Measured Cooling Performance of Two-story Homes in Dallas, Texas; Insulated Concrete Form Versus Frame Construction

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ABSTRACT

Four occupied homes near Dallas, Texas were monitored to compare heating and cooling energy use. Two homes were built with typical wood frame construction, the other two with insulated concrete form (ICF) construction.

Remote data loggers collected average hourly indoor and outdoor temperature, relative humidity, furnace runtime fraction, total building electrical energy and HVAC energy use. The loggers recorded data from November 1999 through August 2000.

Results show that insulated concrete form construction can reduce cooling energy use 17 to 19% in two-story homes in the north Texas climate. Two adjustments to the measured data were made to compensate for differences between the homes: (1) cooling energy use was normalized to remove the impact of miscellaneous energy use that introduces heat into the home (e.g. lights & appliances), and (2) duct leakage differences simulated in a DOE2-based software reduced the measured savings for ICF construction by 4%. Other differences noted between the homes that were not quantified included occupant impacts, exterior wall color (or absorptance) and an attic radiant barrier absent in one of the homes.

INTRODUCTION

Four Centex homes near Dallas, Texas were monitored by the Florida Solar Energy Center as part of the Building America Industrialized Housing Partnership (BAIHP). Centex Homes and the Portland Cement Association are two BAIHP partners that were involved with the study. Two home models (Figures 1 and 2) were constructed twice, one with typical wood frame construction and the other using insulated concrete forms (ICF). The floor plan and building features of each pair of homes were otherwise nearly identical including building orientation.

Figure 1 – Home Model E2051

Figure 2 – Home Model E50

BUILDING DESCRIPTIONS

At the beginning of the project, each home was tested to determine its building airtightness and the amount of any duct leakage. Test results are listed in Table 1 along with other relevant building details. Figure 3 illustrates the wall construction for each home type.

Table 1 – Building Construction & Airtightness Details

Construction	ICF	Frame	ICF	Frame
Model	E2051	E2051	E50	E50
Floor Area (ft^2)	3,767	3,767	2,861	2,861
Heat Pumps 1st/2nd fl.	5 ton /4 ton	5 ton / 4 ton	4 ton / 2.5 ton	4 ton / 2.5 ton
Glass/Floor Area	18%	18%	13.5%	13.5%
Attic Radiant Barrier	No	Yes	Yes	Yes
Exterior Brick Color	Red w/Black Tint	Red	Red w/Pink Tint	Red
CFM50	2,701	3,105	2,632	2,426
ACH50	4.3	5.0	5.6	5.1
$CFM25_{total}$	620	742	602	674
$CFM25_{out}$	268	407	296	385
Occupancy	6	4?	4	4

Notes:
- All homes are 2-story with the front facing north
- All windows are double pane, clear glass, aluminum frame, U=0.81.
- All attics have R-30 blown insulation.
- SEER 12 Heat pumps were designed to run until the outside temperature reached 47ºF after which natural gas backup heat came on. (no electric strip heat)

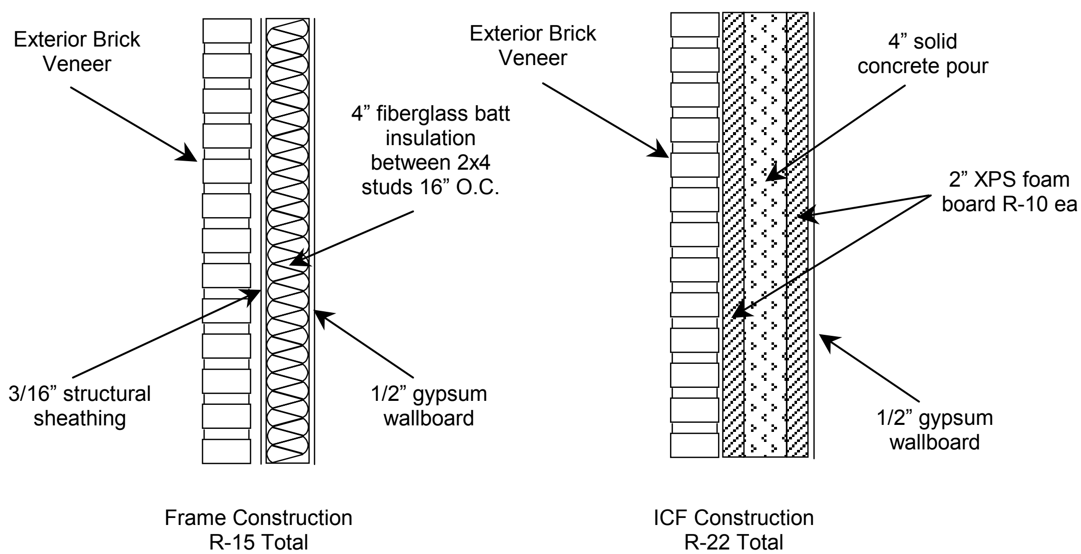

Figure 3 – Frame and ICF Wall Construction Details

DATA COLLECTION

Remote dataloggers were used to collect average hourly readings of indoor and outdoor temperature, relative humidity, furnace runtime fraction, total building electrical energy and HVAC energy use. The loggers recorded data from November 1999 through August 2000.

ANALYSIS

According to conventional wisdom and manufacturer’s claims, the ICF homes should benefit from a higher and more consistent level of thermal insulation as well as greater airtightness wherever insulated concrete forms replace wood framing. The envelope airtightness measurements in Table 1 (CFM50 and ACH50) however, show that in one case the ICF home was tighter than the frame home while in the other the trend was reversed. This may be attributed to the fact that on the ICF homes, only the exterior walls were composed of ICF construction, while the slab-on-grade foundation and wood-framed roof designs were similar. Construction details at the attic and at the junction of the first and second floors are critical to the airtightness of these homes, as is the amount of duct leakage. Leakage at the ceiling plane was the likely cause of reduced envelope airtightness in the E50 ICF home over its frame counterpart.

HVAC energy use was analyzed to illustrate the differences between the two construction types. To provide the most straightforward comparison of the homes, only cooling energy use was isolated since the air conditioners used strictly electrical energy. In contrast, home heating was provided by a combination of electric heat pump and gas furnace with a control strategy that was not always consistent between the homes.

Cooling Energy

To assess the cooling energy difference between the frame and ICF homes the average daily indoor to outdoor temperature difference (delta T) was plotted against the total daily cooling energy use. All hours between Jan 1 and Aug 23 (the last full day of data) were used in this analysis but only the hours where the ambient temperature was above 65ºF are included. This isolated the hours when cooling was taking place regardless of the time of year and excluded heating energy use. In some cases only a few cooling hours from a given day were included, while in others all 24 hours were used. Average daily indoor temperature (IDT) was derived from the same hours when ambient temperature was above 65ºF

Normalized Data

In comparing both sets of homes it was found that the ICF buildings consistently used less miscellaneous energy (lights, appliances, etc.) than the frame structures. The reason for this was not pursued but, assuming much of this energy would be added to the home in the form of heat that the air conditioner must then remove, the energy data was normalized to enable a more direct comparison of the two homes. Water heating energy was not a factor here because it was provided by natural gas.

Only the data from the frame house was normalized, leaving the ICF data unchanged. The difference in miscellaneous energy use between the homes was subtracted from the frame house cooling energy data while factoring in the COP of the air conditioning equipment. Figures 4 and 5 show the collected data and linear trend lines.

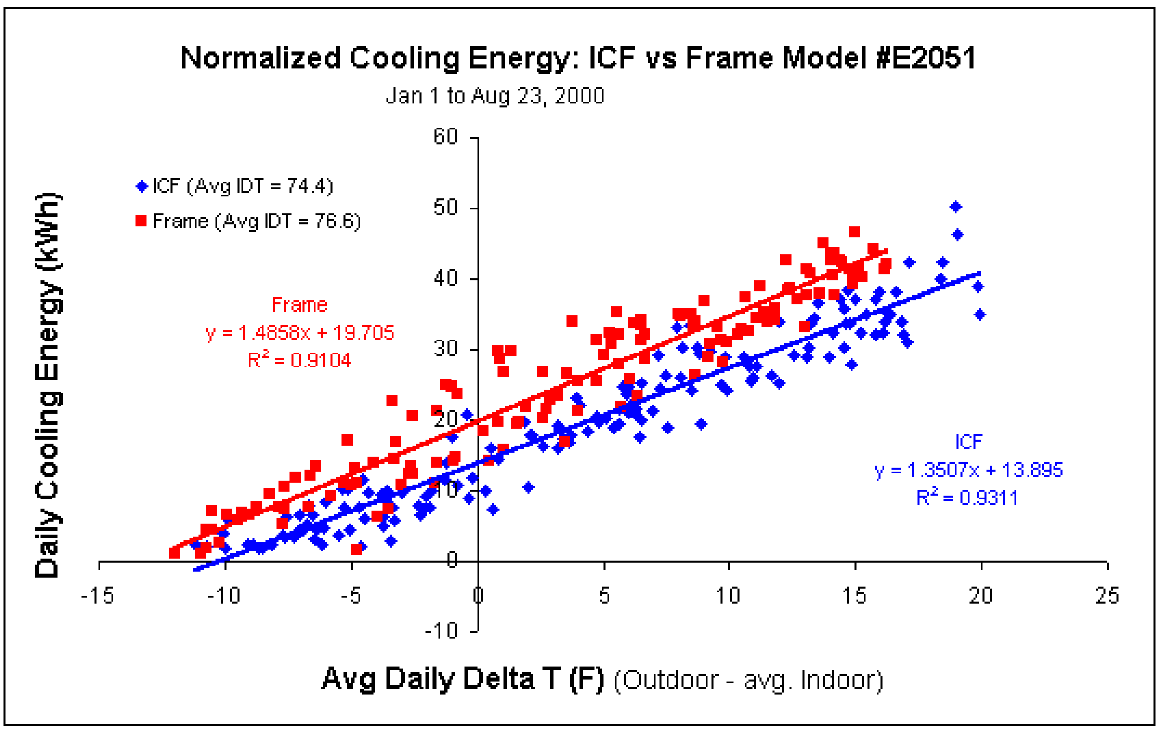

Figure 4 – Normalized Cooling Energy Comparison for Model E2051

Note: Linear fit of measured data when ambient temperature greater than 65ºF

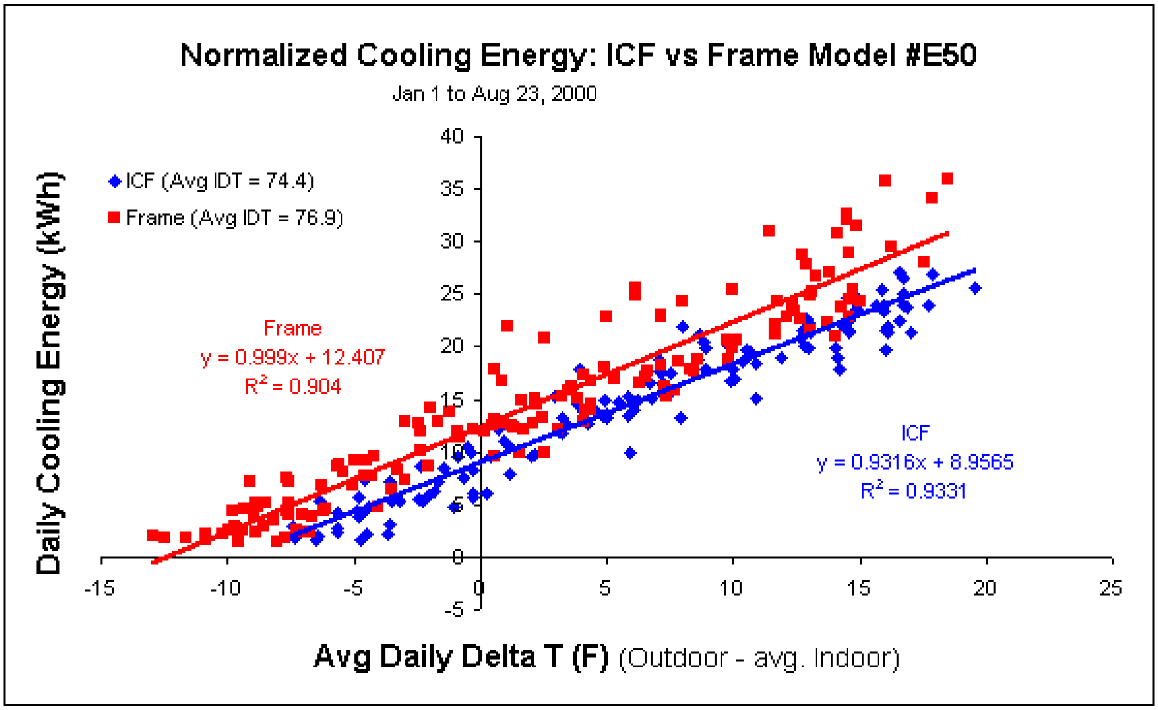

Figure 5 – Normalized Cooling Energy Comparison for Model E50

Note: Linear fit of measured data when ambient temperature greater than 65ºF

Duct Leakage Impact

Analysis of the measured data was complicated by the fact that, while the duct systems in each model were the same, both ICF homes had tighter ducts than their frame counterparts (see CFM25 in Table 1). To estimate this impact, DOE2 simulations were performed.

The computer output was generated using a similar 2-story home design and average TMY weather data for Fort Worth, Texas. Simulations performed with a 76ºF setpoint showed that increasing the duct leakage in proportion to that found in Table 1 (CFM25out), increased cooling energy use by about 4% in each ICF home.

Measured Seasonal Cooling Savings

The measured data shows that, in both models, the ICF home used less cooling energy than the home built with conventional frame construction. Typical savings of ICF construction over frame during the cooling season are shown in Table 2. These values were obtained by using the average set point of the four homes (76ºF) and the average summer ambient temperature (82.3ºF) in the linear fit equations of Figures 4 and 5 and then multiplying by 153, the number of days in the Dallas cooling season (May through September). The final savings values were reduced (4%) to account for duct leakage differences as described earlier.

Table 2: Adjusted Seasonal Cooling Savings – ICF over Frame Construction

E2051			E50		
Energy	Cost	Savings	Energy	Cost	Savings
841 kWh	$67	18.9%	478 kWh	$38	16.7%

Notes:

- Cooling Energy = [slope x ($AvgT_{amb}$ – SetPt) + Y-int] x 153
- Average ambient temperature of 82.3ºF and cooling setpoint of 76ºF used in above calculations.
- Dallas cooling season = 153 days (May through September)
- A utility rate of $0.08/kWh was used to obtain the cost savings

Occupant Impacts

Occupant activity and homeowner habits can have a major impact on residential energy use. Some of these influences are factored-out by describing HVAC energy use in terms of the difference in temperature across the building envelope, which helps account for thermostat settings that are unusually high or low. Some examples of occupant activity that could not be accounted for include:

- The level of interior shade usage
- The amount of outdoor air allowed to enter the home
- Moisture released inside the home by cooking and cleaning activities
- Long-term interior door closure to rooms where insufficient return air pathways exist

Wall Solar Absorptance and Radiant Barriers

Despite efforts to build each pair of homes with identical construction except for the wall assemblies, two over-sites existed – exterior brick color differed between each home pair and an attic radiant barrier was left out of one home.

The solar absorptance level of exterior walls can have a measurable effect on the space cooling load. This effect is even more pronounced in two-story homes where the wall surface area is much greater than with single story construction and where roof overhangs are less beneficial. Brick colors for the four homes are described in Table 1 and the two pictures visually show the difference. In the Model E2051 comparison, the frame home had the lighter (more favorable) brick color, whereas the ICF home had the lighter color in the E50 model comparison.

Three of the homes had roof decking with radiant barrier laminated to the underside to reduce radiant heat transmission to the second floor space. The model E2051 ICF home however did not have this benefit and received a greater cooling load as a result.

CONCLUSIONS

This case study of two nearly matched-pair homes shows that insulated concrete form (ICF) construction can save 17 to 19% over the cooling season with two-story homes in the North Texas climate. Two adjustments to the measured data were made to compensate for differences between the homes: (1) cooling energy use was normalized to remove the impact of miscellaneous energy use that introduces heat into the home (e.g. lights & appliances), and (2) duct leakage differences simulated in a DOE2-based software reduced the savings for ICF construction by 4%. Other differences noted between the homes that were not quantified included occupant impacts, exterior wall color (or absorptance) and the presence of an attic radiant barrier.

Relative cooling savings of ICF versus frame construction would be smaller in single story homes due to smaller wall areas. Two-story construction makes up 33% of US housing, with single story being much more common. Cooling energy savings on single story construction could amount to only half of that found in this study.

Further research is needed to more precisely quantify the energy benefits of insulated concrete form homes. Such research should compare homes that are identical in every aspect except wall construction and ideally should be monitored without occupancy or with simulated occupancy. Results of such carefully controlled experiments and subsequent analysis by validated hourly simulation software can provide a more accurate estimate of the benefits of ICF construction. Any analysis of occupied homes would require monitoring of a statistically valid (large) sample of ICF and conventional residences.

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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)

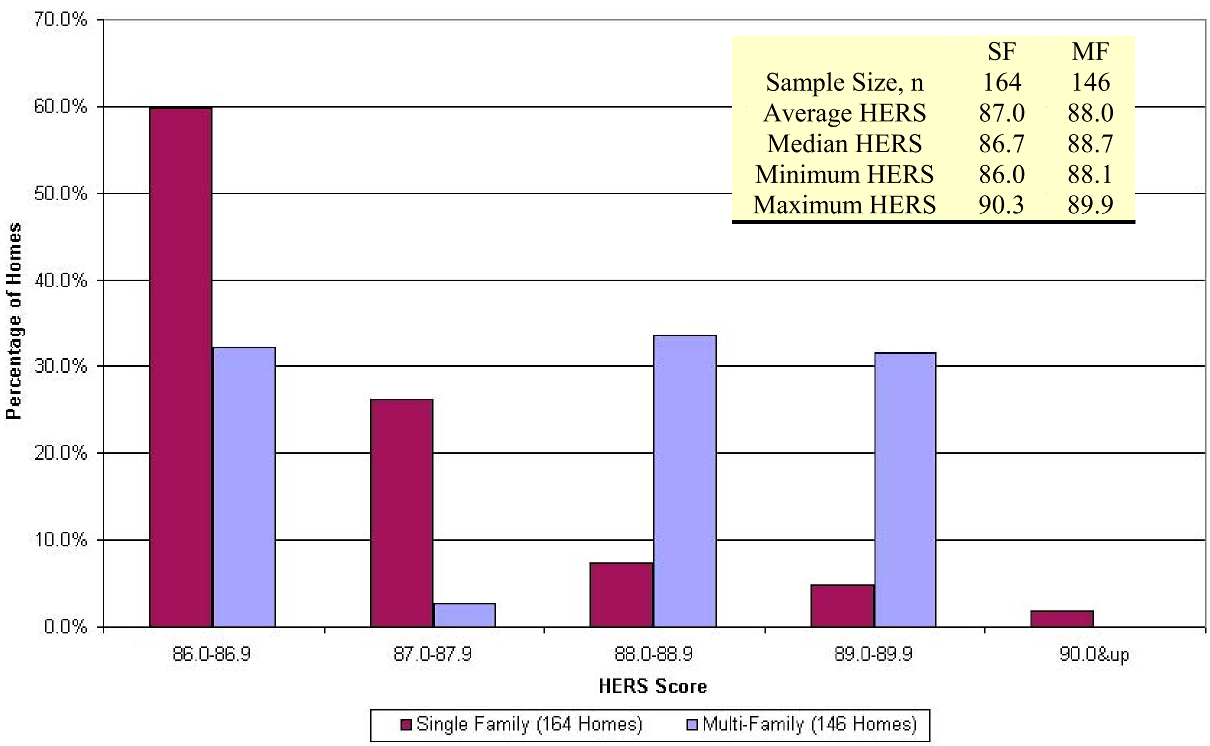

Figure 5 HERS Scores for FL H.E.R.O. Homes

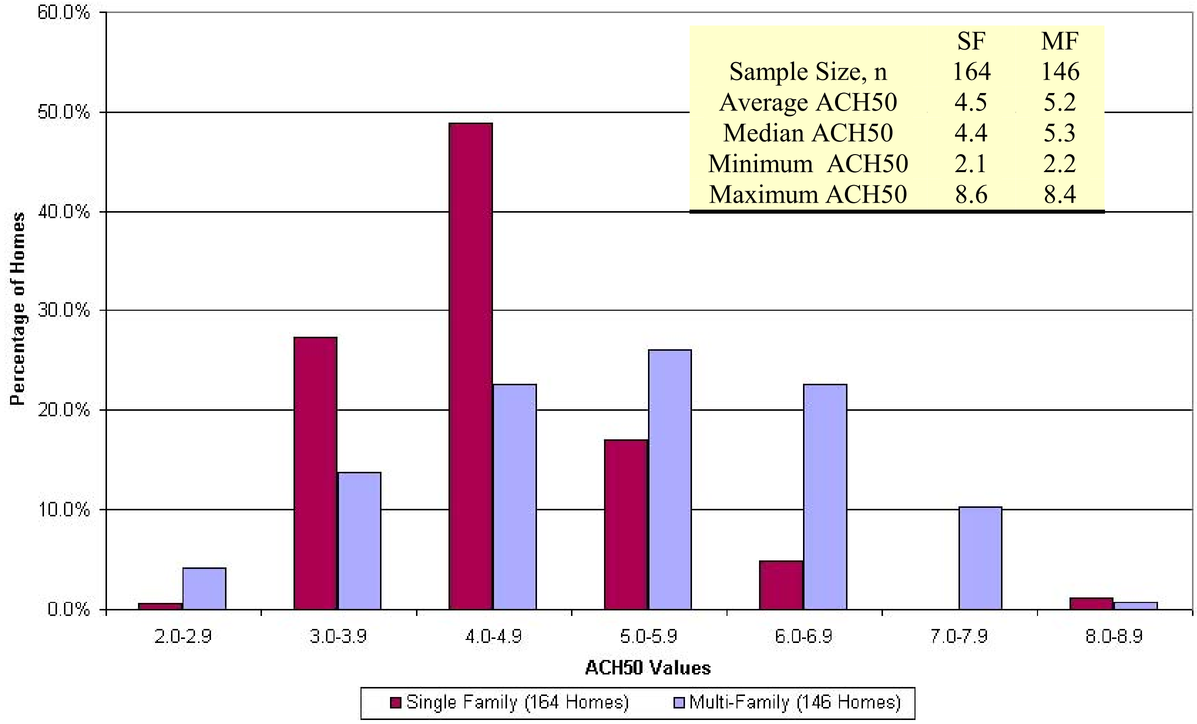

Figure 6 ACH50 Values for FL H.E.R.O. Homes

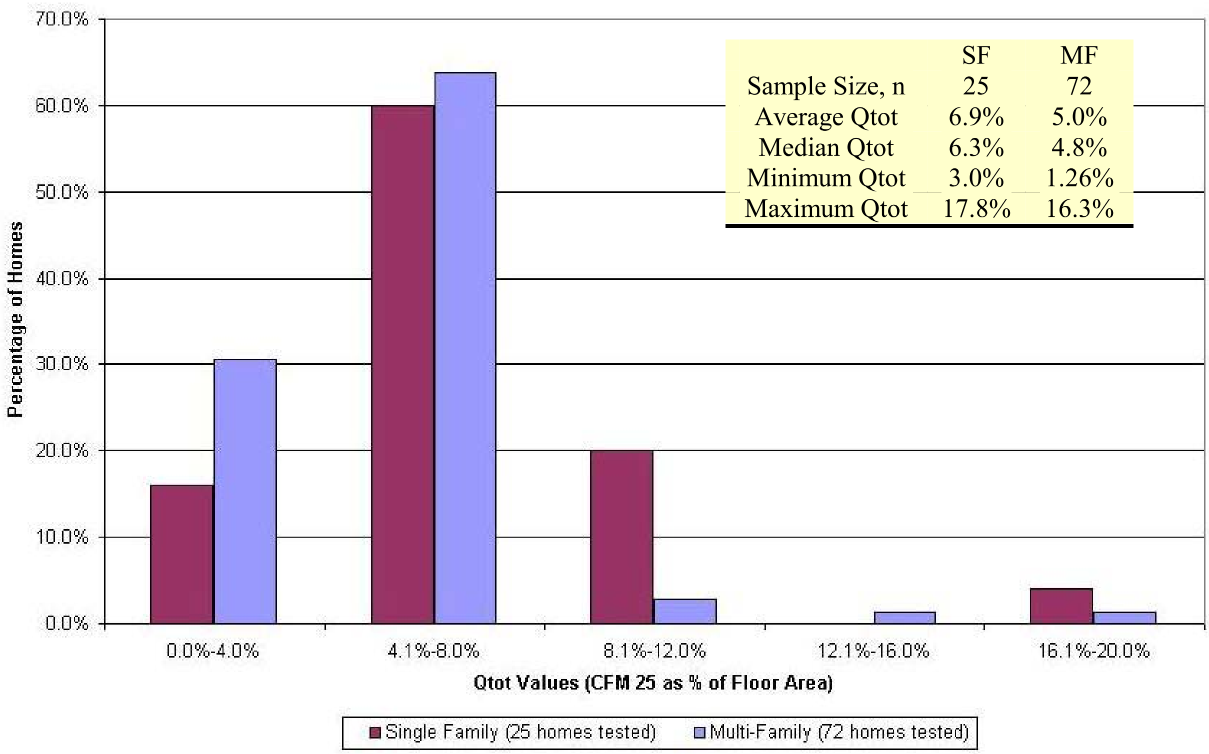

Figure 7 Qtot Values for FL H.E.R.O. Homes

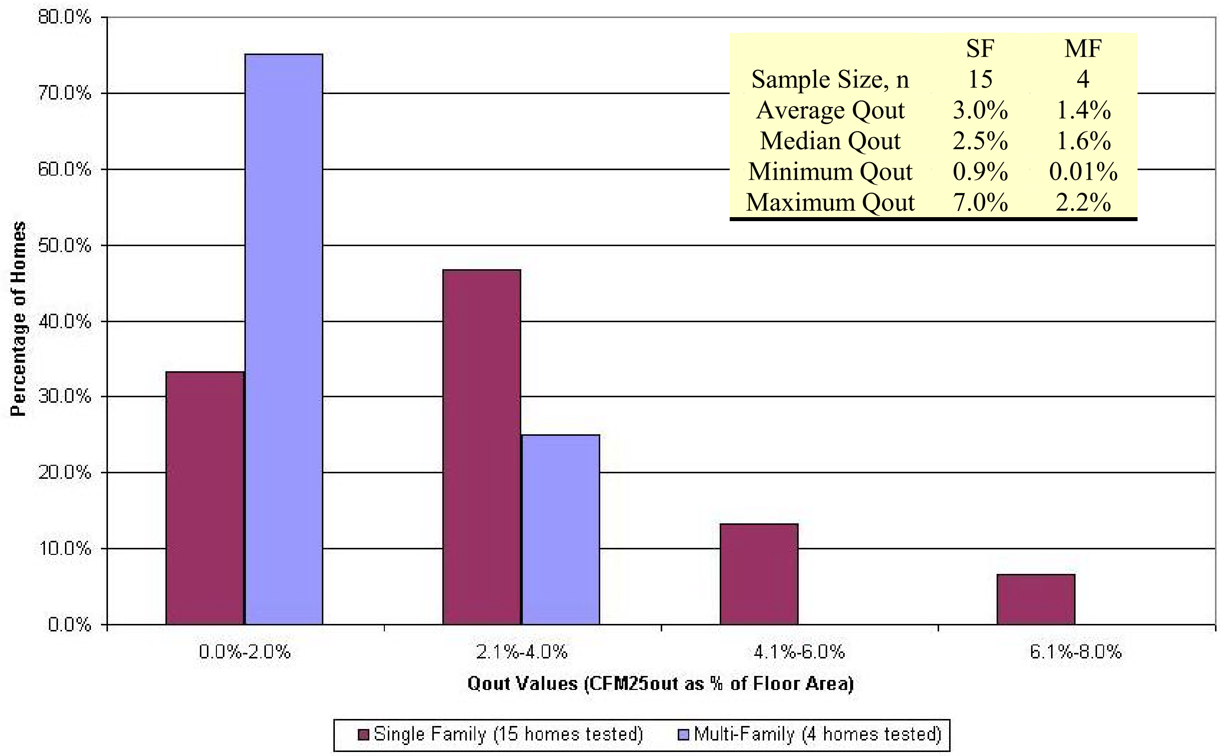

Figure 8 Qout Values for FL H.E.R.O. Homes

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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