Whole House Project Description
Building America Industrialized Housing Partnership (BAIHP)

REVISED PROJECT DESCRIPTION

1. **Project Title: Building America Industrialized Housing Partnership (BAIHP)**

2. **Principal investigator:** Subrato Chandra, Ph.D.
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3. **Other Participating Organizations –**

a) Currently Receiving DOE Funding through BAIHP: Michael Lubliner, Washington State University (WSU) Energy Program; Mike Mullens, Ph.D., UCF Industrial Engineering (UCFIE) ; Ken Fonorow, Florida H.E.R.O. and Dennis Stroer, Calcs-Plus.

b) BAIHP's Active Industry Partners: Atlantic Design and Construction**,** East Dakota Housing Alliance, Fleetwood Homes, G.W. Robinson builders, Habitat for Humanity, Marquis Construction, New Generation Homes, Palm Harbor Homes, Southern Energy Homes, Stitt Energy Systems, The Fechtel Company, Tommy Williams Homes, Valley Manufactured Housing, WCI communities and ~20 others.

4. **Project:**
   1. Schedule
      a: Initiation Date – 9/1/99
      b: Dates of Intermediate Phase Completions or Go/No-Go Points. Project is evaluated and funding is determined annually.
      c: Original/Revised Expected Completion Date – Original 10/31/04, Revised 3/31/06
   2. Funding Status: competitively awarded
   3. Project/technology maturity
      a: Applied research - yes
      b: Product development - yes
      c: Deployment - yes

5. **Statement of Problem:** Improve energy efficiency in industrialized housing while enhancing durability, comfort, productivity, indoor air quality and overall value.

6. **Project Objectives:** Conduct R & D on technologies and strategies to improve energy efficiency by up to 50% and document through analysis and monitoring. Provide technical

assistance to factory and site builders to implement solutions in thousands of homes, with an emphasis on hot-humid and cold climates.

7. Project History & Relationships: This is the sixth year of the BAIHP project and it is slated to be recompeted in 2005. BAIHP is one of five prime BA contractors and the only one which is led by a university based research organization. It is also the only one which is administered by a DOE field office rather than by NREL. Initial administration was by DOE Golden. In 2004, project administration moved to NETL. BAIHP is a cooperative agreement which is reimbursed on a cost basis.

It is to be noted that the BAIHP project started after the other 4 BA teams. BAIHP began during the time where the DOE goal was to assist in the construction of thousands of Energy Star or similar energy efficient homes. Energy savings for these homes range between 15% to 20% on a whole house basis. Around 2002 the DOE goal changed to developing technologies to save 30% or higher levels of energy on a whole house basis and there was a new solicitation which led to the selection of the 4 other current BA teams.

BAIHP has changed its focus to aligning with the new DOE goals through construction of prototypes and subdivisions that save at least 30% on a whole house basis. It has also initiated new research such as Nightcool which should lead to very high performance homes in cooling dominated climates. However, BAIHP also continues its efforts in component level research tasks and assisting industry partners even if they are not building very high performance homes.

8. **Technical Approach:** BAIHP encompasses all housing but focuses on factory built HUD code and modular homes. Work is conducted in three task areas – *Research, Technical Assistance and Other Activities*.

Research includes performance monitoring, ventilation and moisture, cool roofs, Nightcool, condenser fans, fenestration, and manufacturing productivity.

Technical Assistance includes design reviews and energy analysis with the Building America systems engineering approach to meet the BA performance goals and "green" criteria; factory and site inspections, training and testing to assure compliance with goals; and diagnostic testing in the plant and in the field to evaluate moisture, comfort and other call back problems and recommending solutions.

The *Other* activities include serving on ASHRAE, NFPA501 and other national committees, collaborating with other BA teams, assisting in BA benchmark activities, supporting DOE on codes and standards issues, developing and presenting publications, workshops, short courses, expert meetings, regularly updating the project web page and project management activities.

9. Technical Work Plan (including some results):

9.1 *(Research)* Performance Monitoring: (FSEC, WSU, NCATSU, ORNL ,others)

Long term (over a year) monitoring of energy use and environmental conditions has been a key feature of FSEC research since the 1980s. FSEC has a sophisticated system of automated data collection, archiving and web display (www.infomonitors.com) that have been adopted by two other BA teams (IBACOS and CARB). In this task, high performance prototype houses are monitored using 15 to 50 channels of data to monitor indoor and outdoor environmental conditions and energy use of heating, cooling, water heating, whole house, and other points (e.g. Solar PV or Solar DHW system performance) if needed. Examples of monitored projects and savings follow.

Figure 1 *Manufactured homes under test in Greensboro, NC*

During 2000-2002, FSEC worked with partner Palm Harbor Homes (PHH) and North Carolina A&T State U. (NCATSU) to locate and monitor two side-by-side test houses on the NCATSU campus in Greensboro, NC (Figure 1). Monitoring during 2001-2002 showed that compared to the conventional base case house, the BA house saved 70% in heating energy and 33% in cooling and water heating energy for an overall 55% savings in heating,cooling and water heating surpassing the design goal of 50% savings. See http://www.fsec.ucf.edu/bldg/baihp/data/NCATU/index.htm or McGinley et. al. (2004) for more information.

Figure 2 *Zero energy manufactured home under test in Lewsiton, ID*

In 2003, we began monitoring the zero energy manufactured home (ZEMH) and a base case Super Good Cents (SGC) home in Idaho (Figure 2). During the 2003-2004 winter, the ZEMH showed a 45% savings in heating energy over the SGC home which in itself is about 50% better than minimum HUD code. See Lubliner, Hadley and Gordon (2004) or http://www.bpa.gov/Energy/N/tech/zemh/ for more information.

In 2005, we will continue monitoring the ZEMH, an energy efficient Habitat for Humanity home constructed in partnership with ORNL in Lenoir City, TN and the Hoak and Chasar residences in central FL. New FSEC instrumented sites will include the Not So Nig Show House in Orlando, FL and prototype homes built by partners in Ft. Myers, FL; Bartow, FL , Houston, TX (the Federation of American Scientists house) and in one or two other locations. Technologies evaluated in these homes include unvented attics, SIP construction, extensive use of radiant barrier technology , ducts in conditioned space under vented attic, high efficiency HVAC equipment, heat pump water heater, outside air ventilation, efficient lighting, cool roofs and high mass walls.

9.2 *(Research)* Ventilation and Moisture (FSEC ,WSU, LBNL, NIST, others)

9.2.1 *Ventilation experiments in the Manufactured Housing Lab(MHLab)*: A manufactured housing laboratory (MHLab, Figure 3) was procured in 2002 at FSEC and instrumented with automatic simulation of sensible and latent occupancy loads. In 2003 and 2004 six ventilation

Figure 3 *BAIHP Manufactured Housing Lab - MHLab*

strategies with differing amounts of mechanical ventilation were investigated.

Methods:
MHLab Automated Occupancy Simulation

The MHLab simulates a typical family of four using computer control. Automated and computer controlled simulation of A) human moisture production B) human CO2 production C) human sensible heat production D) appliance and processes. These and the automation system are described below.

A. Simulating human moisture production
Simulated human moisture is produced using forced air humidification. This process uses a wick type humidifier and metered flow pump (Figure 4). All of the water that passes through the humidifiers is first run through a tipping bucket connected to a datalogger that records total quantity of water supplied to the units and ultimately to the space. To simulate the quantity of water produced by a family of four, approximately 1.5 gallons of water are pumped into the humidifiers over a 24 hour period. Water vapor was injected into the space using a vaporizer at a rate of approximately 0.4 lbs per hour continuous and an additional 0.4 lbs per hour during the evening hours. This is consistent with documentation of "average" household operation (Christian, 1994). This flow rate is variable over the 24 hour period so that increased moisture levels are seen during times that the home would typically be occupied (5:00pm – 7:00am). To ensure even distribution of moisture throughout the MHLab, condensate is supplied to humidifiers at two different locations – the Kitchen and Master Bedroom.

Figure 4 *Humidifer, pump and visual indicator*

The source of this water comes from air conditioner and dehumidifier condensate. During normal air conditioning and dehumidifier cycles, condensate is produced and stored in a 30 gallon tank. Should supplemental water be needed due to a lack of condensate, such as during heating periods, distilled water is added to the storage tank.

B. Simulating Human CO2 Production
CO2 is stored in a high pressure tank and supplied to a multi-valve metered flow controller (Figure 5). Lines running from the controller terminate in the kitchen and in the master suite for CO2 distribution. The monitored flow rates are varied over the course of the day to reflect occupancy habits of those leaving and returning to the home. A Bruel & Kjaer Multi-gas Monitor Type 1302 is used to monitor the CO2 concentrations in the master suite, the living room and outdoors. Sampling occurs in 10 minute intervals and is logged using the Innova control software. The Bruel & Kjaer 1302 is a highly accurate, reliable and stable quantitative gas analyzer which is

Figure 5 *Carbon dioxide tank and dispenser*

microprocessor controlled. Its measurement principle is based on the photoacoustic infra-red detection method (Figure 6). In effect this means the Bruel & Kjaer 1302 can be used to measure almost any gas which absorbs infrared light. Appropriate optical filters (up to 5) are installed in the 1302's filter carousel so that it can selectively measure the concentration of up to 5 component gases and water vapor in any air sample. The Bruel & Kjaer 1302's detection threshold is gas-dependent but typically in the 10^{-3} ppm region.

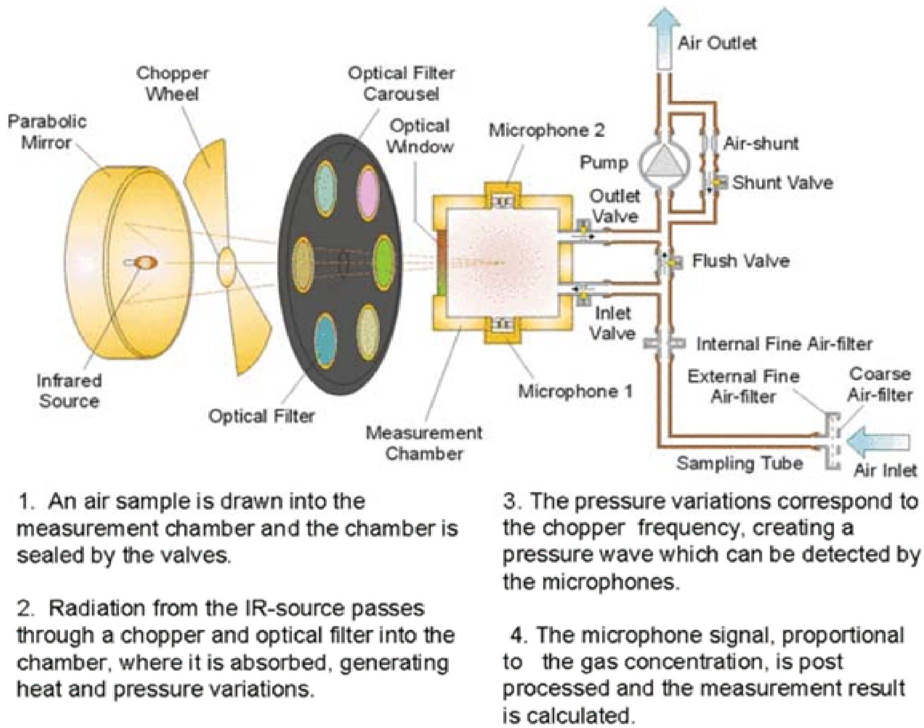

Figure 6 *Principle of the Breul & Kjaer Multi Gas Measurement*

Figure 7 *Heat lamp "occupant"*

C. Simulating Human Sensible Loads

Human heat loads are simulated using high intensity heat lamps (Figure 7) and three 60 watt incandescent light bulbs. The light bulbs are on 24 hours a day, while the heat lamps are on a dimming control which allows them to be adjusted to match heat produced by human loads.

D. Simulating Appliance and Process Sensible and Latent Loads

Additional sensible heat loads result from the use of appliances that cycle on a scheduled basis (Table 1). The contributors to this type of load are kitchen items (oven, dishwasher) and the bathroom shower. Dishwasher and shower activity also contribute to the indoor moisture loads.

Table 1 Power and On Times of Various Components

	Watts	Mon - Wed		Tue - Thr - Sat – Sun		Fri	
		ON Hours	KWH	ON Hours	KWH	ON Hours	KWH
Living Room Heat Lamp	239	14.0	3.3	14.0	3.3	14.0	3.3
Dining Room Light	180	24.0	4.3	24.0	4.3	24.0	4.3
Bedroom 2 (front guest)	235	10.0	2.4	10.0	2.4	10.0	2.4
Bedroom 3 (rear guest)	235	10.0	2.4	10.0	2.4	10.0	2.4
Guest Bath Heat Lamp	243	24.0	5.8	24.0	5.8	24.0	5.8
Kitchen Range Exhaust	51	0.5	0.0	0.5	0.0	1.0	0.1
Range Oven	2585	0.5	1.3	0.5	1.3	1.0	2.6
Dishwasher	216	0.0	0.0	2.5	0.9	0.0	0.0
Master Bed Heat Lamp	235	14.0	3.3	14.0	3.3	14.0	3.3
Master Bath Light	240	0.4	0.1	0.4	0.1	0.4	0.1
Master Bath Fan	19	1.0	0.0	1.0	0.0	1.0	0.0
Shower Solenoid	9	0.3	0.0	0.3	0.0	0.3	0.0
Daily Total			23.0		23.9		24.3

E. Occupancy Simulation Automation System

The occupancy simulation devices are controlled by a central X10 brand control system (Figure 8). The system uses the Power Line Carrier (PCL) communication protocol to send commands through the MHLab's electrical wiring to each of the items being controlled. A schedule (Figure 9) is programmed into the automation system that reflects the habits of the simulated occupants. For instance, the shower is programmed to run for a 15 minute period starting at 6:00am every week day. The dishwasher is programmed to run its cycle every day. In this way the MHLab sees heat, moisture, CO2 and power loads that are similar to those produced by actual occupants.

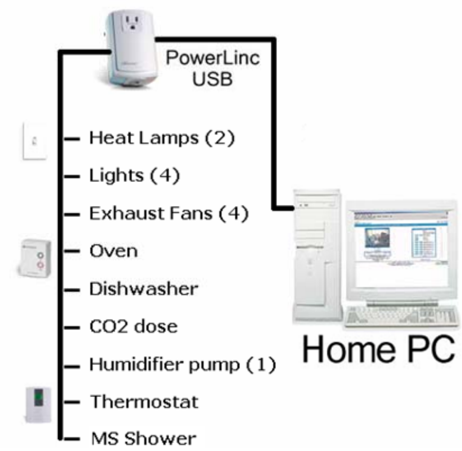

***Figure 8** Computer–X10 Control Schematic*

Using the combination of automation and specially modified appliances, simulated occupancy is done in a consistent and predictable pattern conducive to accurate data analysis.

MHLab Data Collection and Presentation

Whole house power use resulting from simulated occupancy is monitored and logged.. The MHLab features an extensive data retrieval and collection system powered by a Campbell CR10

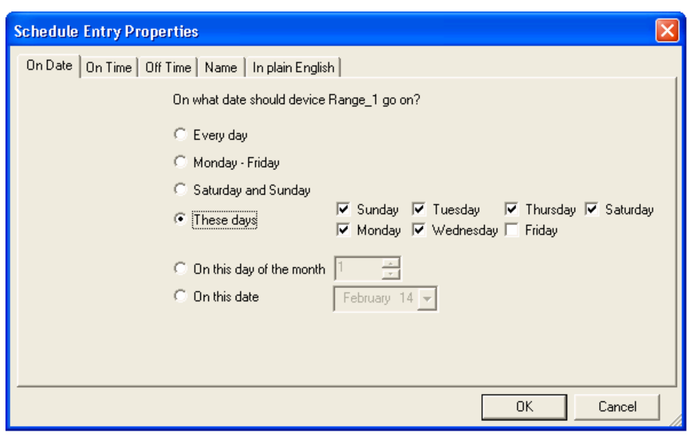

***Figure 9** Control schedule for simulated occupancy.*

data logger. Data is collected and averaged over a fifteen minute period then downloaded via an internet modem several times daily to FSEC's mainframe computer system, where it is processed and made available via the internet for public view on FSEC's Infomonitors web site. For this study, the following data are measured:

- Total Building Power
- Exterior & Interior Co2 Levels
- Air Conditioner Compressor Power
- Ambient Weather Conditions
- Space Heating Power
- Pressure Difference Across Envelope
- Air Handler Fan Power
- Ventilation Airflows
- Dehumidifier Power
- Ventilation Fan Power (If Separate)
- Interior Temperature & Relative Humidity
- Ventilation Cycle Time

Using tracer gas decay methodology (ASTM E 741, "Standard Test Method for Determining Air Leakage Rate by Tracer Dilution"), the building infiltration/ventilation rate was measured, once with the HVAC equipment operating and then again with the HVAC equipment turned off (if possible or practical). More details about MHLab power consumption can be seen by visiting the site at http://www.infomonitors.com/mhl/.

Results show that if the cooling set point is set at a reasonably cool value of 75ºF then the a/c run times are adequate to maintain RH below 60% for all strategies examined (Moyer et al, 2004) . Experiments have been recently completed with ASHRAE 62.2 levels of ventilation (3,000 cf per hour for this house) and a warmer set point of 78ºF.

Figure 10 shows a summary of the recent data collected in the master bedroom. Note that the RH in the master bedroom occasionally exceeds 60% RH during mild but wet days. This points to the desirability of having supplemental dehumidification capability for comfort and health if ASHRAE 62.2 levels of ventilation is provided.

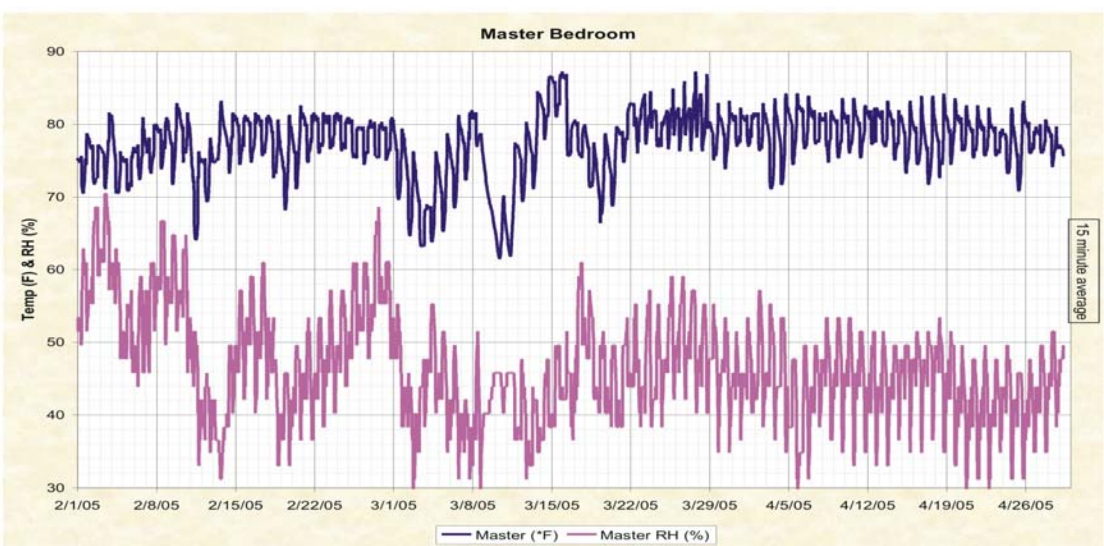

Figure 10 *Summary of MHLab temperature and relative humidity data in Master Bed Room*

9.2.2 *Ventilation Characterization in Manufactured Housing:* During 2000-2003 WSU and the National Institute of Standards and Testing (NIST) conducted experiments to characterize ventilation performance at the NIST test house on NIST campus (Gaithersburg, MD) and the WSU Energy Program house (Lubliner residence in Olympia, WA). These experiments documented that a point source exhaust fan ventilated a 3 section manufactured home quite well (the duct system acted as a distribution system) and the NIST experiments were useful for validating the CONTAMW model (Lubliner, Gordon, Persily, et al, 2003).

9.2.3 *VOC Measurements*: During 2000-2004 FSEC collaborated with LBNL to measure formaldehyde and other volatile organic compounds (VOCs) in one “IAQ improved” and one base case manufactured home. Results are available in Hodgson et al (2002, 2005)

9.2.4 *Ventilation Experiments in Brookside Apartments*: Apartments, especially north facing downstairs units are sometimes plagued with high wintertime humidity and mold. In 2003-4 experiments were conducted in two north facing units of the all Energy Star 176 unit Brookside Apartment complex in Gainesville, FL built by Sandspur housing, a BAIHP partner. All units have fresh air ventilation provided by a 4” duct connected to the return air plenum. Experiments showed that despite occasional periods of high interior RH, outside air ventilation was sufficient to prevent mold in wintertime and did not significantly increase summertime RH.

9.2.5 *Crawlspace Ventilation*: Buckled floors and other floor level moisture problems in manufactured homes are frequently caused by wet and poorly vented crawlspaces. Experiments conducted in 2004 at the FSEC auxiliary site using side-by-side single wides quantified the beneficial effects of a ground cover in reducing crawlspace dewpoints. In 2005, experiments will be conducted in the MHLab whose crawlspace will be well sealed and the data compared to vented crawlspace data from earlier years.

9.2.6 *Unvented Attic Experiments:* Temperature and relative humidity data were collected during 2001-2004 in two unvented attics. In one attic high dewpoints were measured near the peak which was later reduced by introducing conditioned house air into the attic using a low wattage exhaust fan.

9.2.7 *Water Intrusion in Masonry Walls:* The three hurricanes that struck central Florida in 2004 caused significant water intrusion through walls in thousands of new homes, but not in older homes. In 2005 UCFIE is building a wall water-absorption test apparatus (ASTM C16701-04) which will be used to test basecase and improved walls (constructed to resist water intrusion). In addition a survey of several hundred central Florida home owners will be conducted to quantify the damage and discern damage patterns if any.

9.3 *(Research)* Cool Roofs (FSEC)

Roof, attic, and duct heat gains can represent up to 25-30% of total residential cooling load. Previous research at FSEC and LBNL have shown that cool roofing materials on vented attics to drastically reduces these heat gains. Given the emerging importance of reducing attic ventilation to reduce storm damage due to sheathing uplift and rainwater intrusion, we plan to critically examine the role of attic ventilation and corresponding rain water intrusion in 2005 as data in this area is sparse.

Figure 11 The FSEC Flexible Roof Facility, Cocoa, FL.

In 1989 FSEC constructed the flexible roof facility (FRF) in Cocoa, Florida, ten miles west of the Atlantic ocean on mainland Florida (Figure 11). The FRF is a 24 ft by 48 ft frame building with its long axis oriented east-west . The roof and attic are partitioned to allow simultaneous testing of multiple roof configurations. The FRF has been used to collect data on various roofing and ventilation strategies for the past 15 years. In 2005 FRF will be set up in the following configuration (Table 2) to establish relative performance. All cells will have black shingles, save for Test Cell 6 with the white metal roof which has served for years as the best performing roofing system. All test cells will have R-30 insulation installed on the attic floor with the ventilation areas carefully verified.

Table 2 Current Test Cell Specifications at FSEC's Flexible Roof Facility

Cell #	**Description of Experiment**	**Research Justification**
6	White metal roof, 1:300 ventilation	Best performing roofing system.
5	Reference, 1:300 ventilation area	Standard requirement for building codes
4	Black shingles, 1:150 vent area	Added attic ventilation area per codes
3	Black shingles, sealed	New ASHRAE option for humid climates
2	Black shingles, 1:150, soffit vs. ridge	Evaluation impact of soffit vs. ridge venting
1	Black shingles, open soffit with PV vents	Evaluate PV ventilators

Test cell #2 will alternately have the ridge vents opened and closed midway through the summer season to examine influences on performance. Relative humidity sensors will be used to evaluate how the different attic ventilation strategies influence attic moisture conditions. In addition, moisture sensors will be placed in the areas surrounding the ridge vents to see if wind blown moisture is introduced in to the attics during weather events. Monitoring will continue for an entire year to examine both cooling and heating related performance.

Additional details are provided in the Coolroofs technical systems write up separately submitted.

9.4 *(Research)*Night Cool (FSEC)

Using a building's roof to take advantage of long-wave radiation to the night sky has been long identified as a potentially productive means to reduce space cooling in buildings– a major objective within the EERE mission. This is because a typical roof at 75ºF will radiate about 55-60 W/m^2 to clear night sky and about 25 W/m^2 to a cloudy sky. For a typical roof (250 m^2), this represents a cooling potential of 6,000 - 14,000 Watts or about 1.5 - 4.0 tons of cooling potential each summer night. Various physical limitations (differential approach temperature, fan power, convection and conductance) limits what can be actually achieved, however, so that perhaps half of this rate of cooling can be practically obtained. Even so, careful examination of vapor compression space cooling in many homes in Florida shows that roughly 9.2 kWh (28%) of this air conditioning is required between the hours of 9 PM and 7 AM when night sky radiation could greatly reduce space cooling.

The objectives of the Night Cool experiment are to design a simple and productive residential roof-integrated night cooling system, and then simulate performance parameters to test the system concept in a scaled down prototype at FSEC in 2005.

Fundamentally, the system is composed of a metal roof over a sealed attic with an integrated dehumidification system (Figure 12). During the day, the building is de-coupled from the roof (by a continuous air barrier at the ceiling plane), and heat gain to the attic space is minimized by the white reflective metal roof. During this time the prototype is conventionally cooled with a small air conditioner. At night as the interior surface of the metal roof in the attic space falls two degrees below the desired interior thermostat set-point, the building is coupled to the roof by channeling the return air for the air conditioner through the attic space using electrically

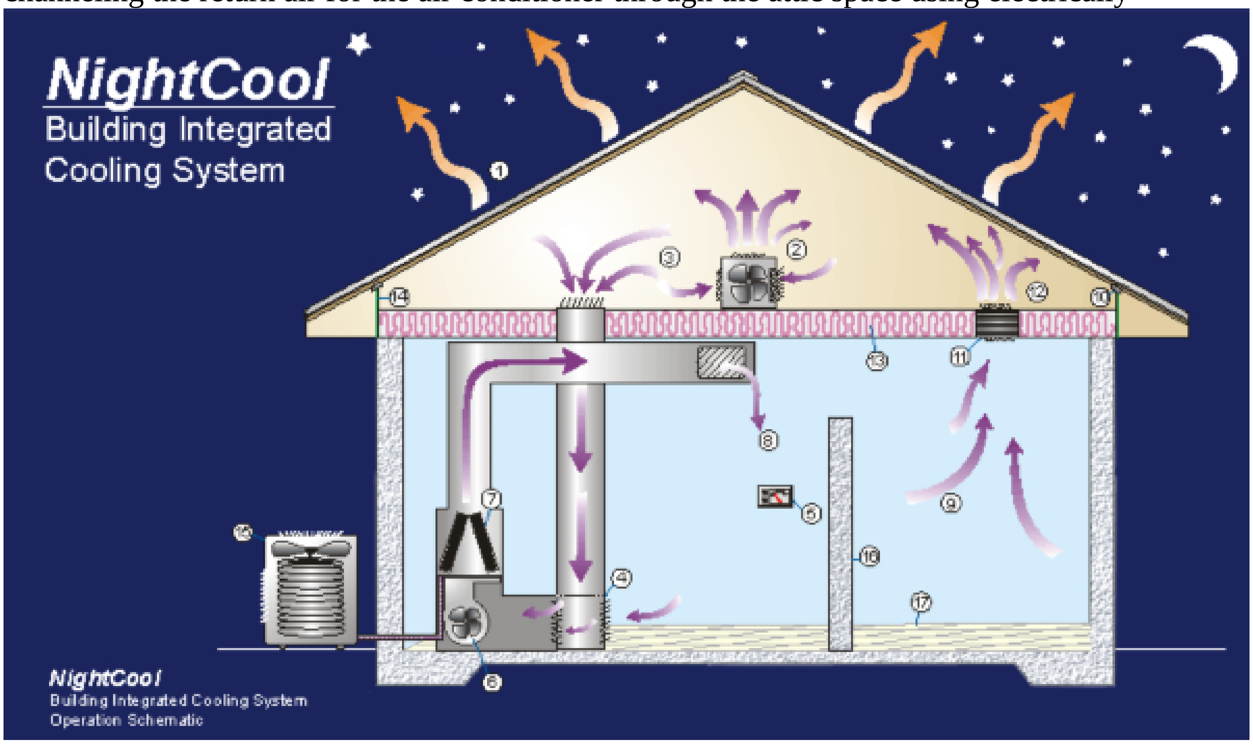

Figure 12 *The NightCool system.*

controlled louvers with a variable speed fan set to low. The warm return air from the interior then goes to the attic and warms the interior surface of the metal roof which then radiates the heat away to the night sky. As increased cooling is required, the air handler fan speed is increased. If the return air temperature does not cool sufficiently or the relative humidity is not kept within bounds (<55% RH) the air-conditioner and/or the dehumidifier in the attic is energized to supplement the sky radiation cooling. The massive construction of interior tile floors and concrete walls will store sensible cooling to reduce daytime space conditioning needs. The concept may also be able to help with daytime heating needs in very cold climates as well by using a darker roof as a solar collector.

The system has been simulated. The simulation shows that in Tampa, Florida from June - September, the system can produce an average of 15 kWh of cooling per day at a use in fan power of about 1.4 kWh for a system SEER of approximately 37 Btu/Wh. Performance during more mild swing seasons show EERs greater than 50 Btu/Wh. Performance was also evaluated in other climate locations: Phoenix, AZ; Baltimore, MD and Atlanta, GA. In each location, June-

September performance was superior to that in Tampa, FL – with greater absolute cooling and efficiencies of 71-88 Btu/Wh. The detailed simulation report is currently available.

Construction is also just beginning on the two instrumented test sheds which will be erected at FSEC's facilities and will be used to collect data on comparative system performance in the fall of 2005.

Additional details are provided in the Coolroofs technical systems write up provided separately.

9.5 *(Research)* Condenser Fan (FSEC)

Air-cooled condensers in residential air conditioning (AC) systems employ finned-tube construction to transfer heat from the refrigerant to the outdoor air. Electrically powered fans are used to draw large quantities of air across the heat transfer surfaces to remove refrigerant heat. Although intensive research effort has examined improvements to compressors, much less effort has targeted improvements of system fans– particularly the outdoor fan used by air conditioners and heat pumps.

Figure 13 *Prototype condenser fan and exhaust housing.*

The primary objective of this work during 2003-2004 was to improve condenser fan performance while reducing motor power. We also examined potential changes to the condenser exhaust configuration to enhance air moving efficiency performance. A secondary objective was to provide sound reductions as lower noise AC equipment is important to consumers.

FSEC tested potential enhancements to the outdoor unit condenser fan by altering its shape and aerodynamic characteristics. Optimized fan blades were designed via a numerical flow simulation and fabricated using stereo lithography. A similar approach was used to design optimized conical diffusers. Figure 13 shows a prototype unit. A highly-instrumented test facility was built that allows evaluation of air flow, motor power, fan rpm and sound emanation. After several months of testing, the research produced a fan exhibiting greatly superior air moving efficiency compared with conventional stamped metal blades. Other improvements were demonstrated using conical flow diffusers and an innovative method of reducing fan tip clearances that reduce sound levels.

Fan-only savings were 40 watts (21%) for the same motor and condenser top. We also showed how a lengthened diffuser with a conical insert after the motor can improve air moving efficiency by over 16% for standard fans and over 27% for high performance fans. Fan tip losses and associated vortex shedding was reduced through the use of a porous foam strip to improve air flow performance while helping to reduce sound.

Current project efforts in 2005 are evaluating potentially more efficient larger fans (27.6") for the larger air flows (4000 cfm+) needed for the most efficient current AC condensers. Other research is evaluating the combined potential with ECM motors as well as potentially shorter annular flow diffusers with temperature adaptive controls. Even higher efficiency levels are anticipated.

9.6 *(Research)* Fenestration (FSEC)
Although included in BAIHP, this task is funded by a different DOE program element. Currently FSEC is conducting ray tracing analysis of complex glazing/shading systems and developing a web based tool for consumers to select windows tailored for specific climates and home types. A web site with considerable depth has been developed: http://www.fsec.ucf.edu/bldg/active/fen/index.htm.

No additional work is planned in this area with FY05 funding.

9.7 *(Research)* Manufacturing Productivity (UCFIE)
UCFIE researchers have continued to assist modular homebuilders as they strive to introduce lean production technologies into their processes. The team believes that labor has a profound impact on all plant operations, affecting product quality, plant capacity, cycle time, material waste, and labor productivity. During 2003-4, UCFIE developed the Status Tracking and Control System (STACS) , a real time shop floor labor data collection and reporting system (Figure 14). The system uses wireless laser scanners and wireless local area networks to simplify integration with the existing manufacturing infrastructure and operations. STACS results can be used for product costing, production scheduling and labor planning. An alpha prototype of STACS was successfully tested at two modular manufacturers. The test was conducted throughout the residential production operation for a period of several weeks. Results are currently being analyzed and summarized in a Masters Thesis. For more details see Broadway and Mullens (2004).

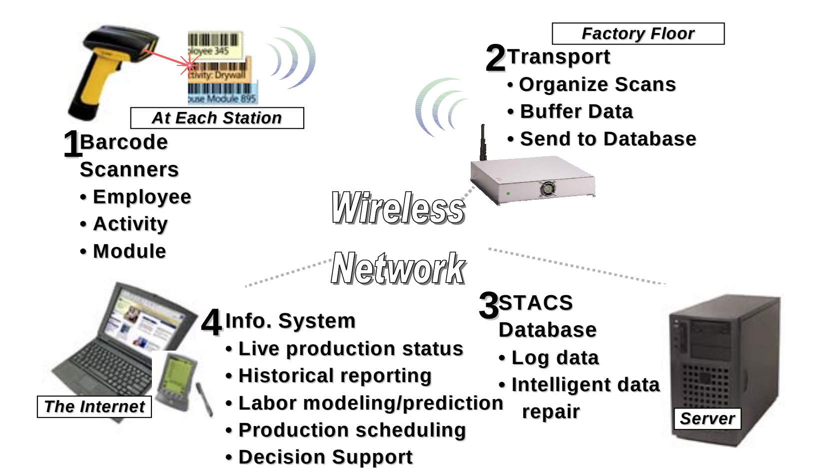

Figure 14 *STACS Architecture*

9.8 (*Technical Assistance Category*) Moisture Diagnostics (FSEC)

During 1999-2000 a significant number of manufactured homes in the hot, humid Southeast were experiencing significant moisture problems. Soft wallboards, buckled floors, damaged wood molding and extensive mold growth were the most common symptoms. These problems did not respond to the standard service and repair strategies for water intrusion. This was identified as the most significant research problem by the industry group, Manufactured Housing Research Alliance. At the request of four manufacturers, over twenty-five such moisture damaged homes were investigated to determine likely causes. Blower door, duct tightness and pressure differential measurements were performed on all homes. Field data on ambient, crawlspace, belly and house temperatures and RH were collected on a few of the homes. Recommendations and reports were prepared for the manufacturers' service, production and design staff. Duct leakage (Figure 15), lack of return air transfers, low cooling set points, oversized air conditioners, lack of ground covers in crawl spaces were identified as the root causes for these problems (Moyer et al, 2001). **During 2001-2004 we visited our industry partners, trained line workers and worked with their engineers to widely implement air tight duct construction practices which has nearly eliminated the moisture problems in addition to saving energy and enhancing occupant comfort at a cost per home of around $30.**

Before: Tape failure at duct joint led to condensation, mold, and decay.

After: Mastic and mesh duct sealing improves IAQ and energy efficiency.

Figure 15 *Duct joint failure and repair.*

Methods

BAIHP's house evaluation consists of a battery of tests designed to establish the integrity of the building envelope and the air distribution system, and to assist in house performance prediction. This technique incorporates the field characterization of critical parameters for indoor environment, thermal comfort, air delivery and distribution systems as well as their interaction with the building envelope. The data collected is used as direct inputs to energy prediction tools, such as EnergyGaugeUSA or DOE-2. The major parts of the testing include building envelope leakage (blower door test), duct leakage test (duct tester), and the measurement of differential pressurization of various spaces with respect to (WRT) the outside and each other.

CFM50 is the airflow (in cubic feet per minute) from the Blower Door fan needed to create a change in building pressure of 50 Pascals (0.2 inches of water column). A 50 Pascal pressure is roughly equivalent to the pressure generated by a 20 mph wind blowing on the building from all directions. CFM50 is the most commonly used measure of building airtightness and gives a quick indication of the total air leakage in the building envelope.

Figure 16 *CFM50 explained*

These tests also assist in determining the path of air transported moisture that can cause severe damage to building components, increase energy consumption and decrease occupant comfort. (Moyer et. al. 2001).

The whole building envelope leakage test employs the calibrated blower door and establishes a leakage rate (or equivalent hole size) for the house at a standard pressure differential. This leakage rate is usually expressed in cubic feet per minute at 50 Pascals (CFM50, Figure 16) or air changes per hour at 50 Pascals (ACH50). Testing continues with the use of a duct system air tightness testing (B) which establishes a leakage rate of the duct system(s). The pressure differential tests (C) uses a digital manometer to measure of pressure differentials across various zones within the house and across the air barrier of the house with air moving equipment operating. The pressure differentials are created by the balanced flow of air to and from the heating/cooling system and barriers that sirupt that balance. A detailed explanation of the diagnostic tests follows.

Figure 17 *Blower door depressurization test*

A. Whole House Air Tightness

The blower door (Figure 17) is a diagnostic tool designed to measure the airtightness of buildings and to help locate air leakage sites. Building airtightness measurements are used for a variety of purposes including:

- Documenting the construction airtightness of buildings.
- Estimating natural infiltration rates in houses.
- Measuring and documenting the effectiveness of airsealing activities.

The blower door consists of a powerful, calibrated fan that is temporarily sealed into an exterior doorway. The fan blows air into or out of the building to create a slight pressure difference between inside and outside. This pressure difference forces air through all holes and penetrations in the exterior envelope. By simultaneously measuring the air flow through the fan and its effect on the air pressure in the building, the blower door system measures the airtightness of the entire building envelope. The tighter the building (e.g. fewer holes), the less air you need from the blower door fan to create a change in building pressure.

A typical blower door test will include a series of fan flow measurements at a variety of building pressures ranging from 60 Pascals to 15 Pascals (one Pascal (Pa) equals approximately 0.004 inches of water column). Tests are conducted at these relatively high pressures to mitigate the effects of wind and stack effect pressures on the test results. Sometimes a simple “one-point” test is conducted where the building is tested at a single pressure (typically 50 Pascals). This is done when a quick assessment of airtightness is needed, and there is no need to calculate leakage areas.

In order to compare the relative tightness of buildings, it is useful to adjust (or normalize) test results for the size of the building (The Energy Conservatory, “Minneapolis Blower Door™ Operation Manual for Model 3 and Model 4 Systems”, 2801 21st Ave. S., Suite 160, Minneapolis, MN 55407, February 2003a.). These data are normalized by dividing the whole house air leakage measured at a test pressure of 50 Pascals (e.g. CFM50) by the floor area of the building, Equation 1.

Normalized CFM50

$$\text{CFM50 per Square Foot of Floor Area} = \frac{\text{CFM50}}{\text{Square Feet of Floor Area}}$$

B. Duct System Air Tightness

Air leakage in forced air duct systems is now recognized as a major source of energy waste in both new and existing houses and commercial buildings. Research conducted by the Florida Solar Energy Center (FSEC), Advanced Energy Corporation (AEC), Proctor Engineering, Ecotope and other nationally recognized research organizations has shown that testing and sealing leaky distribution systems is one of the most cost-effective energy improvements available in many houses and light commercial buildings. (The Energy Conservatory, “Minneapolis Duct Blaster® Operation Manual for Series B Systems”, 2801 21st Ave. S., Suite 160, Minneapolis, MN 55407, November 2003.)

Figure 18 *Duct tester attached to return grill*

The duct tester (Figure 18) used is a calibrated air flow measurement system designed to test and document the air tightness of forced air duct systems. Airtightness measurements of duct systems are used for a variety of purposes including:

- Documenting and certifying compliance with building code or other construction standards requiring airtight duct systems.
- Troubleshooting comfort and performance complaints from building owners.
- Measuring and documenting the effectiveness of duct sealing activities.
- Estimating annual HVAC system losses from duct leakage.

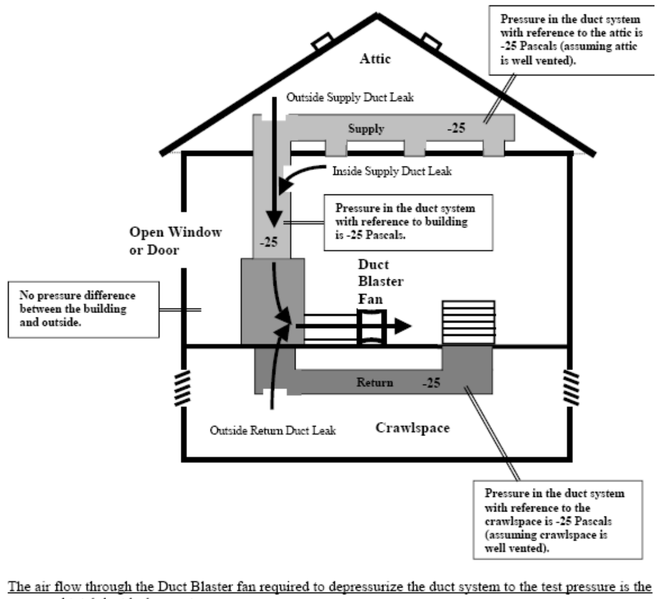

Figure 19 *Illustration of total leakage depressurization test (at a test pressure of 25 pascals) with duct blaster fan installed at air hander.*

Duct airtightness is determined by measuring the leakage rate of the duct system when it is subjected to a uniform test pressure by the duct tester fan. Duct air tightness test results are typically expressed in terms of cubic feet per minute (cfm) of leakage at a corresponding test pressure (e.g. 155 cfm at 25 Pascals). Duct airtightness test results can also be expressed in terms of leakage areas (e.g. square inches of hole) or normalized leakage rates (e.g. measured duct leakage rate as a percent of total system air flow).

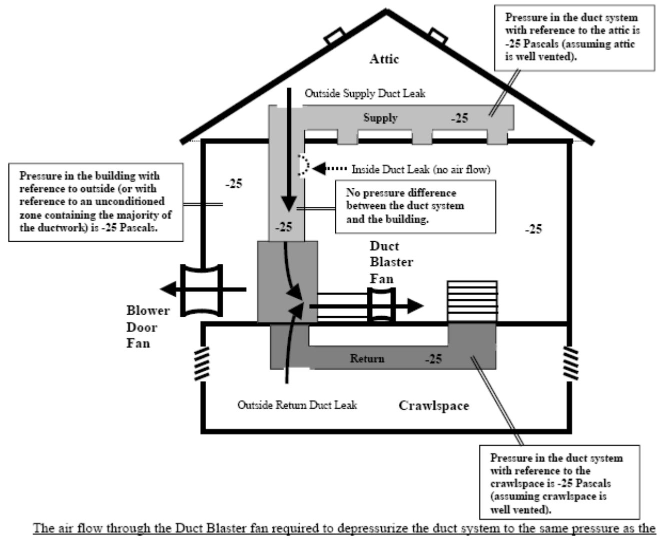

Figure 20 *Illustration of leakage to outside depressurization test (at a test pressure of -25 pascals) with duct blaster fan installed at air handler*

A duct airtightness test is performed by first connecting the duct tester system to the ductwork at either a central return grille or at the air handler cabinet. After temporarily sealing off all intentional openings in the duct system (e.g. supply and return registers, and combustion or ventilation air inlets which are connected to the duct system), the duct tester fan is used to pressurize or depressurize the entire duct system to a standard test pressure (Figure 19). For residential duct systems, 25 Pascals (0.10 inches w.c.) is the most commonly used test pressure. This test pressure has been adopted by most duct testing programs because research has shown that 25 Pascals represents a typical operating pressure in many residential systems. The air flow needed from the duct tester fan to generate the test pressure in the duct system is the measured leakage rate. Both the duct system pressure and the duct tester fan air flow are measured by a calibrated digital pressure gauge.

The next tests establish duct system airtightness. These tests use the duct tester and yield the leakage rate of the duct system in a similar manner to the building air-tightness test and are expressed in cubic feet per minute at 25 Pascals (CFM25). One test measures the total leakage from the duct system to the interior and exterior of the building (CFM25total) by pressurizing the duct system to 25 Pascals. The second test measures leakage to the exterior of the building only (CFM25out) by pressurizing the building and the duct system to the same pressure, removing any driving force for leakage between the building and the duct system. This result is the remaining leakage being to the outside of the building envelope (Figure 20). The results are airflow at 25 Pascals (cfm @ 25 Pa) and air leakage at 25 Pa normalized by the conditioned house square footage (cfm/ft2 @ 25 Pa).

A duct system to be considered to be “essentially leak free” in the BAIHP project when the normalized duct leakage to the outside is less than 0.03 cfm/ft2 and the normalized total duct leakage is less than 0.06 cfm/ft2. The testing process is outlined in the blower door and duct tester manuals for the equipment being used. It follows the ASTM Standard E779-87, "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization" American Society for Testing and Materials.

As with whole building leakage, the measured duct leakage (CFM25) is often normalized by conditioned area (Equation 2) for ease of comparison (The Energy Conservatory 2003b).
Percent Duct Leakage

$$\text{Duct Leakage as a \% of Floor Area} = \frac{\text{Duct Leakage @ 25 Pa (cfm)}}{\text{Floor Area (square feet)}} \times 100$$

C. Pressure Differential Testing

The testing protocol continues with a series of pressure differential measurements across the building envelope and across various zones within the building as defined by interior doors. A digital micromanometer with a resolution of 0.1 Pascal is used in all of the pressure differential measurements. Pressure differences may be created by either normal operation of the building's heating and cooling equipment, ventilation system or exhaust fans (including clothes dryers). Measurements were completed to determine a magnitude and direction of flow across the envelope when the various fans operate. Interior door closure effect was also measured when the air handler fan operated. Ideally, the pressure differentials created across the building envelope and bedroom doors should be fairly close to neutral. (The Duct Handbook – A Practical Field Guide and Reference Ver II, Tooley & Moyer)

9.9 (*Technical Assistance Category*) Airtight Ducts (FSEC)

Between 1996 and 2003 FSEC researchers conducted 39 factory visits at 24 factories of six HUD Code home manufacturers interested in improving the energy efficiency their homes. Factory observations typically showed that building a tighter duct system was the most cost effective way to improve the product's energy efficiency (McIlvaine et al, 2004). This data supported the NFPA 501 committee adoption air tight duct construction standards for manufactured homes. We worked with our partners to implement air tight duct construction practices and as a result our partners Palm Harbor Homes, Fleetwood and Southern Energy Homes produced over 20,000 homes in 2004 with air tight ducts at an average cost of $14XX per house section (McIlvaine et al, 2004). This work also led to the Energy Star certification of 10 factories in six states (Chasar et al, August 2004)

9.10 (Technical Assistance Category) SuperGood Cents/Natural Choice (SGC/NC) Program Support (WSU)

The SGC/NC is a long standing program in the Pacific Northwest to improve the energy efficiency and marketability of energy efficient manufactured homes.
http://www.energy.state.or.us/res/manhme/manhme.htm
During 1999-2004 the program has produced over 21,000 Energy Star or near Energy Star homes with WSU providing technical program support. These technical support areas include:

Conduct quarterly visits to 20 HUD-code factories for in-plant quality assurance inspections in accordance with QA NEEM in-plant manual and specifications (see NEEM manual , online at http://www.energy.state.or.us/NEEM/NEEM2004.pdf).

1. Conduct on-site Problem home visits to assess set-up and plant related building science problems (see NEEM manual)
2. Participate in quarterly meetings with state agencies responsible for manufactured housing set-up training, in-plant HUD IPIA inspections and consumer SAA complaints. (see problem home field protocol in NEEM manual and individual field reports)
3. Participate on monthly conference calls with state energy offices to discuss technical and program issues related to the operation of the regional NEEM program (see NEEM conference call minutes).

4. Conduct and disseminate research on new technologies and building systems to NEEM partners such as foam sheathing, air tight can lighting; Energy Star lighting, appliance and water heating technologies 2x6 advanced framing,
5. Upgrade the NEEM standards to higher levels of energy efficiency including adoption of improved duct efficiency standards
6. Evaluate and demonstrate solar ready concepts (Lubliner et. al July 2004 –ASES) and demonstrate zero energy manufactured homes to meet future Building America benchmark goals (Lubliner et al, Dec 2004 - BTECC).
7. Conduct random sample field studies and of NEEM homes to assess energy performance and further improve NEEM program specifications. (see NEEM random study and billing analysis reports).
8. Publish research results in peer reviewed publications and disseminate information to ASHRAE, ACEEE, BTECC and other building science organizations.
9. Provide technical support to builder organizations such as NAHB and MHRA
10. Assist the Northwest Power Planning Council with information required to continually evaluate the NEEM program utility and consumer cost-effectiveness. As directed by the Northwest Power Act, the Council has designed model conservation standards to produce all electricity savings that are cost-effective for the region. The standards are also designed to be economically feasible for consumers, taking into account financial assistance from the Bonneville Power Administration and the region's utilities. See http://www.nwcouncil.org/energy/powerplan/draftplan/Appendix%20F%20(Model%20Conservation%20Standards)%20(PP).pdf
11. Provide BAIHP research to NFPA-502 Manufactured Housing Standard to improve to consumer cost-effective levels the HUD Manufactured Housing Construction and Safety Standards (MHCSS) in the areas of energy and mechanical codes.

9.11 (*Technical Assistance Category*) Habitat for Humanity (FSEC)

Habitat for Humanity International and its 1600+ domestic affiliates constitute one of the largest builders in America producing almost 6000 houses in 2003. The homes that Habitat affiliates build are usually less than 1200 square feet with average cost of building only $46,600 due to significant donations of labor and materials.

The FSEC and Habitat partnership has been in place for many years and has resulted in direct support of 418 Energy Star Habitat homes, 260 near Energy Star homes, a rich body of collective experience from "blitz" builds, as well as a cohesive set of web based and hardcopy documents. Six of 2003's top 25 producing affiliates in America were Building America Partners, Houston (#4) has achieved Building America HERS scores, as have affiliates in Lakeland, Denver, Golden (CO), Pittsburgh, and Alachua County (FL). In 2003, Habitat International adopted Energy Star certification as one of only two "Construction Best Practices;" an indicator of commitment from the highest levels of Habitat International.

Providing Habitat affiliates with a less complicated way of certifying homes Energy Star has been under consideration for over 2 years. FSEC has worked with both Habitat and EPA to develop an Energy Star Equivalency Program that can be implemented in Habitat's construction environment. In 2005, FSEC will continue trying to overcome theses technical and administrative barriers as well as continue to offer building science training and technical assistance, and, during Habitat's *Congress Building America* project and the *2005 Jimmy Carter Work Project.* Volunteers and paid HFH staff gain hands-on experience with energy efficiency, durability, and systems engineering to volunteers and construction managers.

9.12 (*Technical Assistance Category*) Community Scale Assistance in Gainesville, FL (FL Hero)
In the Gainesville, FL market no builder constructs more than 75 homes a year. The challenge has been to move builder/developers from the construction of high performance prototype homes to the implementation of the systems engineering approach on a community scale.

The primary issue to overcome is the reluctance of builders to increase the initial price of their homes. Their hesitancy is based primarily on the concern that increased price will result in decreased sales and resulting profit, and the fact that current sales of minimum code homes are very robust. Realtors still use the cost per square foot to determine "value". Home buyers are ill-informed of the ramifications of the decisions that are made by others as to the impact on their health and their monthly cost of ownership.

Our approach has been to focus on improving the quality and energy efficiency of the home and reducing callbacks for the builders, and let the market speak for itself. As will be seen in the two case studies below, this approach has been quite successful. In the North Central Florida area, homes which have been built to a higher standard have resulted in increased sales, increased profits for the builder, quicker sales and less call backs. Educated consumers have spurned the old cost per square foot value determination and have voted with their dollars to invest in higher performance homes which not only cost less to operate but also are more comfortable and have better indoor air quality. There is no reason to expect that consumers in other markets would respond differently once they have been educated.

The BA program has had an impact on the entire local construction community. The lessons learned by the sub-contractors have been shared with the other builders they work with.

Consumers increasingly insist that their health and commitment to energy efficiency be addressed. We believe we have contributed to the fact that Gainesville has the lowest per capita use of energy of any utility in the state of Florida. (Source: EIA-861 data for calendar year 2002 for avg. residential customer use by utilities as reported in the Gainesville Regional Utilities planning documents in Dec. 2003). Gainesville also has one of the highest percentage of new homes built and tested to meet the Energy Star for homes standard.

The following two case studies represent two different approaches to achieving the goal of the construction of high performance communities. It is interesting to note that in both cases consumers have overwhelmingly demonstrated a willingness to invest in homes that utilize the systems engineering approach.

Figure 21 *An Atlantic Design home in Gainesville, FL.*

Atlantic Design and Construction - Mentone Subdivision, Gainesville, FL :Buildout 340 homes, 336 completed. Atlantic Design, winner of 2001 EPA Energy Star Small Builder of the Year, has achieved their current level of performance through an incremental process of improvements over several years. While having developed a reputation for building high "quality" homes, the only aspects of their homes which were greater than minimum code requirements was the use of double pane glass and R30 attic insulation. New materials and systems have been adopted over time. This BA partner standard features now include: double pane low-E glass; R-13 cellulose wall insulation; right-sized 13+ SEER air conditioners; 92.6 AFUE sealed combustion natural glass furnaces with variable speed motors and programmable thermostats. These standard production home achieve a HERS score of 88. to 89 (Figure 21). *This translates into whole house energy savings in excess of 30% as calculated by the BA benchmark methodology*. In addition, appropriate moisture management techniques have been employed, as well as the introduction of passive outside air in a manner that insures that the home is under positive pressure WRT the outside when the system is operational. Each home is individually performance tested as a part of an overall commissioning process. The fact that the implementation of these measures increased the initial price of the home's cost per square foot, did not prevent this subdivision being the best selling community in the area for three years running. The BA systems approach is now being used for all of Atlantic Design and Construction's new projects. It is interesting to note, that the increase in value of tested homes in this subdivision was substantiated by independent appraisals of resales. This has led to the local MLS service adding "Energy Star" to the standard list of features.

G.W. Robinson Builder - Cobblefield, Gainesville, FL – Buildout 265 homes, 198 built and Turnberry Lake in Gainesville, FL - Buildout 186 homes, 4 completed . In contrast to Atlantic Design's incremental approach, and despite the recommendation of a market survey, it was this developer's desire to build the healthiest, most energy efficient and "Green" subdivision possible within reasonable financial constraints. This included the implementation of new material and system standards: right sized 12+ SEER air conditioners; engineered distribution system; double pane low-E windows; radiant barrier; bringing the air handler within the thermal envelope; programmable thermostat; passive outside air and new QA procedures. A range of Green/Healthy features were adopted. These include: community wide reclaimed water irrigation system, the use of indigenous drought resistant plants grouped according to their water needs, maximum preservation of natural habitat; low VOC paints, and moisture management techniques. In spite of the local Realtors concern of the increased price per square foot, this BA partner builds almost 70% of all homes in his price range, $300,000+ (Figure 22). This BA partner's success with the program has resulted in an increased level of performance for his latest subdivision, *Turnberry Lake* (Buildout 186 homes,4 completed so far) where homes will feature: 14 SEER air conditioners, 93% AFUE sealed combustion natural gas furnaces with variable speed motor located within the thermal envelope; natural gas instantaneous water heaters, and double pane vinyl frame windows with SHGC of 0.28. It is anticipated that all the homes built in this subdivision will achieve a HERS score of 89 or better. All homes are individually performance tested as part of a commissioning process. *These homes are calculated to have whole house energy savings in excess of 30% as calculated by the BA benchmark methodology.*

Figure 22 *Home built by GW Robinson, Gainesville. FL.*

The Systems engineering process: Upon receipt of a floor plan, elevations and specifications for a home, we begin by reviewing the materials and characteristics to determine if there are opportunities for improvements within the context of the design. An example would be to recommend that an air handler be enclosed to bring it within the thermal envelop of the home or using low e windows. Then a room-by-room load calculation, using Elite software RHVAC8, is performed to determine the heating and cooling equipment size. Next, a duct system is designed using the Elite Ductsize software which is based on ACCA criterion. Finally the duct system is drawn on a full size print. All software is continually updated. Often, site visits are conducted to assure quality, e.g. air barrier continuity and duct system layout without kinks.

Upon completion, six performance tests are conducted: 1) a computerized multi point whole house air tightness depressurization test using the Energy Conservatory APT, 2) a Ductblaster is used to perform a cfm25 total and to out test, 3) the home is pressure mapped using a DG3 digital manometer - all rooms that have doors that can isolate them from the main return are measured to determine the pressure differential, as well as the pressure that the home operates under WRT the outside, 4) the flow of the outside air intake is measured using the Energy Conservatory Exhaust Fan Flow Meter and the damper is adjusted as required, using the digital manometer the static pressure in IWC is measured, 5) the flow of all bath exhaust fans is measured, and 6) the delta T across the coil is measured using digital thermometers. House characteristics such as make and model of the air handler and condenser section, water heater size, energy efficiency of appliances, and lighting types are noted and reported to the builder using a form entitled "Home Energy Rating Report" which also notes areas of deficiency. Meeting with the trades and training often occur to correct deficiencies.

Lessons learned: To a great extent the goal of building “tight” homes has been met. The combination of wall systems, window performance, and Florida Code requirements for air infiltration control have been successful. Virtually all new homes are in need of the introduction of outside air to insure good indoor air quality and to maintain the home under positive pressure WRT the outside when the mechanical system is operational.

The aspect that needs more attention is the mechanical system including the air distribution system. Mechanical contractors have been reluctant to embrace the concept of “right sizing”. “Tweaking” the results of a Manual J load calculation or adding “fudge” factors is still very prevalent. Most still do not perform Manual D duct sizing, and when done, often fail to follow the specifications in the field. Additional education would be appropriate.

Following is a summation of lessons learned and ongoing challenges in achieving the systems engineering approach to new home construction:

- The first step in this process requires a clear and consistent commitment of the final decision maker, be it the builder or the developer.
- The formal development of scope of work must be provided to the subs. These need to include specific performance criteria. An example would be to include in the contract language, a provision requiring that the mechanical system will have no greater then 10% total leakage and 5% to out based on the rated AH flow.
- Effective communication of performance expectations to the person(s) responsible for implementation in the field

- Ongoing QA field inspections by either the project manager or an independent third party.
- Final commissioning of each home, including performance testing.

In order for the builder to achieve sales goals, the sales representative must be knowledgeable about the features and benefits that have been built into the home. A high performance home will cost more to build than a minimum code home. It has been the experience in this market that when a consumer is given the opportunity to choose, they will select the higher performing home in spite of an increase in the cost per square foot.

9.13 (*Technical Assistance Category*) Prototype Homes (FSEC)
To fulfill the BA mandate of building homes that save 30%-60% in whole house energy per the BA benchmark, FSEC has provided technical assistance for the following homes in 2004:

Palm Harbor modular home for the 2005 builders show (Figure 23). Estimated to save 35% on a whole house basis, meeting Florida Green Building Coalition (FGBC) green home standards and sporting a HERS score of 93 this 2,084 sq. ft. house features a partially unvented SIP roof, partial R-33 vented roof, R-22 walls, conditioned crawl space, SEER 18 two speed heat pump w/dehumidistat, fresh air ventilation, instantaneous gas water heater, CFL lights in selected areas, high efficiency filtration with UV lights, Energy Star appliances and water efficient fixtures. This was the most affordable show house in the builders show.

Figure 23 *Palm Harbor modular home for the 2005 International Builders Show*

North Dakota Townhomes. 4 units of a planned 20 unit townhouse complex was completed in 2004 (Figure 24). Estimated to save 40% on a whole house basis, these townhomes in Grand Forks, ND feature very high performance envelope with small windows, AFUE 0.92 gas furnace, SEER 10 air conditioner, programmable thermostat, tankless gas water heater, fluorescent lights and Energy Star appliances.

Figure 24 *Townhomes in Grand Forks, ND.*

WCI green home (Casa Verde) in Venice, FL. This (Figure 25) has a HERS score of 90 and features unvented attic, ICF walls, impact resistant low-e windows, SEER15 AC , tankless gas water heater, Energy Star appliances, all fluorescent lighting, PV powered exterior lighting, ducts in conditioned space and whole house dehumidifier w/outside air and Florida friendly landscape. Estimated to save 40% on a whole house basis this home has one of the highest green scores per the FGBC method.

Figure 25 *WCI Green home in Venice, FL.*

Figure 26 *Not So Big showhouse in Orlando, FL.*

Sarah Susanka Not So Big Showhouse for the 2005 Builders show. (Figure 26) FSEC assisted CARB with the HVAC system design. FSEC tested the airtightness of the ducts and the envelope, assisted in the design and installation of the PV and solar water heater, performed the Energy Star and FGBC certifications. FSEC has installed instrumentation and plans to display the data on the web. More info at http://www.notsobigshowhouse.com/

9.14 *(Other)*Research Collaborations

BAIHP researchers served on ASHRAE, NFPA501 and other national committees, assisted NREL in refining the benchmark for energy savings calculations, collaborated with other BA teams on high visibility demonstration houses, shared FSEC *Infomonitors* online data facilities for acquiring and archiving data from highly instrumented sites (IBACOS, CARB and ORNL are all users of this facility). The FSEC developed software EnergyGaugeUSA® is used by all the BA teams in analyzing homes. BAIHP provided case studies for use in the regional best practices manuals under development by PNNL and ORNL. BAIHP provided support to DOE on codes and standards issues, specifically development and support of Section 404 of the 2004 Supplement of the IECC.

9.15 Publications, Workshops and Conferences

BAIHP researchers are frequent contributors to conferences and workshops. In 2004, BAIHP researchers chaired the Residential Panel at the ACEEE conference and the "Factors Influencing the Energy Performance of Forced-Air Systems" symposium at the January ASHRAE meeting. A total of 10 papers were presented at various technical conferences. Presentations without papers were made at ASHRAE, Affordable Comfort, EEBA, regional Habitat for Humanity and the South Eastern Builders conferences. BAIHP hosted an expert meeting on Residential HVAC Fans and Systems and taught in several energy rater training classes at FSEC.

The complete BAIHP publications list (about 7 pages long) is available on the web at http://www.fsec.ucf.edu/bldg/baihp/pubs/project/index.htm

10. Technical Problems/Barriers: The first cost barrier is more significant for the manufactured housing and affordable housing markets – the ones primarily served by BAIHP. As a result whole house savings of over 25% are difficult to accomplish in this market. However, please note that our work does focus on cost effective energy improvements as demonstrated by the large number of homes we have impacted (see section 13 below)

In the site built market where first cost is not a significant problem, we have successfully converted several builders into building high quality homes that consistently save over 30% on a whole house basis (see the Atlantic Design and GW Robinson case studies above)

11. Status of Research Projects:

The principal 2005 milestones and deliverables are listed below:

11.1	FY 04 Final Report submitted to DOE	7-31-05
11.2	Prototype homes instrumented (Not so big, Fred Clark, Ken Kingon)	4-30-05
	FAS Houston house	10-31-05
	Two test homes with advanced HVAC system (Delima system)	12-15-05
11.3	MHLab experiments completed (ASHRAE 62.2 vent, unvented crawl)	10-31-05
11.4	Water intrusion survey completed	5-31-05
11.5	Water Intrusion tests completed	3-31-06
11.6	Attic ventilation experiments at FRF completed	10-31-05
11.7	Nightcool test facility built and instrumented	9-30-05
11.8	Condenser fan prototypes evaluated	3-31-06
11.9	Technical support to Habitat, manufactured homes and site builders	as needed
11.10	Final Report for FY05	6-30-06

12. Commercialization Plans: BAIHP work positively impacts the manufactured and affordable housing industry in thousands of homes constructed every year by our builder partners (see section 13 below). In addition, specifics are given below for two task areas.

Cool Roof Research: The FRF cool roofs experiments provides detailed data on the real world thermal performance of roofing systems that has not been heretofore available. Results from this research have directly led to development and marketing of IR selective pigments by BASF Corporation, Ferro Corporation and the Shepherd Paint Company. Our research on metal roofing is gaining notice from building code bodies around the U.S.

Condenser Fan Research: Several patents are pending on the described technology. FSEC is working closely with a major U.S. AC manufacturer in the proprietary research. The AC industry is potentially interested in using the developed technology and presentation of a full scale operational prototype was shown in May of 2004. The research has the potential to reduce air conditioning energy use in U.S. manufactured AC equipment by 2-4%. Also, unlike many other improvements, the reductions to peak electrical demand are as large as energy savings. With 50 million AC and heat pumps in use in the U.S., the potential energy savings are potentially 3 - 6 GWh annually. Utility co-incident peak reductions are potentially 2500 - 5000 MW– the output of five to ten typically sized combined cycle power plants.

13. Efficiency Improvement Metrics: Through March 31, 2005, BAIHP has assisted over 60 factory and site builders in the construction of more than 107,000 homes saving their owners in excess of $14,000,000/yr in energy bills. Energy Savings exceed one trillion Btu/yr in end use energy. These include over 100,000 factory built homes and more than 6,000 site built homes by production, custom and affordable housing builders. Affordable housing builders include Habitat for Humanity affiliates (over 600 homes), Sandspur housing (176 Energy Star low income apartments) and East Dakota Housing Alliance (13 energy efficient town homes in North Dakota, including 10 that save >40% on a whole house basis). Over 15,500 factory and site built BAIHP homes meet the Energy Star standard (HERS score >=86).

BAIHP has improved the duct construction practices in 40 manufactured home factories throughout the U.S. and Energy Star certified 10 of them. The net extra cost is about $30 per home (two sections) for tested airtight ducts and incorporation of adequate return air pathways. Improved ducts not only save substantial heating and cooling energy but also improve comfort and nearly eliminate moisture problems in manufactured homes. BAIHP duct testing data was instrumental in NFPA 501 MEC committee acceptance of tighter duct standards which may lead to revisions to the HUD code for manufactured housing.

14. Project Output: In addition to information in item 13 above, measured data from side by side testing of BAIHP and conventional manufactured homes show BAIHP manufactured homes saving 70% and 45% in heating season energy in North Carolina and Idaho respectively. Cooling energy savings of over 50% have been demonstrated in Florida. According to the BA benchmark calculation procedures, prototype BAIHP homes are saving, on a whole house energy savings basis, 60% in Idaho (for the Zero Energy Manufactured Home), 40% in Florida for a production site built home, 40% in North Dakota town homes and >25% for manufactured homes in Florida and the Pacific Northwest. Over 100 homes exceed HERS 88.6 in Florida which is equivalent to a BA benchmark savings of 30% or greater on a whole house basis.

The complete publications list including media citations and web resources (about 7 pages long) is available on the web at: **http://www.fsec.ucf.edu/bldg/baihp/pubs/project/index.htm**

A listing of the technical papers follows with the **five most significant publications and their web links shown in bold (a case study is included in this set):**

Arif, M., Mullens, M., Espinal, D., & Broadway, R. (2002). "Estimating, Planning and Controlling Labor in the Industrialized Housing Factory." Industrial Engineering Research '02 Conference Proceedings, Orlando, FL.

Armacost, R., J. Pet-Armacost,, M. Mullens, and A. Salem (2001). "Information Support for Efficient Assembly of Roof Trusses," in Khattab, M. (ed.), Proceedings of the International Conference on Information Systems in Engineering and Construction (ISEC 2001), Cocoa Beach, FL, 2001, CD-ROM.

Armacost, R., J. Pet-Armacost, M. Mullens, and A. Salem (2001). "Scheduling for Roof Truss Manufacturing," in Harris, R. (ed.), Proceedings of the ICC&IE and IEMS 2001 Joint Meeting, Cocoa Beach, FL 2001, pp. 644-649.

Baechler, M.; Lubliner, M; Gordon, A (2002). "Pushing the Envelope: A Case Study of Building the First Manufactured Home Using Structural Insulated Panels" 2002 ACEEE Summer Study on Energy Efficiency in Buildings Conference, Pacific Grove, CA.

Broadway, R. and M. Mullens (2004). "Shop Floor Information Systems for Industrialized Housing Production," Industrial Engineering Research '04 Conference Proceedings, Houston, May, 2004. http://hcl.engr.ucf.edu/research/Current/Shop_floor_info_mam.pdf

Chasar, D., Moyer, N., McIlvaine, J., Beal, D. and Chandra, S. (2004) "Energy Star Manufactured Homes: The Plant Certification Process," Proceedings of ACEEE 2004 Summer Study, American Council for an Energy Efficient Economy, Washington, DC, August 2004. http://www.fsec.ucf.edu/bldg/baihp/pubs/estar-hudcert/index.htm

Chasar, D., Moyer, N., Chandra, S., Rotvold, L., Applegren, R. (2004). "Cold Climate Case Study; High Efficiency North Dakota Twin Homes," Performances of Exterior Envelopes of Whole Buildings IX International Conference, Clearwater Beach, Florida, December 2004.

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15. Budget: The table below provides the budget information. All figures are in K$. The top half of the table shows the funding received over the years since project inception and the DOE $s that were allocated to FSEC and the subcontractors. It also shows the matching required by fiscal year. Please note that the actual cash and in-kind match provided through 3/31/05 has been $2,079K which is 26.3% of the DOE$s received, greater than the contractually required match of 25%. Unlike some other prime BA teams, we have not counted cost of construction of test homes towards matching funds.

The bottom half of the table provides budget estimates by performing organization, for the 15 tasks that are being performed now. These are only estimates as DOE never required task level details except for some specific tasks from time to time.

BAIHP Funding	(All figures in K$)							
Funding Summary for BAIHP since project inception								
Dates	9/99 10/00	11/00 3/01	4/01- 3/02	4/02- 3/03	4/03- 3/04	4/04- 3/05	4/05- 3/06	
Budget Period	**BP1**	**BP2**	**BP3**	**BP4**	**BP5**	**BP6**	**BP7**	**Total**
FSEC	549.1	378	938.6	1331.3	1171.7	1057	1075.7	6501.4
WSU	130	322	350	217	225	200	206.3	1650.3
UCFIE	99.7	0	150	150	150	138	138	825.7
FLHero	0	0	25	30	50	45	50	200
ALACF	21.2	0	25	12.8	15	0	0	74
NCATU	0	0	24.4	20	0	0	0	44.4
DR Wastchak	0	0	25	30	0	0	0	55
Others	0	0	10	10	10	5	5	40
Total Subs	250.9	322	609.4	469.8	450	388	399.3	2889.4
Total DOE	800	700	1548	1801.1	1621.7	1445	1475	9390.8
Match	321	54	422.7	426.1	399.4	361.3	362.5	2347
Match %DOE	40.1%	7.7%	27.3%	23.7%	24.6%	25.0%	24.6%	25.0%
Current Year (4/1/05-3/31/06) Level of Effort by Tasks					**(DOE K$)**			
Research		FSEC	WSU	UCFIE	FLHero	Calcs-Plus	Total	
1. Performance Monitoring		150	10				160	
2. Ventilation and Moisture		150					150	
3. Cool Roofs		60					60	
4. NightCool		80					80	
5. Condenser Fan		50					50	
6. Water Intrusion		40		93			133	
7. Manufacturing Productivity		10		20			30	
Technical Assistance								
8. Moisture Diagnostics		40					40	
9. Airtight Ducts		40					40	
10. Super Good Cents		40	126				166	
11. Habitat for Humanity		175	10				185	
12. Community Scale		40	20		45		105	
13. Prototype Homes		50				5	55	
Other								
14. Research Collaborations		51	20	10			81	
15. Publications, Workshops		100	20	15	5		140	
	Totals	1076	206	138	50	5	1475	

16. Principal Project Personnel: Brief sketches of researchers involved in the project are summarized below. Additional information is available on line at: http://www.fsec.ucf.edu/bldg/baihp/RESEARCHERS/index.htm

Stephen Barkaszi, MS, 0.4FTE. At FSEC for over 10 years, Stephen is a photovoltaics expert and assists in incorporating renewables and monitoring them in BAIHP homes.

David Beal, BS, 1.0 FTE. At FSEC for over 20 years, David provides technical assistance to home manufacturers and builders as well as conducting building science research.

Subrato Chandra, Ph.D., 0.9 FTE. At FSEC for over 27 years Subrato serves as the project director and principal investigator. He is recognized for his work in Indoor Air Quality and Natural Ventilation.

Dave Chasar, P.E., 0.9 FTE. At FSEC for over 10 years, Dave provides technical assistance to home manufacturers and builders as well as conducting building science research.

Philip Fairey, MS, 0.1 FTE. At FSEC for over 25 years, Philip serves as its deputy director. Philip leads FSEC participation in BA benchmark and support of DOE codes and standards efforts.

Ken Fonorow, 0.75FTE. With over 30 years of experience and as owner of FL Hero, Ken is the force which has transformed the Gainesville, FL housing market to have the most Energy Star homes per capita. Provides technical assistance to production builders to build energy efficient communities. Time is provided under subcontract to FL Hero.

David Hoak, 0.75FTE. With FSEC for 3 years, David is an expert on energy automation, computers and efficient equipment. He lives in a very energy efficient home monitored by BAIHP. Assists in instrumentation, data analysis and in diagnostic testing of homes.

Michael Lubliner, BS, 0.75. At WSU for over 20 years, Michael is nationally recognized for his work in advancing energy efficiency in manufactured housing. Serves on ASHRAE and NFPA committees.

Eric Martin, MS, 1.0 FTE. At FSEC for over 10 years, Eric leads our Green building activities and provides technical support to builders and home manufacturers

Janet McIlvaine, BS, 1.0 FTE. At FSEC for over 15 years, Janet leads our work with Habitat for Humanity and provides technical assistance to home manufacturers and builders.

Michael Mullens, Ph.D., PE, 0.5FTE. At UCF since 1990 Michael is an associate professor and is nationally recognized for his work on advancing housing quality. Leads manufacturing productivity and water intrusion tasks.

Neil Moyer, BS, 0.9 FTE. Neil has over 25 years experience as a building scientist and is nationally recognized. At FSEC for over 5 years he conducts building science research and training.

Danny Parker, MS, 0.7 FTE. At FSEC for over 20 years Danny is nationally recognized for his work on cool roofs, fan blades and monitored energy performance of homes and HVAC equipment.

John Sherwin, BS, 1.0 FTE. At FSEC for over 20 years John is an expert on instrumentation. John leads field monitoring and assists in condenser fan and cool roof research.

Robin Vieira, MS, 0.1 FTE. At FSEC for over 20 years, Rob is the director of buildings research at FSEC. He provides administrative oversight and is responsible for the EnergyGauge USA software.

17. Other Information Sources: Project Website is www.baihp.org