's product line. Several of the other house designs did not accommodate the dropped chases as easily. The builder did, however, move the air handler from the garage to a centrally located mechanical closet in several plans.

Figure 4. HVAC Plan with Dropped Chase Spaces



The Third Approach - Redesign the Trusses to include a Chase Space for the Ducts

One of the goals of the Building America program is to develop new ideas that make housing construction not only more energy- and resource-efficient, but easier to build. With that as a focus, a new truss design was developed to provide a chase space inside the conditioned envelope for running supply ducts. The fact that the builder, Mercedes Homes, also operates three Space Coast Truss plants in Florida made this an attractive alternative.

The center section of the truss is raised (Figure 5) to provide a 16"-deep chase space (hatched area in Figure 6) for running supply ducts to all of the rooms of the 1,400-square-foot model. The interior of the space is finished with an air-barrier membrane isolating the ducts from the unconditioned attic. The attic insulation and the ceiling gypsum board are installed in the builder's conventional manner. Six new models using the new plenum truss configuration were built, and the models were tested during the month of February 2001. Figure 7 demonstrates that the chase space is thermally isolated from the attic.

Figure 5. Truss with Chase Space

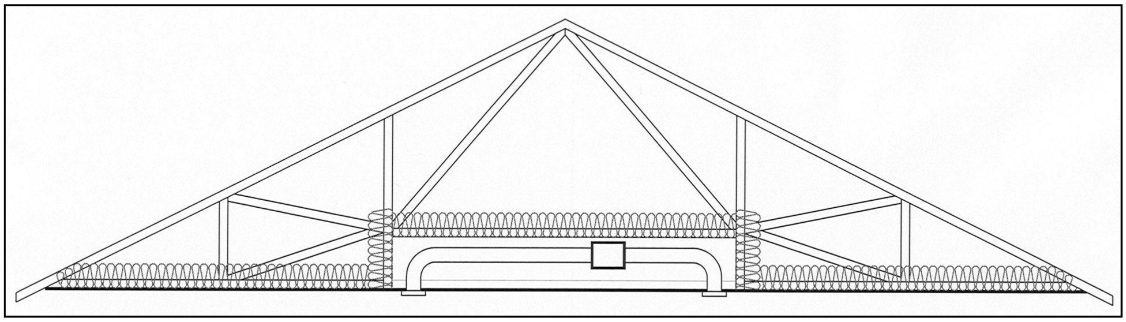


Figure 6. HVAC Plan Truss Chase

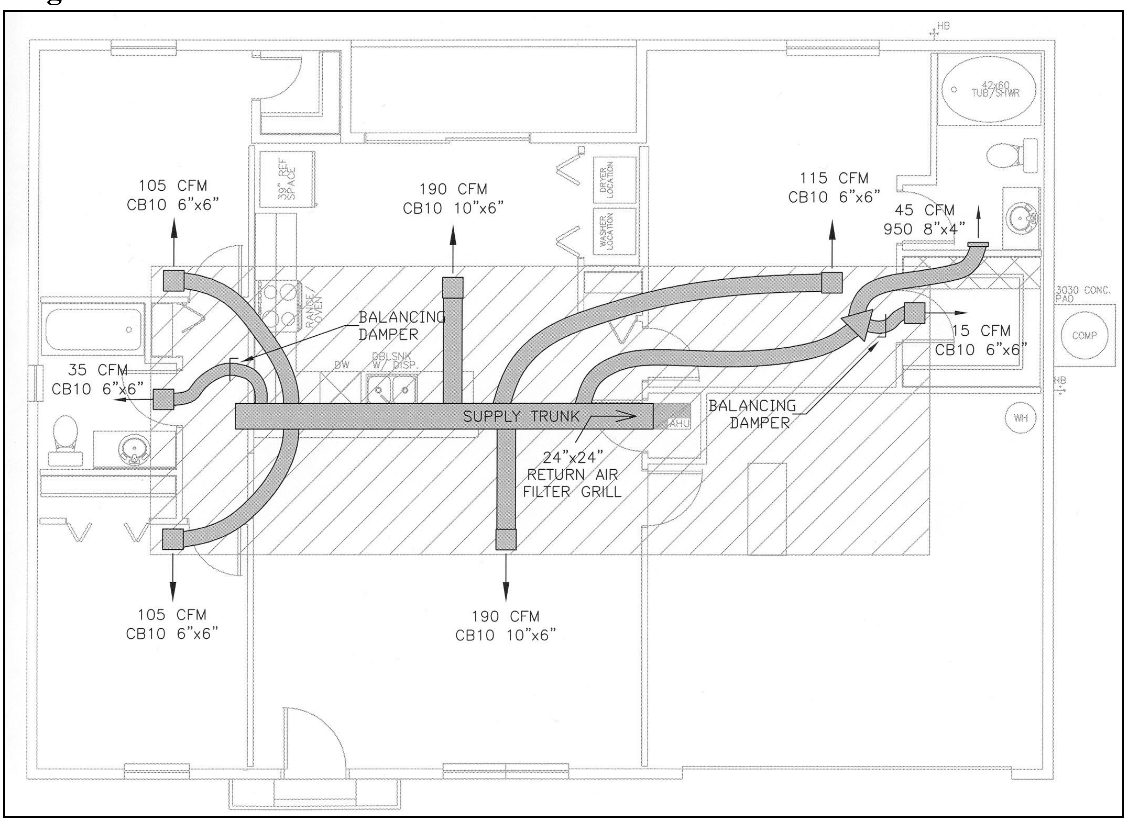
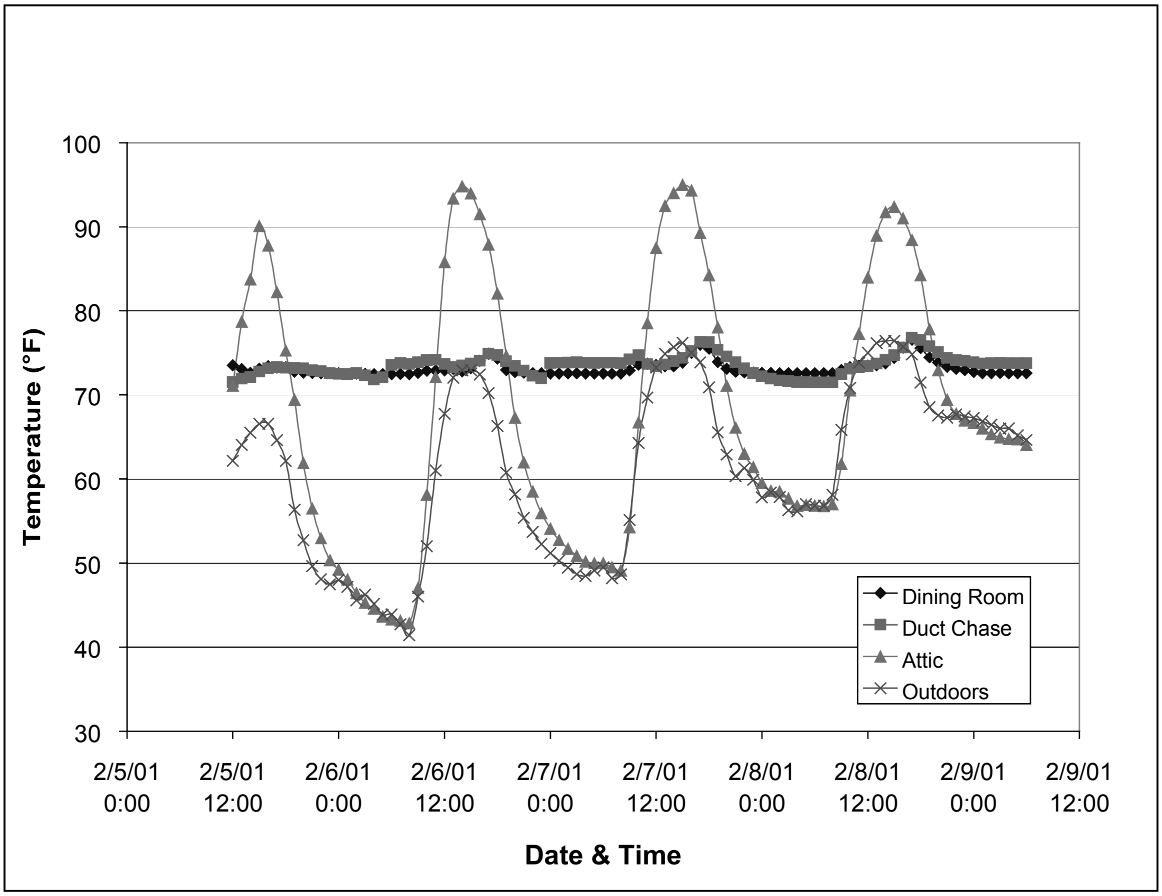


Figure 7. Chase Space Temperature Comparison



Summary

Three different approaches to reducing the heat gains and losses associated with ducts located in the attic space of homes in the hot and humid climate of Melbourne, Florida have been implemented. Each approach presents different concerns and implementation issues.

In the first home, insulated ducts were buried under blown attic insulation and monitoring was performed to evaluate the likelihood of condensation problems. Based upon over six months of observations in this one home, it was concluded that insulated ducts can be buried under attic insulation with little concern for condensation problems. Condensation did occur for brief periods of time, but leakage of conditioned air from the ducts or through ceiling penetrations appears to have minimized the potential for problems. While this approach worked for this home, it is far from an ideal solution. Relying on duct leakage to prevent condensation problems is not a satisfactory solution.

The second concept for minimizing duct gains was to move the ducts within the conditioned space by dropping ceilings in selected areas and adding soffits. While this was a good approach for the particular house design under evaluation, the approach could not be easily applied across the builder’s product line. Having the same specifications across a production builder’s product line is important. Thus, the approach of using dropped ceilings and soffits was abandoned.

The third concept utilizes a unique truss design that provides a chase space within the home's thermal envelope for the placement of supply air distribution ducts to all of the home's rooms. The HVAC ducts are within the conditioned space without the design and aesthetic concerns of dropped ceilings and soffits. This design for minimizing duct losses and gains materialized after the two other concepts were evaluated. Further development of the truss chase approach is ongoing to reduce the material cost and simplify the installation of the air barrier.

Acknowledgements

This research was funded by the Building America Program through the Office of Building Technology, State and Community Programs at the U.S. Department of Energy. The National Renewable Energy Laboratory is acknowledged for their project monitoring role and field testing support with special thanks to Ren Anderson and Ed Hancock. All CARB members and the entire staff at Mercedes Homes are gratefully acknowledged for their support and commitment to this project.

Reference

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