Performance and Impact from Duct Repair and Ventilation Modifications of Two Newly Constructed Manufactured Houses Located in a Hot and Humid Climate

Charles Withers, Jr.
Sr. Research Analyst

Neil Moyer
Principal Research Engineer

Dave Chasar
Research Engineer

Subrato Chandra
Program Manager

Florida Solar Energy Center
Cocoa, Florida 32922

ABSTRACT

Two nearly identical houses situated next to each other in Bossier City, Louisiana were studied in an effort to better understand moisture and cooling energy related problems in manufactured houses with low thermostat set-points during the cooling season. By design, the major difference between houses was the type of air conditioning units. House A had a standard split air conditioner and House B had a two-speed split air conditioner.

In an effort to make the buildings more similar, the building airtightness was adjusted until it was the same in each house, and duct leaks were sealed so that the ducts were tight and there was equal tightness in both houses. A ventilation system was also added at the same time of duct repair. Duct repair and the ventilation modifications resulted in significant impacts on the cooling energy, temperature, relative humidity, and building pressures. Cooling energy decreased 37% in House A and 18% in House B, while the floor space dewpoint increased significantly. It is estimated that 35 % savings was due solely to duct repair in House A and 17% in House B. The primary cause of House A savings being twice House B is attributed to House A operating at nearly twice the capacity most of the time and had more duct leakage repaired. This resulted in higher system pressures and therefore greater duct leakage than in House B. Before building modifications, House A used 15.4 kWh per day (32%) more than House B and 3.4 kWh per day (11%) more after modifications.

A method of characterizing interstitial spaces using dewpoint measurement is presented and shows that the belly space became 2.6 times more like outdoor conditions after repairs in House A and 2.0 times more in House B.

BACKGROUND

Moisture damage has been observed in a significant number of new manufactured houses located in the hot and humid southeast (Moyer et. al. 2001). FSEC has been involved in investigations of moisture damage in over 25 manufactured homes built by various companies from 1999 to 2000. Some floors were found to be buckling under vinyl sections of finished floors. Other problems encountered were soft wallboards, damaged wood molding and mold growth.

Objectives

The purpose of monitoring was to examine how different cooling equipment and building modifications would impact energy usage, temperatures and relative humidity in various zones or cavities. This paper will discuss a seasonal monitoring effort that was designed to study temperature, humidity and energy used in a typical manufactured house model with a very low thermostat set-point.

House Characteristics

Each manufactured house was unoccupied, had no skirt around its bottom and was located on an asphalt lot. The general floor plan was 1311 square feet (122 m^2) of living area with three bedrooms, 2 baths and utility room. Exterior finishing was vinyl siding and interior floors had carpet with vinyl floor in kitchen and utility areas. Both houses were identical with the following exceptions. House B had a living space that was 6 inches (15.2 cm) higher than House A. House B also had a two-speed split DX cooling system where House A had a standard issue single speed split DX cooling system. Both houses had electric strip heat. Air handlers were located in the utility room closet space and supply ducts were located in the belly space with floor mounted air registers. A belly space is a volume directly under the floor that is separated from the crawlspace by a vapor barrier, however, penetrations such as plumbing, and rips often compromise the barrier's effectiveness. Since there were no occupants, ventilation was controlled using exhaust fans on timers. This was done to simulate typical occupancy induced ventilation. The refrigerant charge of both cooling systems was checked before monitoring began.

Monitoring Description

Each house was instrumented with a datalogger and several sensors and meters August 10-12, 2000. About 42 channels of data were sampled at least every 10 seconds and stored at 15 minute intervals. Experiments were conducted from August 13-October 23, 2000. Duct tightness and ventilation modifications happened during September 6-8, when duct leaks were repaired, and a ducted ventilation system was installed in both houses. This ventilation system brings outdoor air into the return side of the air handler before the cooling coil and distributes it throughout the house whenever the unit is on. The exhaust fan controlled ventilation was decreased at this time. Since there was no return duct, only supply leaks were repaired.

Performance Test Results

Building and duct airtightness, airflow and pressures were measured at different stages in the monitoring project. Since comparisons were to be made between both houses, it was desired for them to have similar building and duct airtightness. House A envelope was tightened and House B was made less tight such that both houses had a very similar amount of envelope leakage. The resulting tightness was about 9.5 ACH50. This means 9.5 building air volumes would be exchanged in one hour while the building is depressurized to 50 Pascals.

Table 1 shows duct airtightness and air distribution flow measurement results. CFM25out is a measurement of the accumulated hole size in the duct system. It is the amount of airflow in cubic feet per minute that leaks into the duct from outside when it is depressurized 25 Pascals. The system airflow is in cubic feet per minute (cfm).

Table 1. Duct Airtightness and distribution system flow rate before and after repairs.

House	Pre CFM25out	Post CFM25out	Pre airflow	Post airflow
A	167	31	1248	1355
B	114	23	1271	1421

IMPACT OF DUCT REPAIR AND VENTILATION MODIFICATIONS

The goal of duct repair was to seal as much of the leakage as possible and still have a similar amount between the two houses. House A duct leakage was reduced 136 CFM25 (an 81% reduction) and House B duct leakage was reduced by 91 CFM25 (an 80% reduction). Repairing duct leaks had a significant impact on the airflow, cooling energy, and temperature and relative humidity of both houses. The ventilation was modified the same time as duct repair to evaluate a positive system ventilation technique. It would have been better to evaluate this separate from the duct repair for analysis purposes, however, the amount of available summer weather for monitoring was limited at this time so it was decided to do it at the same time.

Air Distribution Flow

The distribution system airflow in House A increased by 107 cfm, and by 150 cfm in House B as indicated in the last two columns of Table 1. The airflow of the added ventilation system was about 20 cfm.

Cooling Energy

There was also a significant impact on cooling energy from duct repair and ventilation modifications. Large reductions in cooling energy were observed. Cooling energy savings were analyzed in the following way. First the daily average indoor and outdoor temperatures were calculated from data stored at 15 minute intervals. Then the difference was calculated by subtracting the daily average indoor temperature from the outdoor temperature. Next the air conditioner fan and compressor energy were totaled for each day. A least squares linear regression analysis was performed using energy versus delta temperature (dT). This established a linear equation that best predicts cooling energy use for a given monitoring period at different dT. In this analysis the strength of the correlation of energy versus dT is described by the coefficient of determination, known as R^2. R^2 is a number that can be from 0 to 1 where 0 indicates no correlation between variables and 1 indicates an excellent correlation.

Figure 1 shows measured data and best-fit lines for House A (R^2 before repair was 0.83 and 0.92 after.) Using a typical summer average outdoor temperature of 83 F (28.3 C) and the indoor monitored temperature of 71 F (21.7C), the dT would be 12 F. Calculating the energy used before and after duct repair with a dT of 12 F results in a pre-repair daily energy use of 47.66 kWh and a post-repair daily energy use of 29.78 kWh. Therefore, duct repair with the ventilation system operating and bath exhaust schedule off results in a daily reduction of 17.88 kWh (37.5% savings).

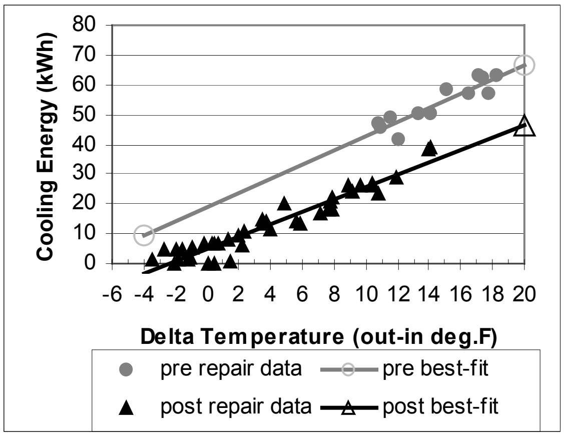

Figure 1 House A Cooling Energy vs. dT.

Following the same calculation procedure as House A with a 12 F dT for House B, results in a pre-repair daily energy use of 32.24 kWh and a post-repair daily energy use of 26.42 kWh. (R^2 before repair was 0.75 and 0.92 after.) Therefore, duct repair with the ventilation system operating results in a daily reduction of 5.82 kWh (18.1% savings).

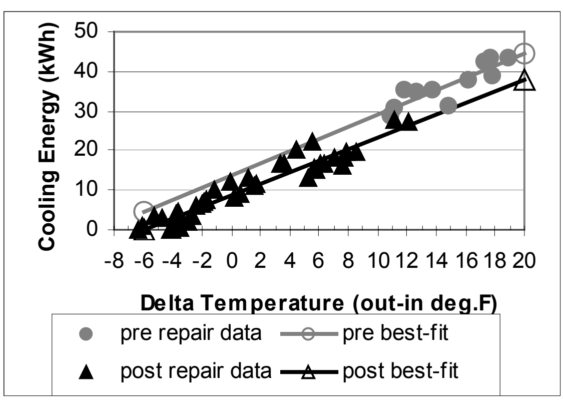

Figure 2 House B Cooling Energy vs. dT.

Duct Pressure, Leak Size, and Location Affect Cooling Energy Losses.

Sealing 136 CFM25 of the leakage in House A resulted in 37% savings and sealing 91 CFM25 of the leakage in House B resulted in 18% savings. It is important, however, to keep in mind that it is not only how much leakage (CFM25) that is repaired that will determine energy savings, but also where the leaks are located. Consider two holes of equal size at different duct locations where the duct pressure is much greater at one location. The hole at the higher pressure location, such as near the air handler, will have a greater amount of duct leakage under operating conditions than a hole near a supply register where the pressure may be ten times lower. Hole location also impacts the severity of energy penalty, which is affected by the energy of the air that is transferred from duct leakage. A return leak from between the floor and belly barrier would have less impact than the same leak that pulled air from a vented attic space.

Cooling Energy Savings Estimate for Duct Repair Only.

Duct repair occurred the same time as modifications to ventilation. A bathroom fan was scheduled using a timing device and operated from 6AM-9AM and also from 4PM-10PM during the monitoring period *prior to* duct repair, however when duct repairs were made, the ventilation system was installed and bathroom exhaust was turned off. This resulted in a change in the indoor ventilation rate, which would have impacted the cooling load. Since the duct repair was not monitored as a separate change, the monitored cooling energy use cannot solely determine the impact from duct repair. However, estimates are made here to suggest what the savings may be in both houses from only duct repair.

The monitored indoor and outdoor temperatures and relative humidity during the experiments were used to determine the average enthalpy using a psychometric chart. The average enthalpy only reflects periods when fans were in operation. Based on airflow of the ventilation and bathroom exhausts and the change in enthalpy, the ventilation cooling load was calculated. The typical run-time of the air distribution system was identified for the seven warmest days during the monitoring and the enthalpy was weighted for time of day when the a/c was on.

After adjustments were made to the impact of ventilation changes, House A saved 16.67 kWh / day (35%) and House B saved 5.47 kWh / day (17.0%) from duct repair.

Energy Comparison Among Houses.

When the two-speed system operates at full capacity, it uses the same amount of power as the standard system, however the two-speed system rarely operated at peak capacity. Based on monitored data, the two-speed system used almost 12% less daily cooling energy on a typical summer day than the standard system. The primary reason is due to less duct leakage when the two-speed system operates at half of total capacity. This results in lower duct pressures than in House A and therefore less total duct leakage.

Moisture Removal Comparison Among Houses.
For days when the outdoor dewpoint was > 60 F (15.6C), the average of several daily condensate totals shows that the two-speed system (House B) removed about 20% more latent heat (condensate) than the standard system. This can be explained by the longer run-time fraction of the two-speed system which ran about 32% more per day during the 7 hottest days of the post duct repair monitoring period. Overall, both systems removed moisture well, which resulted in average indoor conditions shown later in Tables 3 and 4. Indoor relative humidity around 50% is not surprising due to very low thermostat set-points.

Cooling Power

The limited amount of data and cooler temperatures during the post duct repair period made it difficult to find more than one pre and post day that had very similar outdoor conditions. September 7 and 16 were similar days with average outdoor temperature of 80 F (26.7C) (each day), relative humidity of about 50%, and daily solar energy of 5415 Whr pre repair and 5411 Whr post. The days used for comparison do not represent a design day, as there were not any such days available after repair. The comparisons shown in Figures 3 and 4 best reflect the cooling demand during an *average summer day*.

Figures 3 and 4 show the daily profile of measured power usage before and after modifications. Table 2 shows the average cooling demand during the peak utility period from 3PM - 6PM before and after.

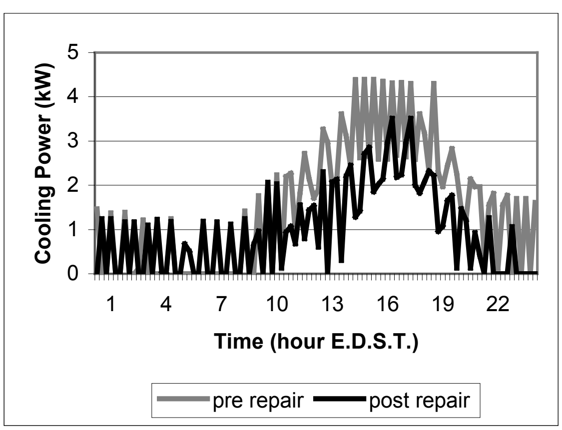

Figure 3 House A Cooling Demand

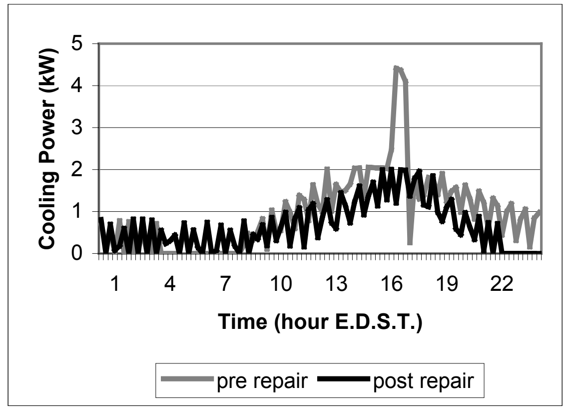

Figure 4 House B Cooling Demand

Table 2. Coincident Peak Demand of Cooling Power from 3pm-6pm

House	Pre kW	Post kW	Delta kW	% Diff.
A	3.464	2.443	1.021	29.5
B	2.332	1.582	0.750	32.2

Impacts on Building Zone Conditions

The most notable impacts that duct repair and the positive ventilation system had on building conditions were on the building pressures and the dewpoint of the belly space. Interior pressures changed from negative to positive with reference to (wrt) outside, and the belly conditions became less dry. There are also indications that the attic space became drier. Three days before repair were compared to three days after repair. Outdoor crawlspace dewpoint and solar insolation were used as criteria for establishing similar days before and after repairs. Changes in building environment are first discussed for House A then House B in the paragraphs that follow. Tables 3 and 4 show three-day period averages of drybulb and dewpoint temperatures and relative humidity at various locations for House A and B respectively.

Zonal Conditions House A

Table 3. Three-day period averages at House A before and after duct repair.

	in db F (C)	in RH %	**in dew F** (C)	attic db F (C)	attic RH%	**attic dew F** (C)	crawl db F (C)	crawl RH%	**crawl dew F** (C)	belly db F (C)	belly RH %	**belly dew F** (C)
Pre	70.8 (21.6)	51.4	**52.1** (11.2)	104.5 (40.3)	39.5	**74.9** (23.8)	83.1 (28.4)	61.8	**68.5** (14.7)	71.3 (21.8)	59.8	**56.6** (13.7)
Post	70.6 (21.4)	51.8	**50.9** (10.5)	89.3 (31.8)	49.4	**67.8** (19.9)	78.9 (26.1)	70.3	**68.4** (14.7)	71.1 (21.7)	75.5	**63.0** (17.2)

House A Interior.

Interior temperature and relative humidity remained nearly constant. Even the inside of exterior wall temperature and relative humidity conditions remained nearly the same after repair. The wall conditions were dry with dewpoints only 2 to 4 F higher than the conditions at the thermostat.

House A Pressure.

The house main body pressure changed by 0.7 pa from -0.4 pa *wrt outside* to +0.34 pa. The main wall pressure sensor malfunctioned during the pre repair period, but the master bedroom wall pressure changed 0.56 pa from +0.46 pa wrt indoor to -0.10 pa.

House A Belly Space.

The belly dewpoint increased by 6.4 F (11.3%). This is likely due to the loss of cool dry air from duct leakage. The impact of duct leakage in the belly space may help explain why some houses have had moisture problems while other identical models have not.

Unconditioned Zone Diagnostic.

Evaluating the nature of interstitial spaces can be difficult and determining the potential for building degradation or other problems can be even more difficult. Pressure measurements taken of interstitial spaces can locate primary air barriers and indicate the potential nature of a space when a calibrated blower door fan is used to depressurize a conditioned space. This test, however, does not characterize the space under real operating conditions and can not evaluate the performance of a vapor barrier. A simple method of determining whether a space is more like indoors than outdoors (during specific conditions) is presented here and can be considered useful to evaluate air, thermal, and vapor barriers in a specific construction through characterizing the space. The usefulness is limited to buildings where there is a reasonable difference between indoor and outdoor dewpoint and the interior has been conditioned (heated or cooled) several hours.

A temperature difference of at least 10 F is preferable, and the greater the out - in difference, the more reliable the characterization can be. Once the dewpoint temperature in the interstitial space and the dewpoint indoors and outdoors is known, the space can be characterized in a relative manner using the equation below, where T is the dewpoint temperature and OA% is the percentage of outside air mixture in the zone.

$$\frac{\text{Zone T} - \text{In T}}{\text{Out T} - \text{In T}} \times 100\% = \text{OA \%}$$

A space with 90% similarity to outdoors can be considered outside the conditioned space, but is influenced by the conditioned space in some way. A space that is 50% is not dominated by either side.

Consider the measurements of House A before repair shown in Table 3. The outdoor - indoor dewpoint difference is 16.4 F, and belly space - indoor difference is 4.5 F.
The similarity to outdoors before duct repair is calculated as shown below:

$$4.5 / 16.4 \times 100\% = 27.4\%$$

Before repair, the belly space dewpoint was about 27 % similar to the outdoor dewpoint, but after repair, it was about 70 % similar to the outside as illustrated in Figure 5. This means that the outdoor similarity increased 2.6 times more like outdoors after repair.

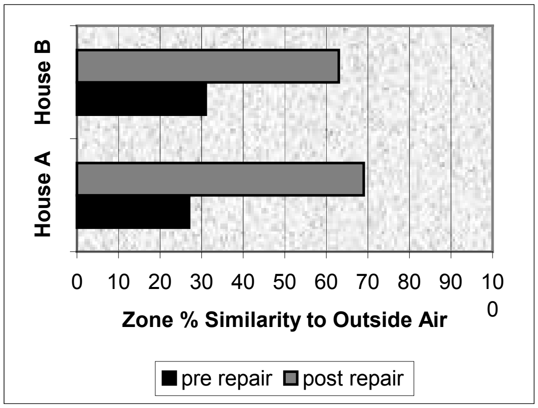

Figure 5 Belly Space Characterizations Before and After Repairs

It became more like the outdoor conditions even though the indoor pressure was positive wrt outside. Positive pressure would cause indoor air to be pushed into the belly space wherever pathways exist. Based on the belly conditions, the interior floor is more airtight than the belly barrier. Since the temperature and relative humidity were only measured in one place in the belly, these results represent the measurement location and not necessarily the entire belly space. It likely represents much of the interior portions of the belly, but the edge areas may be different. The measurement location was below the kitchen about 3/4 the way toward the center of the house from the edge.

House A Attic Space.

The attic dewpoint dropped by 7.1 F. It is not certain what has caused this since the outdoor dewpoint is the same during both periods; however, one likely explanation is that positive pressure in the house after repair is pushing cooler, drier air into the attic through penetrations such as the centerline where the two building halves are joined together. The vented attic is clearly like the outdoors with no influence from indoors before repair, and is about 97 % similar to outdoors (3% influence from indoors) after repair. This would be particularly true for a house that operated under negative pressure much of the time (from supply dominate duct leaks). The attic dewpoint is slightly lower than outdoors after repair likely due to the pressurization of the house as previously mentioned due to tight ducts and added ventilation system.

House B Interior.

Most of the dewpoint and pressure results in House B after repairs were similar to House A . House B interior temperature and relative humidity remained nearly constant. Interior wall temperature and relative humidity conditions remained nearly the same after repair; however, the main wall dewpoint was 4 to 5 F higher than the indoor dewpoint and the master bedroom wall dewpoint was about 10 F higher than the indoor dewpoint.

House B Pressure.

The house main body pressure changed by 0.71 pa from -0.47 pa wrt outside to 0.24 pa. The main wall pressure changed 0.61 pa from 0.31 wrt indoor to -0.30 pa while the master bedroom wall pressure changed 0.78 pa from 0.50 pa wrt indoor to - 0.28 pa.

House B Belly Space.

The belly dewpoint increased by 7.4 F (13.2%). This result is similar to House A, and is also likely attributed to the cool dry air from duct leakage. Using the space characterization based on dewpoint discussed for House A, the belly was 31% similar to outdoors before repair and 63% similar to outdoors after repairs were made as illustrated in Figure 5. The belly space outdoor similarity increased 2.0 times more than pre repair values indicating domination by outdoors conditions.

Zonal Conditions House B

Table 4. Three-day period averages at House B before and after duct repair

	in db F (C)	in RH %	**in dew F (C)**	attic db F (C)	attic RH%	**attic dew F (C)**	crawl db F (C)	crawl RH%	**crawl dew F (C)**	belly db F (C)	belly RH %	**belly dew F (C)**
Pre	70.7 (21.5)	47.8	**50.0** (10.0)	107.4 (41.9)	52.8	**86.4** (30.2)	87.3 (30.7)	56.5	**70.0** (21.1)	76.2 (24.6)	49.8	**56.2** (13.4)
Post	71.6 (22.0)	49.6	**51.8** (11.0)	88.2 (31.2)	56.3	**70.6** (21.4)	78.2 (25.7)	77.3	**70.5** (21.4)	73.9 (23.3)	70.4	**63.6** (17.6)

House B Attic Space.

The attic dewpoint dropped by 15.8 F, which is more than double the amount of House A. The attic humidity appears high (Table 3) and this sensor may have been experiencing problems. The vented attic is clearly like the outdoors with no influence from indoors before and after repair. However, the dewpoint went from being 16.4 F above the outdoor dewpoint before repair to only 0.1 F greater than the outdoor after repair. House B post-repair attic dewpoint may not show any influence from indoor conditions because there are fewer leak pathways.

Energy Simulation of Manufactured Homes.

Simulations were run using measured duct leakage (CFM25out single point test) before and after duct repair. Energy Gauge USA software was used to run the simulations.

- Sizing calculations show that the houses only need about 2.5 tons a/c at most, however a 4-ton unit was used in houses for experimental reasons.
- All duct leakage is due to supply and simulated as if in a vented crawlspace.
- Most of the leakage is at AH connection and crossovers, which will result in supply air lost to outside the conditioned space.

Table 5: Simulation results using thermostat cooling set point at 70°F and actual size a/c*

	annual kWh		Annual	EG calc.
	heating	cooling	% saved	air loss %
A pre	4364	5115	---	11.6
A post	2364	4372	15	2.2
B pre	3377	2767	---	7.9
B post	2130	2359	15	1.6

*House A size = 4 tons, House B has 2 speed system with total size = 4 tons, but 2 tons used since it operated at 2ton capacity most of the time.

The problem with simulations is that one can input the size of the leak (cfm25), but can not tell it anything about the realities of actual leakage from just a standard CFM25 test. CFM25 does not tell where individual holes are, the normal system pressure across each hole, or size of each hole. If all the leakage is small holes in low pressure parts of the system, the energy use will be much less than if there are a few big holes (equal total size) at high pressure.

The standard CFM25 test and leak estimation procedure of ASHRAE 152P deviates from **true measured leakage** by about 24%. (Cummings and Withers 99) Measured system operational pressure was one of the most significant impacts. Meticulous measurements of pressure at designed leak sites resulted in reasonably accurate results, however single point measurement of duct pressure resulted in poorly predicted operational leakage. Energy Gauge USA calculates system air loss using measured CFM25 and assumes an operational pressure based on the capacity of the conditioning system. This means there is a potential for error in comparing this type of simulation to standard duct test measurements of House A and B.

CONCLUSIONS

Increasing the airtightness of the air distribution systems 80% drastically reduced the cooling energy required to cool house A by 16.7 kWh/day (35%), and significantly reduced it in House B by 5.5 kWh/day (17%). The coincident peak cooling power also decreased by 1.02 kW (30%) for House A and 0.75 kW (32%) for House B. The oversized capacity and very low thermostat set-points enabled the savings to be as high as they are.

The lower air flow rate of the two-speed system at House B caused less operational duct leakage before repairs and resulted in lower cooling energy losses than at House A. Before building modifications, House A used 15.4 kWh per day (32%) more than House B and 3.4 kWh per day (11%) more after modifications.

Modifying the ventilation method involved turning off the bathroom exhaust and installing the ventilation system. This impacted the indoor pressure wrt outside in a beneficial way to both houses. House A average pressure was -0.44 pa before changes and became +0.34 pa afterwards. House B went from -0.47 pa to +0.24 pa.

Although there were significant benefits from duct repair, increasing belly space dewpoints after repair may be indicating greater potential for moisture related problems for manufactured houses with either tight or no ducts in the belly and vinyl floor or other finishes that perform like vapor barriers. In both houses, the belly spaces went from being more like conditioned space to being about 2 times more like outdoor conditions. The duct leakage had the benefit of making the belly drier than outdoor conditions. No moisture related damage to building materials was evident during the monitoring period.

As a result of this and several other investigations, some general recommendations to inhibit moisture damage potential are:

- Maintain thermostat settings above ambient dewpoint or at least above 75 F.
- Fan setting should be at the AUTO position.
- Use vapor permeable finishes, avoiding vinyl wall materials and vinyl floors.
- Crawlspaces should be adequately ventilated and have good site drainage.
- Eliminate long-term negative house pressures from inadequate return pathways, duct leakage, or exhaust fans.
- Properly size cooling equipment to encourage good moisture removal.

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Homes produced with airtight duct systems (around 15% savings in Htg and Cooling Energy)

Palm Harbor Homes	22,000
Southern Energy Homes	8,000
Cavalier Homes	1,000
	===
Subtotal	31,000

Technical measures incorporated in BAIHP homes include some or many of the following features - better insulated envelopes (including Structural Insulated Panels and Insulated Concrete Forms), unvented attics, "cool" roofs, advanced air distribution systems, interior duct systems, fan integrated positive pressure dehumidified air ventilation in hot humid climates, quiet exhaust fan ventilation in cool climates, solar water heaters, heat pump water heaters, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems.

HOMES BY THE FLORIDA HOME ENERGY AND RESOURCES ORGANIZATION (FL.H.E.R.O.)

Over 400 single and multifamily homes have been constructed in the Gainesville, FL area with technical assistance from FL H.E.R.O. These homes were constructed by over a dozen different builders. In this paper data from 310 of these homes is presented. These homes have featured better envelopes and windows, interior and/or duct systems with adequate returns, fan integrated positive pressure dehumidified air ventilation, high efficiency right sized heating/cooling equipment, and gas fired combo space/water heating systems. The innovative outside air (OA) system is described below.

The OA duct is located in the back porch (Figure 1) or in the soffit (Figure 2). The OA is filtered through a 12"x12" filter (which is readily available) located in a grill (Figure 3) which is attached to the OA duct box. The flex OA duct size varies depending on the system size - 4" for up to 2.5 tons, 5" for 3 to 4 ton and 6" for a 5 ton system. The OA duct terminates in the return air plenum after a manually adjustable butterfly damper (Figure 4).

Figure 1 OA Intake Duct in Back Porch

Figure 2 OA Intake Duct in Soffit

Figure 3 Filter Backed Grill Covering the OA Intake

Figure 4 Butterfly Damper for OA control

The damper can be set during commissioning and closed by the homeowner in case the OA quality is poor (e.g. forest fire). This system introduces filtered and conditioned ventilation air only when the cooling or heating system is operational. The ventilation air also positively pressurizes the house. Data on the amount of ventilation air or positive pressurization is not available from a large sample of homes. A few measurements indicate that about 25 to 45 cfm of ventilation air is provided which pressurizes the house in the range of +0.2 to +0.4 pascals.

Measured Home Energy Ratings (HERS) and airtightness on these FL. H.E.R.O. homes is presented next in figures 5 through 8. Data is presented for both single family detached (SF) and multifamily homes (MF). See Table 2 below.

Table 2. Summary statistics on FL.H.E.R.O. Homes
n = sample size

	SF	MF
Median cond area	1,909	970
% constructed with 2x4 frame or frame and block	94%	100%
Avg. Conditioned Area, ft^2	1,993 (n=164)	1,184 (n=146)
Avg. HERS score	87.0 (n=164)	88.0 (n=146)
Avg. ACH50	4.5 (n=164)	5.2 (n=146)
Avg. Qtot (CFM25 as %of floor area)	6.9% (n=25)	5.0% (n=72)
Avg. Qout (CFM25 as %of floor area)	3.0% (n=15)	1.4% (n=4)

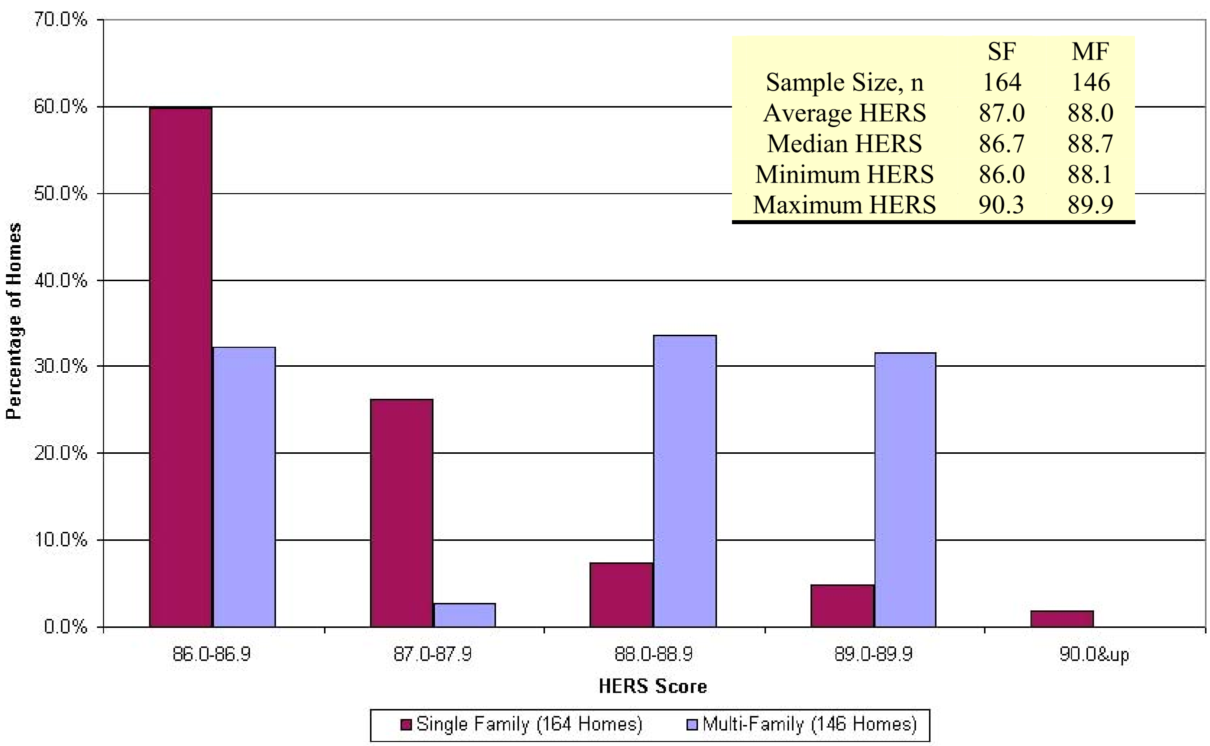

Figure 5 HERS Scores for FL H.E.R.O. Homes

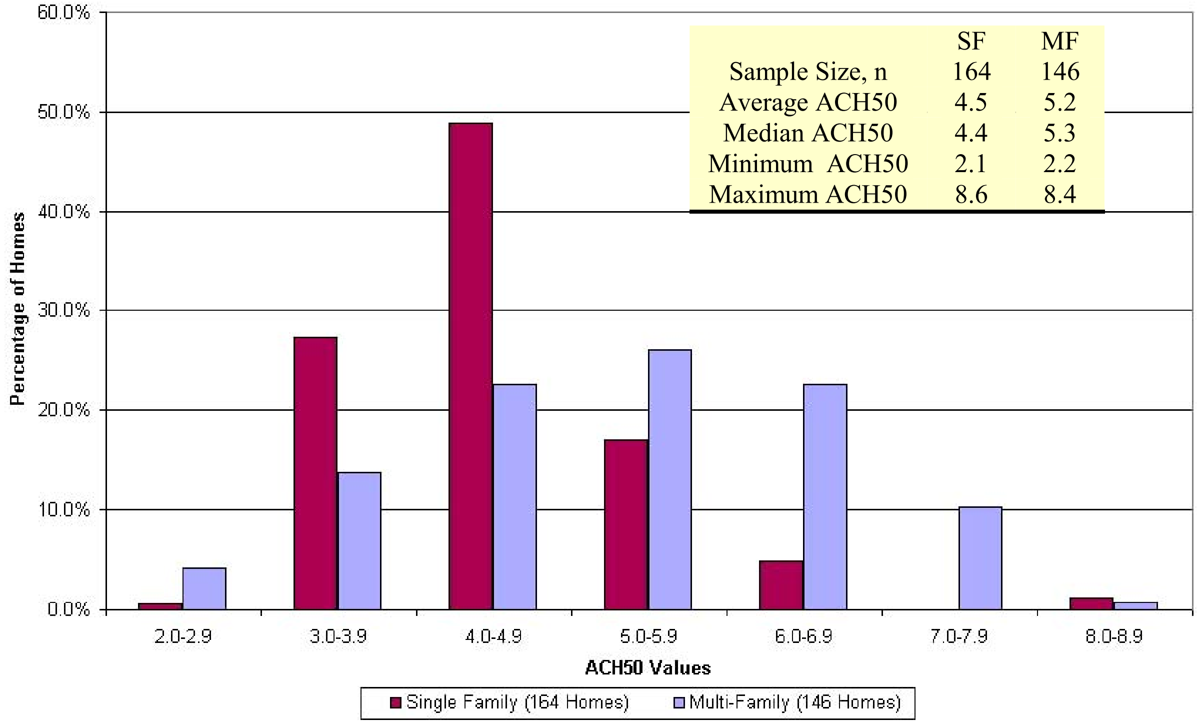

Figure 6 ACH50 Values for FL H.E.R.O. Homes

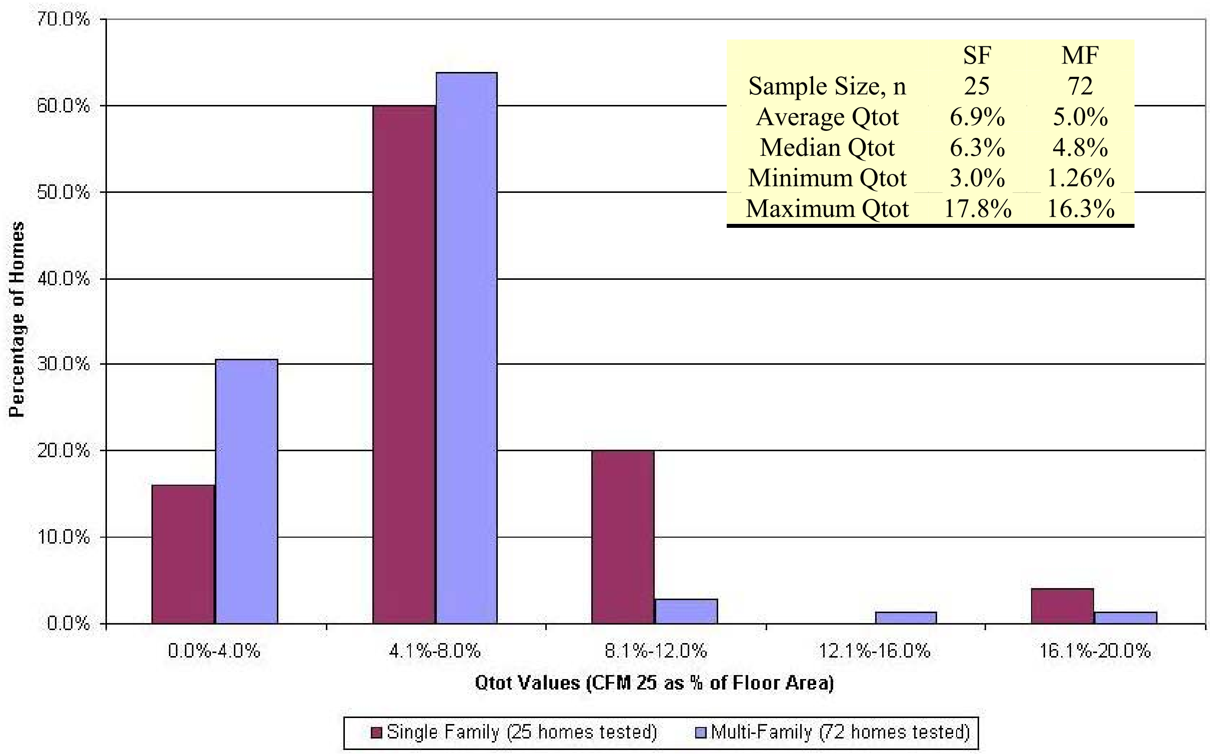

Figure 7 Qtot Values for FL H.E.R.O. Homes

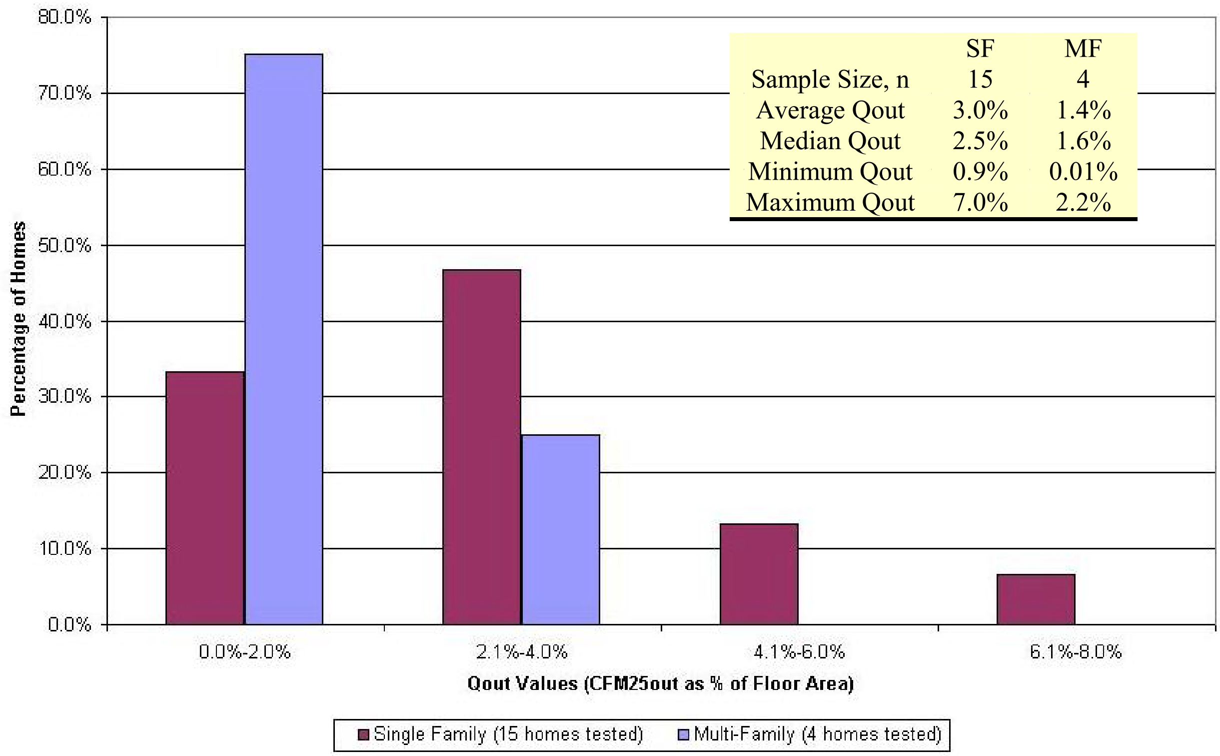

Figure 8 Qout Values for FL H.E.R.O. Homes

Data is available for other typical non BAIHP, new Florida homes (FPL , 1995 and Cummings et al, 2001). The FPL study had a sample size of over 300 single family homes and the median Qout was 7.5% , three times that of the FL. H.E.R.O. homes. In the Cummings study of 11 homes the measured average values were : ACH50= 5.7, Qtot=9.4% and Qout=4.7%. Although the sample sizes are small the FL. H.E.R.O. homes appear to have significantly more airtight duct systems than typical homes.

The remainder of the paper presents status of other tasks of the BAIHP project.

OTHER BAIHP TASKS

Moisture Problems in HUD code homes

The BAIHP team expends considerable effort working to solve moisture problems in existing manufactured homes in the hot, humid Southeast.

Some manufactured homes in Florida and the Gulfcoast have experienced soft walls, buckled floors, mold, water in light fixtures and related problems. According to the Manufactured Housing Research Alliance (MHRA), who we collaborate with, moisture problems are the highest priority research project for the industry.

The BAIHP team has conducted diagnostic tests (blower door, duct blaster, pressure mapping, moisture meter readings) on about 40 such problem homes from five manufacturers in the past two years and shared the results with MHRA. These homes were newly built (generally less than 3 years old) and in some cases just a few months old when the problems appeared. The most frequent causes were:

- Leaky supply ducts and/or inadequate return air pathways resulting in long term negative pressures.
- Inadequate moisture removal from oversized a/c systems and/or clogged condensate drain, and/or continuous running of the air handler fan.
- Presence of vinyl covered wallboard or flooring on which moist air condenses creating mold, buckling, soft walls etc.
- Low cooling thermostat set point (68-75F), below the ambient dew point.
- Tears in the belly board and/or poor site drainage and/or poor crawlspace ventilation creating high rates of moisture diffusion to the floor.

Note that these homes typically experience very high cooling bills as the homeowners try to compensate for the moisture problems by lowering the thermostat setpoints. These findings have been reported in a peer reviewed paper presented at the ASHRAE IAQ 2001. conference (Moyer et al)

The Good News:

As a result of our recommendations and hands-on training, BAIHP partner Palm Harbor Homes (PHH) has transformed duct design and construction practices in all of its 15 factories nationwide producing about 11,000 homes/yr. All Palm Harbor Home duct systems are now constructed with mastic to nearly eliminate air leakage and produced with return air pathways for a total cost of <$10/home!! The PHH factory in AL which had a high number of homes with moisture problems has not had a single problem home the past year!

Field Monitoring

Several houses and portable classrooms are being monitored and the data displayed on the web. (Visit http://www.infomonitors.com/). Of special interest is the side-by-side monitoring of two manufactured homes on the campus of the North Carolina A & T U. where the advanced home is saving about 70% in heating energy and nearly 40% in cooling energy, proving that the Building America goal can be met in manufactured housing. Other monitored sites include the Washington State U. Energy House in Olympia, WA; the Hoak residence in Orlando, FL; two portable classrooms in Marysville, WA; a classroom each in Boise, ID and Portland, OR. See other papers being presented at this symposium for details on two recently completed projects giving results from duct repairs in manufactured homes (Withers et al) and side by side monitoring of insulated concrete form and base case homes (Chasar et al).

“Cool” Roofs and Unvented Attics

Seven side-by-side Habitat homes in Ft. Myers, FL. were tested under unoccupied conditions to examine the effects of alternative roofing strategies. After normalizing the data to account for occupancy and minor differences in thermostat set points and equipment efficiencies, the sealed attic saved 9% and the white roofs saved about 20% cooling energy compared to the base case house with a dark shingle roof for the summer season in South Florida. Visit http://www.fsec.ucf.edu/%7Ebdac/pubs/coolroof/exsum.htm for more information.

Habitat for Humanity

Habitat for Humanity affiliates work in the local community to raise capital and recruit volunteers. The volunteers build affordable housing for and with buyers who can't qualify for conventional loans but do meet certain income guidelines. For some affiliates, reducing utility costs has become part of the affordability definition.

To help affiliates make decisions about what will be cost effective for their climate, BAIHP researchers have developed examples of Energy Star homes for more than a dozen different locations. These are available on the web at http://www.fsec.ucf.edu/bldg/baihp/casestud/hfh_estar/index.htm . The characteristics of the homes were developed in conjunction with Habitat for Humanity International (HFHI), as well as Executive Directors and Construction Managers from many affiliates. Work is continuing with HFHI to respond to affiliates requesting a home energy rating through an Energy and Environmental Practices Survey. 36 affiliates have been contacted and home energy ratings are being arranged using combinations of local raters, Building America staff, and HFHI staff.

HFHI has posted the examples of Energy Star Habitat homes on the internal web site PartnerNet which is available to affiliates nationwide.

“Green” Housing

A point based standard for constructing green homes in Florida has been developed and may be viewed at http://www.floridagreenbuildings.org/. The first community of 270 homes incorporating these principles is now under construction in Gainesville, FL. The first home constructed and certified according to these standards has won an NAHB energy award.

BAIHP researchers are participating as building science - sustainable products advisor to the HUD Hope VI project in Miami, redeveloping an inner city area with over 500 units of new affordable and energy efficient housing.

Healthy Housing

BAIHP researchers are participating in the development of national technical and program standards for healthy housing being developed by the American Lung Association.

A 50-year-old house in Orlando is being remodeled to include energy efficient and healthy features as a demonstration project.

EnergyGauge USA®

This FSEC developed software uses the hourly DOE 2.1E engine with FSEC enhancements and a user-friendly front end to accurately calculate home energy ratings and energy performance. This software is now available. Please visit http://energygauge.com/ for more information.

Industrial Engineering Applications

The UCF Industrial Engineering (UCFIE) team supported the development and ongoing research of the Quality Modular Building Task Force organized by the Hickory consortium, which includes thirteen of the nation's largest modular homebuilders. UCFIE led in research efforts involving factory design, quality systems and set & finish processes. UCFIE used research findings to assist in the analysis and design of two new modular housing factories – Excel homes, Liverpool, PA and Cardinal Homes - Wyliesburg, VA.

CONCLUSIONS

The entire BAIHP team of over 20 researchers and students are involved in a wide variety of activities to enhance the energy efficiency, indoor air quality and durability of new housing and portable classrooms.

In addition to energy efficiency, durability, health, comfort and safety BAIHP builders typically consider resource and water efficiency. For example, in Gainesville, FL BAIHP builders have incorporated the following features in developments:

- Better planned communities
- More attention given to preserving the natural environment
- Use of reclaimed sewage water for landscaping
- Use of native plants that require less water
- Storm water percolating basins to recharge the ground water
- Designated recreational areas
- Better designed and built infrastructure
- Energy efficient direct vented gas fireplaces (not smoke producing wood)

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