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Investigation of Potential Benefits of Revising Exception 1 under FLORIDA BUILDING CODE, ENERGY CONSERVATION, Section 101.4.7.1.1 Duct Sealing upon Equipment Replacement

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Prepared for:

The Florida Building Code Commission

Energy Technical Advisory Committee

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Executive Summary

Section 101.4.7.1.1, Duct sealing upon equipment replacement (Mandatory), of the 2012 Supplement to the Florida Building Code, Energy Conservation went into effect briefly in 2013. The new section required sealing of accessible ducts at the time of HVAC equipment replacement. Exception #1 however, eliminates the requirement for ducts in conditioned space, and by doing so, effectively eliminates the sealing requirement for building cavities in conditioned space that are used as air distribution paths. However, test results show that these building cavities are often connected to adjacent unconditioned spaces, in effect they are not really in the conditioned space because they are not fully separated from unconditioned space.

This investigation concerns repair of building cavities used for return air plenums in interior air handler closets. Researchers worked with three affordable housing entities renovating foreclosed homes in disrepair to address three research questions and modeled improvement to estimate impact of the return repair strategies manifested in the study. Researchers did not attempt to influence the contractors' approaches to the return plenum.

Research Question 1: Was there leakage to the outside in these return plenums located in interior air handler closets?

Yes. For testing purposes, the return side of the air distribution system in each test house was isolated from the rest of the system and tested per standardized industry procedures. Results show that air is flowing into the return plenums (under test and normal operating conditions) from adjacent unconditioned spaces even though it is located in an air handler closet inside the conditioned space. This characteristic is illustrated across the board for these four houses.

Research Question 2: What is the magnitude of return plenum leakage compared to the entire system?

It makes up a significant portion of whole system leakage. Researchers tested the air distribution systems in entirety. The ratio of Return Only leakage to the Entire System ranged from just shy of 50% to 93% for Qn,total and from 36% to 97% for Qn,out.

Research Question 3: Was there improvement in the return plenum air tightness?

Yes, in all homes, return plenum leakage was reduced substantially. For the Return Only tests, Qn,total reduction ranged from 66% to 80%, but more importantly the Qn,out (leakage to outside) reduction range was higher at 71% to essentially 100%. In one house, the return plenum leakage to the outside was essentially eliminated meaning that the return plenum is truly "in conditioned space" with essentially no air exchange with the adjacent wall cavities and attic.

These return-side reductions were made in the context of whole system change-outs that included air handler replacement but not supply duct replacement. Reduction in the Entire System Qn,total ranged from 48% to 78% and for Qn,out ranged from 72% to 89%. These results are outstanding and reflect commendable work of the HVAC contractors involved.

The reduction in estimated annual energy for the these commendable results ranged from $36 (2.3% of projected whole house energy use) to $97 (6%). Researchers developed a hypothetical scenario representing what the projected savings would have been if the return plenums had not been repair so well. This was achieved by modifying post-retrofit test results to reflect pre-retrofit return plenum conditions. The analysis found the annual savings were reduced to a range of $2 to $62.

The HVAC contractors provided material costs associated with repairing the return plenum which ranged from $75 to $130. Labor hours were also provided but the labor rate was not. Based strictly on material costs, the simple payback for capturing the return plenum sealing savings ranged from 1.8 to 4.9 years. Intangible benefits related to occupant health and safety, building durability, and comfort are fully explored in other research.

Although field data from previous studies backs up the findings in this small sample, it would be premature to draw any conclusions about feasibility of sealing building cavities used for return air in the general Florida existing housing stock. However, it is clear that the HVAC contractors in this study all had the same approach: build a platform return lined with duct board sealed at the edges and seams. An approach that is consistent with HVAC requirements and practices in Florida new construction.

1 Introduction

Section 101.4.7.1.1, Duct sealing upon equipment replacement (Mandatory), of the 2012 Supplement to the Florida Building Code, Energy Conservation which was in effect briefly in 2013 required HVAC contractors to seal “accessible (a minimum of 30 inches clearance) joints and seams in the air distribution system” when new equipment is installed (Florida Building Code 2010: Energy Conservation 2011), quoted here for reference:

101.4.7.1.1 “Duct sealing upon equipment replacement (Mandatory)[1].

At the time of the total replacement of HVAC evaporators and condensing units for residential buildings, all accessible (a minimum of 30 inches clearance) joints and seams in the air distribution system shall be inspected and sealed where needed using reinforced mastic or code approved equivalent and shall include a signed certification by the contractor that is attached to the air handler unit stipulating that this work has been accomplished.”

“Exceptions:

1. Ducts in conditioned space.
2. Joints or seams that are already sealed with fabric and mastic.
3. If system is tested and repaired as necessary.”

Exception #1 eliminates the requirement for ducts in conditioned space, and by doing so, effectively eliminates the sealing requirement for building cavities in conditioned space that are used as air distribution paths. However, test results show that these building cavities are often connected to adjacent unconditioned spaces, in effect they are not really in the conditioned space because they are not fully separated from unconditioned space. This happens when the whole house air barrier does not extend to the unconditioned side of air distribution soffits, wall or floor cavities, and duct chases (Beal et al. 2011).

Building cavities used for supply distribution are not likely to meet the accessibility criteria; and therefore would not be subject to the sealing requirement. However, building cavities used for central return air conveyance often are accessible. These commonly occur in air handler closets but also when a garage air handler pulls return air through a wall mounted grille. This investigation concentrated on air handlers locate in closets. This was the most prevalent air handler location in the 70-home FSEC field study, more prevalent in homes built before the 1990’s (Figure 1) when construction code and standards would not have required much attention to duct tightness.

[1] Note that this code requirement was rescinded by the Florida Legislature shortly after it went into effect. Nonetheless, the Florida Code Commission clearly placed value on this efficiency improvement strategy for existing homes. This field study provides additional field data concerning this strategy to further inform the debate of its merits.

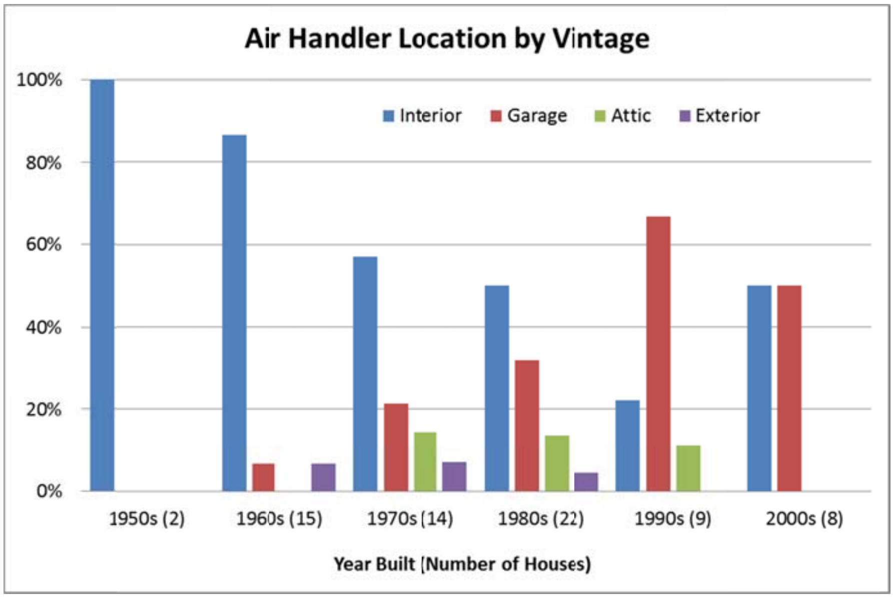

Figure 1. Pre-retrofit air handler location in field study of 70 central Florida renovations (McIlvaine et al. 2013). 40 homes had AHUs in the conditioned space, with greater prevalence in homes built before the 1990s.

Air handler closets typically house a central return plenum, and are usually formed by the walls of the closet. If these walls are unfinished, open wall cavities, it results in a return plenum that pulls air from those wall cavities and the attic above as shown in the infrared image in Figure 2 (Parker et al. 1998).The infrared image shows the wall between the utility room and the main body of the house. The return air path is unintentionally connected to the wall cavity and consequently the attic as evidenced by the signature of hot air being pulled down the wall during air handler operation.

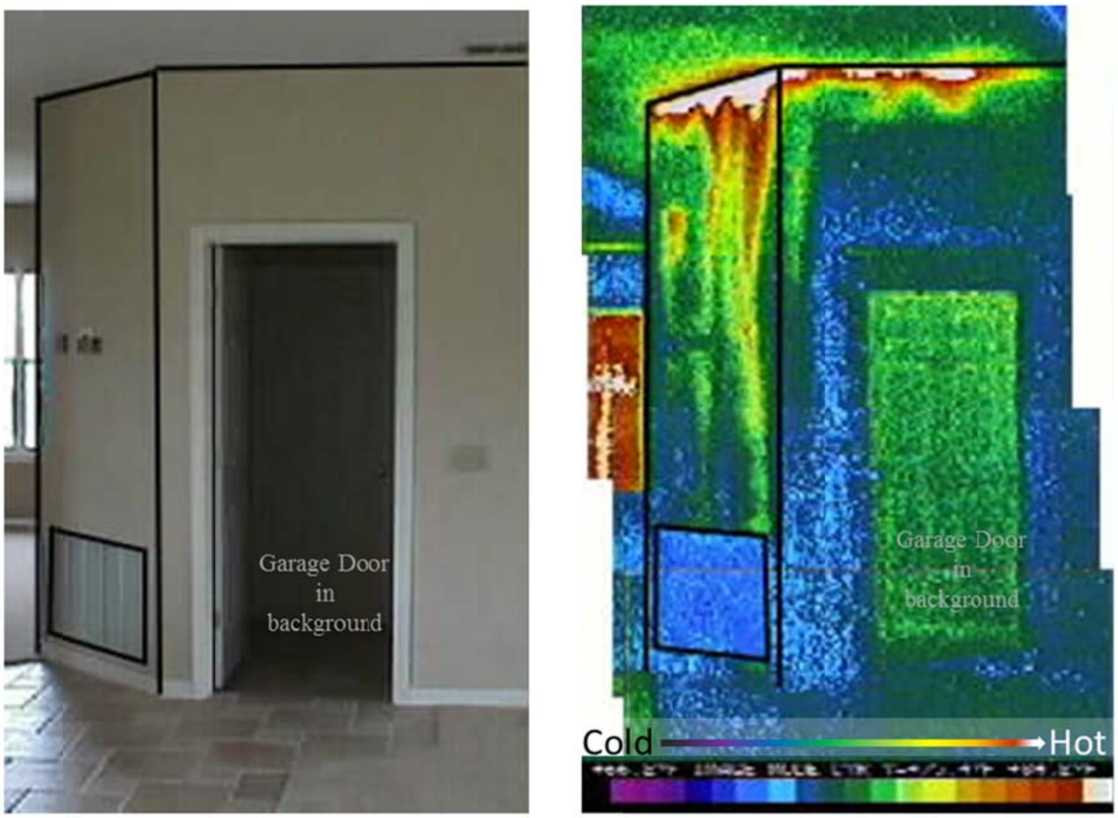

Figure 2. Left: A return plenum formed by unfinished framing under an air handler support platform is on the other side of this wall mounted return air grille in a utility room. Right: Infrared image showing hot attic air (see color scale at bottom of image) being pulled down the interior wall cavity during air handler run time (Parker, et al. 1998.).

By modifying Exception 1 to exclude only accessible *ducted* pathways in conditioned space, not accessible building cavities, from the sealing requirement, this leakage path could be significantly diminished in 1,000's of existing homes at the time of air handler change-out. The benefits would include enhanced HVAC system performance, building durability, comfort, and energy efficiency. These benefits would be rendered by the improvement of duct system air tightness and reduction of uncontrolled air flow from mechanically induced infiltration (Cummings and Withers 1998; Cummings et al. 2012). The Florida Building Code Commission has acknowledged the wisdom of sealed return plenums by requiring them in all new Florida homes under the Florida Building Code, Residential, Chapter 16, Table M1601.4 (Florida Building Code 2010: Mechanical 2011) (See Appendix A.).

The potential benefits must be weighed against potential down sides of such a modification such as additional labor hours and materials and homeowner inconvenience. An informed consideration will require understanding the magnitude of potential savings.

To characterize the effect of such a modification to Exception 1 on the installation process and duct system air tightness, researchers worked with mechanical contractors to document current practices associated with equipment change-outs in interior air handler closets. Researchers did not attempt to direct the work, rather the intent was to identify strategies already in use which are by definition feasible under current market conditions such as labor capability, as-found conditions, and material costs.

This field study is focused on interior air handler closets with the air handler mounted either on a stand where the whole closet functioned as the return plenum or mounted on a platform with a where the space underneath the platform served as the return plenum with a return grill in a sidewall of the plenum.

In four test homes, researchers conducted duct air tightness testing prior to equipment change-out, and after the installation of new equipment was completed. During the testing, the return air portion of the duct system was isolated and tested independently of the rest of the air distribution system. Comparison of test results will be an effectiveness indicator of the associated return plenum retrofit approach.

Phase 1 field work was focused on open frame platform returns (in closets only, not garages) and whole closet return plenums, following this process: and consisted of duct system testing in four homes as follows:

- Pre-retrofit – Test leakage of as-found air distribution system including isolating the return air portion of the system.
- During retrofit - HVAC contractor will replace HVAC equipment and repair/replace any associated components using the contractor's standard procedures. Researchers documented the contractors' standard treatments of the return plenums.
- Post-retrofit – Re-test leakage of air distribution system including isolating the return air portion of the system.
- Analysis - Compare pre- and post-retrofit leakage including the return side improvement and the entire system improvement.
- Modeling – For each house, the pre- and post-retrofit duct leakage measurements were modeled in a single base case home to estimate annual energy savings for improving the air tightness of the whole air distribution system. An additional simulation case was developed to represent what the improvement would have been if HVAC contractor had not made any air tightness improvement in the return portion of the system, which is currently allowed under the Florida Code for Existing Homes as long as the as-found conditions could meet the requirements of the original approved installation.

Evaluation of the retrofit installations was carried out by testing the entire air distribution systems' air tightness, then isolating the return portions. Standard RESNET approved duct testing protocol was used. The results of the testing were used to simulate the impact of the reduction of return leakage using a single base case house to compare the normalized improvement levels achieved in the current study. Using the same base case house for all simulations eliminates all other differences so that, the impact of the return sealing approach alone can be estimated.

2 Testing and Analysis Methods

The air distribution system testing conducted in for this field study is commonly referred to as "duct leakage testing". Pre- and post-retrofit duct leakage was measured using the protocol in common use in the home energy rating industry (RESNET 2013) and for the return side of the air distribution system independent of the rest of the air distribution system (ASHRAE 2004).

2.1 Return Plenum Testing Procedures

To evaluate the impact of return air plenum sealing, it is necessary to isolate it from the rest of the air distribution system. This was not as straight forward as anticipated because of degradation of air handlers in the test homes (missing or inaccessible air handler fans as well as missing air handler covers). Nonetheless, the return side of the air distribution systems were isolated in one of the following ways depending on as-found conditions:

- Blocking air flow at the bottom of the air handler cabinet (Figure 3, left)
- Sealing the opening in the bottom of the platform (Figure 3, right)
- Installing and sealing a plastic bag over the air handler fan to prevent air flow between the return and supply sides. This was necessary when air handler covers were missing (Figure 8 in Section 3.1 below).

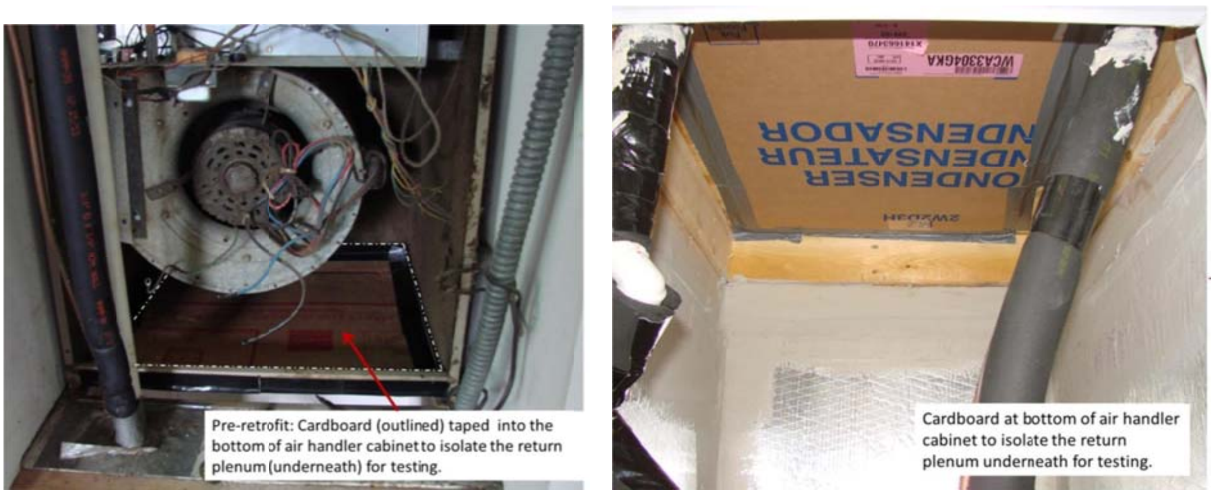

Figure 3 Pre-retrofit (left) and Post-retrofit (right) testing configuration to isolate the return plenum underneath the air handler support platform.

2.2 Test Measurements

For both the isolated return (described above) and the entire system, researchers measured total leakage, meaning leakage to both the conditioned space and surrounding unconditioned spaces such as attics, wall cavities, garages, and the outdoors. This is commonly referred to as “ducts total”. Researchers also measured the leakage to going to or coming from unconditioned spaces, commonly referred to as “ducts to out”. Test results are expressed in cubic feet per minute of air flow measured at a standard test pressure of 25 Pascals (CFM25). “CFM25,total” shows the leakage to both conditioned and unconditioned spaces. “CFM25,out” shows the leakage to or from unconditioned spaces.

This testing protocol resulted in four test values generated pre-retrofit and repeated post-retrofit:

- Test A: Entire system CFM25,total
- Test B: Return plenum only CFM25,total

- Test C: Entire system CFM25,out
- Test D: Return plenum only ducts CFM25,out

For comparison between houses test results can are normalized by conditioned area, expressed as Qn and calculated by dividing duct leakage (CFM25) by the conditioned area of the home (ft^2). Expressed as a decimal, produces a fraction representing the duct leakage per 100 ft2 of conditioned floor space (at the test pressure) thereby allowing comparison of duct leakage in different size homes.

- Qn,total = CFM25,total/conditioned area = total leakage per 100 ft^2 of conditioned space
- Qn,out = CFM25,out/conditioned area = leakage to unconditioned spaces per 100 ft2 of conditioned space
- Example: CFM25,out = 30; Conditioned area = 1000 ft2.
- Qn,out = CFM25,out/Conditioned area = 30 cfm/1000 ft2= 0.03 or 3 cfm per 100 ft2

Qn test results will used for discussion in the rest of the report. Comparing the return only Qn test result to the entire system Qn test result at pre- or post-retrofit gives an indication of the magnitude of return leakage as a portion of the entire system leakage. Comparing pre- and post-retrofit test results indicates the magnitude of improvement achieved by the contractor's approach.

3 Research Partners and Test Houses

The limited time allotted to conduct this research resulted in all participating houses coming from a small pool of Florida Solar Energy Center partners from previous work. Two partners were local municipalities; two partners were local non-profit affordable housing providers. All partners have already adopted standard practices that address the pitfalls of an unsealed return plenums. As such, we feel the test results represent practices of completely sealing the plenum to be, and further, several of the partners require the refrigerant lines to be isolated from the air path which further affects return plenum construction. It's likely that these test results are on the upper end of return plenum improvement and not necessarily representative of general practice among HVAC contractors. This was not done by design, rather a product of needing houses immediately upon commencement of the contract. On the other hand, all of the HVAC contractors involved were using practices standard to their businesses anecdotally indicating a degree of practically consistent with market norms. These homes were in affordable housing programs which anecdotally indicates a level of affordability appropriate for all market sectors.

Research partners put forth houses as candidates for the field study. Sites were evaluated, and those that did not represent a "typical" interior air handler closet were eliminated. The houses were deemed acceptable if they had an interior air handler in a closet, either on a stand in the closet with a louvered door, or built on a platform with a through-the-wall grill. These typical characteristics were manifest in 40 of the 70-house field study of Florida homes primarily in central Florida (McIlvaine et al. 2013). Ultimately four test houses in Brevard County on Florida's central east coast were chosen for Phase 1 research. They range in vintage from 1960 to 1986 (Table 1).

Table 1 Year of Construction for Phase 1 Test Houses

	Year of Construction
House 223	1981
House 261	1980
House 1962	1960
House 194	1986

Details as well as an account of pre- and post-retrofit return plenum configuration for each test house is provided below. Test results for each house are summarized after each description.

3.1 Test House1962

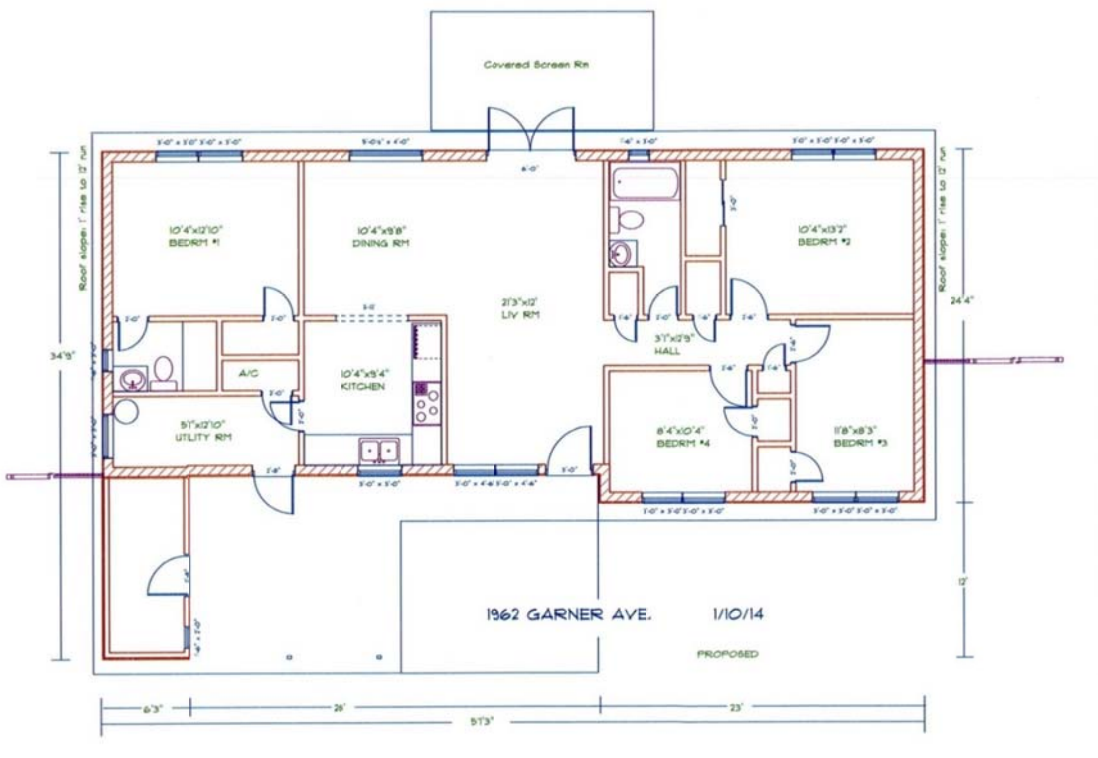

Figure 4 Floor plan for House 1962

Description

This 1276 ft2 CBS house was built in 1960. It has 4 bedrooms, 2 baths and no garage (Figure 4). There is a cathedral ceiling throughout the house, excluding the utility room, hall, master bath and closet, and A/C room.

As found, the home had a retrofitted HVAC system with an air handler installed in a former pantry (note “A/C” in Figure 4). The Air handler unit was installed on a platform in the pantry with a filter at its bottom. The pantry door was solid, requiring a through-the-wall return. This return was accomplished by cutting a hole in the pantry/kitchen wall, directly behind the refrigerator (Figure 5). This hole was completely unsealed from the wall (Figure 6).

As seen in Figure 5 the supply register for the kitchen is located directly above the return opening. This register was merely stuck in the wall, the supply duct feeding it was not attached to a boot, providing conditioned air to the wall cavity that is directly connected to the return (Figure 7). As configured the air handler and the kitchen supply, sources of positively pressurized leakage points, are in the return, a negative pressure area. This in effect is "turbocharged" duct leakage.

A significant portion of the supply ducts were installed in a fur-down chase across the kitchen and living room. Remaining supply duct work was installed in the attic with supply registers in the knee walls created by the cathedral ceiling.

Figure 5. The entire air handler closet serves as the return plenum. Left: Central (only) return air grille mounted in wall between kitchen and air handler closet. Center: Air handler closet showing back of return air grille. Right: Inside the air handler closet, to the left of the door, showing air handler mounted on free-standing wooden supports.

Figure 6. Looking up into the wall cavity from the wall-mounted return air grille. This wall cavity is part of the return air plenum because there is no air barrier separating it from the return air flow path.

Figure 7. Disconnected supply duct

Pre-repair

As found the air handler was gutted, coil removed for scrap and no front cover. However, since the entire air handler closet is the return plenum and the fan motor was still in-place, testing proceeded by bagging the fan with a garbage bag (Figure 8) and installing the duct blaster fan to the return grill behind the refrigerator. By closing the closet door the system was configured in typical operating condition; the lack of a front cover and coils in the air handler deemed not to interfere with the results as the air handler would be fully open to the closet when operating (at the return air intake on the air handler).

Figure 8. Return portion of air distribution system isolated from the supply by sealing around the air handler fan with a plastic bag taped at all edges.

Repair and Post-repair

The HVAC contractor removed the existing air handler unit (AHU) and stand. The contractor built a new platform in the same location as the old AHU. The stand was built to allow for the installation of a filter-backed grill under the AHU. The platform was lined with foil-faced fiberglass “duct board” to seal the entire cavity from the area outside the platform (Figure 9).

Figure 9. Filter-back return grille installed on new platform return in existing air handler closet.

Test Results

In this house the contractor also addressed the obvious failures in the supply duct work, sealing the open supply in the kitchen, re-installing the supply boots found disturbed in the attic portion of the house, and sealing all supply boots with mastic on their inside surfaces. The improvement from these repairs is apparent in the leakage reduction for the entire system shown in Table 2 and Figure 10.

Table 2 Pre- and Post-Retrofit Duct Leakage and Improvement for Test House 1962

	Qn,total		Qn,out	
	Entire System	Return Only	Entire System	Return Only
Pre-retrofit	0.40	0.23	0.24	0.09
Post-retrofit	0.12	0.05	0.07	0.03
Improvement	71%	77%	72%	71%

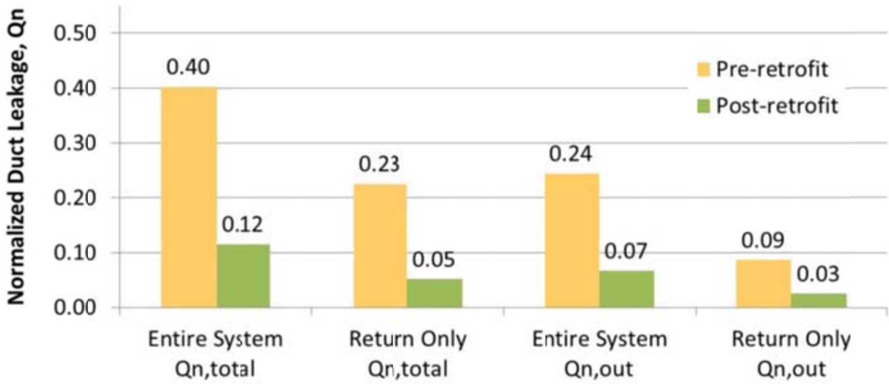

Figure 10 Pre- and post-retrofit normalized duct leakage test results for House 1962

3.2 Test House 194

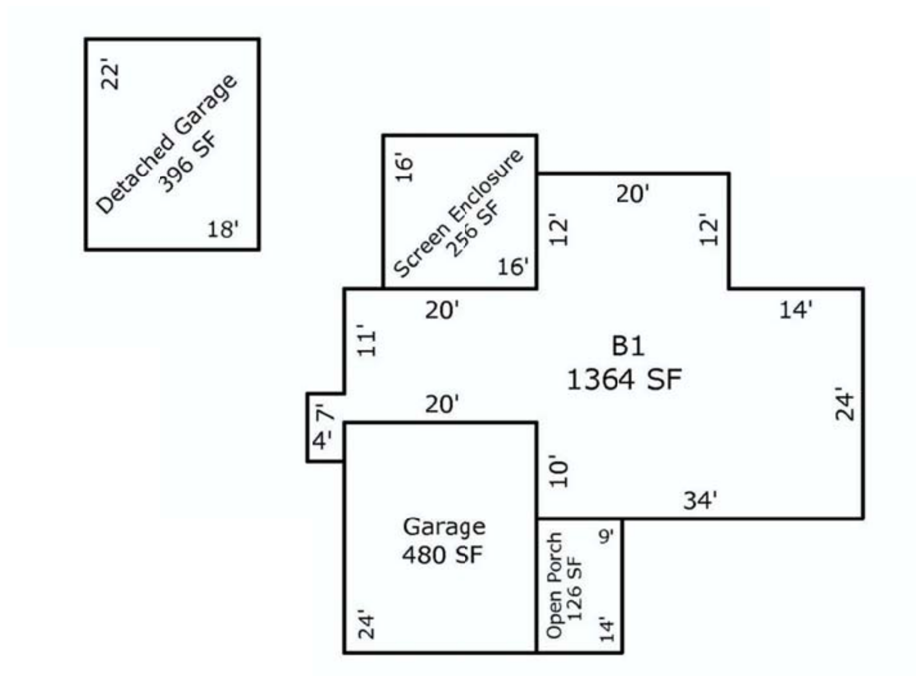

Figure 11 Floor plan for House 194

Description

This 1364 ft2, 3-bed/2-bath slab-on-grade frame house with attached garage was built in 1986 (Figure 11). Approximately 40% of the floor area is under a cathedral ceiling with an 11' height at the peak. The air handler was located on an open platform in a closet behind a louvered door (Figure 12). This installation provided very little access to the sides of the air handler. All supply duct work was in the attic.

Figure 12. Air handler mounted on an open frame platform

Pre-repair

As found the air handler had no filter, and no apparent place to install a filter. Although there was a return platform in the closet the return was open to the entire closet, including the air handler cabinet itself. To simulate operating conditions (louvered door closed, return open to closet) testing was done using a duct blaster curtain in place of the louvered door.

Repair and Post-repair

There was significant repair to the supply duct system, both through the wall over the air handler and in the attic. The living room supply run was relocated and re-run (Figure 13)

Figure 13. The hole in the wall over the air handler closet was cut to facilitate supply plenum installation. Also note the living room supply, to be relocated during repair.

The existing return platform was removed and replaced with new wood. The walls and floor of the plenum was lined with duct board and sealed with mastic. The front of the plenum was prepped for the future installation of a filter-back grill (Figure 14).The finished air handler platform is designed with a filter-back grill under the platform. The air handler is to be enclosed with a half-door closet (Figure 15).

Figure 14 New duct board lining provides an air barrier to separate the return air stream from adjacent open wall cavities.

Figure 15 Completed repaired return air plenum. Note mastic at duct board seams.

Test Results

Pre-testing was conducted using a duct blaster door curtain in place of the louvered bi-fold door found in front of the air handler closet. The curtain is shown in Figure 12, above, awaiting installation in the air handler closet door frame. In light of the installation of a true return platform fronted with a filter-back grill during retrofit the duct blaster was attached to the new filter-back grill under the new air handler platform. Using a duct blaster curtain can introduce errors to the measurement process as it is prone to leakage around its perimeter is not installed perfectly. The results of the Pre and Post repairs are found in Table 3 and Table 16.

Table 3 Pre- and Post-Retrofit Duct Leakage and Improvement for Test House 194

	Qn, Total		Qn, out	
	Entire System	Return Only	Entire System	Return Only
Pre-retrofit	0.19	0.09	0.10	0.04
Post-retrofit	0.10	0.02	0.02	0.00
Improvement	48%	78%	76%	100%

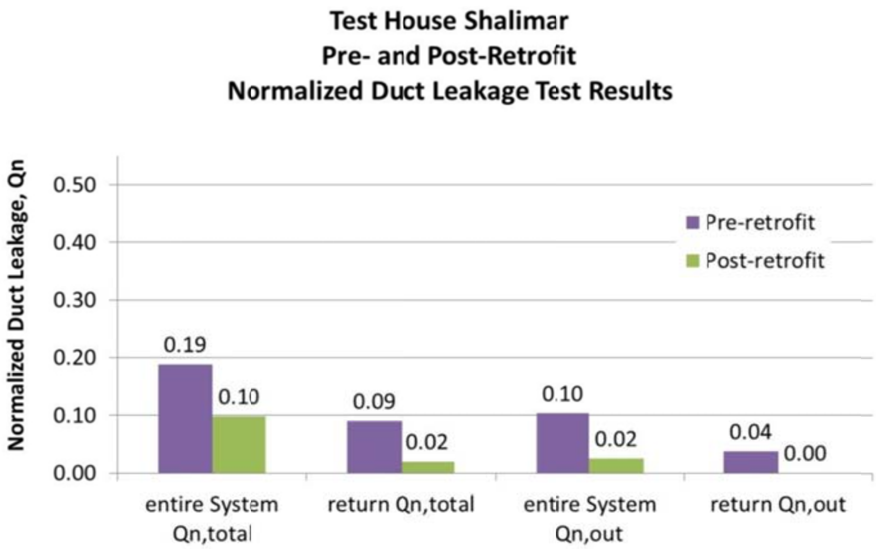

Figure 16 Pre- and post-retrofit normalized duct leakage test results for House 194

3.3 Test House 261

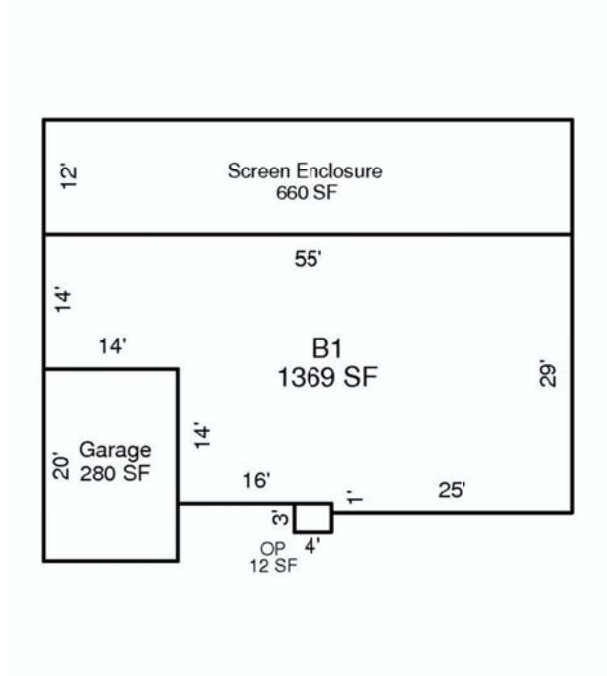

Figure 17 Floor plan for House 261

Description

House 261 is a 1369 ft2 slab-on-grade frame house (Figure 17). It has three bedrooms, two baths and an attached garage. The air handler is installed in a hall closet on a platform with a filter back grill in the closet. The closet has large, 6' wide, louvered bi-fold doors (Figure 18). There was a raised plywood floor in the closet. The return plenum was open to the wall cavities and the floor cavity(Figure 19). There was a filter installed under the air handler that was completely blocked with insulation and other dust and debris.

Figure 18. Note the open wall cavities in the return plenum and the raised plywood floor in the closet (in the lower right corner of the image)

Figure 19. Raised closet floor created a plumbing chase for refrigerant line, condensate drain line and other plumbing run. Chase is fully connected to return air plenum at pipe penetrations.

Pre-repair

House 261 had a true return plenum with a filter-back grill installed. The duct blaster was installed to this grill (Figure 20). Isolating the return was accomplished by removing the up-flow air handler fan and sealing the resulting hole with cardboard (Figure 21). Further isolation was accomplished by taping the air handler seams closed.

Figure 20 Pre-retrofit duct testing in progress

Figure 21 Blocking the supply side of the air distribution system for testing.

Repair and Post-repair

Significant effort was expended on sealing and rebuilding the air handler platform in this house. When the air handler was removed the platform top was found to be rotten. The platform top removal was complicated by the fact that the platform was original installed before the house was drywalled. When the plenum was exposed it was sealed with duct board and mastic at the wall cavities and the raised floor (Figure 22). The new air handler was installed on the new platform and sealed with a combination of tape, mastic and caulk(Figure 23).

Figure 22. Repaired return plenum lined with duct board air barrier sealed with mastic at all edges.

Figure 123. Return air entry to air handler seen from inside the return plenum. Joint between plenum, platform, and air handler is thoroughly sealed with mastic.

Test Results

Pre- and Post-testing configurations were the same, a duct blaster mounted to the filter-back grill found under the return platform. Pre-test return isolation was accomplished by removing the air handler fan and sealing the resulting hole. This method was not possible with the new air handler for Post-testing, so the return was isolated via a trash bag wrapped around the air handler fan inside a well-sealed air handler.

The success of the retrofit's sealing efforts is illustrated by the result tabulated below (Table 4) and shown in Figure 24.

Table 4 Pre- and Post-Retrofit Duct Leakage and Improvement for Test House 261.

	Qn, Total		Qn, out	
	Entire System	Return Only	Entire System	Return Only
Pre-retrofit	0.53	0.37	0.23	0.15
Post-retrofit	0.12	0.07	0.04	0.01
Improvement	78%	80%	83%	90%

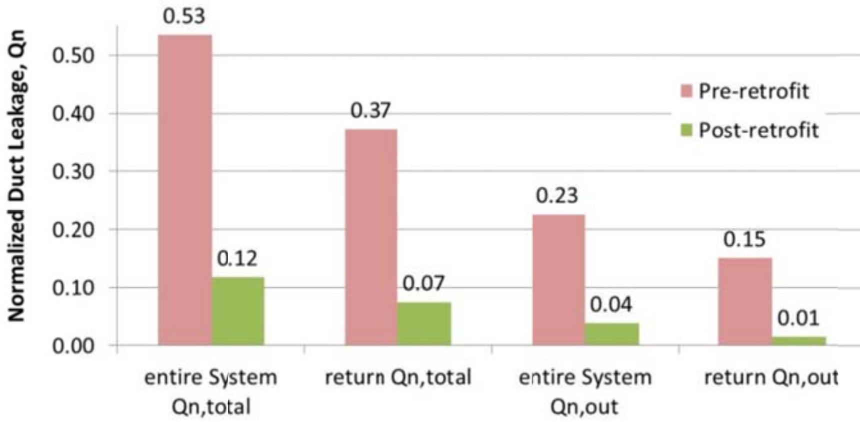

Figure 24. Pre- and post-retrofit normalized duct leakage results for House 261

3.4 Test House 223

Figure 25 Test House 223

Description

This 900 ft2 slab-on-grade CBS house was built in 1981 (Figure 25). It has two bedrooms, one bath and an attached garage. The air handler is located on a stand in a hall closet behind a bi-fold half-louvered door (Figure 26). The return plenum formed under the air handler is un-drywalled, resulting in open wall cavities in the air handler return path (Figure 27).

Figure 26. Air handler closet with open frame platform return plenum.

Figure 27. Open frame platform return.

Pre-repair

As found the air handler cabinet was missing its front panel. However, as the entire closet was actually the return in this house testing of the duct system was carried out using a duct blaster curtain in place of the louvered door. Return isolation was accomplished by placing a trash bag around the air handler fan.

Repair and Post-repair

This contractor did significant work in the attic of the house sealing the supply system. The entire return configuration was changed to a platform with a filter-back grill installed in a well-sealed plenum (Figure 28). Additional time was spent while sealing the plenum to keep the condensate and Freon pipes isolated from the return plenum. The air handler closet will be completed with the installation of a half door to hide the air handler.

Figure 28. Repaired platform return plenum with duct board air barrier sealed at edges.

Test Results

Duct system Pre-testing was done employing a duct blaster curtain and return isolation was done using a trash bag around the air handler fan. Post-testing used a duct blaster attached directly to the new return grill. Return isolation was accomplished by wrapping the air handler fan with a trash bag.

The efforts to seal both the supply and return systems resulted in an extremely tight duct system. The system was so tight that it was difficult to resolve any difference between the entire system readings and the return only test results, as seen below in Table 5 and Figure 29.

Table 5 Pre- and Post-Retrofit Duct Leakage and Improvement for Test House 223.

	Qn, Total		Qn, out	
	Entire System	Return Only	Entire System	Return Only
Pre-retrofit	0.16	0.15	0.11	0.10
Post-retrofit	0.06	0.05	0.01	0.01
Improvement	62%	66%	89%	88%

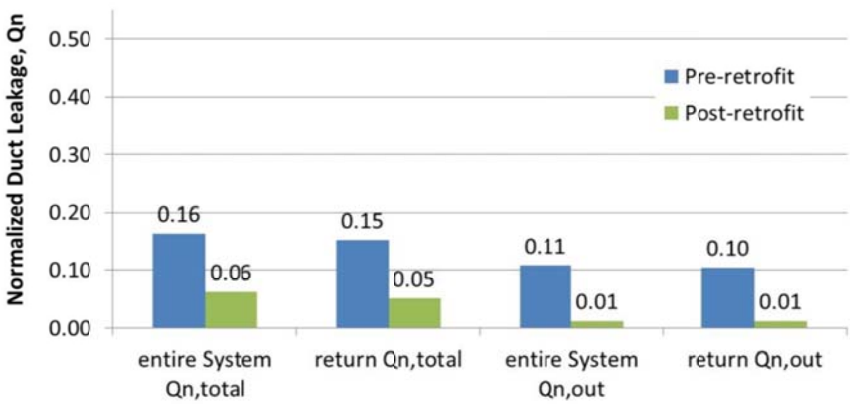

Figure 29. Pre- and post-retrofit normalized duct leakage test results for House 223

4 The State of Duct Leakage in Florida Homes

To put the test results from the four test homes in perspective, consider this background on duct leakage in Florida homes. Since 1979, the Florida Building Code has progressively incorporated requirements for air distribution systems in new home construction (Fairey 2009). This has been done in concert with scientific discovery and advances in labor pool capabilities. This is reflected in the declining duct leakage included in the Florida Energy Code Baseline Home (Table 6). Code requirements combined with utility rebate programs and above-code home performance programs such as ENERGY STAR have led to mainstreaming of duct sealing practices.

Table 6 Characteristics of Florida Energy Code "Baseline" Homes by Code Version (Fairey 2009)

	Energy Code Version													
	'79	'80	'82	'84	'86	'89	'91	'91R	'93	'97	'01	'04	'04R	'07
Base case Qn,out (Entire System)	0.12	0.12	0.12	0.12	0.12	0.12	0.10	0.10	0.08	0.08	0.08	0.06	0.06	0.05

Code Commission sponsored evaluation of code effectiveness has produced two sets of data that indicate typical new construction Florida homes built in the first decade of the 2000's typically have a Qn,out of 0.057 to 0.064 (Table 7). One of the studies included results for return side leakage which averaged Qn,out of 0.02 and, on average, was 27.3% as high as leakage of the entire system.

Table 7. Duct system airtightness from two field studies of recent vintage Florida homes

Year of Construction	Average Qn,out Entire System	Average Qn,out Return Side	Average Return as % of Entire System	Reference
20 2001-02 houses	0.064	NA	NA	Cummings et al. 2002
20 2002-05 houses	0.057	0.02	27.3%	Swami et al. 2006

Regardless of the advances in Florida new home construction, millions of existing Florida homes have significant duct leakage. In a recent FSEC field study, the pre-retrofit Qn,out measured in 53 homes ranged in vintage from 1957 to 2006 ranged from 0.02 to 0.4 for the entire distribution system. Return side leakage measurement was outside the scope of that study. Table 8 shows averages by decade with an overall average 0.12 (McIlvaine et al. 2013). Note that post-retrofit averages are more homogenous (much lower standard deviations) and are generally in the realm of typical new homes built in the 2001-2005 vintage shown above in Table 7.

Table 8 Average Pre- and post-retrofit normalized duct leakage test results for 53 homes in central Florida (McIlvaine et al. 2013)

		Pre-Retrofit		Post-Retrofit	
Decade	n	Qn,out	sd	Qn,out	sd
1950s	1	0.04	NA	0.07	NA
1960s	11	0.15	0.10	0.06	0.03
1970s	12	0.20	0.13	0.11	0.09
1980s	15	0.09	0.04	0.07	0.04
1990s	7	0.09	0.07	0.06	0.04
2000+	7	0.07	0.05	0.03	0.03
Overall	53	0.12	0.10	0.07	0.06

These studies establish that for both new and existing homes, Qn,out test results for entire systems around 0.06 is achievable under current market conditions such as labor capability, material cost, and physical limitations of assemblies.

5 Testing Results Summary

Pre- and post-retrofit results for the test houses in the current study for following tests are shown in Figure 30.

- Test A: Entire system CFM25,total
- Test B: Return plenum only CFM25,total
- Test C: Entire system CFM25,out
- Test D: Return plenum only ducts CFM25,out

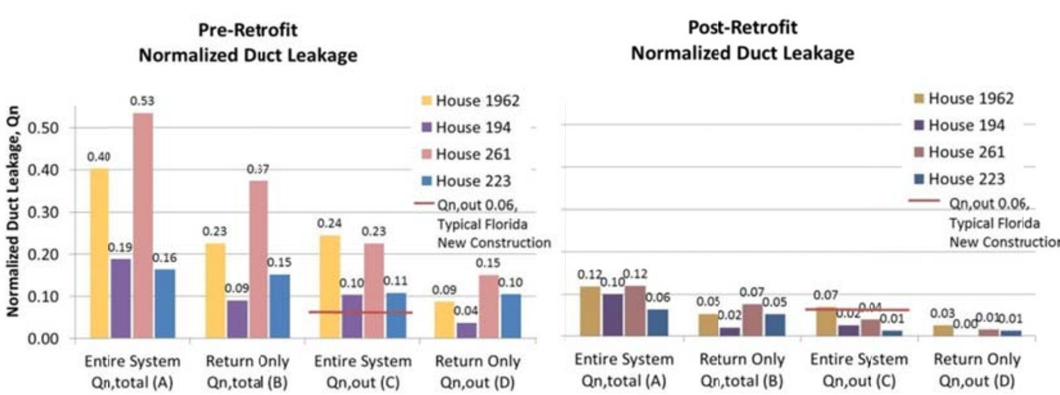

Figure 30. Pre-retrofit (left) and post-retrofit (right) duct testing results.

Pre- and Post-retrofit CFM25,out (duct leakage to the outside) for the entire system (Figure 30, left and right, C) ranges from 0.10 to 0.24 and 0.01 to 0.07 respectively. These are within the range anticipated based on previous field studies (Tables 7 and 8).

Research Question 1: Was there leakage to the outside in these return plenums located in interior air handler closets?

Table 9 shows that, when tested in isolation from the rest of the air distribution system, the return side leakage ranged from 0.09 to 0.37 for Qn,total and 0.04 to 0.15 for Qn,out. If these return plenums were truly isolated from unconditioned space, there would be virtually no leakage (Qn,out < 0.01) to the outside (Qn,out). These test results mean that air is flowing into the return plenums from adjacent unconditioned spaces even though it is located in an air handler closet inside the conditioned space. This characteristic is illustrated across the board for these four houses.

Table 9 Pre-retrofit Qn,total and Qn,out results for the isolated return-side of the system

	Return Only Pre-retrofit Qn,total	Return Only Pre-retrofit Qn,out
House 223	0.15	0.10
House 261	0.37	0.15
House 1962	0.23	0.09
House 194	0.09	0.04

Research Question 2: What is the magnitude of return plenum leakage compared to the entire system?

The relative magnitude of leakage from building cavity return plenums can be assessed by comparing it to the leakage of the entire system. In these four study homes, the return leakage was a large contributor. Table 10 shows the ratio of Return Only leakage to Entire System leakage for both Qn,total and Qn,out, expressed as a percentage. Looking at House 223, the "Return as % of Entire System" for Qn,total is 93%. This means that for every 100 cfm of leakage measured for the entire system, 93 cfm were measured in the Return Only test. Stated another way, the measured Return Only Qn,total was 93% as high as the leakage for the entire system. The return to entire system rations for Qn,total range from just shy of 50% to 93% and for Qn,out from 36% to 97%.

This dominant return-side leakage is particularly evidenced in Houses 223 and 261 where all pre-retrofit return-side test results were in excess of 65% as high as that of the entire system. Return-side leakage ratios are lower in the other two house but still in excess of 35% in all cases. In short, return-side leakage to or from unconditioned spaces is a significant component of the leakage in the entire system in these houses which Exception 1 would exempt from sealing even though they are accessible because they are presumed to be "in conditioned space".

A previous study of 20 Florida homes found that when the air handler was located in the conditioned space, 28% of the return leakage was "to out" (Cummings et al. 2002), somewhat lower than the tightest systems in the current study. This is perhaps related to return plenum construction since the 20 homes were built in the 2001-2002. Homes in the current study were built between 1960 and 1986 prior to code adoption of requirements for return plenum construction and the duct sealing utility programs in the 1990's which introduced HVAC contractors to tight duct construction.

Table 10 Pre-retrofit Qn,total and Qn,out results for the entire system and the return only

	Pre-retrofit Qn,total			Pre-retrofit Qn,out		
	Entire System	Return Only	Return as % of Entire System	Entire System	Return Only	Return as % of Entire System
House 223	0.16	0.15	93%	0.11	0.10	97%
House 261	0.53	0.37	70%	0.23	0.15	67%
House 1962	0.40	0.23	56%	0.24	0.09	36%
House 194	0.19	0.09	48%	0.10	0.04	36%

Research Question 3: Was there improvement in the return plenum air tightness?

Yes, in all homes, return plenum leakage was reduced substantially (Table 11). For all tests of the return plenum isolated from the rest of the system, post-retrofit results show reduced leakage. The "% Reduction" columns show that Qn,total reduction ranged from 66% to 80% but the Qn,out (leakage to outside) reduction range was higher at 71% to essentially 100%. This indicates that, at post-retrofit, a substantially lower percentage of return-side leakage involves air from the attic or wall cavities. In House 194, the return plenum leakage to the outside was essentially eliminated meaning that the return plenum is truly "in conditioned space" with essentially no air exchange with the adjacent wall cavities and attic.

Table 11 Return Plenum Only Test Results and Improvement

	Qn,total Return Only				Qn,out Return Only			
	Pre-retrofit	Post-retrofit	Qn,total Reduction	% Reduction	Pre-retrofit	Post-retrofit	Qn,out Reduction	% Reduction
House 223	0.15	0.05	0.10	66%	0.10	0.01	0.09	88%
House 261	0.37	0.07	0.30	80%	0.15	0.01	0.14	90%
House 1962	0.23	0.05	0.17	77%	0.09	0.03	0.06	71%
House 194	0.09	0.02	0.07	78%	0.04	--*	0.04	100%**

*Leakage below measurement threshold of approximately 12 cfm.

**Leakage to outside was essentially eliminated.

These return-side reductions were made in the context of whole system change-outs that included air handler replacement but not supply duct replacement. One supply duct run was relocated. Duct leakage test results and improvement for the entire systems are reported in Table 12.

Table 12 Entire System Test Results and Improvement

	Entire System Qn,total				Entire System Qn,out			
	Pre-retrofit	Post-retrofit	Qn,total Reduction	% Reduction	Pre-retrofit	Post-retrofit	Qn,out Reduction	% Reduction
House 223	0.16	0.06	0.10	62%	0.11	0.01	0.10	89%
House 261	0.53	0.12	0.42	78%	0.23	0.04	0.19	83%
House 1962	0.40	0.12	0.29	71%	0.24	0.07	0.18	72%
House 194	0.19	0.10	0.09	48%	0.10	0.02	0.08	76%

Reduction in the Entire System ranged from 48% to 78% for Qn,total and 72% to 89% for Qn,out. These results are outstanding and reflect commendable work of the HVAC contractors involved. Houses 223, 261, and 194 achieved post-retrofit Qn,out results satisfy the duct air tightness criteria for high performance housing set by the ENERGY STAR for New Homes program (ENERGY STAR 2012). It is also a positive reflection on the affordable housing entities that wrote the scopes of work for these four houses. Although these housing partners were FSEC partners on previous projects, researchers did not provide any guidance or input on the design or execution of these system change-outs. The pre-retrofit Qn,out in this small sample ranged from 0.10 to 0.24; the maximum being more than double the minimum. Although the sample is small, it's safe to say that these pre-retrofit test results are not uncommon in the existing Florida housing stock. For Qn,out, they all fall well within the pre-retrofit range evidenced in an earlier, larger field study (Figure 31). At post-retrofit, the results fell in the bottom half of the earlier study's range with Houses 223 and 194 in line with the lowest leakages measured (Figure 32).

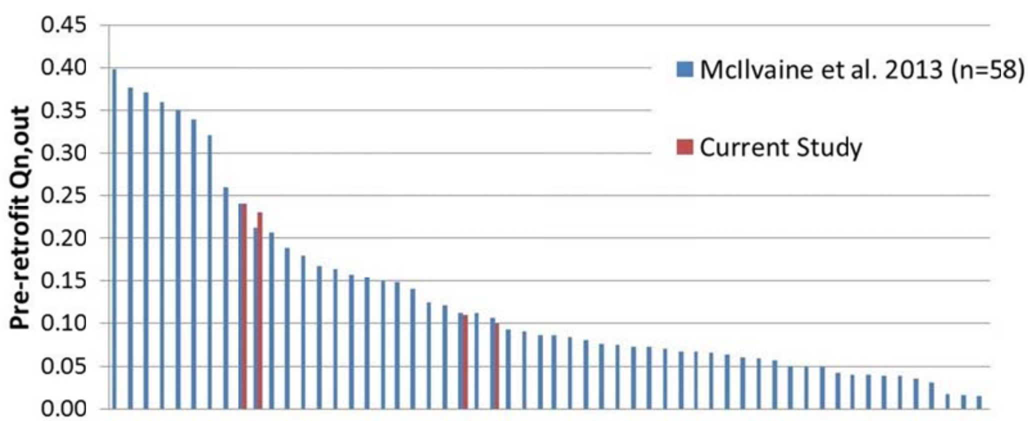

Figure 31. Pre-retrofit Qn,out (red) in relation to those found a previous field study of existing homes in central Florida (blue).

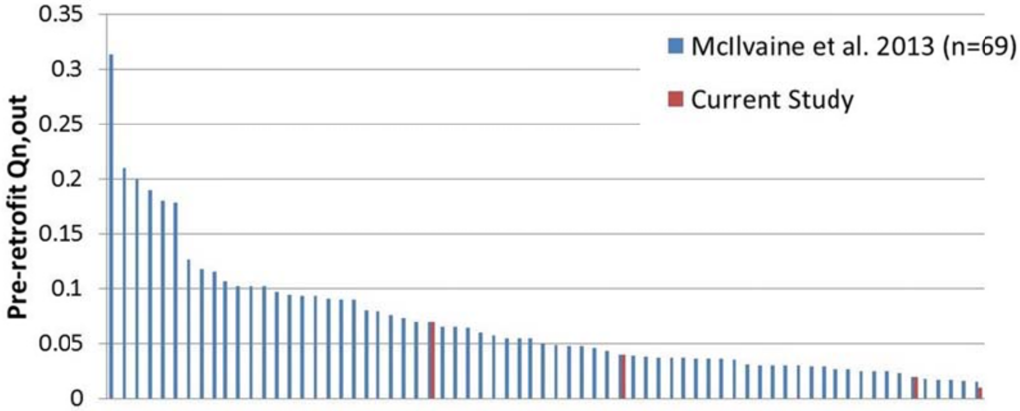

Figure 32. Post-retrofit Qn,out (red) in relation to those found a previous field study of existing homes in central Florida (blue).

The proposed scope of research included assessing the air handler leakage separately from the rest of the system to gauge the contribution of the new air handlers to leakage reduction. The deteriorated state of the as-found air handlers precluded this testing at pre-retrofit.

6 Energy Savings Simulation Results

All of the contractors involved in this limited sample did an excellent job repairing the duct systems, including the returns, in all test houses. Annual energy use modeling software, Energy Gauge USA, was used to analyze the impact of duct leakage repairs on energy use and cost.

Four sets of Energy Gauge USA simulations were, one for each house. The measured, normalized duct leakage test results (Qn,total and Qn,out) were evaluated alternately in a single base case house. By using the same base case house for all simulations the results can be compared and reflect only the variances in the duct leakage. The base case house was modified prior to each simulation to reflect the Qn results found during Pre- and Post- testing in each house successively.

The base case house is a 1230 ft^2, slab-on-grade, frame house with 3 bedrooms, 2 baths and an attached garage built in 1981 and will be configured with identical conditions, equipment and specifications found in Table 13, below. The base case home was chosen from the 70-house field study referenced earlier in this report (McIlvaine et al 2013) as a representative of typical existing Florida homes. A more extensive analysis would reveal the breadth of potential impact.

Table 13 Base case house for projected annual energy savings

Component	Characteristics
Structure	1232 ft2 slab-on-grade, frame, 3/2 with attached garage
Insulation	R-18 attic, R-11 walls
Roof Finish	Medium colored shingles
Mechanical System	Air source electric heat pump, SEER 13/HSPF 7.7 Interior air handler and return, attic ducts

Water Heating	Tank type in garage
Windows	Single pane clear metal frame U = 1.20; SHGC = 0.80 Window to floor area ratio = 11%
Lighting	10% fluorescent
Ducts	Set to test results for each Test House
Infiltration	ACH50= 8.34

For each of the four sets of simulations, the base case house was reconfigured with three levels of duct leakage:

- Pre-retrofit scenario
- Post-retrofit scenario
- Hypothetical post-retrofit scenario as if the return plenum had been left alone (currently allowed under code)

Comparing the hypothetical to the actual post-retrofit scenario reveals the penalty for not sealing the return plenum, a small scale indicator of lost opportunity at system replacement. The duct leakage associated with the hypothetical scenario (no return duct sealing) was developed by modifying the post-retrofit test results for the entire duct system to reflect pre-retrofit condition of the return plenum. Recall that four duct leakage tests were conducted as shown below:

- Test A: Pre-retrofit entire duct system
- Test B: Pre-retrofit return plenum only
- Test C: Post-retrofit entire duct system
- Test D: Post-retrofit return plenum only

Table 14 summarizes which test results were used in the simulation effort. The hypothetical test results representative of NOT repairing were produced by modifying the post-retrofit test results to reflect the pre-retrofit level of return leakage: (Test B – Test D) + Test C. This effectively swaps the pre-retrofit and post-retrofit measured leakage for the return plenum.

Table 14 Test Results used for Three Simulation Scenarios.

Scenario	Qn test results used in the simulation
1 - Pre-retrofit	Test A
2 - Post-retrofit	Test C
3 - Hypothetical post-retrofit as if the return had NOT been repaired	(Test C – Test D) + Test B Stated another way: (Test B – Test D) + Test C

Projected annual energy use and cost is summarized in Table 15 below. These results are from the base case house model modified to reflect the listed Qn,out. Table 16 shows the projected annual energy cost savings for Scenarios 2 and 3, and from comparing the two, the estimated annual cost penalty for NOT repairing the return plenum at the time of system replacement.

Table 15: Summary of the impact of duct repair in the base case house

Test results from:	Scenario 1 Pre-retrofit (As-found Leakage)			Scenario 2 Post-retrofit (Actual Return Repair)			Scenario 3 – Hypothetical Post-retrofit (Return NOT Repaired)		
	Qn, out (Test A)	Estimated Annual Energy		Qn, out (Test C)	Estimated Annual Energy		Qn, out (C-D)+B	Estimated Annual Energy	
	Measured Qn,out	Use kWh	Cost $	Measured Qn,out	Use kWh	Cost $	Modified Qn,out	Use kWh	Cost $
House 223	0.11	12,040	$1,565	0.01	11,712	$1,523	0.10	12,028	$1,564
House 261	0.23	12,538	$1,630	0.04	11,788	$1,532	0.17	12,315	$1,601
House 1962	0.24	12,605	$1,639	0.07	11,888	$1,545	0.13	12,125	$1,576
House 194	0.10	12,022	$1,563	0.02	11,747	$1,527	0.06	11,873	$1,543

Table 16 Estimated Annual Energy Cost Savings Compared the Pre-retrofit Base case and Opportunity Cost of NOT Repairing the Return Plenum

	Scenario 2 Post-retrofit Savings (Actual Return Repair)		Scenario 3 – Hypothetical Post-retrofit Savings (Return NOT Repaired)		
	Estimated Annual Energy Cost Savings	% Estimated Annual Energy Cost Savings	Estimated Annual Energy Cost Savings Reduced to	% Estimated Annual Energy Cost Savings Reduced to	Savings Reduction
House 223	$43	2.7%	$ 2	2.6%	$41
House 261	$97	6.0%	$29	4.2%	$69
House 1962	$93	5.7%	$62	1.9%	$31
House 194	$36	2.3%	$19	1.0%	$16

Because these simulations were conducted with the same base case house characteristics except for the duct leakage values. The variations in estimated annual energy use and cost (Table 15) and savings (Table 16) result wholly from differences in duct leakage before and after the equipment change out.

7 Cost analysis

To no avail, researchers offered an incentive to the HVAC contractors of $250 per house to provide cost data. In all the test homes, the HVAC contractors converted the existing return plenums into platform returns lined with duct board, air barrier side facing the return air stream, sealed with mastic. The contractors material costs and an estimate of labor involved in return plenum detailing (Table 17).

Table 17 HVAC Contractor Input on cost of Repairing Return Plenums in Test House

<table>
<tr><th></th><th colspan="2">Qn,out Return Only</th><th rowspan="2">Pre-retrofit Return Plenum Style*</th><th colspan="2">HVAC Contractor Input</th></tr>
<tr><th></th><th>Pre-retrofit</th><th>Post-retrofit</th><th>Contractor Comments and Reported Cost</th><th>Contractor Reported Labor or Added Labor</th></tr>
<tr><td>House 223</td><td>0.10</td><td>0.01</td><td>Open frame platform return, finished closet above</td><td>Extra wood (no cost provided, estimate $30 plywood and 2X4)
$30 duct board
$15 tape mastic
Total = ~$75</td><td>“Not typical jobs”.
Typically only needs lining and sealing, not rebuilding and takes 1 to 2 hrs.
Extra 4 hours labor.</td></tr>
<tr><td>House 261</td><td>0.15</td><td>0.01</td><td>Open frame platform return, finished closet above, return connected to plumping chase</td><td rowspan="2">Each house:
$30 tape
$40 duct board
$35 mastic
$20 plywood
2X4 $6 ea.
Total = ~$130</td><td rowspan="2">“Both houses extremely messed up”. Lots of duct repair.
4-5 hours labor.</td></tr>
<tr><td>House 1962</td><td>0.09</td><td>0.03</td><td>Finished closet with frame air handler stand</td></tr>
<tr><td>House 194</td><td>0.04</td><td>--**</td><td>Open frame platform return, finished closet above</td><td>Same as typical job.
~$80 materials for lumber and duct materials
Total = ~$80</td><td>“Fairly simple” job. Typical 2 men, 2 hrs. each
No extra labor</td></tr>
</table>

*At post-retrofit, all houses had been retrofitted with a platform return plenum lined with duct board, air barrier side facing the return air stream, sealed with mastic.

*Leakage below measurement threshold of approximately 12 cfm. Leakage to outside was essentially eliminated.

Although contractors provided estimates of material costs and labor hours associated with return plenum repair but not labor *cost*. The material cost to capture the return plenum savings is shown in Table 18.

Table 18. Materials Only Simple Payback

	Materials Only Cost	Captured Savings	Simple Payback
House 223	$75	$41	$1.8
House 261	$130	$69	$1.9
House 1962	$130	$31	$4.2
House 194	$80	$16	$4.9

Missing this important data rules out cash flow or payback analysis. In lieu of that, we have used the estimated annual savings reduction from Table 16 to estimate cumulative savings over the life of the equipment, shown in Table 19. The life expectancy of central forced air mechanical equipment in Florida is debatable. The International Association of Certified Home Inspectors estimates 7-15 years (InterNACHI 2014). The National Association of Home Builders estimates 10 – 16 years (NAHB 2007). The non-profit Consortium for Energy Efficiency with the Air-conditioning, Heating and Refrigeration Institute estimates 12-15 years (CEE and AHRI). Considering this range, cumulative savings from capitalizing on the opportunity to seal the return plenum at equipment replaces (savings reduction, Table 16) ranges from about $100 ($16 annually for 7 years) to about $1,000 ($69 annually for 16 years) as shown in Table 19 below.

Table 19. Cumulative Captured Savings

	Captured Annual Energy Cost Savings	Life Expectancy	
		7 years	16 years
House 223	$41	$288	$658
House 261	$69	$480	$1,096
House 1962	$31	$216	$493
House 194	$16	$115	$262

Energy cost savings, even considered over the life of the equipment are not large, however, other less tangible benefits contributed to extended equipment life, whole house pressure balance and moisture control, and enhanced indoor air quality and comfort. All of these benefits combined contributed to the development of code language in Florida that requires return plenums in new construction to be sealed.

8 Conclusions

Section 101.4.7.1.1, *Duct sealing upon equipment replacement (Mandatory)*, of the 2012 Supplement to the Florida Building Code, Energy Conservation went into effect briefly in 2013.

The new section required sealing of accessible ducts at the time of HVAC equipment replacement, but Exception 1 exempts ducts in conditioned space. This investigation concerns whether or not building cavities used for return air plenums in interior air handler closets are functionally in conditioned space. Further, researchers conducted a limited simulation analysis to the achieved duct sealing in four test houses on estimated annual energy cost.

Researchers worked with three affordable housing entities renovating foreclosed homes in disrepair that had the characteristic of interest: an interior air handler closet with a building cavity return plenum. The pre-retrofit duct leakage characteristics fell within the expected range based on past field studies. Researchers posed three questions:

Research Question 1: Was there leakage to the outside in these return plenums located in interior air handler closets?

Yes. The return side of the air distribution system in each test house was isolated from the rest of the system and tested per standardized industry procedures. Qn,out results ranged from 0.04 to 0.15 which means that air is flowing into the return plenums (under test and normal operating conditions) from adjacent unconditioned spaces even though it is located in an air handler closet inside the conditioned space. This characteristic is illustrated across the board for these four houses.

Research Question 2: What is the magnitude of return plenum leakage compared to the entire system?

It makes up a significant portion of whole system leakage. Researchers tested the air distribution systems in entirety. The ratio of Return Only leakage to the Entire System ranged from just shy of 50% to 93% for Qn,total and from 36% to 97% for Qn,out.

Research Question 3: Was there improvement in the return plenum air tightness?

Yes, in all homes, return plenum leakage was reduced substantially. For the Return Only tests, Qn,total reduction ranged from 66% to 80%, but more importantly the Qn,out (leakage to outside) reduction range was higher at 71% to essentially 100%. In one house, the return plenum leakage to the outside was essentially eliminated meaning that the return plenum is truly “in conditioned space” with essentially no air exchange with the adjacent wall cavities and attic.

These return-side reductions were made in the context of whole system change-outs that included air handler replacement but not supply duct replacement. Reduction in the Entire System Qn,total ranged from 48% to 78% and for Qn,out ranged from 72% to 89%.

These results are outstanding and reflect commendable work of the HVAC contractors involved. The achieved Entire System Qn,out test results are on par with current new construction in Florida. In fact, three houses achieved post-retrofit Qn,out results satisfy the duct air tightness criteria for high performance housing standards set by the ENERGY STAR for New Homes program (ENERGY STAR 2012).

The reduction in estimated annual energy for the these commendable results ranged from $36 (2.3% of projected whole house energy use) to $97 (6%). Researchers developed a hypothetical scenario representing what the projected savings would have been if the return plenums had not been repair so well. This was achieved by modifying post-retrofit test results to reflect pre-retrofit return plenum conditions. The analysis found the annual savings were reduced to a range of $2 to $62.

The HVAC contractors provided material costs associated with repairing the return plenum which ranged from $75 to $130. Labor hours were also provided but the labor rate was not. This is sensitive information that contractors are not eager to share. The reported material costs are minimal compared to the total cost of typical HVAC replacement. However, adding the labor cost could double the incremental cost. Based strictly on material costs, the simple payback for capturing the return plenum sealing savings ranged from 1.8 to 4.9 years. Intangible benefits related to occupant health and safety, building durability, and comfort are fully explored in other research.

Although field data from previous studies backs up the findings in this small sample, it would be premature to draw any conclusions about feasibility of sealing building cavities used for return air in the general Florida existing housing stock. However, it is clear that the HVAC contractors in this study all had the same approach: build a platform return lined with duct board sealed at the edges and seams (Figure . An approach that is consistent with HVAC requirements and practices in Florida new construction. In essence, these return plenums are “as good as new”.

Figure 33. Air barrier lined return plenums in Test Houses (left to right) 1962, 194, 261, and 223.

References

Beal, D.; McIlvaine, J.; Fonorow, K.; Martin, E. (2011). Measure Guideline: Summary of Interior Ducts in New Construction, Including an Efficient, Affordable Method to Install Fur-Down Interior Ducts. Cocoa, FL: Florida Solar Energy Center. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-385-11.pdf

CEE and AHRI (2014). Directory of Energy Efficient HVAC Equipment. Consortium for Energy Efficiency and Air-conditioning, Heating and Refrigeration Institute. Accessed June 2014: http://www.ceedirectory.org/Content/CentralAirConditionerandHeatPumpEfficiency_2.aspx

Cummings, J.; Withers, C. (1998). "Building Cavities Used as Ducts: Air Leakage Characteristics and Impacts in Light Commercial Buildings." *ASHRAE Transactions*, (104) Part 2; pp. 743-452. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1668-98/index.htm

Cummings, J.; Withers, C.; Gu, L.; McIlvaine, J.; Sonner, J.; Fairey, P.; Lombardi, M. (2002). *Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage*. FSEC-CR-1357-02. Cocoa, FL: Florida Solar Energy Center. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1357-02/index.htm

Cummings, J.: Withers, C.; Martin, E.; Moyer, N. (2012). *Managing the Drivers of Air Flow and Water Vapor Transport in Existing Single-Family Homes*. Cocoa, FL: Florida Solar Energy Center. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-384-12.pdf

ENERGY STAR 2012. ENERGY STAR Qualified Homes, Version 3 (Rev. 07) Inspection Checklists for National Program Requirements. Accessed June 2014: http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/Inspection_Checklists.pdf

Fairey, P. (2009). *Effectiveness of Florida's Residential Energy Code: 1979 – 2009.* (Revision of 1979 - 2007 Report). Cocoa, FL: Florida Solar Energy Center. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1806.pdf

"Florida Building Code 2010: Energy Conservation." (2011). Washington, D.C.: International Code Council. Accessed June 2014: http://ecodes.biz/ecodes_support/free_resources/2010Florida/Energy/10FL_Energy.html

"Florida Building Code 2010: Mechanical." (2011). Washington, D.C.: International Code Council. Accessed June 2014: http://ecodes.biz/ecodes_support/free_resources/2010Florida/Mechanical/10FL_Mechanical.html

"Florida Building Code 2010: Residential." (2011). Washington, D.C.: International Code Council. Accessed June 2014: http://ecodes.biz/ecodes_support/free_resources/2010Florida/Residential/10FL_Residential.html

InterNACHI (2014). *InterNACHI's Estimated Life Expectancy Chart for Florida Homes.* International Association of Certified Home Inspectors. Accessed June 2014: http://www.nachi.org/florida-life-expectancy.htm

McIlvaine, J.; Sutherland, K.; Martin, E. (2013). *Energy Retrofit Field Study and Best Practices in Hot-Humid Climate*. Cocoa, FL: Florida Solar Energy Center. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-RR-404-13.pdf

NAHB. (2007). *Study of Life Expectancy OF Home Components.* National Association of Home Builders. Accessed June 2014:

http://www.nahb.org/fileUpload_details.aspx?contentID=99359

ASHRAE. (2004). *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems.* ASHRAE Standard 152P-2004. American Society of Heating, Refrigerating, and Air Conditioning Engineers.

RESNET. (2013). *Mortgage Industry National Home Energy Rating Systems Standards*. Oceanside, CA: Residential Energy Services Network. Accessed June 2014: http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

Parker, D.; Dunlop, J.; Sherwin, J.; Barkaszi, Jr., S.; Anello, M.; Durand, S.; Metzger, D.; Sonne, J. (1998). *Field Evaluation of Efficient Building Technology with Photovoltaic Power Production in New Florida Residential Housing*. FSEC-CR-1044-98. Cocoa, FL: Florida Solar Energy Center. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/html/FSEC-CR-1044-98/index.htm

Swami, M.; Cummings, J.; Sen Sharma; R.; Withers, C.; Basarkar, M. (2006). *Florida Building Code - Enhance Florida's Building to Next-Generation Energy & Mechanical Codes and Energy Compliance*. FSEC-CR-1678-06. Cocoa, FL: Florida Solar Energy Center. Accessed June 2014: http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1678-06.pdf

Appendix A Relevant Sections of the Florida Building Code

2012 SUPPLEMENT TO THE FLORIDA BUILDING CODE, ENERGY CONSERVATION (Florida Building Code 2010: Energy Conservation 2011)

Chapter 1 – Administration, 101.4.7.1 Replacement HVAC equipment

101.4.7.1.1 "Duct sealing upon equipment replacement (Mandatory).

At the time of the total replacement of HVAC evaporators and condensing units for residential buildings, all accessible (a minimum of 30 inches clearance) joints and seams in the air distribution system shall be inspected and sealed where needed using reinforced mastic or code approved equivalent and shall include a signed certification by the contractor that is attached to the air handler unit stipulating that this work has been accomplished."

"Exceptions:
1. "Ducts in conditioned space.
2. Joints or seams that are already sealed with fabric and mastic.
3. If system is tested and repaired as necessary."

2010 Florida Building Code, Residential (Florida Building Code 2010: Residential 2011)

Chapter 16, TABLE M1601.4, DUCT SYSTEM CONSTRUCTION AND SEALING, Excerpt:

Duct Type/Connection	Sealing Requirements
Return Plenums.	Building cavities which will be used as return air plenums shall meet section M1601.4.1.8 and shall be lined with a continuous air barrier made of durable nonporous materials. All penetrations to the air barrier shall be sealed with a suitable long-life mastic material. **Exception:** surfaces between the plenum and conditioned spaces from which the return/mixed air is drawn. Roof decks above building cavities used as a return air plenum shall be insulated to at least R-19.
Mechanical Closets.	All joints between the air barriers of walls, ceiling, floor and door framing and all penetrations of the air barrier shall be sealed to the air barrier with approved closure systems. Through-wall, through-floor and through-ceiling air passageways into the closet shall be framed and sealed to form an air-tight passageway. **Exception:** air passageways into the closet from conditioned space that are specifically designed for return air flow. The following air barriers are approved for use in mechanical closets: 1. One-half-inch-thick (12.7 mm) or greater gypsum wallboard, sealed with joint compound over taped joints between gypsum wallboard panels. 2. Other panelized materials having inward facing surfaces with an air porosity no greater than that of a duct product meeting section 22 of ul 181 which are sealed on all interior surfaces to create a continuous air barrier by one of the following: a. Sealants complying with the product and application standards of this table for fibrous glass ductboard or b. A suitable long-life caulk or mastic for all applications.