

Professional Paper

Design and Construction of Interior Duct System

Report Number:
FSEC-PF-365-01

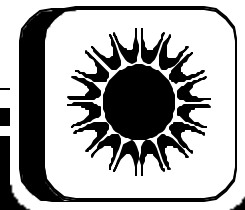
April 2001

Revised
July 2002

Janet E. R. McIlvaine
David Beal
Philip W. Fairey, III

Presented at the Affordable Comfort Conference 2001, April 30-May 5, 2001, Milwaukee, WI. Views and opinions expressed here represent those of the authors and not necessarily those of the Florida Solar Energy Center.

Florida Solar Energy Center
1679 Clearlake Road
Cocoa, Florida 32922



ACKNOWLEDGEMENTS

This work was sponsored by the United States Department of Energy (DOE), National Energy Technology Laboratory (NETL), Cooperative Agreement DE-FC26-99FT40642. The authors appreciate the support and encouragement of the program manager, Esher Kweller, DOE, and the contract administrator, William Hasslebacher, NETL.

This project would have been impossible without the cooperation of our builder partners, James Sargent of Bentwood Custom Homes in Dallas, TX, Kenneth Fonorow of Florida Home Energy and Resources Organization and affiliated builders, Robert Calhoun of the Durham County Habitat for Humanity, NC and Mary Lou Bowman and Russell Cubbins of the Broward County Habitat for Humanity, FL. Their willingness to share their ideas, and see their work validated, made the project possible.

The technical assistance rendered by Jon Andrews of Brookhaven National Laboratory, James Cummings and Neil Moyer of the Florida Solar Energy Center, and Bruce McKendry of WattsRight/Building Science Alliance was invaluable.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Interior Duct System Design, Construction and Performance

Janet McIlvaine, Florida Solar Energy Center

David Beal, Florida Solar Energy Center

ABSTRACT

To combat the energy, durability, and indoor air quality penalties of duct leakage, energy experts have recommended putting the duct system and air handler inside the conditioned space. Two paths of accomplishing this have emerged: unvented attics/crawl spaces and interior chases. This study focuses on the design, construction, and performance of the interior chase approach as implemented by five different builders in Texas, North Carolina, and Florida.

Researchers found that, in many cases, breaches of the air barrier were evident from simple visual inspection. Critical points of design and construction were identified and will be presented through photos, design and construction guidelines, and drawings suitable for construction documents.

Introduction

Energy efficiency experts agree that minimizing duct leakage is one of the most important energy conservation measures. Reducing duct leakage provides rapid payback from energy savings, and mitigates the health and durability issues associated with duct leakage to and from unconditioned spaces. Over the past 15 years, researchers and builders have developed three primary strategies to reduce the impact of duct leakage: sealing ducts, placing ducts in unvented attics or crawl spaces, and placing the ducts in conditioned space. This material focuses on placing the ducts within the conditioned space. The design and construction guidelines in this report are the results of working with four builders and one energy consultant who routinely build homes with ducts in the conditioned space.

- \$ Bentwood Custom Homes (Waxahachie, TX)
- \$ Builders affiliated with Ken Fonorow of the Florida Home Energy and Resources Organization (Gainesville, FL)
- \$ Durham County Habitat for Humanity (Durham, NC)
- \$ Broward County Habitat for Humanity (Ft. Lauderdale, FL)

Duct leakage concepts. Conventional forced air heating and cooling systems employ an air distribution system that includes an air handler and a duct system. The air handler is designed to remove air from the house, condition it, and supply it back to each room.

Duct leakage (Figure 1) can occur on either the supply side or the return side of the air handler as well as in the air handler itself. *Both supply and return* leaks cause air to move in unplanned, unpredictable ways, usually through unconditioned spaces and often bypassing air, thermal, and moisture barriers.

Supply leakage. When supply ducts leak, they create a negative pressure in the house because more air is being removed than is being supplied. The negative pressure draws air from outside and/or unconditioned spaces (infiltration) through holes in the house's air barrier potentially leading to:

- \$ Back drafting of atmospheric combustion devices
- \$ Introduction of outside air pollution, pollen, and other allergens
- \$ Introduction of air borne particles (dust, insulation, VOCs, building material particles) from floor, wall, ceiling cavities
- \$ Degraded comfort (temperature, humidity)
- \$ Greater conditioning load
- \$ Reduced system life

Supply leaks also spill conditioned air into unconditioned spaces, wasting energy, and creating the potential for mold growth, condensation, and rot.

Return leakage. When return ducts leak, part of the return air is drawn from unconditioned spaces, or outside, instead of the house. This dirty air often bypasses the system's filter. The leakage creates a positive pressure in the house because more air is

being supplied than is being removed. The positive pressure forces air through holes in the house's air barrier (exfiltration). Return duct leakage leads to:

- \$ Lowered heating and cooling capacity with degraded comfort.
- \$ Introduction of outside and/or unconditioned air into the air handler, with its attendant moisture, dirt, and pollutants.
- \$ Increased conditioning load
- \$ Reduced system life

Figure 1 Leaky ducts in unconditioned spaces cause unbalanced air flow and can gain or lose heat sufficient to change the supply air temperature by 4⁰ to 5⁰ F



Reducing duct leakage: Three primary approaches.

1. **Sealed ducts:** Researchers and builders have studying the duct leakage phenomenon for approximately 15 years have found that sealing the duct system with a combination of fiberglass mesh and mastic (Figure 2) is inexpensive and cost effective. Several residential studies have shown that these simple repairs can reduce duct leakage to less than 3-5%¹, saving 15 or 20% of cooling and heating

¹Duct leakage to outside measured at test pressure of 25 pascals divided by conditioned floor area multiplied by 100, sometimes referred to as Qn.

costs respectively or about \$60 annually². At an installed cost of about \$200, this improvement generally pays for itself in less than 4 years. The basic premise of this concept is that the air barrier of the duct system needs to be continuous and directly connected to the air barrier of the house.

2. **Unvented attics or crawlspaces:** In recent years, researchers began to explore other ways to reduce the impacts of duct leakage (Rudd 1998). Relocating the thermal and air barriers of the house to the outer edges of the structure creates either an insulated roof deck or foundation walls. The space containing the ducts is not vented to the outside, nor is it conditioned. Research to evaluate the effectiveness of this method is in progress. Code issues and construction process logistics factor large in this approach.

Figure 2 An unsealed duct (left), and a duct sealed with mesh and mastic (right)



3. **Interior ducts:** This concept involves putting the entire forced air system, including the air handler, inside the conditioned space (Figure 3). Technically, this means inside the air boundary as well as the thermal boundary, and within the space that is served by the conditioning system. Field data evaluating the success of this strategy is scant. The primary challenges in this approach involve establishing an air barrier around the ducts, overcoming code challenges, and integrating the new detail into the design and construction process. Theoretically, interior ducts will yield the savings of eliminating duct leakage plus the savings of reduced thermal gain/loss of the duct system.

²Compilation of findings by: Cummings, Tooley, and Moyer, 91 and 93. Davis, 91. Evans and Tsal, 96. Manclark and Davis, 96. See References.)

Figure 3 Interior duct chase, with supply register



Interior Duct System Design And Construction Considerations

Developing Standardized Design and Detail Guidelines

Usually an interior duct system is installed either in a fur-down chase below the ceiling insulation or in a fur-up chase in the attic and insulated with the ceiling. Though ducts in floor cavities between upstairs and downstairs are often thought of as being in conditioned space, this is rarely the case. The floor cavity is not normally bound by a definitive air barrier. However, with careful attention to sealing the perimeter of the floor cavity this may be a viable option.

Fur-up chases. Seen from the living area, the fur-up chases are indistinguishable from the finished ceiling; seen from the attic, they appear as a boxed out area covered with insulation. All sealing should be complete before insulation is installed since access to the chase from below will be limited after the ducts and drywall are installed. All sides of the chase should be thoroughly covered with insulation. Since fur-ups are more obvious from the attic than fur-downs, they are more likely to be targeted for wiring and plumbing runs (Figure 4). The chase needs to be carefully inspected before the builder releases the house. Upon completion of the house, all penetrations should be filled with a code-approved sealant and any missing pieces of the air barrier replaced and sealed.

Figure 4 Fur-up chase compromised by plumbing and wiring



Fur-down chases. Chases built down into the conditioned space generally occupy the upper portion of hallways, run along walls, and/or cut across open living areas as architectural elements (Figure 5). The lowered ceiling height can be offset by widening the hallway and can be used to define living spaces in open floor plans. Most of the houses included in this field study featured fur-down chases.

A standard definition for “conditioned space”. The “conditioned space” is defined by the location of the air barrier and thermal barrier. The air inside these barriers is cycled through the air handler and *conditioned*. To be *in the conditioned space*, the duct system must be isolated from all adjacent unconditioned spaces (including wall cavities) by a continuous air barrier and be within the thermal barrier of the house. The benefits, both thermal and air exchange, of interior duct systems will be severely diminished if not completely lost without these barriers.

Figure 5 Chase used as an architectural detail



Standard duct materials and duct sizes. Interior duct work in a fur-down system typically consists of metal or fiberglass duct board. Space limitations generally rule out the use of flex duct. (Note that the unvented attic/crawlspace strategy, mentioned above, as well as a fur-up system, does not.)

Usually, ceiling heights cannot be less than 7'0" to meet code and allow for door framing (Figure 6). For homes with 8' ceilings, that allows 12" or less for the ducts and the structure of the chase. To minimize the space needed for chase structure, detail the smallest available framing member that will support the weight of the drywall (for the bottom of chase) and ducts (if not supported by straps). This might be 2 x 2s or light gauge metal framing.

Figure 6 Chase in hallway, note 7'0" ceiling and door clearance



Integrating interior ducts into plans. In ranch style homes (homes with all bedrooms grouped together at one end of the house, also incorporating a main hallway), the chase runs the length of the hallway (flanked by bedrooms) and extends out into the main living area (Figure 7).

In split plan homes (homes with bedrooms on either end of the house, separated by the main living area) the duct chase runs from the master bedroom area, across the main living area, and into the other bedrooms. Whereas the hallway fur-down makes use of the upper portion of the hall walls, chases in open areas are built out from one wall (Figure 8) and down from the ceiling framing.

Figure 7 Chase under construction in ranch house hallway



To locate the chase in a specific design, start by examining the plan for an obvious path. The air handler can be located either centrally or at one end of the chase, but as the heart of the duct system, it must be inside the conditioned space. To avoid long run-out ducts, the chase should trace a path down the center of the house and go to all spaces to be served. Otherwise, small supply runs in unconditioned spaces or excessive chase construction will be required to reach distant rooms. Align the central chase with closets, cabinets, or transverse halls to achieve coverage of all rooms.

Figure 8 Chase along wall of open living area. Note chase sealing with drywall compound



The top of the chase should be uninterrupted by framing. Miscellaneous bracing that interrupts the upper air barrier creates additional cutting, fitting, and sealing work. In most cases, the air barrier will be made of an air-tight material (e.g. drywall, rigid insulation) sealed at the edges and seams, and the thermal barrier will be ceiling insulation installed over the top of the chase, plus the sides for fur-ups.

Often it is tempting to use the chase as a “ducted” return to the air handler, as the chase goes to all rooms. This practice is not currently recommended because reliable sealing of the chase from surrounding unconditioned spaces has proven difficult to achieve. Any leakage in the chase air barrier can cause severe return leaks. This is similar to the pitfalls of using building cavities as ducts, such as panned floor joists.

Integrating the new strategy into current construction processes. Indicate the chase and air handler on both the mechanical drawings and dimensional drawings. After laying out the chase on the plans, detail it in section (Figure 12) for clarity, indicating materials, critical dimensions, and sealing details.

To clearly communicate both the intent and specifications to all crews working with the chase provide the plans and detail to each. This may include framing, drywall, insulation, and finishing crews as well as the mechanical contractor. Include the electrical and plumbing contractors who need to either avoid putting holes in the chase or fill any hole they make.

Be sure the mechanical contractor takes the location of the ducts into consideration for system sizing calculations as well as the size of the chase (less than 12" clearance for 8' ceilings) for duct sizing calculations. The duct design should incorporate sizing and design considerations to insure adequate air distribution into all rooms. Fur-down chase systems are difficult to use with a perimeter duct installation, as the chase typically runs down the center of the building. Fur-down chases limit register size and placement.

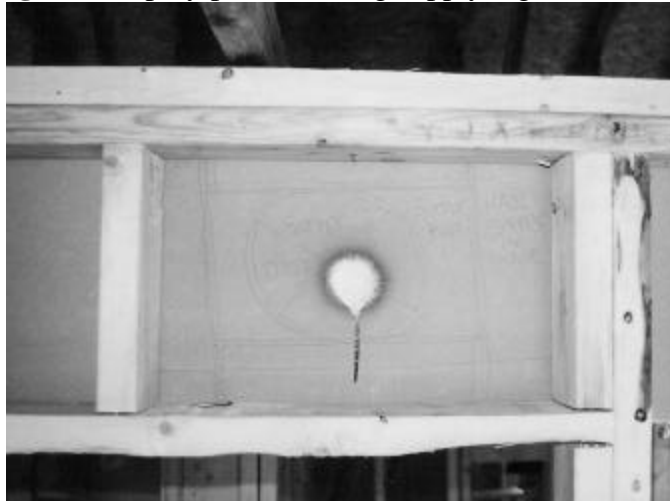
Before construction of the chase. Clearly indicate the chase location at the construction site. Most of the chase is built after rough framing and before the mechanical rough-in. A

copy of the mechanical system plan showing the duct chase location in hatch marks should be posted in the house for reference. Mark the location of the chase after rough framing. Ken Fonorow of Gainesville, Florida, recommends marking the location of the chase for the crew building it. The construction supervisor responsible for the chase spray paints the floor (Figure 9) along the bottom plate of all the walls where the chase is to be built. He starts at the air handler and traces the path of the chase to its end. After the chase is installed, mark the location of supply registers also (Figure 10).

Figure 9 Spray paint marking chase location



Figure 10 Spray paint marking supply register location



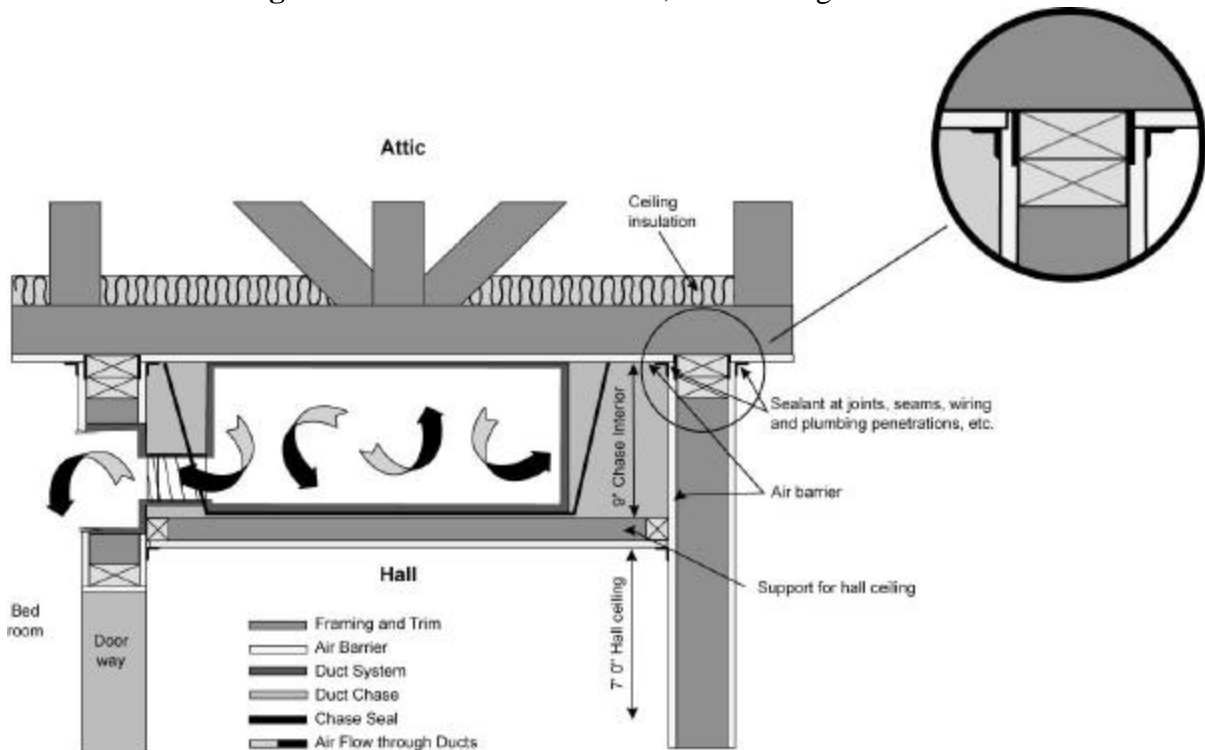
Make sure materials for building the continuous air barrier (and later thermal barrier) are available when needed. If any special materials are needed make sure they are on hand (light gauge metal framing for the chase support, etc.).

Correctly and Successfully Executing the Design and Detailing

General construction guidelines. Let the guiding principal for building an interior duct system be the establishment and maintenance of an air barrier. After an air barrier is established, a thermal barrier in the same location is needed. The chase's ceiling air barrier should be placed first. Next, place the side(s) of the chase. Then, all joints and seams should be sealed with code-approved sealant, including the gap between the air barrier and the top plates of adjacent walls (Figure 11). At this point, the chase's principle air barrier is complete. The open sides face conditioned space and will be finished later when the rest of the house is drywalled (Figure 8).

Next, the mechanical system is roughed in and the rest of the chase is framed. Much of the duct system can be assembled on the floor then lifted and strapped into place. The remaining chase framing is put into place within the chase's air barrier such that it will not interrupt the house air barrier.

Figure 11 Fur-down chase detail, note sealing details



The joints and seams (Figure 8) of the chase must be sealed, as well as any penetrations in the chase that intersect an unconditioned space. Note that unconditioned spaces are any cavity or room that is not served by the mechanical system. These include obvious spaces such as attics, garages and storage rooms as well as hidden areas such as wall and floor cavities.

The penetration in the chase wall for the supply run-out intersects an unconditioned space; the interior wall cavity (Figure 11). To prevent air from coming down from the attic between the drywall and the top plate, the joint between the chase

wall and the interior wall framing must be sealed OR the joint between the top plate and the drywall must be sealed. Without this continuous air barrier, any duct leakage will be in communication with an unconditioned space, either the attic directly or the interior wall cavity. This type of sealing is especially important in the air handler closet since the return side of the air handler induces strong negative pressures, significantly increasing the leakage through any gaps.

Special attention must also be paid to the platform that the air handler sits on in the house. Preferably, central returns should be ducted from the air handler to the return grill instead of being open to the walls of the air handler closet (Figure 12).

A supervisor who understands the intent of the chase should regularly check progress and follow the chase construction through to completion, meaning the ducts are all installed, holes have been sealed (Figure 13), and the chase is ready for close-in. The chase is closed-in as the house gets dry-walled

Protecting the chase after completion. Protect chase from cable, phone and other installers who may want to use it as a convenient way to run wires. The holes that typically result will compromise the air barrier (Figure 13). Identifying the chase as a space intended to be separate from surrounding unconditioned spaces is difficult at best. The authors have not yet seen a consistently effective method. Communication is again an important factor.

Figure 12 Conventional platform return. Rough framing connected to attic through walls of air handler closet, resulting in return leaks



Advisory notices to cable, security, and phone installers should be posted in conspicuous locations such as the panel box, attic access hatch, wiring service entrance, etc. Since these cannot clearly identify the location of the air boundary in the attic, the

notices should advise the installer to seal any penetrations to drywall made from unconditioned spaces. Though this should be standard practice and is often required by code, virtually all services installed post-occupancy are never inspected.

Figure 13 Holes for wiring, plumbing, cables, etc. need to be sealed with a code approved sealant



Conclusions and Further Needs

The authors worked with four builders who adopted interior duct design for both health and energy benefits. A battery of air tightness tests was conducted at more than two dozen homes. For details and experimental results please refer to “Field Study of Interior Duct System Design, Construction, and Performance – Final Report” (McIlvaine, Beal & Fairey 2001).

It is possible to correctly construct the chase so as to achieve the goal of true interior duct work, as was seen in one case during the study, and seen several times by the authors. The methods described in this paper are based on the successfully executed interior duct systems seen in the study and in the field. However, the experimental results and visual observations have shown that chases are typically leaky, meaning they are not isolated from unconditioned spaces. Despite the care taken to ensure the ducts were in conditioned space, the integrity of the chase air barrier was often thwarted by lack of communication among the many trades and the complexity of the chase construction.

The authors and the builder partners agree that it is easier to make an air tight duct system than it is to make an airtight chase, and that it would be a mistake to assume that tight duct systems are not needed when the ducts are placed in an interior chase. Leaky ducts placed in leaky chases will not provide the desired energy or health benefits. Whereas, an airtight duct system in a leaky chase still derives some of the energy benefits of interior ductwork, while not causing the building durability and health problems associated with leaking duct work.

Typical interior ductwork is not insulated, being in conditioned space, and should never have condensation problems. The results of this work lead the authors to believe that it is better to err on the side of caution, and to use insulated duct materials, as the majority of the systems seen in the study were not truly interior duct systems, and could see dew point temperatures that could cause condensation problems.

The fur-down chase system rarely lends itself to perimeter duct installation as it typically runs down the center of the building. This type of duct system limits register size and placement. The duct design should incorporate sizing and design considerations to insure adequate air distribution into all rooms.

Based on builder experience, it is apparent that there is a commitment needed from the builder and the site supervisor to perform the necessary duties required to place the ducts in the conditioned space. There is additional work required from the framers and the drywall crew to build the chase, often requiring additional job site visits to build the chase. There can be added costs for materials, such as custom trusses for a fur-up installation, or additional framing and drywall, or a more expensive duct system required due to space limitations. Field observations and testing consistently revealed compromised chases due to sub-contractors not understanding the purpose of the chase, and it's convenient location for wiring or plumbing runs. The site supervisor or the builder must constantly monitor the progress of the house to insure the chase integrity is not compromised. Ideally, inspection after the mechanical, electrical, and plumbing rough-in should specifically include a visual check of the duct chase.

Other contractors appear after the house is occupied to install security, phone, and cable runs at the owner's discretion. These contractors are not aware of the function of the chase, and often find it a convenient place to run their wiring. Notices to fill all penetrations to the duct chase with code-approved foam should be posted on the electrical panel, by the attic light and on the exterior of the chase itself in several places. The homeowner needs to be briefed on the function of the chase, and the potential for damage to the chase to compromise its function.

It is possible to successfully execute an interior duct system in a chase, building the chase airtight and truly incorporating the ductwork into the interior space. As builders continue experimenting with this technique, patterns of problems and successful solutions will develop. Much like duct sealing a decade ago, this strategy is still in development.

Acknowledgments

This work was sponsored by the United States Department of Energy (DOE), National Energy Technology Laboratory (NETL), Cooperative Agreement DE-FC26-99FT40642. The authors appreciate the support and encouragement of the program manager, Esher Kweiler, DOE, and the contract administrator, William Hasslebacher, NETL.

This project would have been impossible without the cooperation of our builder partners, Jim Sargent of Bentwood Custom Homes in Dallas TX, Ken Fonorow of Florida Home Energy and Resources Organization and affiliated builders, Robert Calhoun of the Durham County Habitat for Humanity, NC, and Mary Lou Bowman and Russell Cubbins of the Broward County Habitat for Humanity, FL. Their willingness to share their ideas, and see their work validated, made the project possible.

The technical assistance rendered by Jon Andrews of Brookhaven National Laboratory, James Cummings and Neil Moyer of the Florida Solar Energy Center, and Bruce McKendry of WattsRight/Building Science Alliance was invaluable.

Help!

For design assistance related to duct systems, contact Janet E. R. McIlvaine, janet@fsec.ucf.edu, 321-638-1434 or David Beal, david@fsec.ucf.edu, 321-638-1433, at the Florida Solar Energy Center

References

Cummings, J. B., J. J. Tooley, N. A. Moyer. *Investigation of Air Distribution System Leakage and Its Impact in Central Florida Homes*. Contract Report, Florida Solar Energy Center, Cocoa, FL, FSEC-CR-397-91.

Cummings, J. B., J. J. Tooley, N. A. Moyer, *Duct Doctoring; Diagnosis and Repair of Duct System Leaks, DRAFT*, Florida Solar Energy Center, Cocoa, Florida, May 1993.

Davis, B. E., *The Impacts of Air Distribution System Leakage on Heating Energy Consumption in Arkansas Homes*. Report submitted to the Arkansas Energy Office, 1991.

Evans, Richard A., and Robert J. Tsal. "Basic Tips for Duct Design", *ASHRAE Journal*, July 1996.

Manclark, Bruce, and Bob Davis. "Duct Improvement in the Northwest, Part II: Mobile Homes." *Home Energy Magazine*, January/February 1996.

McIlvaine, J. E. R., D. Beal, P. Fairey. *Field Study of Interior Duct System Design, Construction, and Performance.- Final Report* Contract Report, Florida Solar Energy Center, Cocoa, FL, FSEC-CR-1256-01 October 2001

Rudd, Armin, J. W. Lstiburek. "Vented and Sealed Attic in Hot Climates." ASHRAE Symposium on Attic and Cathedral Ceilings. June 1998