Building America Industrialized Housing Partnership (BAIHP)

Annual Report – Sixth Budget Period
April 1, 2004 - March 31, 2005

FSEC-CR-1533-05
Produced by the
BAIHP Team

Stephen Barkaszi, FSEC
David Beal, FSEC
Subrato Chandra, FSEC
David Chasar, FSEC
Carlos Colon, FSEC
Ken Fonorow, FLHERO
Andrew Gordon, WSU
David Hoak, FSEC
Stephanie Hutchinson, ALACF
Mike Lubliner, WSU
Eric Martin, FSEC
Ross McCluney, FSEC
Mark McGinley, NCA&TSU
Janet McIlvaine, FSEC
Mike McSorley, WSU
Neil Moyer, FSEC
Mike Mullens, UCFIE
Danny Parker, FSEC
John Sherwin, FSEC
Rob Vieira, FSEC
Susan Wichers, FSEC

Compiled by Janet McIlvaine and Susan Wichers, FSEC

University of Central Florida/ Florida Solar Energy Center
12443 Research Parkway, Suite 207
Orlando, Florida 32826

October 30, 2005

PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY
Under Cooperative Agreement
No. DE-FC26GO10478

TABLE OF CONTENTS

ACKNOWLEDGMENT

This work is sponsored, in large part, by the US Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Building Technologies Program under cooperative agreement number DE-FC26--99GO10478. This support does not constitute an endorsement by DOE of the views expressed in this report. Additional funding was provided by the Florida Department of Community Affairs and the Northwest Energy Efficiency Alliance. Their support is appreciated.

The authors appreciate the encouragement and support from George James, Ed Pollock, and Chris Early, program personnel at DOE, Keith Bennett, project officer in Golden, Colorado and Bill Haslebacher, project officer at the National Energy Technology Laboratory. We also are grateful to our colleagues Philip Fairey, and Safvat Kalaghchy for advice and assistance. Thanks to project staff (Bob Abernethy, Mable Flumm, Wanda Dutton, Rafik Alidina and Joy Mayne) and students (Matt Lombardi, Mike McCloud, and Matt McCloud) for their contributions.

This work could not have been completed without the active cooperation of our industry partners and all collaborators. We greatly appreciate their support.

BAIHP researchers and staff in front of the Manufactured Housing Lab at FSEC (Back row from left to right.) Neil Moyer, Subrato Chandra, Mike Mullens, Wanda Dutton, David Beal, Dave Chasar, Rafik Alidina, Ross McCluney. (Front row from left to right.) John Sherwin, Bob Abernethy, Danny Parker, Janet McIlvaine.

EXECUTIVE SUMMARY

Background and Scope
This report covers the 6th budget period (April 1, 2004 - March 31, 2005) and includes significant material from the first five budget period annual reports (September 1, 1999 - March 31, 2004) for a comprehensive account of the Building America Industrialized Housing Partnership (BAIHP) work to date.

The BAIHP team is one of five Building America teams competitively funded by the US Department of Energy, Office of Energy Efficiency and Renewable Energy-Building Technologies program. BAIHP began work on September 1, 1999 with a focus on improving energy efficiency, durability, and indoor air quality of new industrialized housing.

Industrialized housing includes manufactured housing (built to the HUD code), modular housing (factory built housing modules assembled on site), production housing (site built housing produced in a systematic manner). *Figure E-1* shows 2004 U.S. home production by sector.

BAIHP's work during the 6th budget period included:
- Technical Assistance
- Field and Laboratory Research
- Training and Education
- Collaborations
- Project Management

BAIHP Technical Assistance
The BAIHP team provided technical assistance to HUD Code Home manufactures, modular home manufacturers, and site builders including Habitat for Humanity International and its affiliates throughout the nation. Site builders receiving technical assistance are located primarily North and Central Florida.

BAIHP also collaborates with suppliers and non-profit organizations See *Table E-1* for a list of BAIHP Industry Partners.

Systems engineering forms the core of the Building America approach. BAIHP industry partners evaluate the integration of their construction standards and consider improvements that enhance energy efficiency, durability, indoor air quality, and health.

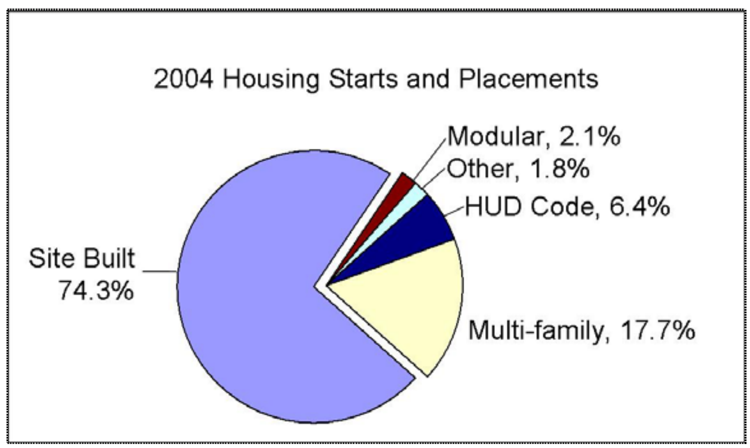


Figure E-1 *2004 census data shows 1.9 million housing starts (site built) and placements (manufactured).*
Note: total exceeds 100% due to disagreement among sources on total starts.
Sources of Housing Starts Statistics:
-Multi Family: http://www.census.gov/const/startsan.pdf
-Site Built, Modular:http://www.census.gov/const/C25Ann/sftotalconstmethod.pdf
-Manufactured Housing Placements: http://www.census.gov/const/mhs/mhstabplcmnt.pdf

In providing technical assistance BAIHP generally recommends improving equipment efficiency and reducing conditioning loads while taking durability and health issues into consideration. Some examples include:

Improving Equipment Efficiency

- High efficiency, correctly sized heating and cooling equipment
- Water heating efficiency
- Duct system design and construction
- Appliances
- Lighting efficiency

Reducing Conditioning Loads

- Orientation, shading, and window characteristics
- Surface heat gain (roof finish)
- Thermal, moisture, and air barrier envelope

Durability and Health Issues Considered

- Fresh air ventilation
- Moisture control and dehumidification
- Pressure balance and return air flow
- Materials selection
- Maintenance

It is the combination of these improvements that enables the BAIHP industry partners to achieve high performance homes like those documented in *Table E-2, Homes Built in Partnership with BAIHP*.

BAIHP tracks Industry Partners production in 4 categories:

- Category A: Homes meeting the Building America program goal of saving at least 30% of whole house energy use compared to the 2005 Building America benchmark, incorporating fresh air ventilation, and including superior durability and health features. HERS Score results are greater than 88.6.
- Category B: Homes meeting the EPA Energy Star criteria for saving 30% of heating, cooling, and water heating energy use.
- Category C: Homes with energy efficiency improvements falling slightly short of the EPA Energy Star criteria for saving 30% of heating, cooling, and water heating energy use. HERS score of approximately 85. Also homes designed and built to this level or higher but not specifically rated and tested by BAIHP.
- Category D: Manufactured homes built with substantially leak free ducts ($Qn_{OUT} \leq 0.03$). This category may include some Category B and C homes.

Since inception, BAIHP has assisted home builders and manufacturers to construct:

- 15,656 homes built to Energy Star level or better *(Category A and B, Table E-2)*
- 13,067 homes built 30% to 50% better than the HUD code - approx 5% below Energy Star *(Category C, Table E-2)*
- ~79,300 manufactured homes with airtight duct systems *(Category D, Table E-2)*

These homes are estimated to save over $14 million annually in reduced energy bills for their owners.

Table E-1 BAIHP Industry Partners (Present and Past)	
HUD Code Home Manufacturers	
Cavalier Homes CAVCO Industries LLC Champion Homes (Redman) Champion Homes (Silvercrest) Clayton Homes Fleetwood Homes Fuqua Homes Golden West Homes Guerdon Enterprises Hi-Tech Homes Homebuilders North West Homes of Merit	Karsten Company Kit Manufacturing Liberty Homes Marlette Homes Nashua Homes Oakwood Homes Palm Harbor Homes Skyline Corporation Southern Energy Homes Valley Manufactured Housing Western Homes
Modular Builders	
Avis America Homes Cardinal Homes Epoch Corporation Excel Homes General Homes	Genesis Homes Nationwide Homes Penn Lyon Homes The Homestore
Production Builders	
All America Homes American Energy Efficient Homes & Investments Inc. AMJ Construction Arvida Homes Atlantic Design and Construction Beck Builders Cambridge Homes Centex Homes	Dye Company G.W. Robinson Builder New Generation Homes by Kingon Inc. On Top of the World Podia Construx Regents Park (Condominiums) Rey Homes WCI Communities Winton/Flair Homes
Affordable Housing Builders	
East Dakota Housing Alliance City of Gainesville, FL City of Lubbock, TX City of Orlando, FL	Habitat for Humanity International HKW Enterprises Sandspur Housing (Apartment builders) Williamsburg (townhouses)
Custom Builders	
All America Homes of Gainesville, Inc. Fallman Design and Construction Marquis Construction & Development, Inc.	Pruett Builders, Inc. Spain Construction Timeless Construction

Table E-2 Homes Built in Partnership with BAIHP (through 3/05)

Category / Industry Partner	Homes	Dates			
A) Homes with HERS scores >=88.6 (counts as 89 in NREL database)					
Homes assisted by FL HERO (Bldrs- Atlantic Design, GW Robinson, Tommy Williams+~12 others)	100	10/02 - 3/05			
Fallman design and construction	2	09/01 - 08/03			
Palm Harbor Homes	2	Aug 04- Jan 05			
Sharpless Construction	1	Jun 02			
WCI	2	Aug 04			
Applegren Construction (East Dakota Housing Alliance)	10	March 05			
Habitat for Humanity, Lakeland, FL	1	Jun 01			
Category A Total	**118**				
B) Homes with HERS scores of approx 86 or more	(Includes Category A homes for now)				
SGC/NC West of the Cascades+Natural Choice	11,152	09/99 - 2/05			
Homes by FL HERO	1278	~01/00 - 3/05			
Palm Harbor Homes	15	~01/00 - 01/05)			
Habitat for Humanity	418	1998 - 12/04			
Homes by D.R.Wastchak in Phoenix, AZ	2,658	~01/00 - 10/02			
Marquis Construction	1	Jun 03			
Applegren Construction (East Dakota Housing Alliance)	13	March 05			
Redman Homes	1	Dec 01			
Cambridge Homes	2	Dec 03			
Category B Total	**15,538**				
C) Homes just below Energy Star (HERS approx 85, homes not rated)					
Old Natural Choice (thru 11/01) + SGC east of the Cascades	11,162	09/99 - 2/05			
Energy Efficient Div of PHH in North Carolina	1,645	09/99 - 02/01			
Habitat Homes (approx.)	260	1995 - 2001			
Category C Total	**13,067**				
D) Homes with just airtight ducts	(May include some Category B and C homes)				
	Total	2000-01	2002	2003	2004
Palm Harbor Homes	45,768	22,361	9,639	6,871	6,897
Cavalier	1,132	1,132	0	0	0
Southern Energy	21,131	8,600	4,203	4,000	4,328
Fleetwood	11,262	0	500	1,280	9,482
Category D Total	**79,293**				
Approximate Energy Savings (mBtu/yr)	**1,011,507**				
Approximate $/yr savings @$14/mBtu	**$14,161,095**				

BAIHP Research

BAIHP's ongoing research strives to identify the strategies and technologies that will enable Industry Partners to reach the Department of Energy's 2010 goals for energy savings. By systematically evaluating the savings potential technologies and construction techniques, research provides the home building industry with vital information needed to meet this challenge. BAIHP Research presented here is grouped into three categories: *Manufactured Housing Research, Site Built Housing Research,* and *Field and Laboratory Building Science Research.*

Manufactured Housing Research

BAIHP has found that using the systems engineering approach to help Industry Partners solve building science related problems develops a strong working relationship and increases the likelihood of the Partner incorporating concepts central to achieving Building America goals such as sealed and tested ducts, right sizing air conditioning, and moisture management. BAIHP's work with the manufactured housing industry illustrates this principal.

BAIHP conducted research for manufactured homes in both field and laboratory which is reported in the following summaries:

- Building Science and Moisture Problems in Manufactured Housing
- BAIHP Field Visits to Moisture Problem Homes
- Manufacturers Participating in Building Science Research
- Side By Side Study Of Energy Use And Moisture Control Comparing Standard Split System Air Conditioning And A Coleman® Prototype Heat Pump, Bossier City, LA
- WSU Energy House
- Zero Energy Manufactured Home (ZEMH)
- Manufactured Housing Indoor Air Quality Study
- Manufactured Housing Laboratory – Ventilation Studies
- Manufactured Housing Energy Use Study, North Carolina A&T
- Portable Classrooms
- Duct Testing Data from Manufactured Housing Factory Visits
- Crawl Space Moisture Research for HUD Code Homes

Site Built Housing Research

Industry Partners rise above "business as usual" production to strive toward the Building America program goals of saving 40% of total energy use while improving durability, indoor air quality, and comfort. BAIHP assists the builders, much as described in Section II, Technical Assistance, but goes on to instrument and collect relevant data to validate the approach.

BAIHP conducted research for site built housing which is reported in the following summaries:

- Building America Prototype, Cambridge Homes
- Unvented Attic Study, Rey Homes
- Sharpless Construction, Hoak Residence Energy and Moisture Studies
- Eastern Dakota Housing Alliance (EDHA), Applegren Construction
- Zero Energy Affordable Housing, ORNL and Loudon County Habitat for Humanity
- Apartment Ventilation and Humidity Study, Sandspur Housing
- Hurricane Retrofit Study

Field and Laboratory Building Science Research
BAIHP builds on a 20 year foundation of basic building science research at the Florida Solar Energy Center. This research generally focuses on issues important in hot-humid climates similar to Florida's but is relevant to our understanding of building science concepts manifest in all climatic regions. BAIHP has conducted field and laboratory building science research in these areas:

- Air Handler Air Tightness Study
- Air Conditioning Condenser Fan Efficiency
- Reflective Roofing Research
- Return Air Pathway Study
- Heat Pump Water Heater Evaluation
- NightCool - Building Integrated Cooling System

BAIHP Training and Education Summary
BAIHP research is communicated to public and industry audiences through the BAIHP web page, conference papers and presentations, and various media coverage. Training events are listed in reverse chronological order, divided by budget period.

BAIHP has presented research findings and Building America systems engineering concept to a variety of audiences including architects, builders, HUD Code home manufacturers, and housing decision makers; construction trades and realtors; attendees at building science conferences; portable classroom producers and decision makers; energy raters and green home certifiers, and college students in academic venues.

The BAIHP web page offers access to any interested parties with presentation of case studies, research, and publications.

BAIHP Collaboration
BAIHP researchers collaborate with a variety of entities in the homebuilding industry and the energy efficiency and research realm including DOE National Labs, Code and Standards Bodies, and Industry/Professional Organizations, Universities, and Product Suppliers.

BAIHP Project Management
BAIHP project management includes participating in Building America program reviews/meetings and preparing monthly and yearly reports for project activities as well as managing all project tasks (see Sections 1-6) and subcontracts. In the 5th Budget Period, BAIHP also held a Project Review Meeting at FSEC in January 2004 to give interested parties an opportunity to give feedback to the project management team. In the 6th Budget Period, BAIHP began participating in DOE's Peer Review process which was completed during the 7th budget period.

Project Contact
Subrato Chandra, BAIHP Project Director
Florida Solar Energy Center
1679 Clearlake Road
Cocoa, FL 32922
321-638-1412

www.baihp.org
www.fsec.ucf.edu
subrato@fsec.ucf.edu

I

BAIHP INTRODUCTION

BAIHP INTRODUCTION

The Building America Industrialized Housing Partnership (BAIHP) team is one of five Building America teams competitively funded by the US Department of Energy, Office of Energy Efficiency and Renewable Energy-Building Technologies program.

BAIHP History
BAIHP began work on September 1, 1999 with a focus on improving energy efficiency, durability, and indoor air quality of new industrialized housing. DOE funding for the project has been supplemented by cost share funding from the Florida Energy Office (now defunct) of the Florida Department of Environmental Protection, the Northwest Energy Efficiency Alliance (NEEA), Florida Solar Energy Center (FSEC), and many Industry Partners. FSEC, a research institute of the University of Central Florida (UCF), serves as the project prime contractor.

Scope of this Report
This report covers the 6th budget period (April 1, 2004 - March 31, 2005) and includes significant material from the first five budget period annual reports for a *comprehensive* account of the BAIHP work to date.

BAIHP's Goals
1. Cost effectively reduce the energy cost of industrialized housing and portable classrooms by up to 50% while enhancing indoor air quality, durability and productivity.
2. Assist in the construction of thousands of energy efficient industrialized houses annually.
3. Make our partners pleased and proud to be working with us.

BAIHP Research Team
The Florida Solar Energy Center (FSEC) and the Department of Industrial Engineering of the University of Central Florida (UCF) serve as the prime contractor. Subcontractors during the 6th budget period included the Washington State University Energy Program (WSU), the Florida Home Energy and Resources Organization (Florida H.E.R.O.) and Calcs-Plus.

Previously funded subcontractors have included the American Lung Association of Washington, the American Lung Associations of Central Florida (ALACF), Blue Sky Foundation of North Carolina, D.R. Wastchak, GreenSmart Inc., North Carolina A&T State University, the Oregon Office of Energy, the Idaho Department of Water Resources, and Alten Design.

What is Industrialized Housing?
Industrialized housing encompasses much of modern American construction including:

- Manufactured Housing – factory-built to the nation wide HUD Code
- Modular Housing - factory-built, site assembled modules meeting local code
- Production Housing - site-built systematically, factory built components

The project scope has also included portable classrooms during 2000-2002.

Of the 1.8 million homes built in the US in 2004 *(Figure 1)*, over 6% were factory built to US Housing and Urban Development (HUD) code (U.S. Department of Commerce, 2003(a)(b) referred to as HUD Code Homes or Manufactured Homes. Manufactured Homes are one of the most affordable types of single-family detached housing available anywhere in the world, generally costing less than $35/ft^2 plus land costs for centrally air conditioned and heated homes with built-in kitchens. Available in all parts of the country, manufactured homes are more popular in rural areas and in the southern and western US where land is still plentiful.

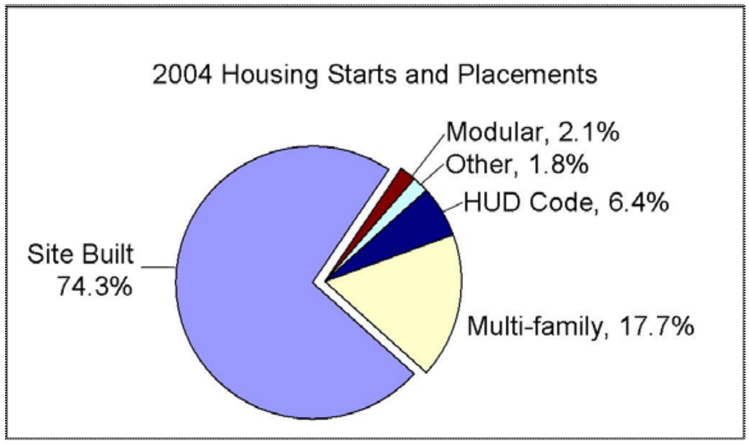


Figure 1 *2004 census data shows 1.9 million housing starts (site built) and placements (manufactured).*
Note: total exceeds 100% due to disagreement among sources on total starts.
Sources of Housing Starts Statistics:
-Multi Family: http://www.census.gov/const/startsan.pdf
-Site Built, Modular:http://www.census.gov/const/C25Ann/sftotalconstmethod.pdf
-Manufactured Housing Placements: http://www.census.gov/const/mhs/mhstabplcmnt.pdf

Scope of BAIHP Activities
Within the larger context of the Building America program, BAIHP works to foster achievement of the Department of Energy's goals. BAIHP researchers work in these areas:

- Technical Assistance (Section I)
- Field and Laboratory Research (Section II)
- Training and Education (Section III)
- Collaborations with the Homebuilding and Energy Industries (Section IV)
- Project Management (Section V)

Industry Partnerships
Many manufacturers, builders, suppliers, and research organizations have joined the Building America Industrialized Housing Partnership. Those receiving Technical Assistance for their projects are described Section II of this report. Those participating in BAIHP Research efforts are described in Section III. *Table 1* lists current and past BAIHP Project Industry Partners by housing sector.

Project Contact
Subrato Chandra, BAIHP Project Director
Florida Solar Energy Center
1679 Clearlake Road
Cocoa, FL 32922
321-638-1412
www.baihp.org
www.fsec.ucf.edu
subrato@fsec.ucf.edu

Table 1 BAIHP Industry Partners (Present and Past)

HUD Code Home Manufacturers	
Cavalier Homes	Karsten Company
CAVCO Industries LLC	Kit Manufacturing
Champion Homes (Redman)	Liberty Homes
Champion Homes (Silvercrest)	Marlette Homes
Clayton Homes	Nashua Homes
Fleetwood Homes	Oakwood Homes
Fuqua Homes	Palm Harbor Homes
Golden West Homes	Skyline Corporation
Guerdon Enterprises	Southern Energy Homes
Hi-Tech Homes	Valley Manufactured Housing
Homebuilders North West	Western Homes
Homes of Merit	
Modular Builders	
Avis America Homes	Genesis Homes
Cardinal Homes	Nationwide Homes
Epoch Corporation	Penn Lyon Homes
Excel Homes	The Homestore
General Homes	
Production Builders	
All America Homes	Dye Company
American Energy Efficient Homes & Investments Inc.	G.W. Robinson Builder
	New Generation Homes by Kingon Inc.
AMJ Construction	On Top of the World
Arvida Homes	Podia Construx
Atlantic Design and Construction	Regents Park (Condominiums)
Beck Builders	Rey Homes
Cambridge Homes	WCI Communities
Centex Homes	Winton/Flair Homes
Affordable Housing Builders	
East Dakota Housing Alliance	Habitat for Humanity International
City of Gainesville, FL	HKW Enterprises
City of Lubbock, TX	Sandspur Housing (Apartment builders)
City of Orlando, FL	Williamsburg (townhouses)
Custom Builders	
All America Homes of Gainesville, Inc.	Pruett Builders, Inc.
Fallman Design and Construction	Spain Construction
Marquis Construction & Development, Inc.	Timeless Construction

II

BAIHP TECHNICAL ASSISTANCE

BAIHP TECHNICAL ASSISTANCE

The BAIHP team provided technical assistance to HUD Code Home manufactures, modular home manufacturers, and site builders including Habitat for Humanity International and its affiliates throughout the nation. Site builders receiving technical assistance are located primarily in the hot-humid region of North and Central Florida.

Systems engineering forms the core of the Building America approach. BAIHP Industry Partners evaluate the integration of their construction standards and consider improvements that enhance energy efficiency, durability, indoor air quality, and health of their homes. The Industry Partner decides which improvements to implement.

In providing technical assistance BAIHP generally recommends improving equipment efficiency and reducing conditioning loads while taking durability and health issues into consideration. Some examples include:

Improving Equipment Efficiency

- High efficiency, correctly sized heating and cooling equipment
- Interior duct systems and unvented attics
- High efficiency water heating, appliances, and lighting.

Reducing Conditioning Loads

- Well orientated and shaded windows
- Climate appropriate windows characteristics
- Reflective or absorptive surfaces (roof, wall)
- Continuous thermal, moisture, and air barriers

Durability and Indoor Air Quality

- Fresh air ventilation
- Moisture control
- Balanced/controlled air flow
- Reduced long term maintenance needs

It is the combination of these improvements that enables the BAIHP Industry Partners to achieve high performance homes *(Figure 2)* to move the homebuilding industry toward DOE's 2010 goals. *Table 2, Homes Built in Partnership with BAIHP*, shows BAIHP Industry Partner production in 4 categories:

- *Category A:* Homes meeting the Building America program goal of saving at least 30% of whole house energy use compared to the 2005 Building America benchmark, incorporating fresh air ventilation, and including superior durability and health features. HERS Score results are greater than 88.6.
- *Category B:* Homes meeting the EPA Energy Star criteria for saving 30% of heating, cooling, and water heating energy use.

- *Category C:* Homes with energy efficiency improvements that fall slightly short of the EPA Energy Star criteria for saving 30% of heating, cooling, and water heating energy use. HERS score of approximately 85. Also homes designed and built to this level or higher that have not been specifically rated and tested by BAIHP.
- *Category D:* Manufactured homes built with substantially leak free ducts ($Qn_{OUT} \leq 0.03$). This category may include some Category B and C homes.

Since inception, BAIHP has assisted home builders and manufacturers to construct:

- 15,656 homes built to Energy Star level or better *(Category A and B, Table 2)*
- 13,067 homes built 30% to 50% better than the HUD code - approx 5% below Energy Star *(Category C, Table 2)*
- ~79,300 manufactured homes with airtight duct systems *(Category D, Table 2)*
- Estimated energy savings to homeowners: Over $10 million annually

Section II describes each BAIHP Industry Partnership, arranged alphabetically. Readers may contact the BAIHP researchers noted in the heading of each summary for further information. Many of these Industry Partners are also featured on the BAIHP website at www.baihp.org.

Figure 2 *Building America homes like this one built by BAIHP Industry Partner G.W. Robinson Homes in the Cobblefield community (Gainesville, Florida) reduce energy bills for individual homeowners while pushing the standard of building closer to DOE's 2010 goals saving 30% in whole house energy use (source energy) compared to the 2005 Building America benchmark.*

Table 2 Homes Built in Partnership with BAIHP (through 3/05)

Category / Industry Partner	Homes	Dates			
A) Homes with HERS scores >=88.6 (counts as 89 in NREL database)					
Homes assisted by FL HERO (Bldrs- Atlantic Design, GW Robinson, Tommy Williams+~12 others)	100	10/02 - 3/05			
Fallman design and construction	2	09/01 - 08/03			
Palm Harbor Homes	2	Aug 04- Jan 05			
Sharpless Construction	1	Jun 02			
WCI	2	Aug 04			
Applegren Construction (East Dakota Housing Alliance)	10	March 05			
Habitat for Humanity, Lakeland, FL	1	Jun 01			
Category A Total	**118**				
B) Homes with HERS scores of approx 86 or more	(Includes Category A homes for now)				
SGC/NC West of the Cascades+Natural Choice	11,152	09/99 - 2/05			
Homes by FL HERO	1278	~01/00 - 3/05			
Palm Harbor Homes	15	~01/00 - 01/05			
Habitat for Humanity	418	1998 - 12/04			
Homes by D.R.Wastchak in Phoenix, AZ	2,658	~01/00 - 10/02			
Marquis Construction	1	Jun 03			
Applegren Construction (East Dakota Housing Alliance)	13	March 05			
Redman Homes	1	Dec 01			
Cambridge Homes	2	Dec 03			
Category B Total	**15,538**				
C) Homes just below Energy Star (HERS approx 85, homes not rated)					
Old Natural Choice (thru 11/01) + SGC east of the Cascades	11,162	09/99 - 2/05			
Energy Efficient Div of PHH in North Carolina	1,645	09/99 - 02/01			
Habitat Homes (approx.)	260	1995 – 2001			
Category C Total	**13,067**				
D) Homes with just airtight ducts	(May include some Category B and C homes)				
	Total	2000-01	2002	2003	2004
Palm Harbor Homes	45,768	22,361	9,639	6,871	6,897
Cavalier	1,132	1,132	0	0	0
Southern Energy	21,131	8,600	4,203	4,000	4,328
Fleetwood	11,262	0	500	1,280	9,482
Category D Total	**79,293**				
Approximate Energy Savings (mBtu/yr)	**1,011,507**				
Approximate $/yr savings @$14/mBTtu	**$14,161,095**				

All America Homes of Gainesville
Gainesville, Florida
Category A, 2 Homes
Awards: 2003 Energy Value Housing Award, Silver Medal, Custom Home/Hot Climate
2002 South East Builder's Conference, Grand Aurora Award for Solar Energy

All America Homes has been in business for 17 years and builds 10 homes each year in the Gainesville (FL) area. After providing design assistance for the award wining 2002 home (*Figure 3*) during the 4th budget period, BAIHP provided additional assistance to All America for a second home with solar and energy efficiency concepts during the 5th budget period. The home was built with a photovoltaics (PV) system, and achieved a HERS rating of 90.6. This home serves as a model for the hot-humid climate using a combination of on-site power generation and energy efficiency to reach near-zero utility demand, similar to the home built in 2002 *(Table 3)*.

Figure 3 *All America Homes of Gainesville, 2003 Energy Value Housing Award, Silver Medal, Custom Home/Hot Climate.*

It incorporates energy efficient air conditioning, hydronic solar water heating, excellent air distribution design and construction (pressure tested for validation) and right sizing of the heating and cooling capacity. It also incorporates envelope improvements in the roof, ceiling, walls, windows and infiltration control. A passive fresh sir ventilation system provides filtered outside air to the return side of the mechanical system during operation. See *Appendix C, Florida H.E.R.O. Standard Technical Specifications.*

Table 3 All America Homes of Gainesville (FL) Specifications

Component	**2002 Home**	**2003 Home**
Conditioned Area	3644 sq ft	2884 sq ft
Hers Score	90.6	90.6
Utility Cost	\$150 for summer (including water, sewer, and trash pickup) (Source: Homeowner records.)	Average summer energy use = 58kw/day (Source: Gainesville Regional Util.)
Solar: PV Array	2.5 kW	1.8 kW
Solar: Water Heating	Integrated storage solar collector (4' x 8') EF . 2.4	Integrated storage solar collector (4' x 8') EF . 4.7
Solar: Water Heating	Solar pool heater	N/A - no pool
Solar: Attic Ventilation	PV powered attic fan	N/A – Unvented attic
Solar: Outdoor Lighting	PV (low-voltage) patio lighting.	N/A – No pool.
Heating	Hydronic coil with solar heated water and gas backup	Hydronic coil with solar heated water and instantaneous gas backup
Cooling	SEER 14 AC Variable speed AHU fan Maintains indoor RH =< 60%	Dual compressor SEER 17 Variable speed AHU fan Maintains indoor RH =< 60%
Ducts	Interior Duct System Fur down construction	Interior Duct System in Unvented Attic
Duct Leakage	$CFM25_{OUT}$ < 5% of AHU flow	$CFM25_{OUT}$ <5% of AHU flow

Table 3 All America Homes of Gainesville (FL) Specifications

Roof/Ceiling Assembly	Radiant barrier roof decking R-30 dense pack cellulose (ceiling)	R-20 Icynene at roof decking unvented attic
Wall Assembly	R-13 Dense pack cellulose	R-15 Blown in batt fiberglass
Windows	Reduced window area	
Glazing & Frame	Double pane, vinyl frame	Same
Window Radiant Gain	Large overhangs (high windows located beneath the roof overhangs to provide daylighting without contributing to solar heat gain)	Low-E glazing for unshaded east and west windows
Lighting	85% fluorescent.	95% fluorescent
Infiltration	Natural ACH < 0.1	Est. natural ach =0.059
Ventilation	Filtered passive fresh air inlet on the return side of AHU	Same

AMJ Construction
Gainesville, Florida
Category A, 54 Town homes (ongoing)

Florida Home Energy Rating Organization (Florida H.E.R.O.) provided an engineered duct system for 26 models in the Regents Park Townhouse development. This downtown urban infill project will result in 54 units with Building America features including ductwork in the conditioned space, outside air ventilation, and combo hydronic heat and 13 SEER cooling. Each of the 54 units will be individually performance tested. Three completed units have been tested, each scoring well over HERS 89.

Applegren Construction, Eastern Dakota Housing Alliance (EDHA)
Grand Forks, North Dakota
Category A, 2 Homes
Category B, 5 Homes
Awards: *North Dakota Housing Finance Agency's Champion of Affordable Housing Production Award*
Papers: *Cold Climate Case Study: High Efficiency North Dakota Twin Homes*

EDHA set a goal of achieving up to 50% energy savings over the 1993 Model Energy Code with superior indoor air quality (AIQ). Phase I (March 2003) and Phase II (Feb 2004) each included two twin homes (duplexes) for a total of eight homes.

Figure 4 *Selkirk Twin Homes, Grand Forks, ND.*

The two story dwellings *(Figure 4)* include an insulated basement with air circulation to the main house, suitable for conversion to living space. Features of the Phase I and Phase II homes are summarized in *Table 4* which also shows a theoretical base case house using local conventional construction and code minimums modeled in DOE2 to determine energy savings and cost effectiveness. Estimated combined gas and electric utility savings ranged from 25% on Phase I homes to 35% on Phase II homes over the base case. The homes also met the BA goal of 40% savings compared to the Benchmark house.

Annual Energy Use

A performance comparison of the base case and improved structures is shown in *Table 5.* The DOE2 model predicts the need for very little cooling, however many new homes in this area, including these, are being built with central air conditioning.

Moisture Issues

Phase II of construction added a layer of R-10 rigid extruded polystyrene (XPS) to the exterior side of the wall assembly. The low water vapor permeance of rigid XPS foam sheathing (1.1 perms) presents a dilemma in this climate where an interior vapor barrier (usually 6-mil polyethylene) is considered mandatory to minimize moisture diffusion from the conditioned space into the wall cavity. The installation of two vapor barriers leaves the wall vulnerable to moisture accumulation should water unintentionally enters the cavity. One BAIHP recommendation calls for removing the interior vapor barrier and relying on two coats of latex paint on the interior to limit diffusion from the conditioned space into the wall. This option allows the wall to dry to some extent in both directions, but was not chosen by the builder.

Ventilation

A heat recovery ventilator (HRV) mounted in the basement provides controlled mechanical ventilation with an energy penalty estimated at $45/year. The unit contains an 80-watt fan that introduces 75 CFM of outside air while exhausting a similar amount at a heat transfer efficiency of 70%. The HRV can operate either continuously or on an intermittent 20 minutes on, 40 minutes off cycle. Intermittent operation was simulated to meet the old guideline. Attempting to meet the new ASHRAE 62.2 standard (ASHRAE 1999) would require 42 CFM of continuous ventilation. For these simulations however, the old ASHRAE guideline of 0.35ACH was used, calling for a continuous rate of 25 CFM.

Table 4 Applegren Twin Home Specifications

Component	Base Case	Phase I (March 2003)	Phase II (Feb 2004)
Conditioned Area Of Each Dwelling	1840 sq. ft. (w/basement)	Same	Same
Hers Score	85.2	89.7	92.2
Estimated Annual Energy Cost	$1179	$815	$701
% Cost Savings Compared to Base		25%	35%
Heating Cost	$458	$366	$294
Cooling Cost	$15	$11	$10
Hot Water Cost	$245	$157	$116
H/C/WH Total Cost	$718	$534	$420
Envelope			
Above-Grade Wall Structure	2x6 wood frame	Same	2x4 wood frame
Above-Grade Wall Insulation	R-19 fiberglass batt	Same	R-15 blown fiberglass
Above-Grade Wall Sheathing	Plywood	Same	R10 XPS foam corners: R7.5+plywood

Table 4 Applegren Twin Home Specifications

Basement Walls	R-11	Same	Same
Vented Attic	R-49	Same	Same
Windows	Double pane, Low-E, Argon-filled, vinyl slider frame U=0.34, SHGC=0.33	Casement (instead of slider)	Same as Phase I
Infiltration (ACH50) (Including Basement)	5 (assumed)	2.8 (average of 4 units)	2.4 (average of 4 units)
Equipment			
Gas Furnace	60kBtu, AFUE=78	60kbtu, AFUE=92 w/sealed combustion	60kBtu, AFUE=92
Gas Furnace Capacity	29.8kBtu/h	33.4kBtu/h	30.7kBtu/h
Air Conditioner	1.5 ton, 10 SEER	Same	Same
Air Conditioner Capacity	9.9kBtu/h	10.6kBtu/h	10.3kBtu/h
Thermostat	Standard	Programmable	Same as Phase I
Ventilation	None	70% efficient HRV	Same as Phase I
Water Heater	40gallon, EF=0.88 Electric	40 gallon, EF=0.62 Natural gas with power vent	Tankless, EF=0.83 Natural gas
Lighting	10% fluorescent	85% fluorescent (linear and CFL) *Note: only bathroom and dimmable fixtures were incandescent*	Same as phase I
Appliances	Standard	Energy Star dishwasher Horizontal-axis washer Energy Star refrigerator	Same as Phase I

Cost Analysis

Tables 5 (Phase I) and *6* (Phase 2) show the cumulative effect of *All Measures* in comparison to the base case home. The heat recovery ventilator (HRV) is also shown separate from the other measures because the HRV is an essential IAQ feature, yet it increases energy use by $45/year. With the exception of the HRV all measures show a positive cash flow on a 6%, 30 year fixed rate mortgage beginning in the first year.

Table 5 Economic Assessment of Phase I Measures*,**

Energy Measure	Annual Savings	Installed Cost	Simple Payback	First Year Cash Flow
Reduce infiltration to 2.8 ACH50	$90	$325	3.6	$68
Upgrade to 92% direct vent furnace	$52	$600	11.5	$11
Switch to Programmable Thermostat	$23	$130	5.7	$11
Upgrade to Energy Star appliances*	$61	$730	12	$12
Change to EF=0.62 power vented water heater	$52	$520	10	$16
Increase from 10% to 85% fluorescent lighting	$31	$200	6.5	$17
All Measures	**$309**	**$2,505**	**8.1**	**$135**
Heat recovery ventilation @75cfm, 33% RTF	($45)	$1,400	N/A	($134)
All Measures with HRV	**$264**	**$3,905**	**14.8**	**$1**

* Energy Star appliances include refrigerator, dishwasher and h-axis clothes washer.

** First year cash flow based on 30 year fixed rate mortgage with interest rate of 6%, down payment of 5%, and discount rate of 5%. A general inflation rate of 3% per year was applied to the upgrade cost of measures replaced at end of lifetime. Final value of equipment is determined by linear depreciation over lifetime. Interest paid on mortgage is considered tax deductible using a tax rate of 28%. Energy costs escalate at 3% per year. A property tax rate of 0.8% was applied to the energy upgrade cost and is inflated at 3% per year.

The higher savings of Phase II over Phase I arise from two energy saving measures unusual for this region: XPS foam sheathing with 2x4 framing and tankless gas water heating. Simple paybacks for these measures were 8.3 and 13.3 years respectively. Electric water heaters are the current norm in the Grand Forks area, but with electricity 26% below the national average and natural gas prices on the rise, simple payback on the tankless model was relatively long. In addition, fluctuating natural gas prices complicate the economic analysis. Initial concerns of how the tankless water heater would perform in this extreme climate were met with positive feedback through the first winter, which was colder than normal including an all-time record low of -44ºF set at the Grand Forks International Airport on January 30, 2004.

Table 6 Economic Assessment of Phase II

Energy Measure	Annual Savings	Installed Cost	Simple Payback	First Year Cash Flow
Upgrade walls to (R10 sheath + R15 FG batt)	$72	$600	8.3	$31
Reduce infiltration to 2.4 ACH50	$106	$325	3.1	$82
Upgrade to 92% direct vent furnace	$40	$600	15.0	-$1
Switch to Programmable Thermostat	$18	$130	7.2	$6
Upgrade to Energy Star appliances*	$60	$730	12.2	$12
Change to EF=0.83 tankless gas water heater	$94	$1,250	13.3	$10
Increase from 10% to 85% fluorescent lighting	$31	$200	6.5	$18
All Measures	**$421**	**$3,835**	**9.1**	**$158**
Heat recovery ventilation @75cfm, 33% RTF	($43)	$1,400	N/A	($134)
All Measures with HRV	**$378**	**$5,235**	**13.8**	**$24**

Four more dwellings (two duplexes) are slated for completion in the summer of 2004. See also *Cold Climate Case Study: High Efficiency North Dakota Twin Homes* on www.baihp.org.

Atlantic Design and Construction
Gainesville, Florida
Category A
Awards: *2001 EPA Energy Star Builder of the Year*

Atlantic Design & Construction (AD&C) is a production builder located in Gainesville, Florida, who builds about 50 homes a year. Though initially producing homes better than the Florida Energy Code minimum, Florida HERO worked with AD&C to increase their efficiency to Energy Star and then to Building America standards. *(Table 7)*. The new upgrades resulted in homes achieving an average HERS score of 89.

Figure 5 *Atlantic Design and Construction home in the Mentone neighborhood.*

Savings from the increased the cooling system efficiency more than offset the additional $250 to $375 needed for improved duct sealing and insulation and air sealing protocol adjustments. This savings, while sufficient to offset those costs, were not enough to pay for all implemented measures. Instead, increasing the price of the home by $1,250 was sufficient to cover the additional costs and derive an excellent profit margin. Despite adding $1,250 to $2,500 to home buyer costs up-front, AD&C's award-winning development, Mentone, has been the best-selling subdivision in Alachua County for four years running *(Figure 5)*.

Kenny Brekenridge, AD&C Project Manager, says that the company believes with energy costs continuing to rise that it makes sense to build energy efficient, and that they emphasize the Building America improvements in their sales literature and discussions.

Table 7 Atlantic Design and Construction Specifications

Component	Original	Mentone
Conditioned Area	1800-2400 sq. ft	1800-2400 sq. ft
Hers Score	~82	~89
Selling Price	~$90,000	$190,000 - $325,000
Cooling	SEER 10 with standard thermostat	System sized using Manual J, SEER 13 with passive, filtered ventilation air and programmable thermostat
Ducts	Local conventional construction	System engineered using manual d, mastic sealed, and performance tested to have cfm25out < 5% of AHU flow
Ceiling Insulation	R-30 fiberglass	R-30 cellulose
Wall Assembly	R-11 fiberglass	R-13 cellulose
Windows	Double pane clear metal frame	Double pane Low-E
Lighting	Standard	Air lock can lights

Avis American Homes
Avis, Pennsylvania

In the summer of 2003, Avis American Homes tested an alpha prototype Status and Control System (STACS) developed by the UCF Constructability Lab researchers (BAIHP Partner). The system is a real-time shop floor labor data collection and reporting system. Production workers use wireless laser scanners to report their current work assignment. STACS reporting is web based and provides both real time manufacturing status and summaries of historical production performance *(Figure 6)*. While labor represents a relatively modest fraction of production cost, typically 10-15%, it has a profound impact on operations, including product quality, cycle time, material waste, and labor productivity.

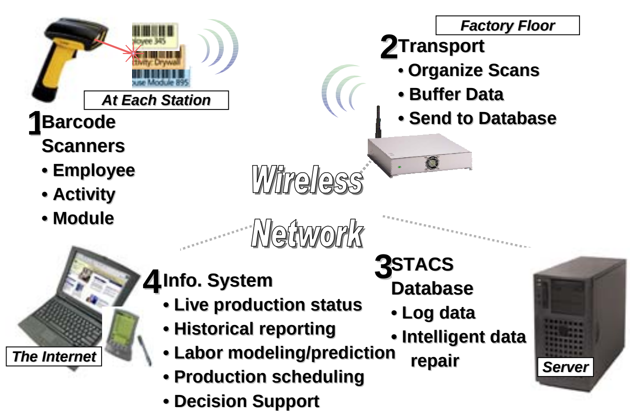


Figure 6 *STACS system components and relationships.*

Avis American employees tested STACS in drywall finishing operations. Test results demonstrated that production workers could operate the system effectively and that the system accurately captured scanned activity.

See also *Penn Lyon Homes* (Technical Assistance section) and *Status and Control System (STACS)* (Research Section III).

Bellview Air
Gainesville, Florida

Florida H.E.R.O. discussed a range of issues with Bellview Air, including the impact of input data on Manual J equipment sizing and the air handler location in an effort to improve indoor air quality, comfort, and energy performance. The potential benefits of unvented cathedralized roof systems were also addressed. Construction anticipated in late 2005.

Bobek Building Systems
Oviedo, Florida

BAIHP conducted a testing visit to new BAIHP partner. Bobek Building Systems building exclusively with steel frame and partial panelized construction (*Figure 7*) to measure whole house and duct leakage and to evaluate envelope insulation with IR camera. BAIHP compiled the results of the testing and sent design recommendations to the builder.

Figure 7 *1800 sq.ft. Steel Frame Residence near Oviedo, Florida*

Table 8 Air Tightness Testing

Blower Door Test Results	Duct System Airtightness
CFM50 = 1693	CFM25total = 285
ACH50 = 7.05	CFM25out = 42
C=157.8, n=0.607, r^2=0.999	Qn = 2.3%

Duct testing shows low leakage to out (2.3%) but an excessive level of total leakage. The ducts are located in the attic which is largely sealed (essentially unvented) with an insulated steel panel roof deck. During blower door testing, the attic space was found to depressurize to 13 pascals while the home was at -50 pascals, showing the space is better connected to the conditioned space than to the outside. One known area of attic leakage to outdoors occurs at the front porch overhang.

The high total duct leakage should be addressed to ensure proper distribution and mixing. In many cases this is caused by leakage where the supply register ties into the supply boot. Supply registers with integral foam seals are recommended to provide a tight fit at the boot connection and where the register meets the ceiling surface.

Infrared Imaging
The IR picture in *Figure 8* shows a corner, side and front wall from inside the home. This picture is typical of IR images from inside the house perimeter. Portions of the wall shown violet in color reflect an indoor temperature of approximately 67º. Lighter and brighter colors indicate higher temperatures. Metal studs and points of joining between the ceiling and side walls can be seen in orange and light yellow.

As can be seen from the IR picture, thermal shorts exist between the outdoor and interior space. Though the overall differential between room temperature and stud temperature is relatively small (5ºF), the cumulative effect may represent a significant conduction load on the space conditioning system. Reducing thermal bridging between outside and inside the home will reduce thermal loading taking place inside the home. This, in turn, will reduce air conditioning run times.

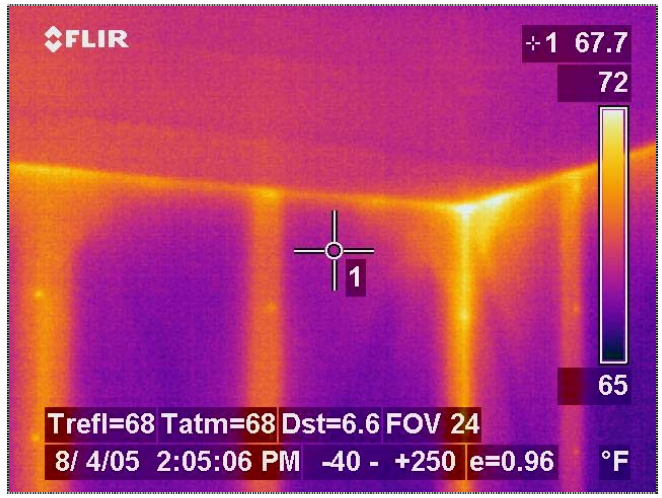


***Figure** 8 Thermal Image of Exterior, Steel-framed Walls*

BAIHP Recommendations included:

- Sealed supply and return registers to reduce total duct leakage and improve distribution efficiency
- More attention to sealing the attic space from outdoors since this is essentially a buffer to the conditioned interior space. This will also lessen any duct leakage to outdoors.

Additionally, some method of breaking the thermal short between the stud and the back of the drywall should be deployed in future construction efforts. Consideration should be given to applying foam board, ¾" minimum, between the stud and the drywall. At a minimum, application of adhesive backed foam strips applied to the stud prior to drywall installation should be considered.

Cambridge Homes
Orlando, Florida
Category B, 1 Home
Note 100% Energy Star Builder

Figure 9 *The Augusta, Cambridge Homes BA Prototype*

This BAIHP partnership resulted in continuation of monitored field research in the Augusta Building America model *(Figure 9)* and a control home. S*ee BAIHP Research (Section III), Site Built Housing Research, Cambridge Homes.*

In November 2004, BAIHP participated in a meeting with this partner to discuss water damage incurred in recently built homes as a result of the 2004 active hurricane season. Approximately 12 people took part in the meeting including BAIHP researchers, and Cambridge Homes design, construction, and architecture personnel. Results of field investigations were shared, and potential solutions discussed.

Cardinal Homes, Inc.

During the 4th budget period in cooperation with the University of Central Florida Industrial Engineering Department (UCFIE), FSEC researchers tested four Cardinal modular homes with the Cardinal sales manager and plant quality engineer. Initial results found that peak loads for heating were almost double that for cooling. All four of the homes had leaky ducts. These leaks accounted for the largest peak load in the homes, averaging 28% of the winter peak and 21% of the summer peak.

Champion Homes
Washington (state)

Champion Homes built the first stress skin insulated panel (SIP) manufactured home now sited in western Washington. The house air tightness was measured at ACH50=3.55, well below the average numbers for all homes previously tested in the WSU random home study (see Northwest Energy Efficient Manufactured Homes). Energy savings are estimated at 50% greater than a home constructed to the HUD Code. These results were presented at the 2003 ASHRAE Summer Meeting, authored by Pacific Northwest National Laboratory (PNNL), with contributions from BAIHP staff.

City of Gainesville, Cedar Grove II
Gainesville, Florida
Category B, 139 Homes
Award: HUD award for Innovation in Housing in 2004

Figure 10 *City of Gainesville house in Cedar Grove II*

Florida H.E.R.O. began working with the City of Gainesville before the ground-breaking in the Cedar Grove II subdivision of HUD housing *(Figure 10)*. Project manager Judy Raymond envisioned a new urban style development (HUD's first) with single family homes featuring high quality construction and individualized character with front porches and front façade details. She worked with Florida H.E.R.O. to develop engineered plans for mechanical and air distribution systems and a whole house package that was recognized with a HUD award in 2004. *Table 9* summarizes the specifications.

Table 9 City of Gainesville, Cedar Grove II Subdivision, HUD Home

Component	Specification
Conditioned Area	~1200-1400 (139 units)
HERS Rating	86-88 (goal = 86)
Cooling And Heating	SEER 12 with hydronic heating; some 80% AFUE furnaces with programmable thermostat.
Duct System	Ducts in conditioned space. Ducts moved to attic in later phase. Return duct and air handler still conditioned space. Duct system engineered using Manual D, sealed with mastic, all homes performance tested for duct air tightness. $CFM25_{OUT} \approx 25$
System Capacity	Cooling and heating systems sized using Manual J calculation procedure
Walls	R-13 cellulose
Ceiling	R-30 cellulose insulation with radiant barrier
Windows	Double pane metal frame

City of Orlando, The Orlando House
Orlando, Florida
Category A, 1 House

Figure 11 *The Orlando House*

The City of Orlando, through the office of Housing and Community Development in the Planning and Development Department, constructed an environmentally friendly demonstration home called *The Orlando House: Florida's Future,* on an infill site within the city *(Figure 11).* The City requested FSEC assistance to assure the home met Building America goals and the Florida Green Home Designation Standards. Ground broke on the demonstration home in December 2001 and the home was open to the public for community education purposes for approximately one year. Specifications are listed in *Table 10.*

The City acquired more than $100,000 in donated materials and services for the project, and completed much of the construction using their own staff. Along with public education, a primary purpose for this project was to give the city staff first hand experience in the use of green building materials and techniques - especially those relating to energy efficiency, indoor air quality, durability, disaster mitigation, and termite resistance. That experience would allow the products and techniques to be effectively used in future low-income housing constructed by the city.

One particular focus of this project was disaster resistance. For protection from wind storms, a durable steel structure was used along with a safe room located in the detached garage. For termite resistance, all structural and exterior finish materials were selected on the basis of providing the least amount of available food source. Materials such as borate treated lumber and sheathing, steel structural components, and plastic/composite finishes were used extensively in conjunction with a Termi-mesh barrier system.

FSEC certified the house for the Florida Green Home Designation Standard in February 2003. FSEC staff also presented information regarding Florida Green Home Designation as part of a builder training event held at the Orlando House. Two CEUs were available to attendees, and approx. 30 people attended from the central Florida area. Training also included talks on Zero Energy Homes, Florida Sun Built Program, and a "builder panel" that included 3 BAIHP partner builders.

The demonstration home was sold in May 2003, and money acquired from the sale will go directly towards the construction of low income housing that utilizes several green building techniques.

Table 10 City of Orlando – Orlando House

Component	Specifications
Conditioned Area	2148 sq. ft.
HERS Score	88.3
Envelope	
Above-grade Wall Structure	Steel Frame 1st and 2nd floors
Above-grade Wall Insulation	R-19 Icynene
Exterior Wall and Roof Sheathing	OSB - Borate treated
Attic	Unvented R-19 Icynene
Roof	Metal
Windows	Double pane Low-E
Equipment	
Heating & Cooling	13 SEER heat pump
Thermostat	Programmable
Ventilation	Passive outside air vent
Water Heater	50 gal, EF=0.88 (Electric)
Lighting	100% fluorescent
Appliances	Energy Star
Additional Green Features: ▪ Termi-mesh ▪ Safe Room ▪ VOC source control ▪ Resource efficient interior finishes	▪ Durable exterior finishes ▪ Ultra-low-flow water fixtures ▪ Low water using landscape ▪ Pervious driveway/walkway

City of Lubbock Community Development
Lubbock, Texas

Through the Portland Cement Association (PCA), contact was established with the City of Lubbock who is building low income houses with insulated concrete form (ICF) systems *(Figure 12)*. FSEC researchers visited Lubbock twice to conduct diagnostic tests and provide training and technical assistance. FSEC also conducted initial HERS ratings on four Lubbock Habitat for Humanity (see Habitat for Humanity, Texas) homes plans and introduced the Habitat affiliate to the City of Lubbock's other low-income housing activities.

Figure 12 *Low income housing built by the City of Lubbock using insulated concrete forms.*

Clayton Homes
Waycross, Georgia

FSEC personnel conducted a plant visit of the Clayton Homes factory in Waycross, Georgia in June 2002. A singlewide home was tested and observations recorded of home and duct construction techniques. Findings and remedies for leaky ducts found during the visit were reported to factory representatives in a follow-up trip report (see *Appendix A).*

Dukane Precast
Naperville, Illinois

FSEC made a February 2002 site visit to Dukane Precast in Naperville, Illinois and provided technical design assistance in a follow-up telephone conference call in March '02.

In 2003, Dukane Precast requested BAIHP assistance in the design phase and monitoring of the first prototype of a new line of homes called "The Fortified House *(Figure 13)*. Objectives of Dukane's Fortified House include energy efficiency, comfort, durability, and good indoor environment conditions.

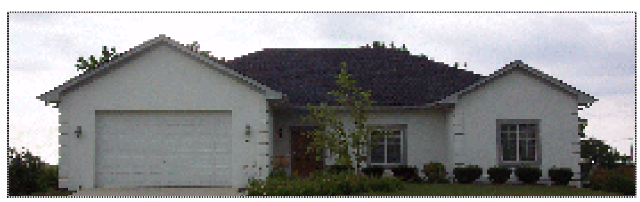


Figure 13 *Completed Dukane Precast home tested by BAIHP*

In December 2003, FSEC visited 3 prototype buildings in various stages of construction in. One was complete. Researchers made recommendations regarding window flashing, below grade drainage and waterproofing, interior ducts, air sealing, attic access detail, floor finishes with radiant heating, radiant heat zoning, ventilation system design and operation.

In February, FSEC returned to Dukane for testing and infrared evaluation of 3 completed prototype Fortified Homes built by Dukane's sister company, Mustang Construction at Keller Court, Boilingbrook, IL, just west of Chicago.

Infrared images were recorded from the inside and outside during a calm morning with ambient air temperature of about 25°F and interior temperatures of about 70°F, and whole house air tightness was assessed with a blower door test. Whole house infiltration was ACH50=1.28 (very low) 11 Keller Court data (*Specifications, Table 11)* was obtained with a multipoint blower door test. IR scans found no major infiltration pathways.

Table 11 Dukane Precast's *Fortified Home* Specifications

Component	Dukane Home
Conditioned area	5100 (with basement)
HERS score	NA
Envelope	
Floors and Ceiling	Precast concrete panels
Walls	R-23 (~3") Polyisocyanurate between precast concrete
Attic	Vented with R-38 Polyisocyanurate and Batt
Windows	Insulated glass, vinyl frame, u-value=0.36, SHGC=0.45
Infiltration	Ach50=1.28
Equipment	
Heating	Radiant floor
Boiler	140kBtu, 50 gallon AFUE=92 Gas Boiler
Cooling	3 ton, 10 SEER, Unico-type
Ducts	High velocity, small ducts, unconditioned space
Thermostat	Programmable
Ventilation	Honeywell 150cfm HRV
Water Heating	From Boiler

The ceiling and gable end of the vaulted living room were built with wood frame construction instead of precast concrete. Both showed higher heat loss than was generally found in the precast panels. Flaws in the continuity of ceiling insulation over the vaulted ceiling were visible from the vented attic. especially around can lights. The flat ceilings in this home were insulated with R-38 rigid polyisocyanurate loosely laid on the concrete ceiling panels. Dukane has now switched to an R-23 precast panel for ceilings.

Opportunities for Improvement

Infrared scans were performed on the ranch home and two other homes nearing completion on Keller Court. All three had the space heating system in operation holding the interior near 70 F. Initial scans of the exterior clearly showed increased heat conduction at the truss locations in the precast panels *(Figure 14)*. The metal truss members are cast into the assembly to connect the interior and exterior panels and allow for approximately 3 inches of polyisocyanurate foam (R-23). Exterior infrared scans showed a 2 - 4º F temperature rise at truss locations; exterior temperatures were between 12º and 24ºF.

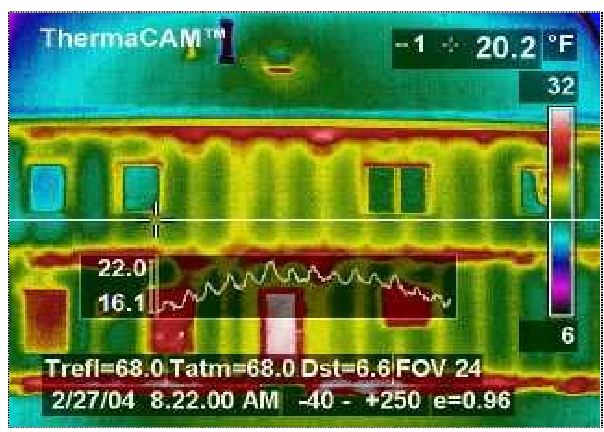


Figure 14 *IR-scan showing metal trusses in precast walls. Temperature at the crosshairs is 20.2°F. Overlaid temperature graph shows temperature variation of the surfaces at the white line running horizontally through the crosshairs.*

Increased heat loss was also visible at the top and bottom of precast sections where field connections are made during construction and filled with grout. Each panel has at least two lifting fasteners imbedded in the top edge for the crane to connect to during home construction. Foam insulation around these fasteners is sometimes removed to connect the lifting hook and the void is re-insulated in the field. Insulation levels are reduced where precast walls are connected to floors and ceilings. These areas have one inch of rigid XPS foam (R-5) next to the outer panel but are otherwise left open until structural and electrical conduit connections are made in the field after which they are filled with grout.

Interior Ducts and Moisture Issues

FSEC Researchers met with Dukane Precast staff, their architect and mechanical contractor to identify a way to incorporate interior ducts into a new model of the *Fortified House.* Ducts are used primarily for cooling and ventilation as all Dukane Precast homes are designed with in-floor radiant heat driven by a high efficiency (92 AFUE) boiler. The boiler also provides domestic hot water in conjunction with a 50-gallon storage tank.

The main obstacle to building interior ducts was finding a place to run ducts from the basement mechanical room to the first and second floors. Agreement was made to run supply risers near the center of the home and returns in a chase on an outside. The two-story foyer offers the best placement for a central return for both the first and second floor supplies.

Dukane is currently using a high velocity, small duct air conditioning system by Unico with 2-inch diameter supply branches that are easier to fit into walls and chases than low velocity ducts. One unoccupied home had problems with condensation accumulating on the attic-mounted ducts. The cause was traced to humid indoor air contacting cold metal trunk lines in the vented attic.

No occupant-related moisture was present but the precast panels, which are still in the process of drying, are one possible source. Periodic mixing of the indoor air may be all that is required until moisture output from the panel is reduced. Otherwise, introducing dry air was recommended to prevent condensation. Findings and recommendations were sent of the Dukane Precast in a Trip Report.

Dye Company and DelAir - Southern Living Home

Category A, 1 Home

Category B, 1 Home

Florida H.E.R.O. met with Dye Company president and his staff to discuss the new Southern Living Home planned for showcase at the 2003 Southeast Building Conference (SEBC) in Orlando, Florida. This firm has a strong desire to differentiate their homes by emphasizing healthy and energy efficient homes. Florida HERO introduced the Building America systems engineering approach to the builder and subsequent discussions resulted in Dye’s commitment to partner with Building America in this project. As a result, researcher met with DelAir mechanical contracting to discuss the development of mechanical specifications for the Southern Living project.

This home did have a Honeywell ERV added and had a HERS score of 88.5. While this home did not meet the BA standard of performance for the 2003 SEBC show, retrofits were being completed to bring it up to BA performance level.

The 2004 home achieved a HERS of 89.6. Both homes have unvented attics with ducts in conditioned space, and used heat pumps with SEERs ranging from 13.5 - 14.1. Windows in the 2004 home had a SHGC of .29 and gas (LP) instant hot water heaters were used.

EnergyGauge® USA
FSEC - Cocoa, Florida

This software uses the hourly DOE 2.1E engine with FSEC enhancements and a FSEC-designed user friendly front end to calculate home energy ratings and energy performance. *(Figure 15)* Researchers continue to improve the software's features and accuracy. Version 2.0 incorporates many enhancements, which may include multiple zones, multi-fuel use, and a detailed solar thermal and solar electric system analysis. For more information, please visit www.energygauge.com.

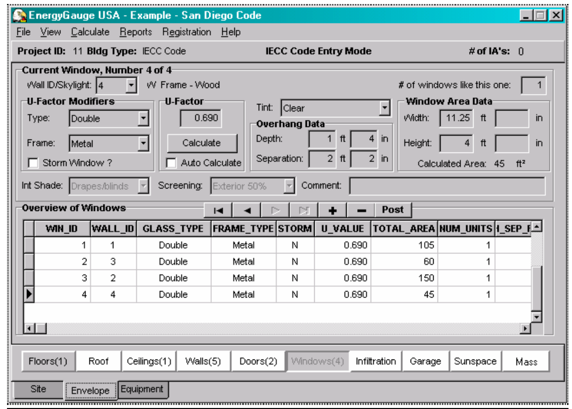


Figure 15 *Window input screen from EnergyGauge USA home energy rating and simulation software.*

Fleetwood Homes
Category D, 500 Homes Auburndale, Florida factory

FEMA Homes
In September of 2004 BAIHP researchers tested and inspect single-wide homes built by Fleetwood under contract with the Federal Emergency Management Agency (FEMA) to identify possible areas of moisture-related damage and provide recommendations to mitigate problems.

These homes are destined for victims of hurricane Charley in Southwest Florida. Various singlewide floor plans are being constructed with the typical size being 14x66, several of which were tested for duct and envelope tightness. Other construction specifics include:

- In-line, metal floor duct system with 1 or 2 short branch ducts
- Duct risers sealed with mastic
- Branch duct joints sealed with mastic, then covered with metal tape
- Down flow gas furnace installed in central hallway
- Large door undercuts plus small door-mounted return vent in bedrooms
- Central exhaust fan ventilation strategy
- Vinyl interior wallboard throughout
- Vinyl exterior siding

FEMA-required specifications that differ from typical Fleetwood design include:

- Vinyl flooring throughout
- Double floor decking (½-inch OSB over ½-inch plywood)
- R22 floor insulation
- "Chicken wire" installed below the belly board

- 80% AFUE, 70 kBtu gas furnace with no cooling installed
- FEMA provides a 2.5-ton split system (coil & condenser) to be installed on-site
  - Goodman CKL30-1L condenser & Mortex 96-842J-OP A-coil

Cooling System and Air Handler Issues

The immediate concern with these homes is the FEMA-provided cooling system that, at 2.5 tons, may be oversized for the application. This, coupled with the fact that a vapor barrier is located on the wrong side of the exterior wall and floor assemblies, increases the potential for moisture damage to those surfaces. Other issues that can impact the moisture durability of these homes are addressed below, but initial envelope and duct test results indicate no immediate cause for concern.

A properly sized cooling system should be an integral part of any strategy to mitigate moisture damage in a hot humid climate. We recommend using the latest version of Manual J calculations to determine proper cooling system size and it appears these homes may be oversized by as much as one ton. Oversized systems are prone to short-cycling for much of the year which tends to cause higher indoor humidity levels than properly-sized systems.

Another issue with an oversized system is it allows homeowners to maintain lower indoor temperatures than might otherwise be possible. Maintaining indoor temperatures below the outdoor dewpoint can lead to moisture damage over time especially in homes with interior vapor barriers (vinyl floor and wallboard). Average summer ambient dew point temperatures in Southwest Florida are in the low to mid-seventies.

Beyond reducing the cooling system size, some benefit can be gained from adjusting the air handler fan speed in cooling mode and adding outdoor air ventilation. Lower airflow over the coil will remove more moisture, help to reduce indoor RH levels and possibly encourage higher thermostat settings by the occupant. Adding a passive supply (not more than 40CFM) of outside air to the return side of the air handler will promote positive pressurization of the home which may lessen the likelihood of moisture damage to wall and floor assemblies.

In-Plant Construction

Metal duct fabrication was observed during production where mechanical fastening and sealing methods appeared suitable for a tight durable system. Duct ends and branch duct joints were first fastened with screws then mastic was applied by tube. Metal tape was placed over the mastic (shown below at top right). This method produced tight duct systems as demonstrated by the 3 to 4% leakage rate found in four completed homes.

The continued use of mastic is encouraged for a long-lasting, positive seal. While there is little harm in using metal tape over mastic it does not provide much additional sealing. One possible drawback of tape over mastic is that it may hide gaps that could otherwise be seen and corrected by workers. Applying mastic alone by brush should prove adequate and less costly. A fabglass mesh is useful when applying mastic by brush to cover any large gaps that may occur.

A bead of mastic was applied to supply risers *(Figure 16* bottom right photo) prior to being attached to the trunk line with screws. Once the riser was attached an opening in the trunk line was cut out. The same method was used for the return plenum riser. This method can provide a positive seal when adequate mastic is applied – not always certain from observations on the production floor. Although testing showed four such systems to be fairly tight, some leakage at the risers was evident at the interface of the thin metal of the trunk and riser collar where unfilled gaps where found.

Figure 16 *Metal duct fabrication on FEMA homes, Fleetwood plant – Douglas, GA*

To prevent leakage at risers, mastic should be visibly squeezed out at the interface when attached. The mastic bead should be 1/2 to 5/8 inch in diameter (size of your little-finger) to allow full contact between surfaces.

<u>Post-Production Testing</u>
Four newly completed singlewides (all 14x66) were tested at the Douglas plant. Total duct leakage was measured on all homes but only two homes were measured for envelope tightness and duct leakage to out.

Table 12 Envelope and Duct Tightness Test Results
Four 14x66 FEMA Homes (Area = 924 ft^2)

Unit	CFM50	ACH50	cfm25tot	cfm25out	Qn
14x66	646	5.6	32	20	0.022
14x66	709	6.1	42	26	0.028
14x66			46		
14x66			49		
Notes: Only 2 homes tested for envelope airtightness & duct leakage to out					

Blower door testing showed the envelope on the tighter side (0.73 CFM50/ ft^2) of the airtightness range typically found in new homes (0.75 to 1.0 CFM50/ft^2). Of greater importance is where this leakage occurs. With sheet vinyl flooring installed throughout these homes, air leakage through the floor is the biggest concern. A history of floor moisture damage has been documented in manufacture homes located in hot/humid climates where vinyl products are installed. Increased air leakage between the floor and belly has greater potential to force outside air into the belly should a negative pressure situation arise in the home (caused by duct leakage and/or inadequate return air transfer). Both the interior floor surface and the exterior belly board should be sealed as tightly as practicable. Plumbing penetrations make up most of the holes through upper floor surface and can be difficult to seal. One simple option currently being used by the Fleetwood plant in Washington state involves the use of a EPDM rubber sheet cut to fit plumbing pipes and stapled in place prior to vinyl flooring installation, providing a durable, flexible seal *(Figure 17).*

Figure 17 *Rubber seal – Washington Fleetwood plant*

One 14x66 home was tested for interior pressure imbalances by turning on the air handler fan. Depressurization of the interior space can occur if duct leakage is excessive or insufficient return air pathways exist between rooms with closed door. No detectable depressurization was measured during the test indicating sufficiently tight ducts and adequate return air pathways from closed rooms.

Duct system airtightness testing showed four systems in 14x66 singlewide homes to have duct leakage rates to out of between 2 and 4% of conditioned floor area at 25 Pascals. A value of 3% is generally considered sufficient to inhibit negative pressurization of the conditioned space. Leakage to out was directly measured in the first two test homes at 2 and 3%, while the last two homes were judged to be slightly higher as inferred by the measured total leakage rate. While these leakage numbers are good, only a small amount of leakage is necessary to dramatically increase the leakage percentage in homes of such relatively small size.

There are three general areas in these duct systems where leakage is likely to occur:

- End of duct runs
- Trunk to branch connection
- Supply risers and the air handler supply plenum

The first two of these areas were isolated and tested by duct blaster in the plant on a newly fabricated system prior to installation in the home. This particular duct system had only one branch connection whereas the four previously tested homes had two branches. Results showed a leakage rate of about 8-10 CFM at 25 Pascals, attributed to two closed duct ends and one branch to trunk connection. This would indicate that on the four duct systems tested earlier (with two branches each), roughly one-half to two-thirds of the leakage to out (20 to 30 CFM50) occurs at duct ends and branch connections with the remainder occurring at the risers and plenum.

Fleetwood Factory Visits in 2002-05

In 2002, researchers visited four Fleetwood factories in southern Georgia to investigate the cause of moisture-related building failures when units were installed in a hot-humid climate. The factories are located in Douglas, Alma, Pearson, and Willacootche. As a result of FSEC recommendations, the factories have changed their duct construction practices and are now constructing airtight ducts with mastic.

Six Fleetwood homes, all in Florida, were tested for moisture and mold damage from April 2002 through March 2003. All of the homes had damaged flooring due in part to a lack of ground cover and poor crawlspace ventilation. Damage to the floor in one home was exacerbated by a plumbing leak. Only one home had moisture damage to the wallboard material, and this home showed a history of thermostat settings below 72° F. A report for each home was submitted to Fleetwood for corrective measures. One additional high bill complaint in Cobb, Georgia was investigated during that period. Between April 2003 and October 2004 ten Fleetwood moisture damaged homes were investigated by BAIHP, seven in Florida, one in Texas, and two in Georgia.

In May 2003, FSEC researchers were asked by Fleetwood and Coleman to travel to Fleetwood's five southeastern plants and test three homes built by each factory to get their plants certified for building ENERGYSTAR Homes. A sample of the data collected is shown in *Table 13.*

At the Auburndale, FL plant, BAIHP researchers conducted the tests in houses set up in the factory's parking lot. The houses did not have air handlers, but total duct leakage was within range to achieve Fleetwood's goal for this plant which was to build houses according to the EPA EnergyStar Building Option Packages (BOPs) for manufactured housing, Climate Zone 4, and to attain a less than 5% duct leakage rate (Qn,total#5%). The houses showed some need for additional envelope sealing which was implemented after the first house was tested. The other two houses showed marked improvement in whole house air tightness. Recommendations and test results were provided to Fleetwood via email (no formal trip report). Similar testing was conducted at the Georgia Fleetwood factories in Willacoochee, Pearson, Douglas, and Alma.

Table 13 Test Results, Factory Certification at Fleetwood's Auburndale facility

House #	Size	ACH50	Estimated natural ach (ACH50/18)	Qn_{TOTAL} ($CFM25_{TOTAL/COND.\ AREA}$)
1	24 X 48	8.7	0.48	0.031
2	28 X 52	5.5	0.31	0.034
3	28 X 52	5.5	0.31	0.029

Woodland, Washington
Category C, 222 homes

Industry partner Greenstone has been working with BAIHP staff and SGC/E-STAR manufacturers to evaluate a hybrid floor insulation system. These systems, composed of one R-11 belly blanket and R-22 blown cellulose insulation eliminates over-compression and reduces the chance of leakage during transport and set-up, while minimizing material and labor costs. Fleetwood Homes of Washington adopted this system for all of their homes in 2001. Other manufacturers have adopted the hybrid floor insulations system, which provides less insulation voids and reduces first cost of R33 floor system over 3-R11 fiberglass batts. One potential consequence of using the hybrid system is increased moisture in the belly; in 2003, BAIHP staff installed data loggers in two homes to determine whether this is a problem; after the data loggers were retrieved in 2004, BAIHP staff submitted a report to Fleetwood suggesting no dew point problems within the floor system (*Figure 18*).

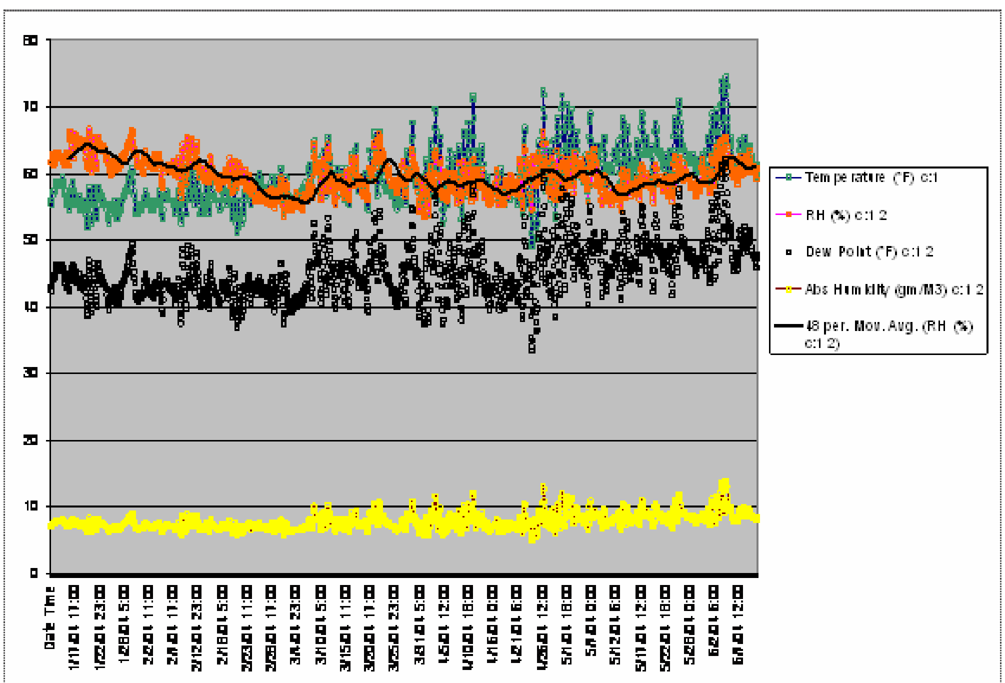


Figure 18 Temperature and Dew Point Under Hybrid Floor Decking

Florida International University, 2005 Solar Decathlon
Miami, FL

FSEC provided technical assistance to FIU (Florida International U.) for the 2005 Solar Decathlon (http://www.eere.energy.gov/solar_decathlon/). An introductory meeting was held at FSEC in October 2003. Subsequently, a design competition was held among FIU students and the team, comprised of architecture and engineering students, to merge the 10 winning designs into a single conceptual design. In April, the team met with BAIHP researchers at FIU to review the schematic drawings and model.

Researchers discussed strengths, weaknesses and technical needs of the schematic design including cooling loads and strategies for mitigating each (reflective roofing, advanced glazing, shading, ventilation, point source moisture exhaust, etc.), building integrated solar (PV) systems, solar water heating, mechanical system design, energy storage, construction challenges, and the aesthetics of energy efficiency. Students plan to use ray tracing capability of the CAD tools they are already using to study shading and daylighting and will schedule another review with BAIHP researchers this summer as they move into design development.

G.W. Robinson Builder/Developer
Gainesville, Florida
Category A, 143 Homes

This builder, a leading member of the BAIHP program, takes care to incorporate features and measures that enhance not only the energy and resource efficiency, but also the indoor air quality, safety, durability, and comfort, consistent with the spirit of Building America.

<u>Cobblefield Development</u>
G.W. Robinson committed to building the first “green homes” community, as designated by the Florida Green Building Coalition (FGBC), and to achieving Building America standards in each home built *(Table 14)*. Individual home performance testing by Florida H.E.R.O. ensures that the homes meet both program specifications. G.W. Robinson proudly refers to these programs in weekly newspaper ads. *(Figure 19).*

Figure 19 *G.W. Robinson home in Cobblefield neighborhood.*

Table 14 G. W. Robinson Specifications

Component	Original	Cobblefield
Conditioned Area	1,812 - 3,128	1,812 - 4,107
Hers Score	~82	~89
Cooling and Heating	SEER 10 air conditioner and AFUE=80% gas furnace with standard thermostat	System sized using Manual J SEER 12, 13, and 14 (depending on construction date, higher seers more recent) and AFUE=90% gas furnace with programmable thermostat and variable speed air handler
System Capacity		Reduced capacity up to 2 tons; eliminated bonus room system by zoning main system.
Outside Air Ventilation	None	Passive, filtered ventilation air. Ceiling fans in all bedrooms.
Ducts	Local conventional construction	System engineered using manual d, mastic sealed, and performance tested to have cfm25out < 5% of AHU flow, coated duct board
Water Heating	Conventional builder model EF=0.56 gas water heater	EF=0.60 gas water heater, solar water heaters - Now instant
Roof/Clg Assembly	R-30 fiberglass	R-30 cellulose and radiant barrier
Wall Assembly	R-11 fiberglass	R-13 cellulose
Windows	Double pane clear metal frame	Double pane Low-E metal frame SHGC = 0.36 - Now vinyl with .28 SHGC
Lighting	Standard	Air lock can lights
Construction Process Innovations		Statement of Work for each trade. Load calculations and duct engineering done with in-house design team.
Durability And Green Features		Low VOC interior paint, 15 year exterior paint, 30 year architectural shingles, Enviro-scaping: saved trees, community wide reclaimed water for irrigation, native plants grouped according to water needs, wildlife habitats, no turf near house.

Initial discussions between Florida H.E.R.O. and the builder, sales manager, project manager, and mechanical, insulation, and solar system subcontractors resulted in the original decision to include batch solar water heating and hydronic heating systems.

Florida H.E.R.O. undertook a redesign of the air distribution system for the Cobblefield homes to insure that ducts are properly sealed with mastic and that the air handler closet (or mechanical room) is sealed from the attic. Field tests showed that leaks on the return side of the air handler depressurized the mechanical rooms. When the ceiling was not properly sealed, air from the attic was introduced to the home, which diminished indoor air quality, increased summer latent loads, decreased comfort, and increased the home's operating costs.

In response to an ongoing challenge to achieve a reasonably air tight mechanical equipment closet, a new protocol shifted installation of ductboard adjacent to the ceiling to rough-in instead of finish mechanical, which allowed maximum accessibility for the field technicians. Once the main supply and return trunk line were stubbed out, the ductboard was custom cut and installed over the ducts, then affixed to framing members with nails or screws and plastic grommets. The duct line seam between the ceiling and duct was sealed with pressure sensitive tape and mastic and perimeter seams were caulked after sheetrock installation. A flow hood CFM test on a Cobblefield model found less than a 5% deviation from the anticipated design flows.

Initially Florida H.E.R.O. recommended using hydronic heating systems for the Cobblefield Development. Since the original decision to include these systems, additional County requirements for anti-scald mixing valves and automatic air vents have added to the difficulty and precision of system installations. Larger models also required bigger water heating units which proved difficult to locate and costly. Installation irregularities and inconsistencies, despite repeated training attempts, exacerbated the situation and compromised the envelope tightness. While the hydronic system offers many benefits, Florida H.E.R.O. decided that the benefits did not justify the costs and problems associated with installing these systems in this development. Instead, a cost effective line of high efficiency (90% AFUE) condensing natural gas furnaces will replace the hydronic systems in all 17 models. This furnace style uses PVC for the exhaust flue and to deliver outside combustion air directly to the unit. This eliminates the need for high and low outside combustion air vents in the furnace closet and insures the maximum amount of system location flexibility. Changing the heating system type did not affect the model duct designs.

Reducing Home Moisture After Plumbing Leaks

Florida H.E.R.O. surveyed, performed diagnostic tests, and made recommendations to G.W. Robinson on how to prevent moisture-related problems in several water damaged homes. Two homes had significant moisture problems with one home flooded several days before it was scheduled to show in the 2002 Gainesville Fall Parade of Homes. The "flood" in this home was likely a result of a material failure in a kitchen sink supply riser. The large plumbing leak, however, did provide researchers with the opportunity to initiate and monitor the "drying out" process.

Interior, exterior, and internal ambient moisture readings enabled the monitoring of this situation with a goal of preventing mold growth. To begin the process, all carpets and cabinets were removed from the home and discarded. Two commercial dehumidifiers and several fans were installed to reduce the home's humidity. After 24 hours, moisture readings were taken at a variety of points throughout the home. Wall surface moisture readings ranged from 45% to 99%. After five days of continuous drying, no surface moisture reading exceeded 10.9% at any point in the home. The process and procedures employed seem to have been successful.

Eliminating the effects of a plumbing line leak and the resulting water damage proved more difficult in the second home where the lasting effect of the water damage was mostly odor. Based on recommendations from FSEC and Florida H.E.R.O., the home's water heater was disconnected, all water-damaged sheetrock, wood, and insulation removed and replaced, and the water heater reconnected. Though initially this fix seemed to work, the smell eventually reappeared. Because the odor was evenly distributed through the home, further investigation determined that the odor source was most likely airborne. The air handler, distribution system, and carpeting were fogged with "May-Clean" solution, whose active ingredients include "cleaning solutions and caustic acids." For now, this appears to have eliminated the home's odor problem. The home was sold and now is occupied, so additional data collection may be difficult.

High Bill Complaint

G.W. Robinson's sales manager expressed concern that the model center's monthly utility bills were significantly higher then they expected - more than $300 a month! To locate the source of this high electric usage, Florida H.E.R.O. arranged a site survey with the mechanical contractor and conducted a two-week temperature/humidity study. Since the home had been individually performance tested for both whole house infiltration and duct leakage rates, the detective work was fairly simple. After determining that the mechanical equipment was correctly functioning and properly charged, researchers tested the flow rate of the outside air intake with an Energy Conservatory exhaust fan flow meter. Higher than anticipated readings, led researchers to test the return air plenum temperature. With an indoor temperature of 77° and an outdoor temperature of 93°, the air temperature in the plenum measured 84°. The in-line damper was adjusted to reduce the volume of outside air introduced.

While investigating this problem, researchers also noted that sales staff continually overrode the programmable thermostat, typically after returning from lunch. Indoor temperature readings as low as 71° were recorded in the model. All findings were reported to the builder and subsequent measurements have indicated that utility bills have dropped.

Standardized HVAC Installations: Florida H.E.R.O. Duct Designs

Prior to this, the distribution system was field "designed" by the duct mechanic. Florida H.E.R.O. developed duct designs for all of the community models. To insure that mechanical design specifications are correctly interpreted by the HVAC installer, Mr. Robinson has agreed to allow the mechanical contractor to conduct a final review of all architectural CAD drawings before each house project begins. With the designer and installer in agreement on installation parameters, placing the design emphasis on performance excellence and standardization of supply and return register size, HVAC installation has proven to be more timely and the installer's profits enhanced.

Florida Green Building Certification

Florida H.E.R.O. researcher Ken Fonorow met with University of Florida Urban Horticulture Extension Agent, Wendy Wilber, at the Cobblefield model center to survey and complete the FGBC checklist required by the green certification process. Green Features are listed in Table 13.

Fluorescent Lighting

Florida H.E.R.O. used an infrared thermometer to demonstrate to the builder the operating temperature differential between an incandescent and compact fluorescent bulb. After viewing operating temperature differentials of 75°, the builder indicated an interest in replacing as many bulbs as possible with CFL bulbs. The incandescent bulb measured 158°, while the CFL bulb measured 83°.

Green Housing

"Green" or sustainable housing is defined as energy efficient housing with added features such as disaster resistance, improved indoor air quality, universal design, resource efficient products and materials, and low water landscaping. BAIHP collaborates with the Florida Green Building Coalition (FGBC), and other organizations to develop or define green home standards, participate in educational programs, and assist in demonstration houses and related activities.

Florida Green Building Program
BAIHP staff has been extensively involved with the Florida Green Building Program administered by the Florida Green Building Coalition (FGBC), Inc. (www.floridagreenbuilding.org). The intended result of this involvement has been to create Building America homes that include additional "green" or sustainable attributes like those listed above, and to promote the incorporation of various Building America principles to the home building community at large.

The primary tool used to incorporate "green" concepts into homes built by BAIHP partners is the Florida Green Home Designation Standard, developed and maintained by the Florida Green Building Coalition, Inc. with significant support and technical assistance from BAIHP staff. Select BAIHP partner builders have constructed homes that have achieved the designation in this budget period including G.W. Robinson and WCI Communities. Since the inception of this standard, WCI Communities has constructed over 100 homes that meet this standard, including two showcase homes to educate the public about the benefits of green construction. In addition, the Palm Harbor Homes Showhouse and the Not So Big Showhouse for the 2005 IBS (DOES were each certified under this program. In all homes, BAIHP staff assisted with outreach, implementation, and certification. The standard has been incorporated in affordable homes, with several achieving the designation.

The standard also has proved useful to other Building America teams when they work with Florida partners who are interested in achieving green and sustainable housing. One example is the Lakewood Ranch community in Sarasota/Bradenton, FL, which recently began requiring all builders to build all homes to the Florida Green Home Designation Standard. Much of the technical assistance has been provided by CARB, but FSEC staff has been involved with each builder to ensure minimum requirements are achieved, and to assist with development of submittal packages.

Florida city and county governments have begun to incorporate this standard into the permitting process to offer incentives. The City of Gainesville was the first, passing an ordinance allowing certified properties half price permit fees and free fast track permitting. Sarasota County recently passed a similar ordinance, and Miami-Dade County is currently developing a similar ordinance.

BAIHP staff developed and delivers training to individuals interested in how to use the Florida Green Home Designation Standard to achieve the outreach, implementation, and certification phases of green housing. The course has been taught at least biannually since 2001 and attendance averages continue to grow. The course is now required by the Florida Green Building Coalition for anyone aspiring to certify homes to the Florida Green Home Designation Standard. Several builders and subcontractors have also attended the class to gain insight on green construction. Sarasota County building officials are now offered a salary incentive for completing the course.

National Green Building Program

FSEC staff members have been involved with the LEED Homes Committee of the US Green Building Council. Efforts continue to formulate a national green residential standard. FSEC researchers have participated in biweekly conference calls, and separate break out committee meetings. A pilot for this program is expected during the Summer of 2005, and it is expected that Building America partner builders will participate.

During the sixth budget period, BAIHP staff contributed an article as part of a "green series" for the Florida Real Estate Journal in the Orlando Sentinal. *(See Appendix A for reproduction of articles)*:

Habitat for Humanity-BAIHP Partnership

Americus, Georgia (HFHI) and Habitat affiliates nationwide
Category A, 1 Home (Lakeland HFH)
Category B, 265 Homes
Category C, 260 Homes

The Building America-Habitat for Humanity partnership, formed in 1995 at Habitat's Environmental Initiative Kickoff, has brought BAIHP into the design, construction, and evaluation process of over 500 Habitat homes across the nation built by 50+ Habitat for Humanity affiliates in more than 20 states. BAIHP activities with Habitat (including those conducted under the Energy Efficient Industrialized Housing Project) are listed in *Table 15.*

BAIHP energy efficiency recommendations for Habitat homes need to meet 4 criteria to be successfully integrated into Habitat's construction process. They must be:

- Cost effective
- Volunteer friendly
- Readily available in current market
- Easily maintained and repaired

In the fifth budget period BAIHP conducted training, provided design assistance to HFH affiliates, and continued development of the "HabiBOPS" program begun in the fourth budget period, BAIHP's outreach to Habitat affiliates has shifted away from assistance to individual affiliates and toward regional and national initiatives. Researchers continue to provide one-on-one design assistance to affiliates who request help. In addition, group training sessions were conducted at conferences and "blitz" builds with organizations like the Southface Energy Institute, Oak Ridge National Laboratory, and Energy Efficient Building Association members.

Technical Assistance to Habitat for Humanity International (HFHI)
Americus, GA

Partially because of Building America (and other DOE supported organizations) involvement with Habitat over the years, HFHI adopted Energy Star as one of their two Best Construction Practices for all U.S. affiliates. Best Practices are used to evaluate affiliate status. This represents a major commitment to energy efficiency from the highest ranks of Habitat. Habitat affiliates are encouraged to consistently achieve Best Practices and the demand for Energy Star ratings for Habitat affiliates is likely to surge as a result.

During the 6th budget period FSEC researchers met with Habitat for Humanity International staff at HFHI headquarters in Americus, Georgia to discuss HabiBOP and a new Habitat initiative tentatively named "Habitat Better Built." This new program will incorporate an energy package (HabiBOP, Energy Star Rating, local program, etc.), green building concepts, outside air ventilation, and combustion safety-related criteria tailored for small, affordable homes. A program draft was submitted in 2002 and the US EPA Energy Star Home Program committed to developing the technical option packages through ICF. ICF and BAIHP discussed the project and anticipated work beginning in April 2003.

The BAIHP-HFHI draft included a request to analyze additional Builder Option Packages (BOPs) for various Climate Zones as test runs for adding BOPs that emphasize envelope improvements over expensive equipment improvements. This is where the progress stalled and HabiBOPs remains a strong area of research need. The Jacksonville affiliate, HabiJAX, volunteered to pilot the HabiBOP Program in Year 5.

Table 15 Habitat for Humanity Activity with BAIHP (and EEIH prior to 9/099)

Year	Project/Location	State	Houses/Description
02-03 (June)	**Jimmy Carter Work Project** Energy Details, Program Development, and Volunteer Training *Calhoun County HFH, Anniston* *Troup-Chambers County HFH, LaGrange*	 AL GA	 35 Near Energy Star (c) 22 Energy Star (B)
02-03	**HabiBOPs Energy Star Plus Program** Provides Habitat appropriate (small houses) Builder Option Packages to fast track affiliate adoption of energy efficiency. Includes duct system and whole house testing protocol as well as IAQ and green building elements.	USA	Collaboration between BA, EPA, and Habitat International for nationwide application. Pilot tentatively set for Fall, 2003. Launch anticipated in 2004.
2003	**Habitat Better Built Program** Programmatic backbone for integrating energy programs such as HabiBOPs with IAQ and green building elements. Will replace the Green Team and provide for energy/environment program validation, affiliate communications via web and printed materials, and affiliate reporting.	USA	Collaboration between Habitat International, BA, and other supporting organizations for nationwide application. May launch using existing site built BOPs in 2003.

Table 15 Habitat for Humanity Activity with BAIHP (and EEIH prior to 9/099)

Year	Project/Location	State	Houses/Description
02-05	**2 Zero Energy Houses** **Loudon County HFH & Oak Ridge National Lab** BA fully instrumented two high performance homes to evaluate features including HPWH, PV, and waste water heat recovery. Data available on line and streamed to ORNL for analysis; See publication 2004 Christian et al. *Loudon County HFH, Lenoir City*	TN	SIP houses with many features developed by Jeff Christian at ORNL 2 ZEH (A)
2003 (Fall)	**Jacksonville Habitat for Humanity** Largest U.S. affiliate; plans to build Energy Star in 2003 and BA in 2004. Pilot for HabiBOPs Program. *HabiJAX, Jacksonville*	FL	New partnership in Feb
02-03	**DESIGNHabitat House** – Energy Efficient Prototype developed by Auburn University and the Alabama Association of Habitat Affiliates. Multiple reproductions expected in 2003-04.	AL	3 BA – Provided design review, analysis, rating, and technical support. (B)
02-03	**Design Assistance and Energy Analysis** FL: *Pasco, Orange, and Brevard Counties* NM: *Albuquerque* OH: *Clark, Geauga, Lorain, Marion, & Morrow Counties; Firelands.* OK: *Central Oklahoma* PA: *Greene County* TX: *Lubbock, Smith County*		
97-03	**Regional Training with Habitat for Humanity International & HFH Regional Offices** Southeastern HFH Conference 1996 HFHI 20th Anniversary 1997 Florida HFH Conference 1998 Syracuse, NY 1999 Southeastern HFH Conference 1999 Affordable Comfort 2 day HFH Training 1999 Florida HFH Conference 2000 Portland, OR 2000 New York City, NY 2000 Southeastern HFH Conference 2002		
2002	**Florida Affiliates Construction Round Table**	FL	Energy code changes
2002	**Training** for 20 Ohio affiliates eligible for 1st Energy Grants	OH	Full Day training on reaching Energy Star and Beyond
2002	***Greater Denver Habitat***	CO	6 Building America (A)

Table 15 Habitat for Humanity Activity with BAIHP (and EEIH prior to 9/099)

Year	Project/Location	State	Houses/Description
2002	**Joint Proposal** for development of Home Owner Manuals	USA	BA with HFHI Was not funded.
2002	**BA Roofing Experiment** *Lee County HFH, Mt. Myers*	FL	6 Roof assemblies with energy monitoring (c)
01-02	**Comprehensive Survey** Energy Practices in Habitat Affiliates	USA	Collaboration of HFHI and BA to assess state of Energy Efficiency in U.S. Affiliates
01-02	*Lakeland Habitat, Lakeland*	FL	3 Building America (A) 2 BA Pending Cert (A) 5 Energy Star (B)
00-01	**Design Assistance and Energy Analysis** AL: *Birmingham* MS: *Jackson*	AL	1 Energy Star Cert (B)
2001	**Easter Morning Build** *Sumter County Habitat, Americus*	GA	23 Energy Star (B) On Site Training and testing
2000	**Jimmy Carter Work Project** *New York City HFH, Harlem* *Sumter County HFH, Americus*	NY GA	Volunteer and Homeowner Training with HFHI Produced 23 Ratings (C)
98-01	*Broward County HFH*	FL	40 Energy Star (B)
99-03	*Brevard County HFH*	FL	20 Energy Improved (C)
99-01	**Energy Fact Sheets** Developed by organizations supporting HFHI.	USA	BA reviewed/contributed to various documents
97-00	**Easter Morning Community** *Sumter County HFH, Americus*	GA	125, Most Energy Star (B)
98-03	*Greater Houston HFH*	TX	97-65 Energy Star Houses (B) 98-100 Energy Star Houses 02-began striving for BA (B)
97-00	*Greater Canton HFH, Canton*	OH	20, Energy Improved (C)
99-01	*Durham County HFH, Durham*	NC	20, Energy Star (B)
98-99	**Design Assistance and Energy Analysis** CA: *Long Beach HFH* DE: *Wilmington HFH* FL: *Indian River, Lake, & Sumter Counties,* MI: *Grand Rapids HFH* NY: *Albany, Syracuse, & Yonkers* VA: *Lynchburg HFH*		
1997	**Jimmy Carter Work Project**	TN, KY	50 Energy Improved (C)
95-97	**Energy Affordable House** *Greater Houston HFH*	TX	65 Energy Improved (C)

Structural Insulated Panel Construction Study, Plains, GA
At the request of HFHI, BAIHP tested a home built by Home Front, Inc. in Sarasota, Florida. The house scored an 87.6 on the HERS scale *(Figure 20)*. Built with structural insulated panels (SIP), which contain a polystyrene core faced on both sides with a thin concrete board. The exterior finish is stucco with Hardy board trim. A structural steel wind-frame welded to steel plates imbedded in the slab was engineered to withstand hurricane force winds. The panels passed Dade County large missile impact and wind load testing.

Figure 20 *Habitat SIP house built in Plains, Georgia.*

Interior ducts are housed in a central corridor and connect to a heat pump in a central closet. Return air is drawn from each room through extra registers on the duct chase. A whole house fan at one end of the chase provides ventilation during shoulder seasons.

2003 Jimmy Carter Work Project (2003 JCWP)
Habitat International Director of Construction and Environment requested FSEC assistance for all three Carter Project affiliates: Calhoun County (AL) and LaGrange (GA). The JCWP affiliate in Valdosta (GA) did not request BAIHP assistance; however, a former Energy Monitor working at the Valdosta site organized an informal corps of volunteers to tackle air sealing and insulation details. The construction manager and executive director made the 2003 JCWP an example of high performance, high quality housing for affiliates and other builders in the region and consequently asked BAIHP for assistance in reviewing construction techniques.

Calhoun County HFH: The Calhoun County HFH affiliate (Anniston, Alabama) built 35 near Energy Star homes during the 2003 JCWP.

BAIHP worked closely with the mechanical contractor and the construction supervisors prior to the build to bring the initial HERS ratings of 78 up to 86. Though the houses had been slated to be Energy Star, a miscommunication resulted in the air conditioning efficiency being SEER 10 instead of SEER 12. In Anniston's mixed-humid climate the difference was enough to drop HERS ratings below the 86 target. However, the homes are much more efficient than the previous convention and many volunteers were exposed to energy efficient design and construction as well as combustion safety design *(Figure 21)*. Radon mitigation systems were provided by an Alabama environmental group.

Figure 21 *Homeowner Sandy Sedano installs rigid insulation (part of the energy package) on her new home during the 2003 JCWP at the Anniston (AL) site.*

Congress Build America (CBA)
Newspaper clipping (copy) from the Pendleton Times notes our announcement of the DOE's Building America partnership with Habitat for Humanity International's (HFHI) Congress Building America (CBA) project. The announcement was made at the dedication of Almost Heaven's CBA house (*Figure 22*) which was built in partnership with Shelley Moore Capito, United States Representative second congressional district of West Virginia. Identical concurrent resolutions--Senate Concurrent Resolution 43 and House Concurrent Resolution 184-- express the Congressional support of this project.

Figure 22 *Almost Heaven Habitat for Humanity' Congress Building America house on day of dedication.*

At the event, Michelle Connor, Executive Director of Almost Heaven HFH, and John Reisenweber, District Field Represntative for Representative Capito were presented with DOE approved "Certificates of Recognition" for their dedication to building energy-efficient, durable affordable homes.

According to HFHI's Congress Building America estimates, about 100 houses will be built by Habitat affiliates working in partnership with members of U.S. Congress. The MOU between the affiliates and the HFHI includes language making the Building America technical review part of the standard process. BAIHP is working with Ren Anderson at NREL to develop the details of the technical review now. We will keep you posted on progress.

Washington D.C. Following this field work, BAIHP researchers attended HFHI's Urban Conference in Washington D.C. where they talked about the technical support being available to Habitat's CBA affiliates (and other affiliates). Response was very positive. Mr. Edward Pollock and George James attended a CBA luncheon and addressed the group with an introduction into Building America and our systems engineering approach.

J. McIlvaine visited the office of Senator Bill Nelson, a native of Brevard County, home of the Florida Solar Energy Center, and met with Ms. M. Bridget Walsh, Deputy Legislative Director, introducing her to Building America program and encouraging Senator Nelson's office to participate in the Congress Building America project.

Troup-Chambers HFH (LaGrange, Georgia): The executive director for this affiliate adopted the Energy Star goal and spearheaded the construction of 22 Energy Star homes during the 2003 JCWP *(Figure 23)*. Four plans were rated and scores ranged from 86.5 to 88.5. BAIHP consulted with the affiliate on window specifications,

Figure 23 *2003 Jimmy Carter Work Project house in LaGrange GA – one of 22 Energy Star homes built in one week.*

insulation levels, AC efficiency, and air sealing details particularly with regard to the air handler closets which were previously built with return plenums open to the attic. The affiliate plans to continue building using the JCWP specifications.

Habitat for Humanity Affiliates

BAIHP's technical assistance to Habitat affiliates has shifted away from assistance to individual affiliates, and toward regional and national initiatives including

- Ohio's First Energy grant program for Energy Star affiliates,
- Building America level affiliates in Lakeland (FL), Houston, and Loudon County (TN), the latter being an ORNL partnership to build houses with FSEC monitoring assistance.

A cumulative list of affiliates receiving direct design assistance from BAIHP is shown in *Table 15*. Work conducted with individual Habitat affiliates, independent of national initiatives, is presented here, organized by state.

Alabama: Auburn HFH

David Hinson from the Auburn University College of Architecture contacted BAIHP about a prototype "DESIGNhabitat" home. Three Energy Star homes have now been built with the local Habitat affiliates in Auburn. The prototype will be offered to affiliates statewide through the *Alabama Association of Habitat Affiliates (AAHA)* and non-profit *Design Alabama*. AHA requested indoor air quality and combustion safety testing plus design input on the prototype home in 2002 and 2003. The design features vernacular touches that enhance energy efficiency such as the screened front porch, operable transoms over doors (for ventilation and return air flow), metal roofing, and large overhangs *(Figure 24)*. A sealed combustion closet for the gas water heater, sealed and tested ducts, and high efficiency heating and cooling complete the energy package.

Figure 24 *Transom return air pathway with operable louvers blends in with the vernacular aesthetics of this DESIGNhabitat Energy Star home built in conjunction with Auburn University's College of Architecture.*

Alabama: Birmingham HFH

In 2001, BAIHP researchers tested and rated 3 homes for this affiliate and provided the local construction manager with energy analysis and recommendations. Birmingham HFH continues to Energy Star homes in 2004 - many with HUD approved safe room construction.

Alabama: Calhoun County HFH

Please see 2003 JCWP above, in the summary of work conducted with HFHI.

Florida: Jacksonville (HabiJAX) HFH

This affiliate, located in Jacksonville, Florida, is one of Habitat's most productive alliances. In anticipation of HabiJAX involvement in the HabiBOP pilot program, BAIHP completed preliminary HERS ratings on planned homes. Follow-up test results indicate that HabiJAX is a good candidate for the program, particularly after the construction manager agreed to incorporate a ventilation strategy and energy efficient lighting into their home designs.

Florida: East Orange County HFH
After attending courses and seminars taught by BAIHP staff over several years, this affiliate's construction manager began building interior duct systems. One of those homes was tested in April and found to be well separated from the unconditioned attic above as desired.

Florida: Lakeland HFH
This affiliate has constructed 8 Building America level houses since 2002 *(Figure 25).* During this budget period, the affiliate ramped up construction and trained a new group of construction volunteers completing 8 more homes in the first quarter of 2004. Testing is underway and these will be the first Habitat homes put through the BA Benchmark exercise by BAIHP.

Figure 25 *Habitat for Humanity energy efficient home in Lakeland, Florida.*

Florida: Alachua HFH
Florida H.E.R.O. has worked with Alachua Habitat for Humanity for many years. Currently the affiliate is building a subdivision called Celebration Oaks. Summary of specifications is provided in *Table 16.*

Table 16 Alachua Habitat for Humanity Specifications for Celebration Oaks

Component	Specification
Conditioned Area	~1100 (2 built, 6 in progress, 64 units total)
HERS Rating	NA
Cooling and Heating	SEER 12 Air Conditioning with homeowner choice of heat pump or standard gas furnace heating, Air handler in the conditioned space.
Ventilation	Filtered passive fresh air ventilation.
Duct System	Duct system engineered using Manual D calculations, sealed with mastic, performance tested for air tightness
System Capacity	Cooling and heating systems sized using Manual J calculation procedure
Water Heating	Standard Gas (considering tankless gas)
Walls	ICF Construction with wood frame roof and interior walls
Ceiling	R-30 cellulose insulation
Windows	Double pane Low-E vinyl frame

Georgia: Atlanta HFH
Energy simulations were conducted for insulated concrete form (ICF) homes in Houston and Atlanta. Comparative studies could be conducted in both cities since the same floor plans will be used to build ICF and wood frame homes in those areas. Simulation results from the homes were evaluated to develop suggested improvements that would bring the homes to Energy Star levels. The Houston affiliate is planning a 100-home development and is looking for home performance strategies that would allow them to reach Energy Star at a minimum. Simulations using the measured test data were conducted and recommendations made for their consideration.

The Atlanta home will incorporate substantial thermal mass with concrete ceilings and concrete interior walls. Simulations on the thermal mass benefits were completed and reported. These simulations focused on the use of thermal mass to reduce the size of the heating, ventilation, and air conditioning systems.

Georgia: LaGrange (Troup-Chambers) HFH
Please see 2003 JCWP above.

Georgia: Sumter County HFH
This affiliate attended several courses and seminars taught by BAIHP staff in recent years. As a result, in 2000 the Sumter construction manager began building interior duct systems. One of those systems was tested in March 2002, as part of the Air Handler Air Tightness Study, and found to be connected to the unconditioned attic above. These results were similar to findings in BAIHP's sister project on Interior Duct Systems. After discussions at the April construction roundtable, modifications were made to the construction approach which became part of their standard building practice for the affiliate.

As of 2003, Sumter County HFH is no longer building houses because all remaining qualifying residents have declined partnership.

Ohio Affiliates
A utility grant program in Ohio spurred a broad interest among HFH affiliates in reaching Energy Star level. Affiliate homes built to the Energy Star standard in the utility's service area will receive a grant that equals the cost of the home. Several affiliates acquired the Example Energy Star Packages from HFHI's web site and called to discuss them. In response to this interest, HFHI conducted a workshop in early July 2002 attended by sixty people. Subsequently, all affiliates (~30) attending the course have built and had certified at least one Energy Star home. Each has collaborated with a local certified HERS rater. Several affiliates contacted BAIHP to clarify aspects of the process and only one affiliate experienced difficulty with the certifying process and received direct support from BAIHP.

Louisiana Affiliates
FSEC arranged a partnership with Superior Environments in Metarie to provide support to the Baton Rouge HFH affiliate's April Energy Star home "blitz build." Four high efficiency homes were built during the 2002 blitz build. Though all home met Energy Star status, documentation has not yet been received that the homes were registered. (Please see *Table 17.*)

Table 17 HERS scores for Baton Rouge Habitat Energy Star homes.

House ID #	Address	Score	Est. Utilities
118	635 N. 17th Street	88. 7	959
119	58320 Long Street	87.2	1122
120	58330 Long Street	87.2	1364
121	58340 Long Street	87.2	1120

Nevada Affiliates
FSEC was contacted by Portland Cement Association (PCA) to collaborate on an HFH house planned for the 2003 Builders' Show in Las Vegas. This collaboration was a joint effort between BAIHP, PCA, and the Las Vegas Habitat for Humanity.

New Mexico: Albuquerque HFH
BAIHP completed an initial home design analysis for the Albuquerque HFH which was revised with feedback from the affiliate. Final recommendations were submitted to Albuquerque HFH to assist them in reaching Energy Star status.

Tennessee: Loudon County HFH
In partnership with Oak Ridge, BAIHP prepared to instrumented a second zero energy home (ZEH) built by Loudon County (TN) HFH - their fourth *(Figure 26)*. BAIHP previously instrumented and collected data on ORNL's behalf from Loudon County's first ZEH which showed results of $80 net annual electric cost and an ACEEE paper was authored by ORNL and FSEC. The affiliate has provided valuable feedback on the SIP construction process to other interested affiliates. The fourth ZEH, like the first one, features SIP construction, a PV array, a heat pump water heater with damper to harvest cool dehumidified air in the summer, high performance windows, optimum orientation, overhang shading, and interior ducts. The model also features poured walls in the walkout basement with a side by side comparison of damp-proofing products. Data is available on-line at www.infomonitors.com.

***Figure 26** Local sponsors in front of 2nd ZEH built by Loudon County HFH in partnership with ORNL. FSEC provided monitoring for the 1st and 4th ZEHs.*

Texas: Ellis County HFH
This affiliate reports that they have been building Energy Star homes and now are interested in moving toward a Zero Energy Home similar to the Loudon County HFH project in Tennessee.

Texas: Houston HFH
In 2001, BAIHP completed a preliminary evaluation of the concrete homes built in partnership between Houston HFH and the Portland Cement Association. Staff tested and rated the homes in January 2002 and made recommendations for reaching beyond Energy Star to the Building America standard. Later that year, the affiliate's construction manager reported that they were

now implementing BAIHP energy efficiency, durability, and indoor air quality recommendations. Final home design recommendations included construction of a passive ventilation system and an interior duct system. In 2004, this affiliate reported that all homes (~100) built since FSEC's 2002 recommendations have exceed Energy Star (rated by local utility) and have passive fresh air ventilation ducted to the air handler with a separate, soffit-mounted filter.

Washington Affiliates
In 2004, WSU staff began providing technical support to Habitat for Humanity for two site built projects in Olympia, WA (marine climate) and Grant Co. (cold climate). Technical support included HVAC design, Energy Gauge analysis and field testing assistance. WSU continues to evaluate these homes; final case studies will be completed by the spring of 2006.

The Grant country home utilized standard construction materials and framing, ENERGY STAR HVAC, lighting and appliances. This home moved 100% of the duct system into the conditioned space; from the attic, crawlspace and garage where it was to be installed, at little or no additional cost.

The Olympia home highlighted the challenges of integrating "green" technologies; such as Icynene insulation, and Rastra block walls. The home also used instant flow gas combo hydronic HVAC and HRV systems, and energy star lighting, appliances and was built "solar ready".

Heat Pipe Technology
Gainesville, Florida

Florida H.E.R.O. met with Chuck Yount, National Sales Manager, and the residential engineering staff to discuss the requirements and anticipated performance of their stand-alone dehumidification system, the BKP series. This system has the ability to provide outside air and maintain positive pressurization, and it can be used in conjunction with a condensing section to reject heat generated through dehumidification. During the 4th budget period, Florida H.E.R.O. suggested the use of this technology to several contractors who build large homes.

HKW Enterprises (Lewis Place Association, Ltd., Meadowbrook Development Inc., Millpond Development Corp., and Joyner Construction.)
Gainesville, Florida
Category B, 333 Homes
Awards: NHBA Energy Value Gold Medal Award

Florida H.E.R.O. worked with HKW Enterprises and its subsidiaries to incorporate Building America specifications in

- 1 apartment complex with 112 units (Lewis Place)
- 2 town house developments with 210 units (Williamsburg and Monticello),
- 1 single family home built by Joyner Construction.

Lewis Place was the first Energy Star low income apartment complex in the country and it incorporated an interior duct system *(Figure 27)* with a comprehensive air sealing protocol that included cellulose wall insulation with a gasket between the top plate and the drywall. The units also featured direct vent gas water heaters for good indoor air quality. The Williamsburg and Millpond townhouse developments and the single family home built by Joyner Construction were built with similar features.

Figure 27 *Interior duct system under construction at Lewis Place – the first Energy Star apartment complex in the country.*

Homes of Merit
Marathon, Florida
Category B, 14 Homes

In 2002, Florida H.E.R.O. performed multiple diagnostic tests and conducted a site survey on a mobile home with mold problems in Marathon, Florida. Florida H.E.R.O. determined that the mechanical system was significantly oversized, and the home was operating under negative pressure during system operation. The owner left the central system fan in the "on" position, further exacerbating the indoor humidity problem. Measured indoor relative humidity levels were about 70%, consistent with outdoor humidity levels. Since this case has gone into litigation, researchers have not had the opportunity to determine the final outcome.

In 2001, Florida H.E.R.O. met with plant personnel and LaSalle Air Systems at Lakeland Homes of Merit factory to discuss Energy Star compliance for model homes and HUD code factories. The researcher also performed duct tests on several models at the Bartow manufacturing plant, assisted in development of material and system specifications, and conducted the Energy Star Energy Star Manufactured Home Plant Certification at the Lake City and Bartow plants.

2005 International Builders Show Showhomes

From January 13 to January 16, 2005, Orlando was host to the 2005 International Builders' Show, sponsored by National Association of Home Builders. The show was a massive success; the best attended International Builders' Show on record, with over 105,000 housing professionals in attendances. Located adjacent to the International Builders' Show is an adjunct show, the Show Village.

The Reed Building Group, publishers of Professional Builder, Professional Remodeler, Custom Builder and GIANTS magazines, sponsored the Show Village. The show village is a unique environment where attendees explore showcase homes. Attendees see and learn about products in actual houses, which allows for interaction with manufacturers' products and gives some idea how the products will appear and function in their actual installed environment.

A. New American Home, Built by Goehring Morgan Construction
Orlando, Florida
Category A, 1 home

Builder of the New American Show Home for the 2005 National Builders Show in Orlando, Florida. BAIHP supported IBACOS by testing (*Table 18*) and rating the home and. Data collected at this home by IBACOS will be processed and archived with support from FSEC's data management system.

Table 18 Test Results for 2005 New American Home

Test	Measurements	Notes
Whole House Air Tightness	CFM50=5552 ACH50=5.0	C=549, n=0.591, r=.9996
Duct Leakage AHU1 Master Suite	CFM25,total = 160 CFM25,out = 48	3 Ton AHU Flow = 1203
Duct Leakage AHU2	CFM25,total = 300 CFM25,out = zero	5 Ton AHU Flow = 1550
Duct Leakage AHU3 Suite 2	CFM25,total = 104 CFM25,out = 32	2 Ton AHU Flow = 898
Duct Leakage AHU4 Foyer	CFM25,total = 155 CFM25,out = 40	2 Ton AHU Flow = 1120
All Duct Leakage	CFM25,total = 719 CFM25,out = 120	12 Tons AHU Flow = 4771

B. Discovery Custom Homes Modular Showhome

In 2005 the Show Village featured a Discovery Custom home, made by a division of Palm Harbor Homes in their Plant City, Florida factory. The Tuscany model of the Palm Harbor show house is a one-story, three-section, modular factory-crafted home. It has three bedrooms, two bathrooms, and a home office. It has 2084 ft^2 of air-conditioned space, a 528-ft^2 garage, a 48-ft^2 portico, and a 385-ft^2-patio deck.

When Palm Harbor was presented with this opportunity to showcase one of their homes, they solicited help from BAIHP to showcase energy efficiency, good indoor air quality, and green building practices. Features incorporated into the home are:

Energy Features

- Unvented structurally insulated panel (SIP) roof over master bedroom and hearth rooms
- R-33 vented ceiling over first two sections
- Conditioned, unvented insulated crawlspace
- Low-E Argon metal windows U=.47, SHGC=.32
- R-22 walls
- SEER 17.95/ HSPF 7.95 two-speed compressor right-sized heat pump, programmable thermostat with outdoor thermostat which prevents strip heat turn-on above freezing
- Instantaneous propane water heater
- Compact fluorescent lights in selected areas

- Energy Star Appliances
- Estimated energy savings = 35% on a whole house basis
- Home Energy Rating Scale (HERS) Score = 93 Out of 100

Indoor Air Quality Features

- Fresh air ventilation with filter on outside air intake (fresh air is provided only when the air handler unit is on)
- Dehumidistat (built-in with thermostat)
- MERV9 media filter with 3500-hour life
- Ultra-violet A lights with catalyst to reduce volatile organic compounds
- Low VOC materials and VOC Source Control

Green Building Features

- Enhanced indoor air quality and energy efficiency
- Resource efficient construction and construction waste management
- Water efficient appliances and fixtures
- Durable, low maintenance design
- Meets Florida Green Building Coalition standards

After the show, the home will be donated to Orlando's Home Builders Association's Foundation. Palm Harbor is the 2001 Gold Award winner of the National Housing Quality Award.

C. Not So Big Showhouse

Sarah Susanka Not So Big Showhouse for the 2005 Builders show. (*Figure 28*) 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.

Figure 28 *Not So Big showhouse in Orlando, FL.*

The home's energy saving features which were selected with the hot-humid Florida climate in mind, include:

- High efficiency air conditioning (SEER 16)
- Active dehumidification and ventilation
- Solar water heating with tankless gas backup
- High performance glazing
- Reflective metal roofing

FSEC has installed instrumentation and plans to display the data on the web. The measured energy use will help determine if the energy features are working out as planned. More info at http://www.notsobigshowhouse.com/

- Comfort conditions (temperature and relative humidity)
- Total energy use
- Detailed data on cooling, heating, and water heating energy use (the three main energy users in American homes)

Kit HomeBuilders West
Caldwell, Idaho

Kit Home Builders West was the builders of the Zero Energy Manufactured Home in response to an RFP issued by the Bonneville Power Authority in partnership with BAIHP staff in Washington and Idaho. See Zero Energy Manufactured Home in the Research section of this publication.

Marlette Homes, Kokanee Creek
Everett, Washington

In 2004, Marlette was involved with a new 32 home multi-story development called Kokanee Creek *(Figure 29).* BAIHP staff conducted field evaluation on the first set of homes and provided technical assistance to Marlette and the developer HomeSight, related to the envelope and duct leakage improvements.

Figure 29 *Kokanee Creek HUD-code Multi-Story HUD-code housing*

Marlette Homes, NOGI Gardens
Seattle, Washington
Technical Assistance by BAIHP Contractors Washington State University Energy Program, Oregon Office of Energy and Idaho Department of Water Resources, Energy Division
Awards: HUD Secretary's Gold Award for Excellence
Energy Value Housing Award

Nogi Gardens is a 75-home community located in southeast Seattle The project contains the first two-story, HUD Code attached "townhouse homes." *(Figure 30)* All the homes have been built by Marlette Homes in Hermiston, OR to Super Good Cents/Energy Star specifications. A blower door test of the building envelope showed 5.0 ACH at 50PA, average for a manufactured home in the Pacific Northwest. Duct leakage is very low, due to Marlette's use of mastic and duct risers.

Figure 30 *Nogi Gardens, America's first HUD Code attached town houses.*

Miami-Dade HOPE VI Project
Miami (Dade County), Florida
Technical Assistance by BAIHP Researchers Rob Vieira and Eric Martin

This project was a community revitalization program aimed at lessening poverty density by demolishing dilapidated public housing and replacing it with new, less dense housing. In this HUD-sponsored inner city redevelopment project, about 860 public housing units were to be torn down and replaced with 450 new units. The new units would have included duplexes, townhouses, and single-family homes.

As part of a sustainability team, FSEC participated in the initial design charette which reviewed project home designs, made architectural recommendations on wall and roof assemblies, exterior finishes, and other energy-related design and construction features.

During 2002, FSEC provided assistance to Miami-Dade Department of Environmental Resources Management when they emphasized the importance of Building America principles and techniques to the Miami-Dade Housing Authority. The Housing Authority conducted a mandatory value-engineering meeting to ensure that their Hope VI Project would meet the available budget. FSEC staff, as well as other stakeholders, took part in housing discussions and analysis to ensure that the Building America principles and techniques specified early in the project would be considered and not engineered out of the project.

Unfortunately, this project never got past the design stage due to a lack of cooperation among existing residents of the area.

Midgard Associates
Panama City, Florida
Category A, 358 Homes

Midgard Associates is a new developer partner aquired by BAIHP in November 2004. The developer plans to develop a community called East Bay, in the Florida panhandle, with ground to break sometime in Summer 2005. Although the developers will not be building any of the homes, they have a wealth of building knowledge in the hot/humid climate, and are responsible for the construction of the Captain Planet Zero Energy Cottage.

The developers have a vision to oversee development of a high-performance, sustainable community that responds to the environment of Florida's gulf coast. They have enlisted the assistance of BAIHP to help develop a builder program, including home specifications and performance reviews. They have also inquired about having BAIHP develop and deliver training to the selected builders. Midgard Associates have expressed an interest in all homes achieving green certification, and implementing other innovative community scale measures such as community scale geothermal heat pumps.

In March 2005, Midgard toured select developments in Central Florida including Lakewood Ranch to see how others have implemented builder programs that emphasize high performance home construction. The visit culminated at FSEC, where collaborations and partnership was discussed. Discussions are currently underway for the design of a demonstration/info center. This will be similar in nature to the Captain Planet Zero Energy Cottage, yet be more reminiscent of the scale and architecture of other homes to be built within East Bay.

Nez Perce Fish Facility
Cle Elum, Washington

Three SGC homes were built at the Nez Perce tribal fish facility in Cle Elum, WA. One of these homes is equipped with Energy Star appliances and lighting; all three homes are heated with Insider heat pumps. Monitoring equipment was installed in Year 2. In Year 3, preliminary blower door testing indicated a high leakage rate. During Year 4, tests found significant duct leakage due to failure of butyl tape at risers on 2 year old home. (See also *Section III Research Zero Energy Manufactured Home.)*

New Generation Homes
Ft. Myers, FL

Ken Kingon of New Generation Homes became a BA partner at the end of the 5th budget period. Of particular interest is the performance of the high efficiency 5 ton 15 SEER AC system and the use of outside air ventilation (measured air flow = 32 cfm) to the air handler. A house was tested and instrumented in February 2005 by FSEC researchers *(Figure 31)*, showing that duct leakage and air tightness are consistent with new home construction, there are opportunities for improvement. The HERS score is 87.9.

Figure 31 *New Generation Home*

Northwest Energy Efficient Manufactured Housing Program (NEEM)
Idaho
Oregon
Washington (State)

The Washington State University Energy Program (WSU), together with partners Oregon Office of Energy and Idaho Department of Water Resources, Energy Division, continue to provide technical and research support to the Northwest Energy Efficient Manufactured Housing Program (NEEM program in the Pacific Northwest. The NEEM program involves 20 plants in three states, hundreds of retailers and thousands of homebuyers.

The NEEM program includes the brands Super Good Cents and ENERGY STAR, and includes homes heated by electricity and Natural Gas/propane. Prior to 2003, the NEEM program also included the Natural Choice brand, which was exclusive to homes heated with Natural Gas or propane. In 2003, the Natural Choice brand was phased out; now, all gas heated homes are branded ENERGY STAR. In 2004, a new path for ENERGY STAR was developed for Super Good Cents homes with electric furnaces. Homes will be built to this path beginning in 2005.

In the fall of 2004, NEEM staff began to provide technical assistance to Champion Homes on a 700 unit private military modular housing development at Ft. Lewis. In-plant verification, certification and on-site verification of these homes began in spring of 2005 and will continue as a major BAIHP effort.

In the fall of 2004, technical assistance by NEEM staff to the Energy Trust of Oregon resulted in the development of a million dollar utility incentive program that promotes the production of a more NEEM homes built to higher benchmarking levels consistent with BAIHP goals. A technical analysis of the ETO program has been provided to FSEC.

Throughout the BAIHP effort, WSU staff provided technical assistance and guidance to the NAHB Research Center Energy Value Housing Awards, judging submittals, providing de-briefing to builders, and participating on workshops. NEEM builders Fleetwood, Champion, Valley and Marlette have received EVHAs for factory built housing.

Aligning with New Building America Goal

In the summer of 2004, BAIHP staff performed a benchmarking evaluation to assess the improvement of NEEM homes over the entire BAIHP project period (note that this evaluation was included in the Year 5 (April 2003 – March 2004) annual report). The benchmarking was based on a home defined by NREL (built to IECC requirements). The savings over the benchmark home were estimated using version 2.2 of Energy Gauge USA. Evaluations were performed for a typical 1600 ft^2 double wide home with 12% glazing to floor area (the NEEM fleet average) in three Pacific Northwest climate zones: Portland, OR; Spokane, WA; and Missoula MT.

The homes were benchmarked assuming a continuously operating whole house ventilation system, resulting in a significant thermal energy penalty. Additional benchmarking was also conducted using the 164 kWh/year ventilation assumption in the NREL benchmark, in an effort not to penalize the homes for improved IAQ associated with HUD whole house ventilation system requirements and ASHRAE 62.2.

In 2004-2005, improvements were made to NEEM HVAC systems and duct specifications as a result of BAIHP research (see Refinement of NEEM Specifications, below.) Additional benchmarking is presented that reflects these improvements.

The results of the benchmarking vary considerably by HVAC type, water heat and climate, as noted in *Table 19* below. Some key observations:

- In all climate zones, electric homes result in negative savings if the ventilation penalty is assumed. This is largely the result of the assumption that the benchmark home has a heat pump that performs without installation problems; an assumption that will be evaluated by BAIHP research.
- Gas heated NEEM homes came closest to meeting the overall BAIHP goal of 40% over the NREL benchmark, but only met the goal if gas heat is paired with electric water heat, in cold climates with no ventilation system penalty.
- Eliminating the ventilation system penalty has a higher impact on benchmarking results (9 to 23 percentage points) than improved duct leakage tightness (3 to 11 percentage points).
- It should be noted that Benchmarking these NEEM homes against the HUD-FMCSS requirements (Uo=.079) for manufactured homes rather than the IECC (Uo=0.06) would yield considerably higher savings than current benchmark assumptions.

Table 19 Benchmarking Savings Results

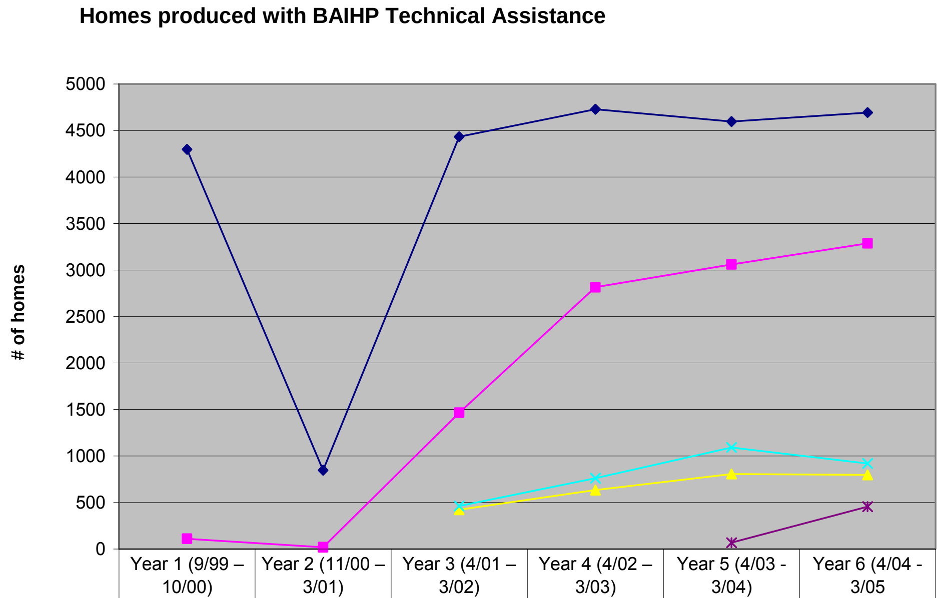
Duct Leakage	Pre-2004*	2004**	Pre-2004*	2004**
Ventilation System Penalty	Yes	Yes	No	No
Portland				
Electric Furnace	-31	-20	-8	0
Heat Pump	11	14	20	22
Gas Heat/Elec DHW	16	22	32	37
Gas Heat/Gas DHW	15	20	30	34
Spokane				
Electric Furnace	-18	-9	2	10
Heat Pump	17	21	27	30
Gas Heat/Elec DHW	22	27	36	41
Gas Heat/Gas DHW	21	26	35	39
Missoula				
Electric Furnace	-12	-3	8	15
Heat Pump	17	22	28	32
Gas Heat/Elec DHW	21	26	35	40
Gas Heat/Gas DHW	20	25	34	38

* Pre-2004 – Duct leakage of -132 cfm@25PA
** 2004 – Duct leakage of -60 cfm@25PA

Figure 32 shows, by program year, the number of homes produced with technical assistance from BAIHP, as well as the number of homes submitted for ENERGY STAR designation by BAIHP staff and the breakdown of homes by benchmarking score. Please note the following:

- The benchmarking includes the assumption, based on the NEEM 5th Budget Period random that showed 24% of all homes included after-market heat pumps.
- No benchmarking was performed for Years 1 and 2, due to a lack of accurate regional data.
- In 2003 and 2004, the appearance of homes that achieved a 30+% benchmark is the result of the improvements made to the NEEM HVAC specifications.
- Figure 32 averages benchmarks for Spokane and Missoula for homes in cold climates and uses the Portland benchmark for marine climates. *Figure 32* also assumes an average value between ventilation penalty and no ventilation penalty.

The continued success of the program is due to several factors. BAIHP and NEEM staff worked to increase awareness within the manufactured housing industry of the marketing value of energy efficiency, increase participation by utilities in incentive programs, and promote the co-branding of NEEM with ENERGY STAR.



	Year 1 (9/99 – 10/00)	Year 2 (11/00 – 3/01)	Year 3 (4/01 – 3/02)	Year 4 (4/02 – 3/03)	Year 5 (4/03 - 3/04)	Year 6 (4/04 - 3/05
Total homes	4296	848	4434	4729	4596	4694
Homes Submitted for Energy Star© Designation	112	18	1465	2816	3061	3286
10-20% over NREL benchmark	*	*	423	635	808	797
20-30% over NREL benchmark	*	*	463	763	1092	921
30+% over NREL benchmark	*	*			69	456

* Homes not benchmarked due to a lack of regional data

Figure 32 *Homes Produced with BAIHP Technical Assistance*

The increase in ENERGY STAR designations is due to refinement of the SGC duct sealing specifications, resolving a discrepancy between the SGC specifications with ENERGY STAR's duct sealing protocols (while this question was being resolved September of 1999 through early 2001, BAIHP staff did not submit homes to DOE for ENERGY STAR designation). In 2003, remaining discrepancies with manufacturers in Idaho were further resolved, allowing BAIHP staff to accurately report all qualifying homes.

Refinement of SGC specifications
BAIHP staff continually work to refine the existing SGC specifications, a result in large part to innovative building technologies researched in BAIHP.

In 2003, BAIHP staff worked with NEEM staff and manufacturers to develop revisions to NEEM specifications, including allowing only mastic for duct sealing, requiring metal flex duct for whole house ventilation fans, and changing the air infiltration specification from 7.0 ACH_{50} to 5.0 ACH_{50}.

The revised specifications were voted on and accepted by the manufacturers; they took effect on January 1, 2004.

In year 2004 in Oregon, 1 in Idaho plant began testing the ducts in all the NEEM homes they produce, which is expected to result in even tighter duct systems. Field testing of a sub-sample of these homes duct testing began in 2004 and continues. This field testing is also evaluating homes that employed a "thru-rim" crossover duct system.

BAIHP staff continues to work with EPA and other regional partners on clarifying the equivalency of SGC with ENERGY STAR. In 2002, BAIHP staff developed a new ENERGY STAR compliance path for climate zone 2 that does not require a heat pump. The non-heat pump path uses a heat recovery ventilation system, a .93 EF hot water heater and tighter ducts and envelope. This path was not utilized due to reluctance by manufacturers to install HRV systems. In 2004, this path was modified to eliminate the HRV, and include options such as set-back T-stats, ENERGY STAR dishwasher, adjusted glazing limits, improved window U-factors, and in-plant tested duct systems.

Revised In-plant Manual
In 2003, in light of the revisions to the NEEM specifications, BAIHP staff from the Oregon Department of Energy developed an updated in-plant inspection manual, with new graphics, including details on correct installation of heat recovery ventilation. Many of the manual updates are the result of BAIHP research and demonstration efforts, including use of hybrid floor systems and proper duct sealing with mastic. The manual also now includes a regionally consistent problem home inspection protocol.

In-plant QC Training
In 2004, BAIHP staff from the Oregon Department of Energy developed a PowerPoint presentation, based on the revised In-plant manual. In 2004, BAIHP staff began using this presentation to train QA staff at each plant; this effort will continue until all NEEM plants have received this training.

In-Plant Inspections
On a quarterly basis, BAIHP staff visits each of the manufactured housing plants to verify compliance with SGC/E-Star specifications. Inspections include a plant audit, ventilation system testing, and troubleshooting construction-related problems with plant staff and independent inspectors. Consistent issues in the plant include wall insulation compression or voids due to improper cutting of batts, attention to duct installation and air sealing. Specific in-plant inspection reports conducted in Washington in program Year 6 (March 2004 – April 2005) are provided to FSEC.

Transition to mastic
As mentioned above, the NEEM program eliminated the use of butyl tape for duct sealing, and required the use of mastic. As of spring 2004, ten manufacturers have successfully transitioned to mastic. Testing in-plant has indicated significant improvement in duct leakage rates of homes in these factories– an average 36.8 cfm @ 25 PA (versus 50.1 cfm @ 25 PA pre-mastic), a 27% improvement. This trend continued into 2005.

WSU and ODOE began working with Fleetwood engineers to evaluate a new lower cost duct leakage testing device that Fleetwood is considering using in all of its plants throughout the USA. The preliminary results suggested a need utilize 10 second averaging and set a higher pressure ratio from 86% to 90% to be consistent with NEEM duct leakage targets. This work will continue through program Year 7.

Duct Workshops
Through the spring of 2005, BAIHP staff continued to provide workshops focused on improved duct installation and inspection oversight, working in partnership with BAIHP partners. One in-plant duct leakage workshop resulted in the identification of significant duct leakage (branch disconnect) which re-enforced the need to consider duct testing of all units at that plant.

New Technology Evaluations

High Efficiency Gas Furnaces
Initial evaluations of 90% efficient gas furnaces indicates that there is no incremental installation cost to the use of these furnaces, as no field modifications are required. In 2003, Nordyne and Evcon came out with furnaces with an appropriate footprint for manufactured housing; Intertherm also continues to offer a 90% efficient model. Discussion with BAIHP home manufacturer partners Fuqua, Marlette, Champion, and Fleetwood, and furnace manufacturer partners Evcon and Nordyne, indicate the that this market is growing quickly, especially in homes with high pitch "tilt-up" roof systems, and multi-story homes such as at Nogi Gardens and Kokanee Creek *(Figure 33)*. The ability to use wall venting instead of roof venting with condensing furnaces makes them more attractive where tilt-up roofs are employed.

Figure 33 *90% AFUE Furnace, as installed at Kokanee Creek*

Through the rim crossover duct system
Three Oregon manufacturers, Marlette, Skyline and Homebuilders Northwest, adopted a crossover duct system that runs through a cut out section of the rim joist, effectively placing the entire crossover system in the heated space. A gasket on the marriage line provides a seal between sections. Challenges with the use of this system include the need for very accurate measurements to insure matching of the duct connection, and careful treatment of the gasket material during set up, so that it doesn't detach from the rim.

Evaluations suggest that that further improvement to gasket systems may be needed to ensure set-up that achieves effective duct sealing.

La Salle Duct Riser
BAIHP staff worked with BAIHP partner La Salle Air to design and produce a duct riser for manufactured homes that uses mastic instead of tape. BAIHP staff demonstrated prototype designs of the riser to Northwest manufacturers in Year 3. Most NEEM manufacturers adopted the new risers or equivalent systems in year 6. BAIHP staff worked with Fleetwood's national office to promote the use of the riser in all Fleetwood plants. During 2003-2004, BAIHP staff promoted the use of this technology at the annual MHI conferences and energy road-mapping meetings.

Flexible Technologies:

BAIHP partner Flexible Technologies has developed innovative systems that improves the heat and tear resistance of the duct inner liner, reduces the crimping of ductwork without the use of sheet metal elbows, and an improved system to air seal where the crossover duct penetrates the bottom board. BAIHP staff evaluating the use of this system in the WSU Energy House and ZEMH *(Figure 34)*, and worked with Flexible Technologies staff to promote the use of the new system to the region's manufacturers. Efforts to gain market adoption of the technology remain challenging due to first cost increases and lack of demonstrated benefits.

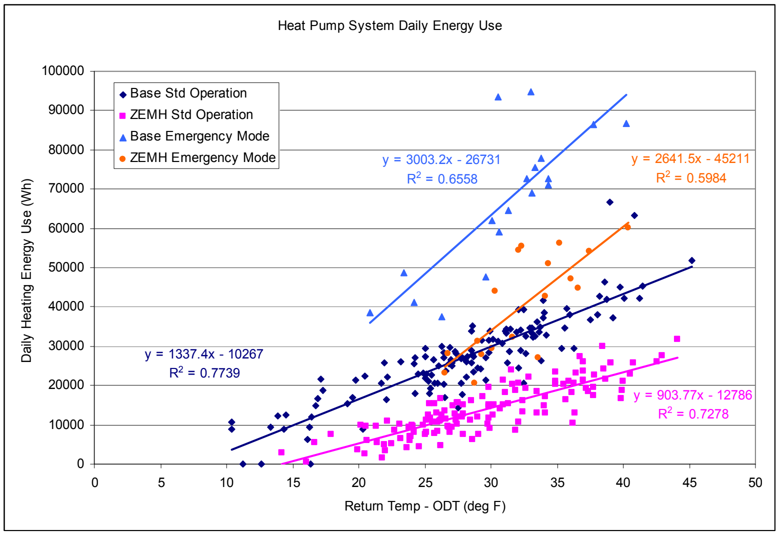


Figure 34 *Insider Heat Pump in ZEMH and Base Home – Operation in HP and Strip Heat Mode*

Insider Heat Pump

Monitoring of the Insider heat pump at the WSU Energy House was begun in 1999. Measured flow rate of the indoor unit was good (850 CFM total, 425 CFM per ton), but BAIHP staff identified two performance issues: a too-frequent operation of the defrost cycle and a lower than expected airflow at the outdoor coil. Continued testing of the Insider in 2002 indicated a 10% increase in COP due to increased airflow at the outdoor coil. At Vincent Village, the property manager indicated a high degree of satisfaction with the Insider heat pumps, with no comfort complaints. Flip flop testing that varies the compressor and electric resistance heat were conducted in the WSU and ZEMH. The results of those tests being analyzed for a ASHRAE paper to be submitted in 2005. The Insider Flip flop test results are presented in *Figure 34.*

Energy Conservatory

BAIHP staff work with the Energy Conservancy (EC) to evaluate their new products for measuring air handler and exhaust fan flows. In 2004, BAIHP staff worked with EC staff to develop an automated test that will provide duct leakage to outside. Discussion with EC indicated significantly increased sales of duct blasters to HUD-code manufacturers as a result of BAIHP efforts. WSU continues to work with EC to develop new building science tools for HUD-code housing.

Other Technologies
In 2004, BAIHP staff submitted a status report summarizing program efforts to introduce BAIHP manufacturers to new technologies. The report highlights the barriers and successes made regarding:

- 24" OC Wall Framing
- Air-Tight Can Lighting Fixtures
- Solar Ready design
- Improved flashing/drainage systems
- High Efficiency Water Heaters
- Blown Cellulose Hybrid Floor Insulation
- Condensing Gas Furnaces
- Heat Pump Water Heaters – Site built
- Hi-R wall Systems (Foam Sheathing + Icynene) – Site Built

Research Support

ASHRAE
During 2003, in the capacity of chairing ASHRAE's 6.2 Technical committee, BAIHP staff directed a major effort to revise Chapter 9 of the ASHRAE Systems Handbook, "Design of Small Forced-air Heating and Cooling Systems." The revisions to the chapter, which incorporated BAIHP research, were accepted by the committee, and forwarded to ASHRAE for publication. In 2004 BAIHP staff provided assistance to other BA teams to improve chapter 43 of the ASHRAE Applications Handbook – Envelopes.

BAIHP staff have also participated in ASHRAE research projects, conferences, symposiums, seminars and forums, including:

- Authoring a paper on duct leakage, which was submitted and approved for presentation at ASHRAE summer meeting in 2004.
- Making a presentation at the ASHRAE summer meeting in 2003, "Uncontrolled Air Flow in Small Commercial Buildings."
- Moderating a forum on HVAC experiences in HUD code housing at ASHRAE's summer meeting in 2002. 20 industry and building science professionals participated in the forum.
- Co-chairing ASHRAE's Technical Committee 6.3 – Residential Forced Air Heating and Cooling Equipment, which is responsible for ASHRAE standard 152 – Thermal Distribution Systems.
- Building America research on ductwork and HVAC systems will be included in the next version of the ASHRAE standards. Building America research will also be a part of future efforts in TC 6.3.

NFPA-501
BAIHP continues to support the NFPA standards process. The NFPA standard is typically incorporated into the HUD code, which governs the construction of over 250,000 HUD code homes each year.

- In 2003, BAIHP staff integrated BAIHP duct leakage and cost data into proposals to the NFPA-501 committee. Based on this data, NFPA approved a new standard on duct tightness, as well as a refined duct testing protocol.

- In 2002, BAIHP staff cited Building America research and demonstration efforts in support of additional successful proposals for standards revision, including duct testing, and use of mastic in duct sealing.

ACEEE

- BAIHP staff have co-authored two papers presented at ACEEE Conferences, "Pushing the Envelope: A Case Study of Building the First Manufactured Home Using Structural Insulated Panels," and "Washington State Residential Ventilation and Indoor Air Quality Code (VIAQ) - Whole House Ventilation Systems Field Research Report."
- In 2004, BAIHP staff coordinated 24 peer reviewed papers for the Residential technologies track at the Summer Study and coordinated informal sessions on HUD-code housing.

National Institute of Standards and Technologies (NIST)
BAIHP staff continues to work with NIST staff and industry representatives to evaluate ventilation and IAQ issues in HUD code homes.

- BAIHP staff also worked with NIST and the Energy Conservancy to perform tests on a typical HUD code model house on the NIST campus in Gaithersburg, Maryland. Testing indicates low flow rates of the whole house ventilation system and significant duct leakage.
- In 2004, discussions with NIST, LBL, Ecotope and Energy Conservatory continued on a retrofit research effort with Dupont Tyvek, and development of new ventilation system controls with Panasonic. These discussions will continue.

National Manufactured Housing Research Alliance (MHRA)
BAIHP staff continues to participate on MHRA's ENERGY STAR committee, which is developing Quality Assurance procedures with USEPA on ENERGY STAR manufactured homes. An article on the ZEMH appeared in the MHRA newsletter. WSU worked with MHRA to provide an article on the ZEMH project. WSU continues to provide technical support to MHRA on ENERGY STAR and other building science/energy related efforts such as the MHI roadmap.

Oakwood Homes
Moultrie, Georgia
Hillsboro, Texas
Kileen, Texas
Technical Support by BAIHP Researcher David Beal

BAIHP assisted Oakwood Homes with one problem home investigation between April 2003 and March 2004. This large HUD code manufacturer previously requested an FSEC duct installation review and consultation on ways to make the home's systems work better together. In 2002, plant visits were made to the Oakwood plant in Moultrie, Georgia and to the Hillsboro and Kileen, Texas plants. Recommendations for appropriate duct system design and manufacture were reported to Oakwood Homes.

An Energy Gauge USA analysis of Energy Star and non-Energy Star homes in Boston, Minneapolis, and Indianapolis was performed. Researchers determined that Oakwood Homes could meet Energy Star standards if they increased installed gas heating and cooling system efficiencies, and floor and roof insulation levels. These results were communicated to Oakwood management via email.

Palm Harbor Homes
Category A, 2 Homes
Category B, 13 Homes
Category C, 1,645 Homes (North Carolina factories)
Category D, 32,000 Homes
Technical Assistance by BAIHP Researchers Subrato Chandra, Neil Moyer, Dave Chasar, and David Beal
Awards: 2004 Energy Value Housing Award

First under the Energy Efficient Industrialized Housing Program (EEIH) and now under BAIHP, FSEC collaborates with Palm Harbor Homes (PHH) offering building science advice, energy ratings, and conducting diagnostic testing including infrared building and duct air tightness thermal imaging camera inspection. As a result, PHH now incorporates added return air transfer ducts to minimize pressure imbalances in the conditioned space and measures leakage of every duct system to ensure losses below 3% (Qn_{total}) at every factory *(Figure 35)*.

Figure 35 *A Palm Harbor Energy Star home manufactured in Plant City, Florida.*

FSEC provided assistance to Bert Kessler (PHH VP of Engineering) with submission of an NAHB nomination for the 2004 Energy Value Housing Award.

Energy Star Plant Certification for Palm Harbor Factories nationwide
With FSEC guidance, PHH Plant City produced the world's first two HUD-code Energy Star homes in 1997 *(Figure 35)*. Since then, EPA has implemented an Energy Star factory certification procedure which involves testing in both the factory and at the home sites. The procedure verifies consistent factory production of Energy Star level manufactured homes.

Nine Palm Harbor factories have completed certification *(Table 20)* under the new Energy Star guidelines for manufactured homes.

Table 20 Energy Star Certified Palm Harbor Plants

Plant Location	Certification Date
Plant City, FL	April 2002 (4^{th} Budget Period)
Sabina, OH	June 2002 (4^{th} Budget Period)
Austin, Buda, Ft. Worth, and Burleson, TX	June 2003 (5^{th} Budget Period)
Boaz, AL	September 2003 (5^{th} Budget Period)
Albemarle, NC	December 2003 (5^{th} Budget Period)
La Grange , GA	December 2003 (5^{th} Budget Period)

Energy Star Ratings using *EnergyGauge USA*

In the fifth budget period, FSEC rated two PHH modular homes produced in Texas. Prior to that, FSEC staff conducted several Energy Gauge ratings and related energy analyses for PHH Plant City (FL) and performed two energy analyses comparing standard HUD code specifications to PHH energy improved homes sited in Detroit, Morgantown (WV), and Missoula (MT).

EnerGMiser Energy Management System

Researchers conducted an analysis of the PHH EnerGMiser Energy Management System and quantified the energy savings over base-case HUD code homes in 40+ US cities. Energy savings ranged from 28% to 42%. The results of these analyses are listed at the PHH corporate web site at www.palmharbor.com/our_homes/home_features/energy_management_system.

Factory in Albemarle, North Carolina

FSEC contacted the North Carolina engineering manager for information on Palm Harbor's typical model construction specifications in order to begin Energy Star qualifying procedures. Two PHH model analyses for three different climate zones were run to assess initial energy efficiency. These tests were rerun once specific window SHGCs were received from PHH.

On February 24 and 25, 2003, FSEC conducted a plant visit to direct and oversee Energy Star certification tests on six floor models. Tests were completed by FSEC and by factory personnel with FSEC oversight. All models passed the 3% leakage limit. To complete the certification, three additional site installed homes will be tested for compliance.

FSEC staff also worked with the plant engineer on builder option packages (BOPs) versus software options as a means to qualify homes for Energy Star. It was determined that qualifying homes in Energy Star zones 3 and 4 will be feasible using BOPs, but EG USA will be needed to certify at least some of the zone 2 homes.

Factory in Austin, Texas

PHH initiated certification procedures for Energy Star per the EPA/MHRA guidelines. Staff completed the reporting and certification on two PHH Austin homes in the Houston area for Energy Star compliance. One home passed and the other failed due to belly board installation problems. *(Figures 36 and 37)* These belly board problems have since been addressed and the Austin plant and the remaining three Texas plants are currently being certified for Energy Star production.

Figure 36 *Another belly tear found during inspection.*

Figure 37 *Worst belly tear near plumbing penetration.*

<u>Factory in Plant City, Florida</u>

Energy Star Plant Certification
Researchers initiated certification procedures for Energy Star per the EPA/MHRA guidelines. FSEC reviewed the Design Approval Inspection Agency (DAPIA) packages and design procedures. The PHH Plant City factory was certified in February 2003 and registered one Energy Star home in Polk County, Florida.

FSEC met with the plant engineer on September 16 and 17, 2002 to analyze several new models for Energy Star eligibility. The analysis was conducted using EG USA software (v-1.32). Researchers assisted the plant engineer with a combination of EG USA software and BOPs, so that all plant models over several states could reach Energy Star levels.

Insider Heat Pumps
In 2001, five model homes at PHH-Plant City were tested for return air performance. Two of the homes were modular with Insider heat pumps. Performance results and recommendations were submitted to the plant engineer.

Staff retested two modular homes with Insider heat pumps and determined that leakage in the condenser fan compartment was depressurizing the homes. Further testing on other Insider installations is needed to uncover the scope of this problem and plans are in progress to find the best corrective course of action. BAIHP will visit PHH Plant City and observe the installation when the next Insider heat pump is requested. Researchers will look for installation problem areas and perform additional home tests.

Technical Assistance
Diagnostic tests were conducted in 2002 and 2004 on homes in Odessa and Plant City, Florida manufactured by PHH-Plant City. These visits were requested by PHH after they received a

homeowner high-utility bill complaint. In Odessa, inspections with the infrared (IR) camera found no insulation problems and duct blaster and blower door tests revealed airtight duct and envelope systems. Other than an oversized air conditioning system, there were no obvious reasons for the high bills. The homeowner was satisfied with the investigation and apologized for their written complaint. In Plant City, problems with the sizing of the field-installed A/C ducting had caused temperature differences in the home. PHH redid the ducting and BAIHP hasn't heard further complaints.

Building America Homes
Palm Harbor Plant City built two homes that meet or exceeded current Building America energy goals, one study home used in the Manufactured Housing Indoor Air Quality (IAQ) study detailed in Section III, and a high visibility modular home built for the 2005 International Builders Show (IBS) in Orlando FL. Both homes were built in cooperation with BAIHP researchers. The IAQ house's HERS score was 91.1, the IBS building scored a 93. The IAQ home demonstrated a 50% saving in A/C energy compared to an Energy Star rated home (HERS of 86.5) used for control in the same experiment. The IBS showhouse is detailed in the Technical Assistance section under "International Builders Show Showhouses."

<u>Factory in Sabina, Georgia</u>
PHH signed an Energy Star Partnership Agreement to begin certification of the Sabina Plant. Two model home plans were analyzed, each with a gas furnace and a heat pump, using EnergyGauge USA software. The plant certification visit and site-installed home ratings were done in Spring 2002 and certification paperwork was forwarded to the EPA for plant registration. PHH is planning a 54-unit development in Wilmington, Ohio. Modifications made at the Sabina Plant should be very helpful for the Wilmington endeavor.

Patrick Family Housing, LLC.
Satellite Beach, FL
Technical Assistance by FSEC, Calcs-Plus

The group represents a partnership between the US Air Force and American Eagle Communities, and is handling a housing privatization project, taking place on Patrick Air Force Base in Satellite Beach, FL. Plans are underway to construct several hundred single-family housing units, which will be leased to Air Force personnel. BAIHP is providing design assistance to the project, and will closely monitor construction of 5 prototype homes.

BAIHP researchers met with partner Patrick Family Housing to discuss mechanical design issues in five model homes, and coordinated a review of HVAC design and system sizing for partner Patrick Family Housing. Review and design analysis conducted by partner Calcs-Plus. Advice was given to adapt systems to Florida's hot-humid climate.

FSEC staff visited the site where 5 prototype homes are being constructed. Five slabs have been poured, and wall and roof structure erected for one home. Builder feedback was received on the use of a solid pour wall system, and recommendations on insulation, stucco application, and attic venting were provided.

Penn Lyon Homes
Selinsgrove, Pennsylvania
Technical Assistance by BAIHP Contractor University of Central Florida, Industrial Engineering Department

In March of 2004, Penn Lyon Homes (Selinsgrove, PA) began a large scale plant wide test of a prototype Status and Control System (STACS) developed by BAIHP researchers at the UCF Constructability Lab. The system is a real time shop floor labor data collection and reporting system. Production workers use wireless laser scanners *(Figure 38)* to report their current work assignment.

Figure 38 Scanning *drywall activities with new STACs device.*

STACS reporting is web based and provides both real time manufacturing status and summaries of historical production performance. While labor represents a relatively modest fraction of production cost, typically 10-15%, it has a profound impact on operations, including product quality, cycle time, material waste, and labor productivity. The test will continue through the summer of 2004, and results will be used to develop labor models using linear regression and neural nets.

See also, Avis American Homes (Technical Assistance section) and Status and Control System (STACS) (Section III, Research).

Podia Construx/Rainbow Springs Construction
Gainesville, Florida
Category B, 22 Homes
Technical Support by BAIHP Subcontractor: Florida H.E.R.O.

Florida H.E.R.O. worked with David Sullivan, owner of Podia Construx, his sales staff, project management, and principal sub-contractors to incorporate Building America concepts into the communities of Rainbow Springs, Hidden Lake, and Ocala Waterway.

Podia builds mostly concrete block homes with a continuous, interior layer of ¾" unfaced rigid wall insulation and unvented attics. Spray foam insulation is applied to the underside of the roof deck and is sometimes used for wall insulation. Some of Podia's homes are performance tested for duct and whole house air tightness. The homes also feature SEER 13 heat pumps or SEER 13 air conditioners coupled with standard gas furnaces. All homes have filtered outside air ventilation and double pane Low-E vinyl frame windows.

Podia tried replacing roofing felt with Tri-Flex material for moisture transmission reduction on home, but after complaints from the roofers regarding a lack of footing on the slick material, the Tri-Flex was removed and replaced with standard felt paper.

Condensation Complaint
In response to a homeowner's concern about excessive condensation on interior windows, Florida HERO performed a site survey of ambient, interior, surface, and subsurface moisture readings to determine the cause. This home has Icynene sprayed on the underside of the roof sheathing and an outside air duct. The outside air duct damper had been shifted to the closed position. The damper was reopened and the moisture related complaints were eliminated.

Sandspur Housing
Maitland, Florida
Category B

Since 2002, FSEC staff have been working with Sandspur Housing, the largest affordable home builder in the nation. Sandspur constructs approximately 4,000 apartment units per year, primarily in Florida and Georgia. The company's primary interest in Building America is in receiving assistance for designing low energy-use units with good indoor air quality and resolving recurrent moisture problems in Florida's hot-humid climate. Contact with Sandspur was initiated by BAIHP subcontractor Florida H.E.R.O. in Gainesville, Florida.

Sandspur Housing staff were taken on a tour of the David Hoak demonstration home to show specific equipment and the role it plays in an overall systems engineering approach. After the tour, discussions continued on the Landing Community analysis. This allowed personnel to view firsthand some of the Building America principles and practices so that they could explain these concepts to others in the Sandspur organization.

BAIHP has worked with Sandspur in three Florida cities: Naples, Orlando, and Gainesville.

Naples, Florida
For Camden Cove, Sandspur's community in Naples, BAIHP researchers conducted an energy analysis on all individual units and several apartment buildings slated for construction in 2003 and 2004. Information from Sandspur's building plans was combined with Florida H.E.R.O.'s field experience in Sandspur's Gainesville apartment complex Harbor Cove Community. Results indicated an opportunity to cost-effectively reduce energy use/cost in a 16-unit apartment building by more than 20% while improving indoor air quality and durability. Since Sandspur was already building fairly tight duct systems, savings potential in this area was already being achieved. Additionally, heating and cooling loads in multi-dwelling buildings are lower than similar size and construction single family detached housing because there are fewer exterior surfaces.

Energy efficiency recommendations included:
- Switching to 75% fluorescent lighting
- Reducing duct leakage to the outside to 3% ($Qn_{OUT} \leq 0.03$)
- Reducing window area to 6% of floor area
- Window shading strategies to provide overall solar heat gain coefficient of 0.2
- Installing ducts inside the conditioned space
- SEER 13.0 cooling systems

- White metal roofing or radiant barrier
- Programmable thermostats
- Ceiling fans in all bedrooms and main living areas

Air quality improvement strategies focused on including:
- Pleated return air filters rated with an Minimum Efficiency Reporting Value (MERV) of 11
- Filtered mechanical ventilation of 7.5 CFM/person + 0.01 CFM/ft^2
- Supplemental dehumidification
- Quiet, energy efficient bathroom exhaust fans with timer switches ($\leq$0.3 watts/ft^3)
- Quiet, energy efficient vented kitchen range hoods in each unit

A summary of all analysis results and building design features was prepared and submitted to Sandspur Housing. Two meetings were held to review the recommendations.

Orlando Moisture Investigations

FSEC staff tested four Sandspur-built apartment units and installed datalogging equipment in six units at the Landings Community in Orlando where some units had reported moisture problems. Measured envelope leakage was typical for new construction, and all but one unit had very tight duct systems. Dataloggers (stand alone temperature RH loggers) were deployed in the air handler of each unit to record interior moisture levels. Three weeks of data were plotted for six apartments as temperature, relative humidity, and dew point. Ambient weather data from the nearby Hoak house datalogger was included and compared favorably with published Orlando airport weather.

To continue investigating the cause of excess moisture in the apartment units, datalogging equipment was installed in six additional units. To remedy problems, prototype schemes were evaluated such as utilizing a humidistat in conjunction with thermostat, and installation of a dedicated dehumidifier. Data analysis will be completed in 2004.

Gainesville, Florida Brookside Apartment Complex

During the 5th budget period, work was completed on testing and rating all 176 units in Sandspur's Energy Star apartment complex *Brookside* in Gainesville, FL. Apartment features are given in *Table 21.* Each apartment was individually tested for envelope and duct air tightness as well as flow through the passive outdoor air system by Bob Abernethy, FSEC technician, in collaboration with Florida H.E.R.O. Results are listed in *Table 21* below. The complex consists of one to four bedroom models grouped into two-story buildings of eight to 16 units.

Table 21 Brookside Apartments Characteristics

Component	Description
Conditioned area	1 Bedroom unit =717 sq. ft. 2 Bedroom unit = 990 sq. ft. 3 Bedroom unit = 1313 sq. ft. 4 Bedroom unit = 1582 sq. ft.
HERS Score	86.1 - 87.7
Mechanical and System	Interior air handler Fresh air ventilation Engineered and right sized systems Engineered duct design
Fresh Air Ventilation	4" fresh air duct provides 34 to 45 cfm to house side of HVAC filter when mechanical system is running. Manual damper provided.
Heating	Hydronic heat coils fed by a conventional gas water heater in an exterior closet
Cooling	SEER 12 AC - was SEER 10 1 and 2 Bedroom units = 1.5 Ton - was 2-2.5 Ton 3 and 4 Bedroom Units = 2 Ton - was 2.5-3 Ton
Ducts	Mastic sealed and tested
Duct Leakage	$CFM25_{OUT}$ < 5% of AHU flow
Wall insulation	Unfaced fiberglass batt (first cost savings of $0.22/sq ft and reduced site labor)
Windows	
Glazing & Frame	

Cary Park, North Carolina

BAIHP researcher compared two energy savings improvements: (1)upgrade from SEER-10 to SEER-11, and (2) add a programmable thermostat to the SEER-10 unit.

ANALYSIS

The Groves at Cary Park Apartments include a group of five buildings with 12 units each for a total of 120 units. A detailed computer simulation analysis was performed on a single, representative unit to compare the two energy saving measures using Energy Gauge USA version 2.3, which is based on the DOE2.1E simulation engine. The apartment chosen was a top floor 2-bedroom unit with north-facing windows since these units make up 50% of the complex whereas the remaining 1, 3 and 4 bedroom units make up 17%, 20% and 13% respectively and because the top floor 1 and 2 bedroom apartments are the only ones with exposure to an attic space over their entire floor area. The top floor 3 and 4 bedroom apartments are only partially exposed to an attic space while the remainder (about half the floor area) is below a 1-bedroom unit. The added attic exposure increases the heating and cooling loads on the top floor 1 and 2 bedroom units and is likely to present a worse-case scenario in terms of space conditioning load per square foot.

An hourly computer simulation of a top floor 2-bedroom apartment with north-facing windows was performed using TMY weather data for Raleigh, North Carolina. Four of the five buildings shown on the site plan are oriented at or very near to an east-west axis, causing the majority of windows to have either north or south exposures. The fifth building is oriented on a north-south axis. Specifications as taken from the plans provided are listed in *Table 22*.

Table 22 2-Bedroom Apartment Specifications

Conditioned Area	1,081 sq.ft.
Walls	Wood Frame (R-13)
Ventilated Attic	R-30
Roof	Dark shingles, 1:300 ventilation
Floor	R-99 (to simulate no load)
Double Pane Vinyl Windows	U-0.57, clear glass
Infiltration	5.0 ACH50, or 0.183 ACH
Ducts	R-6, Qn-0.06, 9.4% air loss
Thermostat	Non-programmable
Setpoints	Cooling 75°F, Heating 70°F
Lighting	10% Fluorescent
Ventilation	none

SEER-10
The HVAC schedule in the building plans specifies a Carrier 38YKC024 heat pump compressor and FF1CN024 air handler for the 2-bedroom apartments. Literature downloaded from the Carrier website lists this combination as having efficiency ratings of SEER-10.3 for cooling and HSPF-7.0 for heating.

SEER-11
Product data on the 38YKC shows that several other air handler models (most of which are variable speed) can be used to achieve a SEER rating of 11 or higher and can boost the HSPF to 7.2. These efficiency ratings were compared against the SEER-10 unit in an hourly simulation and showed a savings of 138 kWh/year or $12/year at an electric utility rate of $0.0826/kWh.

SEER-10 plus Programmable Thermostat
Estimated savings from using a programmable thermostat in conjunction with the SEER-10 heat pump slightly exceeded the savings from going to the SEER 11 efficiency upgrade alone and showed a savings of 177 kWh/year or $15/year. A 3°F temperature difference was used for a nighttime heating set-back from 11pm to 7am and daytime cooling set-up from 9am to 3pm.

Table 23 Estimated Annual Heating and Cooling Energy Use

	SEER-10.3 / HSPF-7.0	SEER-11 / HSPF-7.2	SEER-10.3 w/prog.t-stat
Heating kWh	1,542	1,511	1,397
Cooling kWh	2,006	1,899	1,974
Total kWh	3,548	3,410	3,371
Annual Savings ($)*		$12	$15
**Estimated annual savings based on electric utility rate of $0.0826/kWh*			

CONCLUSION
While it appears from the Carrier literature that the cooling efficiency on this heat pump model can be brought to SEER-11 by upgrading only the air handler, equivalent or better savings can also be obtained by employing a modest (3°F) set-back/set-up schedule with a programmable thermostat

Southern Energy Homes
Addison, Alabama
Category D, 12,803 Homes
Technical Assistance by BAIHP Researchers Neil Moyer and David Beal
Trip Report

During the 1st budget period, BAIHP held a meeting to introduce Building America to the industry. Representatives from Southern Energy Homes attended in hopes of finding solutions to moisture problems they were experiencing in coastal areas. In 2000, BAIHP researchers conducted building science diagnostics in several moisture damaged homes in coastal Louisiana and found contributing factors to be duct leakage and inadequate return air pathways from bed rooms.

Southern Energy Homes took steps to achieve substantially leak free duct systems in all their homes. They switched from UL 181 approved tapes to mastic and fiberglass mesh for forming component connections in all their duct systems and began testing duct systems during production *(Figure 39)*.

Figure 39 *Southern Energy Homes quality control engineer conducts in-plant duct leakage test.*

In 2002 FSEC received a request to certify the Southern Energy Homes (SEH) factory in Addison, Alabama for Energy Star compliance. A plant visit in August 2001 examined opportunities to enhance manufacturing productivity. Three model homes were tested for Energy Star certification, recommendations were made, and Energy Star plant certification paperwork submitted to US EPA.

In 2003 discussions continued with SEH plant personnel for conducting an analysis at one of their factories using the UCFIE simulation tool. On January 27 and 28, FSEC conducted site visits and performed diagnostic tests on several problem homes and submitted recommendations in a trip report in February. Based on these recommendations, FSEC conducted duct test training for factory personnel in four Southern Energy Homes factories.

In May of 2003 FSEC certified a Southern Energy Homes factory for EnergyStar production. FSEC conducted diagnostic field visits to Southern Energy homes in December 2003 and January of 2004 and provided recommendations in trip reports. Infrared inspection of the recommended retrofits were done in April 2004.

In 2004 two Moisture related home inspections were done, the first in August and the second in September. Recommendations were made in trip reports.

Spain Construction
Gainesville, Florida
Category B, 33 Homes

In the 6th budget period an evaluation of a homeowner complaint of significant condensation on the interior of the windows was made. Recommendations made were the installation of a passive outside air system which solved "95%" of the problem according to the homeowner, and the use of independent dehumidification to eliminate the rest.

Florida H.E.R.O. worked with Spain Construction in the 5th reporting period to address a homeowner comfort complaint and to assist the builder's mechanical contractor in designing a distribution system in a new Willowcraft community custom home. Diagnostic tests and Manual J calculations performed for the homeowner complaint determined that the mechanical system was oversized by one ton. In addition to the air handler filter, the researcher also located a second filter at the return grill. The homeowner was unaware of this filter, so its replacement significantly improved the system airflow. Florida HERO recommended the introduction of outside air to the return side of the system to facilitate positive pressurization and to slightly increase the load and diminish some of the effects of oversizing.

The builder has improved his specifications from standard code compliance (SEER 10, single pane windows, etc.) to HERS ratings of 87.5 - 89.4 for 100% of his homes. They feature SEER 13 air conditioning, double pane vinyl frame with low-E glass (SHGC of .34), air handler in conditioned space, R-30 ceiling and R-13 wall cellulose insulation. A few homes had ducts in conditioned space.

Stylecrest Sales (Coleman HVAC Systems)

Stylecrest Sales, formerly called Coleman HVAC Systems, is a major provider of mechanical system components to the manufactured housing industry. IN helping various home manufacturers resolve duct leakage issues, BAIHP has worked extensively with the engineering staff at Stylecrest to resolve such problems as dimensional coordination of duct components, assembly procedures, and standards in duct joining recommendations.

BAIHP researchers also met with Stylecrest Sales to discuss Energy Star plant/home certification procedures and collected cost data for a variety of HVAC system sizes. In 2004, FSEC visited a moisture damaged home in Port Fouchon (LA) at the request of Stylecrest that was built by Southern Energy Homes using Stylecrest components. (See Section III, Research, Moisture Damaged Homes.)

Timeless Construction
Long Island, New York
Technical Assistance by BAIHP Researchers Subrato Chandra and Dave Chasar

This custom builder planned to build a large energy efficient custom home in New York with photovoltaic (PV) grid-connected panels. Discussions began on optimizing electrical energy use and including solar water heating panels for household water. The builder planned to use gas appliances wherever possible and a floor radiant heating system (pump energy is one-third that for a fan air distribution system). FSEC recommended a solar water heating system with gas backup and forwarded information on two solar water heater designs available from Duke Solar. FSEC also provided several choices in heat recovery ventilator (HRV) units which would provide 200 CFM of outside air.

New construction drawings were received and EnergyGauge USA analysis results were discussed with the builder and Alten Design, since PV grid-interconnect requirements and architectural changes were needed to accommodate the PV panels. FSEC's PV group laid out a 7 kW PV system that included 4.5 kW's of flat roof panels (unique for a residential application) and sent information to the architect. This activity ended in 2002 with no home construction.

Tommy Williams Homes
Gainesville, FL
Category A, 19 Homes completed, 231 ongoing

This builder has gone from Florida energy building code minimum homes to being committed to build over 250 homes in two new sub-divisions that meet the BA goal of a HERS score of 88.6 or above. Each home will be serviced with a "right-sized" Seer 14 heat pump with a variable speed air handler, double pane low-E windows with a SHGC of .36 or less, passive OA system and a programmable thermostat. Each home will be performance tested and commissioned.

Top of the World Retirement Community
Gainesville, Florida
Category B, 212 Homes
Technical Support by BAIHP Subcontractor: Florida H.E.R.O.

Florida H.E.R.O. worked with project managers in charge of *On Top of the World Central,* a retirement community in Ocala developed by Sidney and Kenneth Colen who have built 15,000+ homes for senior citizens and have a commitment to developing communities that meet the needs and desires of that unique population.

Project managers of *On Top of the World Central* have every home performance tested for duct and whole house air tightness. Other features of the homes are summarized in *Table 24.*

This is the largest plotted sub-division in Florida, with over 24,000 homes slated to be built. Top of the World has gone from code minimum construction to Energy Star.

Table 24 On Top of the World Characteristics

Component	Specification
Conditioned area	1120-2093 sq. ft.
HERS Score	86-89
Mechanical and System	Engineered and right sized systems Engineered duct design
Heating	Standard 80% AFUE furnace
Cooling	SEER 12 AC
Ducts	Mastic sealed and tested
Duct Leakage	$CFM25_{OUT}$ < 5% of AHU flow
Wall	Block with steel interior framing
Windows	Double pane

Trinity Construction Corporation
Coral Springs, Florida

Trinity Construction Corporation is a large shell contractor serving Florida homebuilders. Faced with increasing demands for higher quality, lower cost and more timely delivery, Trinity is actively exploring innovative alternatives to conventional concrete block construction, the predominant homebuilding technology in the central and south Florida market. Trinity operates a pre-cast concrete panel production facility, in South Bay, Florida where concrete panels are pre-cast *(Figure 40),* transported to the construction site, and quickly assembled using a construction crane *(Figure 41).* The UCF Housing Constructability Lab (HCL) was asked to assist Trinity in improving the current panelizing process by incorporating lean production principles such as "just in time" materials handling.

Figure 40 *Panel forms on forming bed.*

Figure 41 *Setting pre-cast concrete wall panel.*

Preliminary research involved extensive observation and analysis. Value stream mapping, a process to isolate waste and production efficiency opportunities, identified activities that contributed value to the customer as well as activities that added little or no value. Material handling and rework were primary contributors to the 47% of labor consumed by non-value added activities. Once construction started, the flow of value-added activity was routinely interrupted. Poor access to materials and tools, rework, ill-defined process flows, and workforce/1st line supervision issues were contributing factors. To address these issues, BAIHP researchers utilized lean production principles - challenging non-value added activities and removing the obstacles to continuous production flow. Recommendations addressed issues of organization/communication, structured procedures and work flow, material handling, and off-line sub-assembly.

Table 25 Panel Productivity in Square Foot of Wall per Labor Hour

Process Phase	"Tested Sample" Process	Potential Process Results	Pilot Test Process	Productivity Increase During Test
Layout	53	152	91	72%
Prep	52	149	79	52%
Pouring	146	211	296	103%
Lifting	75	440	75*	0%
Total	17	49	25	47%
*Not altered during pilot test.				

To test the recommendations, Trinity allowed BAIHP researchers to perform a 3-day pilot test. The test involved a single house consisting of 25 panels. The panels had a total of 21 window and door openings and a gross wall area of 3,119 ft^2. The first day was used to organize and train the test production team. The second and third days were dedicated to production. All 25 panels were produced. Productivity increased *(Table 25)* for all observed activities. Lifting productivity was not observed. Conservatively assuming that lifting activity will remain at historical levels, overall labor productivity increased by 47% during the Pilot Test. If lifting productivity is assumed to increase at the average rate observed for the other activities, overall productivity increase of the Pilot Test would be 68%. Not all recommendations could be realized during the test. Some equipment and personnel issues could not be resolved on a short-term test basis. This suggests that the true potential is significantly greater than that observed during the Pilot Test – possibly approaching 200% increase in labor productivity. Corresponding cycle time reductions are estimated to be 20-25%.

The BAIHP research team recommended that Trinity precede with implementation of the lean production recommendations. In addition to the technical recommendations, the research team also made recommendations involving worker empowerment, dealing with the heat and sun, and material/equipment availability. Potential future research areas include covers for the production area, on-site factories in new home developments, and factory installed wall insulation. This successful pilot test has given Trinity the opportunity to develop a competitive advantage in the housing construction market and a solid foundation to gain dominance.

Vincent Village
Richland, Washington

Vincent Village is a 49 home rental community, located in Richland, WA. All of the homes are small, single section HUD Code homes, heated and cooled by Insider heat pumps. Half the homes were built to Super Good Cents standards, the other half were not. Metered utility data indicate average yearly savings of $241 for the SGC homes. (See also *Appendix D, WSU*)

WCI Communities, Inc.
Bonita Springs, Florida
Category A, 2 Houses
Technical Support by BAIHP Researcher Eric Martin
Awards: *2004 SEBC Green Demonstration Home Aurora Award*
2004 SEBC Green Production Home Aurora Award
2004 SEBC Green Home Grand Aurora Award
2004 Energy Value Housing Award, Silver Medal, Custom /Hot-Humid Climate
2004 NAHB America's Best Builder, 501-plus closing category

Builder/Developer WCI Communities continues to embrace green building by having constructed over 100 homes to the Florida Green Home Standard, including two very high performance demonstration homes. They received the second ever Florida Green Land Development certification for their Venetian Development in Venice, FL in which all homes constructed within will also be green certified. Upon build-out, this will amount to over 1,000 homes.

WCI Communities architecture division is providing architectural services for the 2006 New American Home. During a meeting at FSEC in July 2004, elements of green certification of this home were discussed. The principal architects have completed the green certification training offered by FSEC, and the project is on track to receive the Florida Green Home Designation once complete.

WCI is also planning another high performance demonstration home in a new community being developed on the south east coast of Florida. They have expressed interest in this being a Zero Energy home, and BAIHP conducted training in October 2004 for WCI staff and subcontractors providing an overview of ZEH design strategies and implications to the WCI architecture staff.

During the fourth budget period, in November of 2002, BAIHP staff members were planning to meet with WCI to discuss a partnership. Because of their corporate environmental mission, WCI plans to build a significant number of homes to the Florida Green Home Designation Standard and has requested the help of Building America to ensure a systems engineering approach, to conduct efficiency monitoring, and to offer staff training. WCI constructs approximately 2,000 homes per year across south Florida. In 2002 they committed to having houses incorporate a variety of green principles. In some WCI communities, every home will meet the Florida Green Standard.

Figure 42 *WCI Home in Evergrene Community, Palm Beach Gardens (FL), HERS Score = 92.*

FSEC received sample home plans and conducted an energy analysis using EG USA. Recommendations were adopted by WCI *(Table 26)* for a model "green home" in the Evergrene Community *(Figure 42)* in Palm

Beach Gardens (FL). BAIHP monitored progress on the prototype and installed monitoring instrumentation in April 2003 (fifth budget period).

The home and the instrumentation were completed in August 2003. A device called WebDAQ was installed, which acts as a server to provide an internet web page to display real time data as part of WCI's community education approach. WCI maintains a website dedicated to the home at www.greengeneration.org.

In September 2003, WCI held a grand opening at Evergrene. Staff from BAIHP and the DOE Atlanta Regional Office attended the event which included tours of the home and a program of distinguished speakers such as local government and business leaders.

This prototype “green home” received the highest score to date on the Florida Green Home Designation Standard. With a HERS score of 92, it is estimated to save 31% compared to the Building America benchmark home and 38% compared to the HERS reference home on a whole house basis.

In February 2004, FSEC staff visited the Venetian Development in Venice, FL developed and built by WCI Communities, Inc. Over 1,000 homes will be constructed in Venetian, and all will meet the requirements of the Florida Green Home Designation Standard.

Table 26 WCI Evergrene Community - Green Home Model Specifications

Conditioned Area	**1460 sq ft**
HERS Score	**92**
Envelope	
Above-grade Wall	ICF - first floor; 2X6 with Icynene - second floor
Attic	Unvented, insulated at roof deck w/Icynene
Roof	Tile
Windows	Laminated Impact Resistant with SHGC = 0.42
Equipment	
Ducts	Sealed with mastic; Located in unvented (Insulated) attic
Heating & Cooling	Variable speed SEER 15 with strip electric heating
Thermostat	Programmable thermidistat
Water Heater	Conventional gas unit with EF=0.62
Lighting	CFL and fiber optic lighting with occupancy and daylight sensors
Appliances	Energy Star
Indoor Air Quality	Extensive VOC source control through paint, cabinet, and counter top selection
Ventilation	Passive fresh air duct to mechanical closet; Whole house filtration with UV sterilization
Green Features	
Lumber	All lumber certified sustainable, treated lumber is ACQ, other lumber is engineered
Water Conservation	Dual flush toilets, automatic faucets, drought tolerant landscape, micro irrigation, rainwater harvesting.
Resource Efficiency	Eco-friendly flooring and finishes Construction waste management plan

In addition, WCI constructed another "ultra green" model. WCI consulted BAIHP during the initial planning stages, and this home was expected to have higher performance and contain more green features than the Evergrene Community home. WCI took the initiative to develop in-house expertise and capabilities in this area and needed much less support from BAIHP. BAIHP did involve IBACO, another BA Team, to help develop an advanced lighting design.

III

BAIHP RESEARCH

BAIHP RESEARCH OVERVIEW

BAIHP conducts research with Industry Partners in manufactured and site built housing and using the laboratory facilities at the Florida Solar Energy Center.

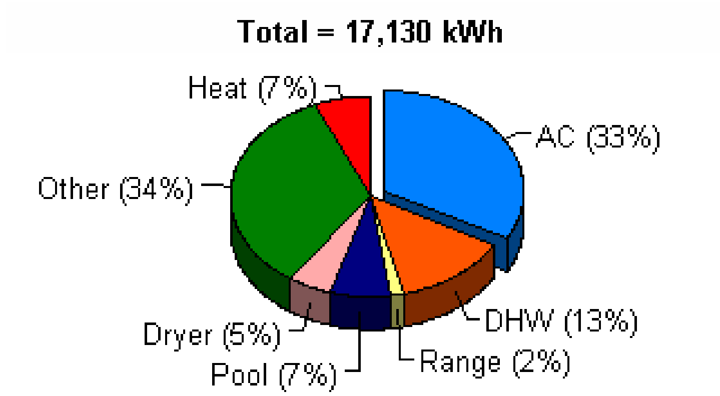


Figure 43 *Distribution of Residential Energy Consumption measured in 171 Florida homes shows typical energy profile for homes in hot-humid climates.* Source: Parker, D. S., 2002. "Research Highlights from a Large Scale Residential Monitoring Study in a Hot Climate." Proceedings of International Symposium on Highly Efficient Use of Energy and Reduction of its Environmental Impact, pp. 108-116, Japan Society for the Promotion of Science Research for the Future Program, JPS-RFTF97P01002, Osaka, Japan, January 2002. (Also published as FSEC-PF369-02, Florida Solar Energy Center, Cocoa, FL.)

Research Context for Hot-Humid Climate

The primary opportunities for improving energy efficiency can be generalized into two categories: increasing equipment efficiency and reducing equipment loads. The latter of these contributes to improving comfort, durability, and indoor air quality also.

In hot humid regions, the primary building energy use *(Figure 43)* is air conditioning (AC) with heating making up only a small portion of total. As in other climates, water heating constitutes the second largest residential energy draw. Refrigerators follow just ahead of other household appliances such as stoves and dryers.

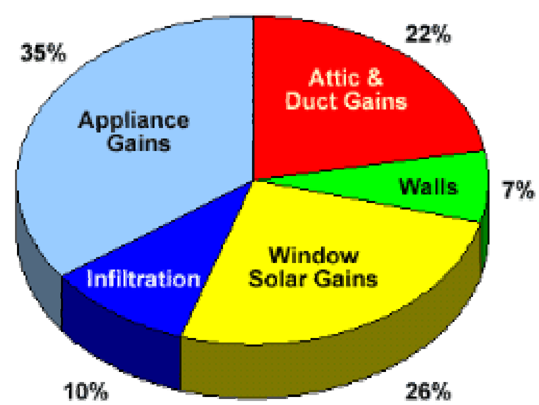


Figure 44 *Typical components of annual residential cooling load in hot-humid climates.*
Source: Florida Solar Energy Center web site:
http://www.fsec.ucf.edu/bldg/fyh/priority/Index.htm

The primary loads on residential AC systems *(Figure 44)* are appliance generated heat, window *radiant* heat gain, attic and duct related heat gain, infiltration (primarily latent heat gain), and wall heat gain coming in last.

By systematically evaluating the savings potential technologies and construction techniques, research provides the home building industry with vital information needed to meet the Department of Energy's industry challenges of building high performance homes. BAIHP Research presented here is grouped into three categories:

- Manufactured Housing Research
- Site Built Housing Research
- Field and Laboratory Building Science Research.

A. Manufactured Housing Research

BAIHP has found that using the systems engineering approach to help Industry Partners solve building science related problems develops a strong working relationship and increases the likelihood of the Partner incorporating concepts central to achieving Building America goals such as sealed and tested ducts, right sizing air conditioning, and moisture management. BAIHP's work with the manufactured housing industry illustrates this principal.

BAIHP conducted research for manufactured homes in both field and laboratory which is reported in the following summaries:

- Building Science and Moisture Problems in Manufactured Housing
- BAIHP Field Visits to Moisture Problem Homes
- Manufacturers Participating in Building Science Research
- Side By Side Study Of Energy Use And Moisture Control Comparing Standard Split System Air Conditioning And A Coleman® Prototype Heat Pump, Bousier City, LA
- WSU Energy House
- Zero Energy Manufactured Home (ZEMH)
- Manufactured Housing Indoor Air Quality Study
- Manufactured Housing Laboratory – Ventilation Studies
- Manufactured Housing Energy Use Study, North Carolina A&T
- Portable Classrooms
- Duct Testing Data from Manufactured Housing Factory Visits
- Crawl Space Moisture Research for HUD Code Homes

Building Science and Moisture Problems in Manufactured Housing

Papers: Subrato Chandra, Danny Parker, David Beal, David Chasar, Eric Martin, Janet McIlvaine, Neil Moyer. Alleviating Moisture Problems in Hot, Humid Climate Housing. *Position Paper for NSF Housing Research Agenda Workshop, UCF Feb. 12-14, 2004.*

Moyer, N., Beal, D., Chasar, D., McIlvaine, J., Withers, C, & Chandra, S. (2001). "Moisture Problems in Manufactured Housing: Probable Causes and Cures." ASHRAE - IAQ 2001 Conference Proceedings, San Francisco, CA.

Manufactured homes have a permanent steel chassis attached below the floor and are constructed in a factory *(Figure 45)* to meet a national code maintained by the U.S. Department of Housing and Urban Development (HUD). After production, homes may travel a few hundred miles, hauled by truck, before final setup. The homes are setup by placing blocks under the steel I-beams and anchoring the beams firmly to the ground. A skirting covers the blocks and steel frame in a fully setup home *(Figure 46)*.

Figure 45 *Palm Harbor HUD Code Manufactured Housing factory – production line.*

Figure 46 *Completed HUD Code Manufactured Home, Palm Harbor Homes*

Manufactured homes are typically heated or cooled by a system of ductwork, which delivers hot or cold air from the air handler unit (AHU). The ductwork can be in the attic or in the belly cavity of the home. The ducts are typically made of aluminum or fiberglass trunk lines which supply air to the floor registers through in-line boots or flex ducts. The boots or ducts terminate at perimeter registers on the floor. Supply duct leaks represent one of the biggest causes of moisture problems in manufactured homes. *(Figures 47 and 48)*. Poor design and construction leave holes at the AHU connection to the main trunk, and where the boots connect to the trunk, supply registers, end caps, cross-over duct connections, and other connection points. When the AHU blows air, some air leaks into the belly and eventually to the outside through belly board tears. This loss of air creates a negative pressure inside the house and a positive pressure in the belly. The negative pressure pulls outside or attic air into the house through cracks and crevices which connect the inside of the house to the outside or to the attic. During northern winters, this outside air is cold and dry and its entry increases occupant discomfort and heating energy use.

During summer in the Southeastern US, the air is consistently at or above the dewpoint of 75. If a homeowner keeps their home thermostat set below this 75 F dewpoint, the moisture laden outside air condenses as it comes into contact with the cold inside surfaces. If it condenses behind an impermeable surface such as vinyl flooring or wallpaper, serious mold, mildew, and floor buckling problems can result.

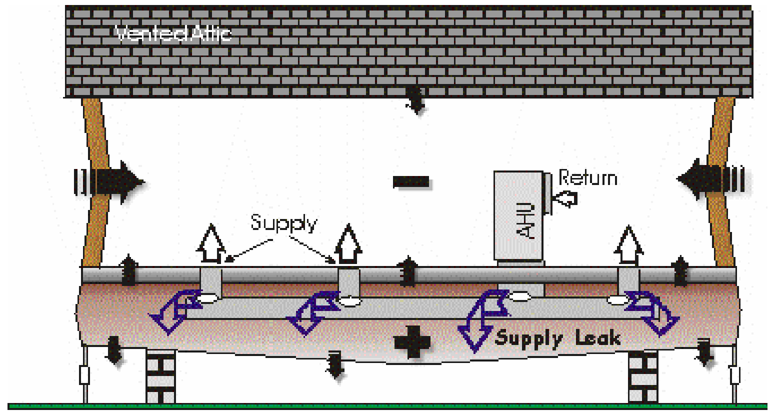


Figure 47 *Pressure field and unintentional air flow created by supply duct leaks.*

Many manufactured and site-built homes have only a single return and, therefore, very little return air transfer from the bedrooms (basically via the undercut at the bottom of interior doors). When interior doors are closed, rooms off the main body (e.g., bedrooms) become pressurized and the main body of the house depressurizes. Even though negative pressures are usually only one to three pascals (Pa) - they can cause serious problems in a home.

Researchers use a calibrated fan called a ductblaster to measure duct leakage. The ductblaster is attached to the return grill or the crossover duct opening (*Figure 49*) and all supply registers are masked off and the fan is turned on. Once the house ductwork reaches –25 Pa, airflow through the fan is read (in CFM). The resultant measure is the total duct leakage. In good airtight ductwork, total duct leakage (CFM@25 Pa) should be less than 6% of the homes square footage.

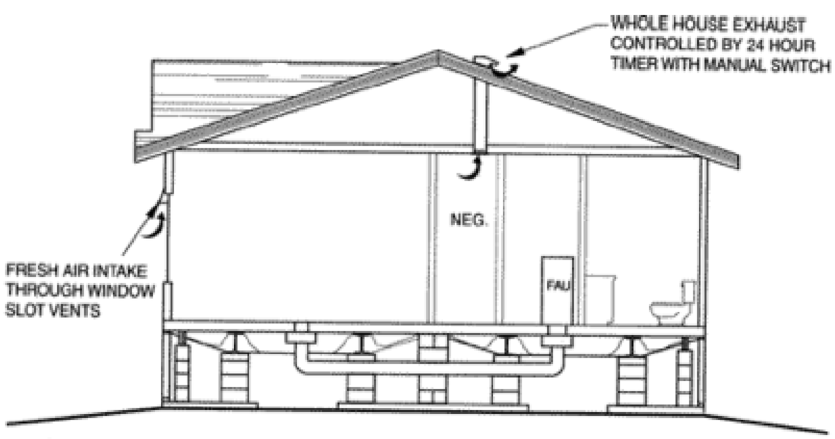


Figure 48 *Cross section showing foundation support, crossover duct, and one type of ventilation system in a manufactured home.*

A second duct leakage test measures leakage to the outside. This leakage is calculated by depressurizing the entire house to –25 Pa with a blower door, then adjusting the ductblaster flow so there is no pressure difference between the house and the ducts. This measurement is a true indicator of duct air loss to the outside and is used in energy calculations for estimating the energy loss from leaky ducts. In good duct systems, duct leakage to the outside (in CFM) is less than 3% of the home's square footage.

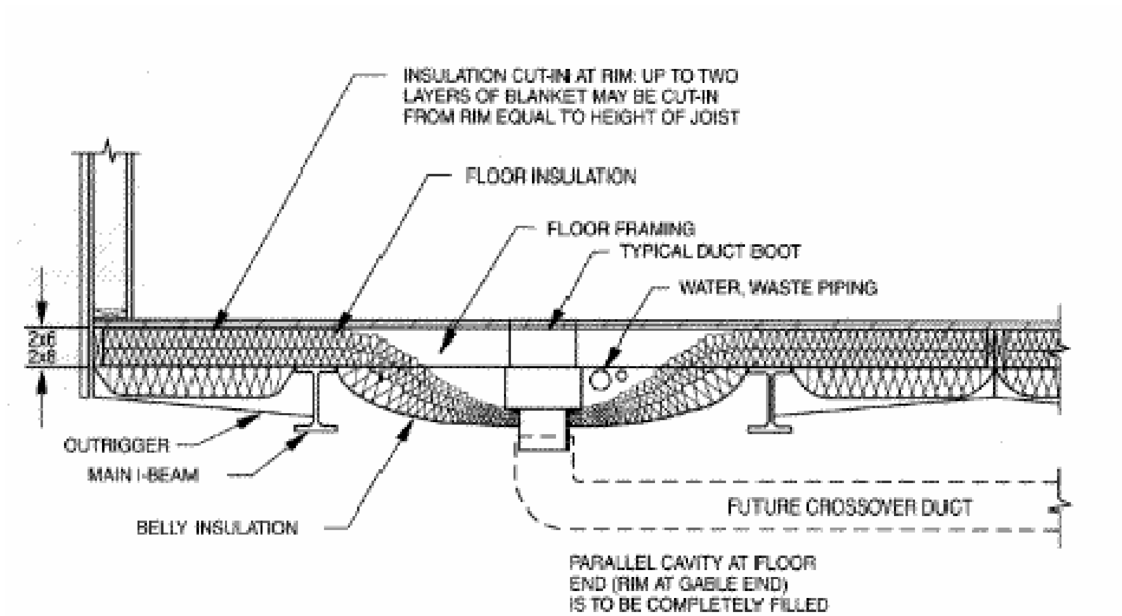


Figure 49 *Floor and belly area with supply ducts. These ducts supply conditioned air to all rooms through floor vents, a common duct system layout in manufactured homes.*

The battery of tests run in a problem house typically includes measuring the airtightness of the house with a blower door, depressurizing the house to –50 Pa. At that time, the house to belly and belly to crawlspace pressures also can be measured. Researchers also test pressure differentials caused by AHU operation and closed interior doors. An additional measurement of duct leakage, called pressure pan, is conducted on some houses to pinpoint specific registers which might have large leaks. In this measurement the house is first depressurized to –50 Pa and all the register vents are unmasked. Then the registers are covered one by one and the pressure difference between the covered register and the house is measured. A zero reading indicates no leakage at that register. Readings over one Pa indicate a sizeable leak that should be repaired.

BAIHP Field Visits to Moisture Problem Homes

Papers: *Moyer, N., Beal, D., Chasar, D., McIlvaine, J., Withers, C, & Chandra, S. (2001). "Moisture Problems in Manufactured Housing: Probable Causes and Cures." ASHRAE - IAQ 2001 Conference Proceedings, San Francisco, CA.*

A significant number of new manufactured houses built to HUD code and located in the hot, humid Southeast have exhibited moisture problems. Soft wallboards, buckled floors, damaged wood molding, and extensive mold growth are the most common symptoms. These problems do not respond to the standard service and repair strategies for water intrusion. (Please see Appendix B for sample problem home inspection trip reports.)

Summary of 1st-4th Budget Period Field Visits to Moisture Problem Homes

At the request of six manufacturers, 69 such moisture damaged homes were investigated from 1999 to the end of reporting year four (through March 31, 2003) to determine likely causes. In Year 4 alone, 18 homes were investigated by FSEC. One-time blower door, duct tightness, and pressure differential measurements were performed on all homes. Field data on ambient, crawlspace, belly and house temperatures, plus relative humidity levels were collected on a few of the homes. Recommendations and reports were prepared for the manufacturers' service, production, and design staff. Field repairs were performed in most of these homes. A general theme was found in the houses investigated.

- Air conditioner thermostat settings (typically 68 to73 F) set below the ambient dew point.
- Negative pressures across the envelope from high supply duct leakage (CFM @25Pa >10 per 100 square feet of conditioned floor area), inadequate return air paths, interior door closures, exhaust fans, or a combination thereof.
- Inadequate moisture removal from disconnected return ducts, continuous fan operation (air handler or ventilation), inadequate condensate drainage, oversized air conditioners, or a combination thereof.
- Moisture diffusion from the ground into the house because of poor site drainage, inadequate crawl space ventilation, tears in the belly board, or a combination thereof.
- Vapor-retardant in the wrong location (i.e., vinyl or other impermeable wall or floor coverings located on the colder surfaces).

Recommended solutions provided to the manufacturers to eliminate moisture problems included:

- Maintain air conditioning thermostat settings above the ambient dew point (at least 75°F).
- Eliminate long-term negative pressures created by air handler fans or ventilation equipment.
- Tightly seal all ductwork and provide adequate return air pathways.
- Enhance moisture removal from the conditioned space by correct equipment sizing and maintenance.
- Eliminate ground source water and provide an adequate moisture barrier for the floor assembly.
- If possible, remove vapor barriers located on the wrong surfaces.

Research continues to determine if these steps will be sufficient to prevent problems even when vapor barriers are incorrectly located in homes in the hot, humid climate. Preliminary results are encouraging. One manufacturer has not reported a single new moisture problem in any of the homes produced since 2000 in a factory that previously had a significant number of problem homes. Steps taken by the factory were inclusion of airtight duct systems (a zero net-cost increase), right-sized cooling systems (a negative cost), return air ducts from all bedrooms (a cost of about $15), installation of a ground vapor barrier (no change from previous practice).

Summary of 5th Budget Period Field Visits to Moisture Problem Homes

BAIHP researchers at FSEC received fewer requests in the 5th budget period for assistance with moisture damaged homes *(Table 27),* reflecting improvement of duct construction and sealing, addition of return air pathways from bedrooms, and reduction of vapor impermeable interior surfaces. Additionally, service personnel who have attended BAIHP training and participated in field work with BAIHP are more prepared to resolve problems without assistance. Service personnel report installing passive return air vents in bedrooms, providing appropriate moisture barriers, and sealing duct leaks to resolve humidity, comfort, and moisture damage call backs.

Figure 50 *Flow lines under house, indicating running water under the house. Also note the "tide line" on the support column.*

When service personnel have been unable to resolve a problem, they request assistance from BAIHP researchers who attend a service call and conduct various diagnostic tests to identify factors contributing to the moisture, comfort, or high energy bill problem. (MHRA has been providing similar services on a fee basis to the industry also.) After BAIHP researchers complete a field visit, a trip report is issued detailing the findings and recommendations, include basic building science background material.

Table 27 5th Budget Period – FSEC Field Visits to Problem Manufactured Homes

Manufacturer	Location	Date
Fleetwood Homes	Florida (2 homes)	August 03
	Florida (2)	November 03
	Texas (1)	December 03
	West Virginia (1)	March04
Cavalier Homes	Florida (1)	November 03
Southern Energy Homes	Kentucky(1)	December 03
	Texas (1)	January 04
Style Crest	Louisiana (1)	February 03
20 NEEM Program Manufacturers	Field Visits in Washington, Oregon, and Idaho (19)	April 03-March 04
Total Homes	**29**	

It has been BAIHP's experience that corrective measures from repeated moisture problem Diagnostics have been incorporated into the production process, resulting in thousands of improved manufactured homes. These are noted in *Category D of Table 2.*

A common problem that remains unresolved involves the combination of abundant crawl space moisture *(Figure 50 and 51)* and poorly vented skirting *(Figure 53).* In the hot-humid coastal regions, this combination raises vapor pressure across the belly to critical levels. This was evident in several of the homes visited this year. As a result of this field research, BAIHP has designed a study that will be initiated in the summer of 2004 to evaluate the moisture flow characteristics of crawl space conditions.

Northwest BAIHP Random Home Testing

SGC Random Home Testing: In 1994-1995 (prior to implementation of BAIHP), SGC staff conducted field testing of 178 SGC homes built in 1992-1993. In 1999, the first year of the BAIHP effort, staff in Idaho and Washington field-tested 49 SGC homes built in 1997-98. In 2000, analysis of field test data confirmed some improvements to home set-up procedures and air leakage control, while highlighting a need to improve duct tightness and ventilation system operation (through homeowner education.) In 2001, BAIHP staff produced an updated homeowner ventilation brochure.

In 2002 and 2003, BAIHP staff worked with Ecotope to develop a valid sample for the next round of field testing, and began to develop the field testing protocol. In 2004, Ecotope selected 105 homes from the total production for the years 2001-2002. The field testing took place in the summer of 2004. Findings from the testing include:

- Average house size is 1769 ft^2; double section homes are also getting bigger, on average. The house size is very comparable to the homes built in 1997-1998 but 20% larger than the homes in 1994-1995 study
- Houses are getting tighter, according to the blower door results. The average air leakage rate at 50 Pa is 4.2, which represents a tightening of almost 25% over the original MAP home average. The median equivalent leakage area (ELA) for double-section homes has decreased by about 12% despite a substantial increase in house size.
- Only about 20% of NEEM homes in this study contain intentional outside air inlets. This is the result of BAIHP research indicating that intentional outside air inlets are unnecessary to provide adequate fresh air.
- 2/3 of homes in the study have dedicated whole house fans and a substantial fraction of homeowners are using their whole house fans. However, a significant minority (30%) does not turn them on.
- About half of homes in the study use central cooling, with more than half of these homes using a heat pump.
- Duct systems are about 20% leakier than in the Year 1 study and about 10% leakier than in the 1994-1995 study (when the comparison is normalized by house size).
- The median supply leakage fraction is 11-13% for the homes in this sample. The duct loss translates into a heating system efficiency loss of between 10-20% overall, depending on the location of the home (west side or east side of the mountains) and type of heating equipment (heat pumps perform worse).

In 2004, BAIHP staff conducted a billing analysis on a limited number of random field study homes. The conclusions (although not statistically significant) suggest that temperature related energy use in NEEM homes remains similar to previous larger studies on cost-effectiveness. The analysis attempted to evaluate total and space conditioning energy use by HVAC system types but was limited by small sample size.

In 2004, a sub-sample of homes that are believed to represent the best case for duct tightness were selected for additional field testing. These homes include those with in-plant tested ducts and thru-rim crossover duct systems. The goal of this effort is to establish a "tightest" duct case benchmark. Field testing will be completed in 2005; report will follow.

Northwest BAIHP Field Visits to Problem Manufactured Homes

In offering technical support to owners of over 100,000 homes built since 1990, the BAIHP staff in the Northwest answers questions from homeowners, manufacturers, retailers and others. In The 6th budget period, staff from Washington, Oregon and Idaho responded to over 70 phone calls and conducted 27 field visits. The number of field visits to problem homes has significantly decreased over the history of the program, in large part because of manufacturers' and installers' increased adoption of the NEEM Super Good Cents/Energy Star (SGC/E-Star) specifications which include duct air tightness specifications (duct leakage is a major contributor to pressure and air flow related moisture problems), and the requirement that manufactured home installers be certified in Washington and Oregon.

Figure 51 *The downstream exit for the water draining across the site via the crawl space. Note flow pattern away from house.*

Northwest BAIHP staff began to utilize Energy Gauge USA as a toll for evaluating high bill complaints in 2003-2004.

BAIHP staff participated in quarterly meetings of the Washington State Manufactured Housing Technical Working Group, which coordinates the certification of manufactured housing set-up crews.

Figure 52 *HUD Code required perforations in skirting may not allow adequate volumes of ventilation, creating higher than usual vapor pressure difference across the floor assembly even though the ground cover and belly board are in good condition.*

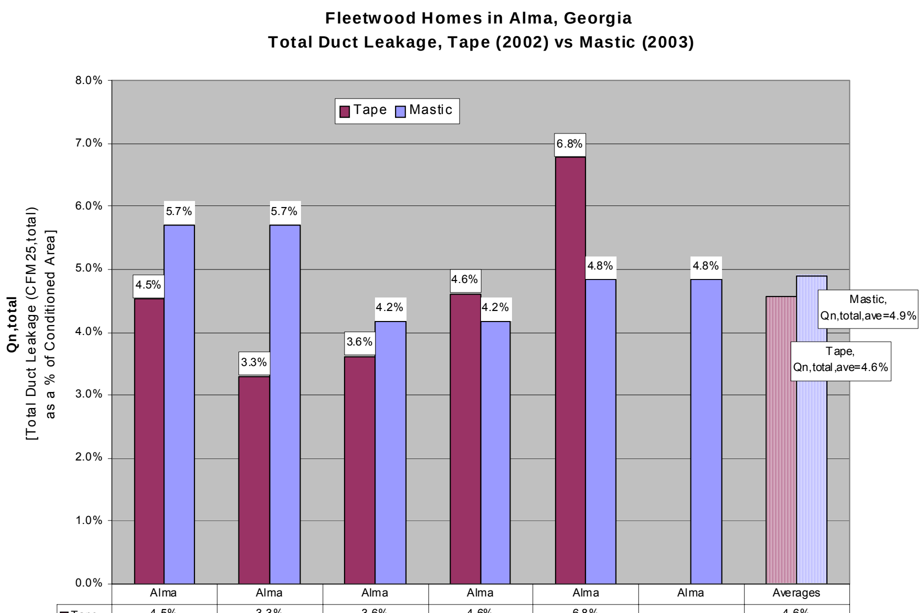
While butyl duct tape is no longer allowed under current NEEM SGC/E-Star specifications, a consistent issue in the field continues to be excessive duct leakage, due in large part to failures of duct tape. These findings were brought to the attention of the NFPA-501 Manufactured Housing Standards Committee, resulting in a successful proposal to revise the duct sealing specifications to eliminate the use of duct tape in favor of better performing mastic and fiberglass mesh in the NFPA-501 standard. See a summary of supporting research findings in *BAIHP Duct Data Compilation.*

Manufacturers Participating in Building Science Research

Blue Sky Foundation
Blue Sky Foundation, in coordination with FSEC, conducted an evaluation of energy efficiency and the moisture damage potential in 16 North Carolina homes in the summer of 2001. Blue Sky foundation proposed that the energy and moisture evaluation focus on the building envelope integrity, HVAC duct systems, and the moisture impact of unvented space heaters. All of the homes in the study were manufactured models located in Carteret and Craven counties, each located on the North Carolina coast. Field teams gathered additional energy and moisture information from homeowners.

Only three of the 15 tested homes recorded moisture and/or mildew problems. Because of the small sample size, the results are mostly anecdotal and would need to be evaluated within a larger data set. Planning for this is underway. Data from the summer field program as well as the final report are now on the BAIHP website (www.baihp.org) under *Publications*.

Cavalier Homes
BAIHP visited one Cavalier Home in Florida for a moisture damage investigation in response to home owner complaints of persistent air flow problems and floor damage. BAIHP made recommendations to correct the installation of the duct system and supply registers, repair the rodent barrier to make it air tight, do site work to reduce flooding under house, place a ground cover if site work done, increase crawl space venting, and replace damaged flooring with plywood.



	Alma	Alma	Alma	Alma	Alma	Alma	Averages
Tape	4.5%	3.3%	3.6%	4.6%	6.8%		4.6%
Mastic	5.7%	5.7%	4.2%	4.2%	4.8%	4.8%	4.9%

Figure 53 *Testing Results from Fleetwood Homes Plant in Alma, Georgia illustrate that tape sealed ducts can result in total duct leakage under Qn=<6%. This initial tightness, however, is often eroded by adhesive failure.*

Fleetwood Homes
During the 5th budget period, BAIHP continued to support Fleetwood's service department making six visits to moisture damaged homes in Florida (4), Texas (1), and West Virginia (1). Six Fleetwood homes, all in Florida, were tested for moisture and mold damage from April 2002 through March 2003, the 4th budget period. All of the homes had damaged flooring due in part to a lack of ground cover and poor crawlspace ventilation. Damage to the floor in one home was exacerbated by a plumbing leak. Only one home had moisture damage to the wallboard material, and this home showed a history of thermostat settings below 72 F. A report for each home was submitted to Fleetwood for corrective measures. One additional high bill complaint in Cobb, Georgia was investigated during this reporting period.

In 2002, four Fleetwood factories in Southern Georgia were visited to investigate possible causes of moisture related building failures found in homes installed in hot, humid climates. The factories were located in Douglas, Alma, Pearson, and Willacootche. *(Figure 53.)*

Homes of Merit
In 2002, researchers performed multiple diagnostic tests on a home located in Marathon, Florida that was experiencing "mold problems." Researchers determined that the mechanical system was significantly oversized and that the home was operating under negative pressure when the system was operational. The home's owner exacerbated humidity problems by leaving the fan in the "on" mode. On-site relative humidity readings showed that indoor and outdoor relative humidity were the same, approximately 70%.

Palm Harbor Homes
(See also, Palm Harbor Homes in Section I, Technical Support and Manufactured Housing Indoor Air Quality Study in Section III, Research, below).
Palm Harbor Homes, James Hardie®, and FSEC performed two separate drywall assembly tests to determine the cause of some moisture damage occurring in homes sheathed with Hardipanel. Hobo dataloggers recorded temperature and relative humidity measurements inside the assembled panels on eight different wall panel configurations. *(Figure 54.)*

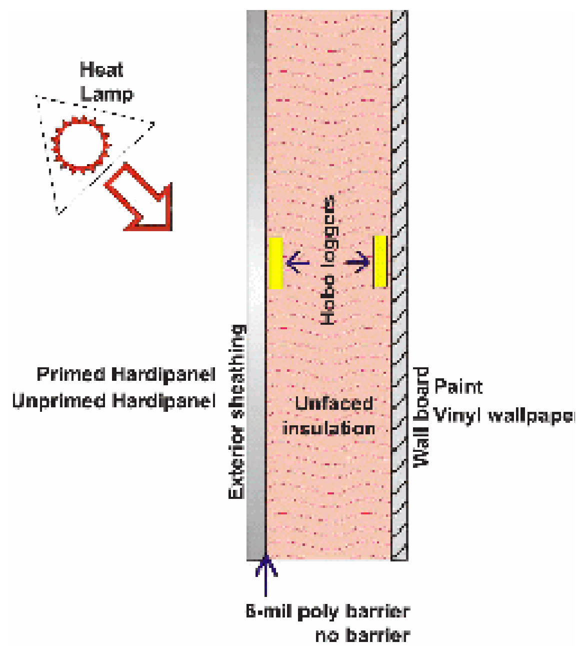


Figure 54 *Wall assembly used in moisture transmission experiment.*

Results determined that the unprimed, unwrapped sheathing performed best. The painted drywall assemblies allowed the greatest moisture movement - or wall assembly drying. *(Table 28)* The vinyl-covered drywall held moisture longest, recording the slowest drying time. Adding perforations to the vinyl reduced the drying time.

Table 28 Hardipanel exterior wall configurations

Test Panel	Drywall	Insulation	Wall Wrap	Sheathing
#1	Vinyl	unfaced	none	primed
#2	Vinyl	unfaced	none	unprimed
#3	Vinyl	unfaced	house wrap	primed
#4	perforated vinyl	unfaced	none	primed
#5	House wrap glued to drywall	unfaced	house wrap	primed
#6	vinyl	unfaced	Thermo Ply	primed
#7	painted	unfaced	none	primed
#8	painted	unfaced	none	unprimed

In 2002, two Palm Harbor homes with comfort problems were tested in Ocala and Okahumpka, Florida and one high bill complaint was investigated in Odessa, Florida. Duct leakage testing and infrared imaging revealed a duct disconnect near the attic crossover in the Ocala home. Inspections with the IR camera found no insulation problems in the Odessa home. Ductblaster and blower door tests revealed airtight duct and envelope systems. Other than an oversized air conditioning system, there were no obvious reasons for the high bills.

Southern Energy Homes
(See also, Southern Energy Homes in Section I, Technical Assistance.)
During Year 2001, 12 homes were field tested in the Houma, Louisiana area. Some of the homes had new moisture damage. Others were rechecks of previous moisture problems already repaired by SEH personnel. FSEC inspectors reported improper repairs and recommended additional dealer and staff training. An additional five homes were field tested in Houma during the 4th reporting period, with another home in Mississippi and one in Alabama also field tested.

During the 5th budget period, BAIHP visited two Southern Energy Homes in Texas (1) and Kentucky (1).

Side By Side Study Of Energy Use And Moisture Control Comparing Standard Split System Air Conditioning And A Coleman® Prototype Heat Pump, Bousier City, LA
Research led BAIHP Researchers Dave Chasar, Neil Moyer, and Chuck Whithers

Papers: *Withers, C., Chasar, D., Moyer, N., and Chandra, S. "Performance and Impact from Duct Repair and Ventilation Modifications of Two Newly Constructed Manufactured Houses Located in a Hot and Humid Climate", Thirteenth Symposium on Improving Building Systems in Hot and Humid Climates, May 20-22, 2002 Houston, Texas.*

In 2001, the BAIHP team conducted research on two homes to define how tight ducts and a prototype Coleman® heat pump (proprietary technology) affect energy use and moisture control in a hot, humid climate. FSEC, in collaboration with Fleetwood Homes, York International Manufactured Housing Division (now Stylecrest Sales), and Coleman®, monitored two nearly identical side-by-side homes in Bossier City, Louisiana. The homes contained different air conditioning systems. House A used a standard split air conditioner, while House B used the Coleman® prototype unit (a more efficient, two-speed split air conditioner).

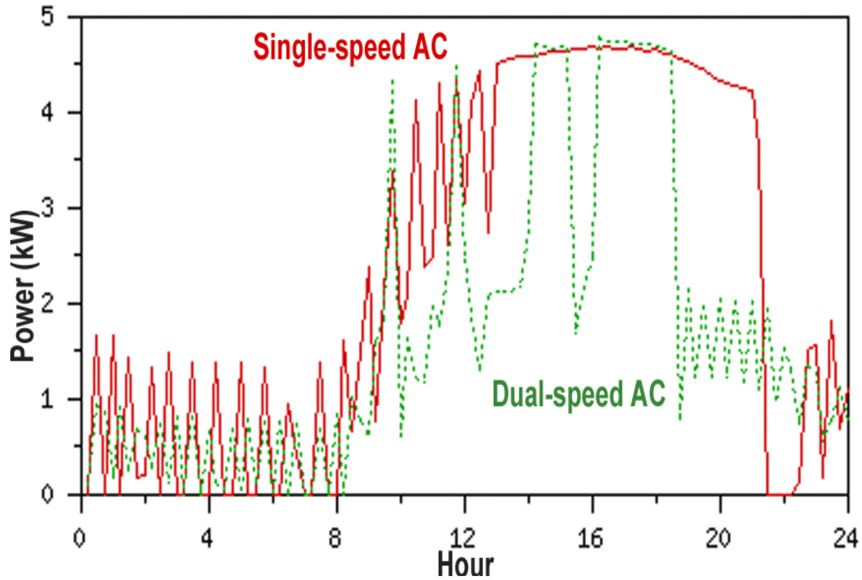


Figure 55 *Power draw over a 24-hour period, September 2, 2000.*

Figure 55 shows the reduced power draw of the two-speed compressor (green, dotted line) over a 24-hour period on September 2, 2000. With the unit operating at low-speed for most of the day, the cooling energy savings were 28% when compared to the energy use in House A. Average daily cooling energy was reduced by about 12% over the monitored period. An added benefit of the two-speed air conditioner was 20% greater moisture removal on days with an outdoor dewpoint above 60 F.

Savings from Duct Repair and POS Ventilation: In addition to comparing one house to the other, the BAIHP team also compared home performance before and after ductwork and ventilation system changes were made.

To make the comparison, duct and other leaks were sealed in both houses until the two were equally airtight. The ventilation method in each home also was changed from exhaust-only to a positive pressure system (POS). With exhaust-only ventilation, bathroom fans removed stale air from the home which caused fresh air to be pulled in through the building envelope. To simulate occupant use, two bath exhaust fans were operated by a timer for three hours in the morning and six hours in the evening.

In contrast to exhaust ventilation, the POS system introduced a small amount of fresh air on the return side of the air conditioning cooling coil. A POS system was installed in each home at the same time the ducts were repaired. Subsequent monitoring looked at the effects of this alternate ventilation system. Tightening the ducts and installing a POS ventilation system resulted in an 18% and 37% cooling savings in the two homes. Only about 2% of these savings were attributable to the ventilation system change, the remaining savings are a result of duct repair.

WSU Energy House
Olympia, Washington
Technical Assistance by BAIHP Contractors Washington State University Energy Program, Oregon Office of Energy and Idaho Department of Water Resources, Energy Division

This 2600 ft^2 home was built beyond SGC standards and incorporates Energy Star lighting and appliances. The home (*Figure 56*) has received significant national exposure through WSU campus and alumni newsletters, tours, the BAIHP website, and local and trade media including an article in the Automated Builder magazine and a feature by KING 5 News of Seattle.

Figure 56 *WSU Energy House in Olympia, WA*

WSU staff uses the house to try out innovative technologies and testing methods.
In 2003, BAIHP staff developed a moisture case study based on research at the WSU Energy House, published under a separate Building America project. The WSU Energy House has been monitored since 2000. Collected monitoring data includes weather, temperature, humidity, CO_2, CO, and eight differential pressures. Energy use data is being collected for water heating, laundry, fireplace and heating, ventilating, and air conditioning (HVAC). Data from the house is available on the BAIHP web page (under Current Data) and has been presented to the building science, indoor air quality (IAQ) and HVAC research communities at conferences sponsored by ASHRAE, Air Infiltration and Ventilation Center (in the UK), HUD/NIST, NFPA, and BTECC. (See also *Appendix D, WSU)*

Working with Ecotope, ASHRAE, and the Energy Conservancy, BAIHP staff conducted "Delta Q" and "nulling" duct leakage tests in 2001. Follow up pressure tests and analysis of test data conducted in 2002 indicate these tests are effective methods of measuring duct leakage in manufactured homes, and may be included in the upgrades to the National Fire Protection Association-501 standards for manufactured homes.

Blower door and duct leakage testing indicate very good whole house and duct airtightness (2.4 ACH50 and 61.6 $CFM50_{out}$). Tracer gas testing demonstrated that the use of a furnace-based intake damper does not change the leakage rate of the home.

In 2004, moisture problems associated with siding and trim details were eliminated using and an improved window flashing system. The adoption of this system is currently under discussion with some manufacturers, and NFPA-501

Zero Energy Manufactured Home (ZEMH)
Nez Perce Fish Hatchery, Idaho
Category A, 1 home

Figure 57 *Zero Energy Manufactured Home, on site at the Nez Perce Fish Hatchery*

BPA, working with BAIHP staff in Idaho and Washington, provided funding for the most energy efficient manufactured home in the country. The RFP was sent to 18 Northwest manufacturers; Kit HomeBuilders West of Caldwell, Idaho was selected as the manufacturer of the home. BAIHP staff solicited 24 industry partners to provide energy efficient building components, including Icynene wall, floor and roof insulation, a low-cost HUD-approved solar system, sun-tempered solar design, and Energy Star© windows, appliances and lighting. Partners include Building America Team members such as Flexible Technologies, Icynene and LaSalle. Complete list of specifications provided in *Table 29*.

The ZEMH *(Figure 57)* was built in the Fall of 2002 along with a control home. The ZEMH was displayed at the 2002 Spokane County Interstate Fair before siting at the Nez Perce tribal fish facility near Lewiston Idaho. Blower door and duct leakage tests at the plant and on-site indicate that this is the tightest home ever tested by BAIHP staff.

Working with FSEC and BPA, BAIHP staff installed monitoring equipment for the ZEMH. Monitoring began in the 2003 and includes the following:

- Total electric use from grid
- Resistance elements in heat pump
- Heat pump compressor and fan motors
- Water heating equipment, including gallons used
- PV energy production (ZEMH)

Table 29 Zero Energy Manufactured Home (ZEMH) and Base Case Home (Control)

Component	ZEMH	Base
Wall Structure	2x6 ft, 16 in on center	Same
Wall Insulation	R21 foam-spray	R21 batt
Floor Structure	2x8 ft, 16 in on center	Same
Floor Insulation	R33 (R22 Foam + R11 batt)	R33 Blown Cellulose
Vented crawl space wall	R14 foil faced foam	None
Roof/Attic Structure and Finish	16 in on center 40 lb roof load 4/12 pitch metal roofing	24 in on center Standard 30 lb roof load Same pitch and finish
Roof/Attic Insulation	R49 foam	R33 blown cellulose
Window/Floor area ratio	12%	Same
Windows	Vinyl Frame, Argon filled, low-e, Energy Star Approved	Same

Table 29 Zero Energy Manufactured Home (ZEMH) and Base Case Home (Control)

Component	ZEMH	Base
Window Shading	Dual blinds, heavy drapes, awnings	Single blinds, light drapes
Doors	U=0.2 metal, foam w/thermal break	Same
Solar	Solar ready design (mounts, flashings and electrical chase) 4.2 kW peak rated PV system with a 4 kW inverter and 12 kWh battery array	None
HVAC	2 ton unitary air-source heat pump 12 seer, 7.8 HSPF	Same
Zone heat	150 W Radiant Panel in kitchen	None
Ducts and cross over	R8 crossover Flex Flow crossover system Mastic with screws More efficient duct design	R8 crossover Sheet metal elbows Standard foil tape
Lighting	100% Energy Star T8 and CFL fixtures	T12 and Incandescent fixtures
Appliances	Energy Star washer and dryer, refrigerator, dishwasher	Standard equipment
Whole House Ventilation	Heat Recovery Ventilator w/HEPA, continuous operation (turned off in 8/04)	Quiet (low-sone) Energy Star exhaust fan, continuous operation
Spot Ventilation	Energy Star bath fans, std. Kitchen fan	Quiet (low-sone) bath fans, std. Kitchen fan
Ceiling Fans	Energy Star with dimmable CFL	Standard with Incandescent bulbs
Domestic Hot Water	PV controlled, active anti-freeze solar water system, with 80 gallon storage, and 64 ft^2 of collector area solar pre-heat tank (pre-plumbed), 40 gallon standard tank EF=0.93	EF=0.88 standard electric
Air Sealing	Wrap with tape flashing Marriage line gasket (new product) Penetrations sealed with foam insulation	Wrap without tape flashing Standard practice marriage line sealing
Air/Vapor Barrier	Walls and Ceiling: Painted Drywall Floor: Floor decking	Same

Data logger collects 15 minute data from wired sensors and transmits daily to the host computer at FSEC via modem. Summary data reports are available at www.baihp.org under “Current Data.” Plug-type loggers were installed in mid March 2003 to sub-meter the energy use of the refrigerator, freezer and clothes washer in each home, as well as the radiant heat panel and HRV in the ZEMH. Data from these loggers was collected by occupant readings in mid-December 2003.

Preliminary findings

Measured net energy use of the ZEMH 6% is lower than the base home, not normalized for occupant behavior. This also does not take into account the fact that the ZEMH’s PV system was only fully operational for one month.

The ZEMH required 45% less space heating energy, possibly due to improved building envelope measures, and the lack of consistent HRV operation.

The measured envelope leakage in the ZEMH was 2.0 ACH50, much lower than the base home (indeed, lower than any other NEEM home tested in the field) and substantially tighter than typical HUD code homes.

The ZEMH total duct leakage was 46% lower than the base home; leakage to the outside was 405% lower than the base home. The BAIHP staff speculates that the unprecedented low leakage to the outside value is the result of the ducts in the ZEMH being located within the conditioned space, and effectively within the pressure envelope of the home, surrounded as they are by foam insulation.

The solar water heating system in the ZEMH provides most, if not all of the hot water needed during the summer months, and roughly 45% of the total hot water demand. The PV system with net metering provides 38% of the total ZEMH energy use.

The project highlights the importance of occupant choices and behavior on the performance of energy efficient housing. Based on the preliminary monitoring data and occupant surveys, the behavior patterns of the ZEMH occupants are not themselves "energy efficient". These patterns create the appearance of a less efficient home. On the other hand, the behavior of the ZEMH occupants may shorten the payback for the innovative technologies of the ZEMH.

BAIHP staff also performed a benchmarking analysis on the ZEMH, as part of the overall benchmarking effort. The ZEMH reached a level of 60% above the NREL prototype, which indicates the difficulty of obtaining a high benchmarking score.

In December of 2004, a research paper was presented at BTECC which provided a preliminary evaluation of the ZEMH performance without the full operation of the PV net metering system. By the spring of 2006, there will be a full year of ZEMH data, with the PV system operational.

Manufactured Housing Indoor Air Quality Study
Plant City, Florida, and FSEC MHLab
Papers: Hodgson, A.T., Apte, M.G., Shendell, D.G., Beal, D. and McIlvaine, J.E.R. (2002a). Implementation of VOC source reduction practices in a manufactured house and in school classrooms. In Levin, H. (Ed.), Proceedings of the 9th International Conference on Indoor Air Quality and Climate. Indoor Air 2002, Santa Cruz, CA, Vol. 3. pp. 576-581.
Hodgson, A.T., D. Beal and J.E.R. McIlvaine. 2002b. Sources of formaldehyde, other aldehydes and terpenes in a new manufactured house. Indoor Air12: 235-242.
Hodgson, A.T., A.F. Rudd, D. Beal and S. Chandra. 2000. Volatile organic compound concentrations and emission rates in new manufactured and site-built houses. Indoor Air10: 178-192.

This is a summary of several indoor air quality (IAQ) projects designed to improve the IAQ of manufactured homes; specifically to find ways to reduce the formaldehyde levels found in manufactured homes. This was a collaborative effort of the Florida Solar Energy Center (FSEC), Lawrence Berkeley National Laboratory (LBNL) and Palm Harbor Homes, Inc. (PHH), a leading nationwide producer of multi-section, high-end, manufactured houses with corporate offices in Addison, TX.

In 1999 – 2000 a study was conducted to identify and verify the major sources of formaldehyde, aldehydes, and terpene HCs in a new manufactured house. Laboratory emission tests were conducted with a number of wood and engineered wood products and aldehyde and volatile organic chemical (VOC) measurements were made in the house. Although only a single house was studied, the information on sources is anticipated to have broad application to residential construction due to the widespread use of similar materials and building practices.

The manufactured house was typical of better quality two-section houses produced in Florida. It was completed in November 1999. Within three weeks of manufacture, it was installed at a nearby site. The house was used daily as a sales model. It was decorated, fully furnished, but unoccupied. There were three bedrooms and two bathrooms.

The manufacturer supplied a detailed list of materials used in the house. Between December 1999 and January 2000, ~30 specimens of the major materials were collected from the production facility. These were cataloged, packaged in aluminum foil, and shipped to the laboratory by airfreight. The specimens were stored at room conditions in their original packages until they were tested. Most materials were tested within three months of collection. Measurements were made after about a 3-week exposure, and area-specific emission rates (i.e., emission factors) were calculated.

Air sampling in the house and outdoors was conducted in March 2000. The house ventilation rate was quantified concurrently by tracer gas decay. The ventilation rate measurement and the VOC air sampling and analytical methods for field and chamber work have been described previously (Hodgson et al., 2000)

Whole-house emission rates for combined materials were predicted based on the emission factors and the corresponding material quantities. These predicted values were compared to whole-house emission rates derived from measurements of VOC concentrations and ventilation rates. For 10 of the 14 target compounds, including formaldehyde, the predicted and derived rates agreed within a factor of two, which considering the uncertainties involved is considered good agreement. The predominant sources of formaldehyde in the house were bare particleboard (PB) and medium density fiberboard (MDF) surfaces in the cabinetry casework and molded high-density fiberboard doors. The plywood subfloor under the carpet was a smaller source of formaldehyde and the major source of higher molecular weight aldehydes and terpene hydrocarbons.

As the result of this study, recommendations were developed for reducing concentrations of formaldehyde and other VOCs in new house construction (Hodgson et al., 2002a). These are reproduced here in *Table 30.* The first five recommendations are aimed at controlling or eliminating important sources of formaldehyde. Other potential sources of formaldehyde not addressed in the house study or in the table include tack strips used for the installation of wall-to-wall carpet and fiberglass insulation used in wall, floor and ceiling cavities. Use of barrier materials on the floor may result in moisture condensation problems in hot-humid climates and possibly other situations and, therefore, should be used with caution.

Table 30. Recommended VOC Source Reduction Practices For New House Construction

No.	Source Reduction Practice
1	When alternates exist, avoid wood products with urea-formaldehyde resin system
2	Construct cabinet cases with fully encapsulated wood products
3	Use frameless cabinets to eliminate MDF stiles
4	Apply laminate backing sheet to undersides of PB countertops
5	Use alternate low-formaldehyde emitting passage doors
6	Apply barrier material over plywood subfloor in carpeted areas

In 2004 a pilot demonstration project was conducted at PHH's production facility and sales office in Plant City, FL. The project was originally conceived in 2002 as a side-by-side demonstration of simultaneous improvements in energy performance and IAQ to be achieved using existing technologies. The concept was to build two houses, essentially identical with respect to their size, floor plan, and major materials. One house would have added features to improve energy performance and IAQ. The other house would have no special modifications and would serve as the control. They would be sited in a residential community on adjacent, identical lots. Both would have computer-simulated occupancy (i.e., controlled use of lights, appliances, heating and cooling). Monitoring of energy usage and performance and IAQ metrics would be conducted over at least a one-year period. Finding the appropriate residential site and the funds needed to cover the costs associated with maintaining the houses at the site for a year proved difficult. Consequently, the study plan was modified in 2003 to reduce costs and take advantage of PHH's model home sales office in Plant City.

Approximately on an annual cycle, PHH builds examples of their new houses for display at their sales office. The houses present PHH's range of models and features. They are decorated and furnished, but unoccupied. The houses are open to the public during normal business hours seven days a week and their heating and cooling systems are operated accordingly. The use of these houses as study houses has some limitations. The houses generally vary somewhat with respect to size and floor plan, interior finishes and furnishings may vary, orientation with respect to sun and wind may vary, monitoring instrumentation must be kept out of sight, and sampling can only be conducted outside of normal business hours. In addition, computer controlled simulations of occupancy are not possible.

To the extent possible, the study plan was revised to accommodate these factors.
In June 2003, two model houses, then in the planning stage, were selected for use in the project. A 1,440-ft2, double-wide house designated as "Monte Carlo" was selected to receive the energy and IAQ modifications. A 1,540-ft2 double-wide house designated as "Edison 2" was selected to serve as the primary control house. The houses were to be installed on nearby lots in the sales center in approximately the same orientation.

The project participants early on developed specifications for enhanced IAQ. These specifications were reviewed and revised in June 2003 to reflect those energy and IAQ modifications determined by PHH management to be relatively easily installed on the production line and/or during installation. The revised IAQ specifications are listed in *Table 31.*

Table 31 Revised IAQ Specifications

Component	Specification
Cabinet Construction	Use plywood face frame material and vinyl-two-sides (V2S) particleboard for all casework
Countertops	Construct all countertops with V1S particleboard with vinyl surface on underside of tops
Carpeted Floors	Install Tyvek (Dupont) house wrap over plywood subfloor before installing carpet. Use Nylon 6,6 carpet and synthetic fiber carpet cushion (both CRI Green Label)
Wall & Ceiling Paint	Use low VOC interior paints (Sherwin-Williams Harmony brand)
Passage Doors	Use vinyl-coated doors
Trim	Use wood lumber trim throughout house; avoid use of MDF trim
Recessed Light Fixtures	Install gasketed light fixtures

The two houses were produced in late July and early August 2003. Installation of the two houses was completed and the heating and air conditioning (HAC) systems were operational by the end of September. Not all of the originally planned IAQ modifications (Table 2) were installed in the Study house. Standard molded high-density fiberboard, passage doors were used, as the door manufacturer no longer produces vinyl-coated doors. Medium-density fiberboard (MDF) was used for the face frames of the cabinets because PHH did not have sufficient stock of the plywood material. Standard tack strips with unquantified emissions of formaldehyde were used for the carpet installation, as LBNL was unable to identify an alternate with low formaldehyde emissions.

Energy Gauge ratings of the experimental house (Monte Carlo) and the control (Edison) showed that the control house was an Energy Star home, scoring 86.5, while the experimental house was a Building America house, scoring 91.1. There were many obstacles to successfully retrieving data from the houses, but available results show that the BA house saved about 50% more air conditioning energy than the control house. *Figure 58* illustrates this. The plot normalizes the data by plotting the daily air conditioner energy use pre ft^2 of conditioned space versus the average daily temperature difference between the inside and the outside (Average Daily)T).

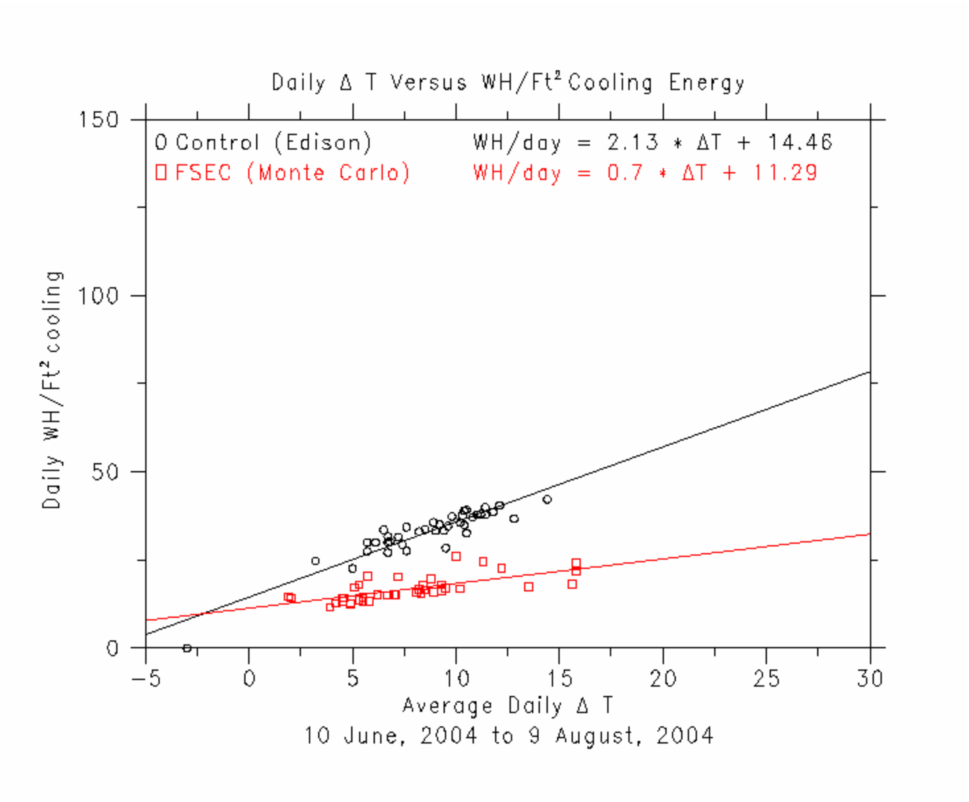


Figure 58

IAQ work started with an initial set of active air samples for VOCs and aldehydes collected outdoors and in the Study and Control houses on December 11, 2003, approximately 2.5 months after the houses were fully operational. The second set of active samples was collected three months later on March 2, 2004. Passive aldehyde samples were obtained in the Study and Control houses and in an additional triple-wide house of the same age over four one-week intervals between these dates.

There were some distinct differences between the concentrations measured in the two houses. Notably, the concentrations of formaldehyde in the Study house were about three times higher than concentrations in the Control house. This difference was not anticipated based on the source reduction measures aimed at lowering the emissions of formaldehyde in the Study house.

Based on previous laboratory measurements of formaldehyde emissions from interior components, we anticipated a minimum 25% reduction in the formaldehyde emission rate in the Study house relative to the Control house. This was anticipated due to the use of fully encapsulated particleboard for the cabinetry casework, a diffusion barrier on the undersurface of the particleboard countertops, and the weatherization barrier applied over the plywood subfloor (Hodgson et al., 2002b). We additionally expected the difference to persist over the course of a year. The two-fold higher formaldehyde emissions in the Study house prompted us to abandon our original plan of quarterly measurements and instead to focus on identifying the unexpected source of formaldehyde emissions in this house. Firstly, FSEC and PHH staff jointly inspected the houses. This inspection confirmed that the intended formaldehyde source reduction measures had been implemented in the Study house.

Two other potentially relevant differences between the houses were known at the time. Due to the energy efficiency specifications for the Study house, a different manufacturer than the HAC system in the Control house produced the HAC mechanical system in the house. Secondly, some furniture believed to be solid wood had been newly purchased for decoration of the Study house. Older furniture taken from PHH's stock was used to decorate the Control house.

In July 2004, the potential for the HAC systems to emit formaldehyde was investigated. Each system is located in a closet near the central living area. Active sampling for formaldehyde was conducted in each house. The differences between the return and supply measurements were small, about plus 3% for the study house and about minus 8% for the control house. These differences are within the uncertainties of the measurements and, therefore, are not significant. Another inspection revealed that some of the backsides and undersurfaces of the new wood furniture were fabricated from particleboard, a typically high formaldehyde emission source (Kelly et al., 1999; Hodgson et al., 2002b). Due to delays imposed by PHH model center needs and 2004's hurricane season, in December 2004, approximately 14 months after the furniture was first delivered, we located the furniture pieces in a storage garage. From one accessible piece, we obtained 4.4-cm diameter specimens of 3-mm thick particleboard using a hole-saw. Specimens of 13-mm thick particleboard were similarly collected from a furniture piece that was several years old and was used in the sunroom of the house.

The emissions of formaldehyde from the two specimens of furniture particleboard individually were measured in the laboratory using small-scale environmental chambers as described by Hodgson et al. (2002b).

From the purchase requisition and the company's sales literature it was determined there were eight new pieces of living room and master bedroom/retreat furniture that likely contained some particleboard. The total exposed surface area (one side) of particleboard in these pieces was estimated to be 8.5 m2. Thus, the estimated formaldehyde emission rate attributable to the new furniture was about 80% of the total formaldehyde emission rate derived for the house in December 2003. Based on the formaldehyde emissions from the particleboard from the older furniture, it is likely that the formaldehyde emissions attributable to furniture would have been substantially lower if older furniture pieces had been used.

This study did not progress as originally intended, and the results did not conclusively show the efficacy of low-cost measures intended to reduce the sources of formaldehyde in the Study house. However, it is likely that the source of the elevated formaldehyde emissions was correctly identified to be a component of the new wood furniture installed in this house and not in the Control house. If one-half the estimated formaldehyde emission rate from the new furniture (i.e., approximately the difference between the emissions from new and old furniture particleboard) is subtracted from the whole-house emission rate, the formaldehyde emission rate in the Study house is nearly equivalent to the rate in the Control house.

A formaldehyde concentration of 50 ppb and below has been suggested as a reasonable target for new houses (Sherman and Hodgson, 2004). The source reduction measures directed toward other VOCs were successfully demonstrated. The use of the weatherization barrier applied over the plywood subfloor in the Study house appeared to function as predicted to reduce the emissions of higher molecular weight aldehydes and terpene hydrocarbons from this source, and the use of the low VOC interior paint reduced the emissions of a major VOC component associated with latex paints.

Data collection was curtailed by the onset of 2004's hurricanes, three of which impacted Plant City, and sales activity resulting in houses moving. The collected data did show that the energy goals established for the house were met, with a 50% reduction of energy use for air conditioning compared to the control house

Manufactured Housing Laboratory – Ventilation Studies
FSEC, Manufactured Home Laboratory
Paper: Moyer, Neil, Chasar, Dave, Hoak, Dave, Chandra, Subrato, "Assessing Six Residential Ventilation Techniques in Hot and Humid Climates," Proceedings of ACEEE 2004 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC, August 2004. (Also available online at www.baihp.org under Current Data *and* Publications**)**

Ventilation Study
The MHLab (*Figure 59)* is a research and training facility of 1600 ft^2. This Energy Star® manufactured home has two separate heating and cooling systems:

1. An overhead duct system connected to a package unit air conditioner with electric resistance heating.
2. A floor-mounted duct system connected to a split system air conditioner, also with electric resistance heating.

Only the floor mounted duct system was used in these ventilation experiments.

Figure 59 *Manufactured Housing Laboratory at FSEC (above and below) was site for study of six residential ventilation systems.*

Introduction
Ventilation is a HUD code requirement. The goal of ventilation is to add fresh air to the home. This may be accomplished by supplying outside air to the house or mechanical system, exhausting air from the house (which consequently pulls air into the house through joints in the walls, floor, and ceiling), or a combination of the two.

Supply based ventilation tends to slightly pressurize the home whereas exhaust based ventilation does the opposite slightly depressurizing the house. The disadvantage of supply based ventilation is that it forces conditioned air into the floor, wall, and ceiling cavities, possibly leading to condensation or mold growth in cold climates and during the heating season. Likewise the disadvantage of exhaust systems is that they pull unconditioned outside through the floor, wall, and ceiling cavities into the conditioned space, possibly leading to condensation, mold growth, or uncomfortably high indoor humidity levels in hot and hot-humid climates and during the cooling season. The six residential ventilation strategies evaluated are described in *Table 32*.

House Operation and Experimental Procedure

Occupancy Simulation: Automated, computer controlled devices, such as appliances, showers, and lighting, simulate the sensible/latent heat generation and carbon dioxide (CO_2) production of a family of four persons with periodic showers, cooking and cleaning.

The simulated latent occupancy load from breathing, bathing, cooking, and laundry was achieved by adding 14 to 15 pounds of water per day based on documentation of "average" household operation based on ORNL research conducted by Jeff Christian. 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.

Table 32 Ventilation Strategies Studied in the MHLab

Case (Name)	Strategy	Description
# 1 (None).	No mechanical ventilation	Base Case scenario included only the heating and cooling system of the home with no outside air (OA) ventilation.
# 2 (Spot)	Spot ventilation (exhaust only)	Bathroom and kitchen exhaust fans. Operation scheduled for 30 minutes after a simulated moisture producing event such as a shower or oven use.
# 3 (OA)	Outside air (supply based)	Dedicated, filtered outside air duct to return plenum when the heating or cooling system is operating. Quantity of ventilation air provided depends on air handler run-time.
# 4 (Dehumid)	Outside Air plus 10/20 Cycle and Dehumidification (Supply Based)	Same as #3, except with an added air handler fan controller (10-minute “on” - 20-minute “off” minimum duty cycle). Provides scheduled ventilation when no cooling or heating is called for. A stand alone room dehumidifier (set to approximately 50% RH) located in vicinity of the return air grill.
# 5 (10/20 Cycle)	Outside Air plus 10/20 cycle (Supply Based)	Same as #4, except without the room dehumidifier.
# 6 (ERV1) (ERV2)	Energy recovery ventilator (ERV1, ERV2)	Two different enthalpy transfer media were used. Outside air was drawn in through the ERV at a rate to meet the ventilation requirements.
# 7 (Hstat)	Outside Air plus Humidistat (Supply Based)	This is a modified air handler fan speed control. When dehumidification is needed, the air handler fan is operated at lowest speed for enhanced latent control. A higher speed is selected when sensible cooling is needed. Ventilation air supplied via an outside air duct, with air handler fan operation controlled as in #4.

Ventilation Rate: Researchers conducted whole house air tightness tests using sulfur hexafluoride as a tracer gas for a decay analysis (*Figure 60*) to determine if each ventilation strategy met the ASHRAE 62-2 Ventilation Standard during the test period. The spot ventilation strategy (#2) did not meet the standard on a daily basis as the runtime was not long enough. The outside air method (#3) was marginal in meeting the standard. Strategies #4-#7 met the standard.

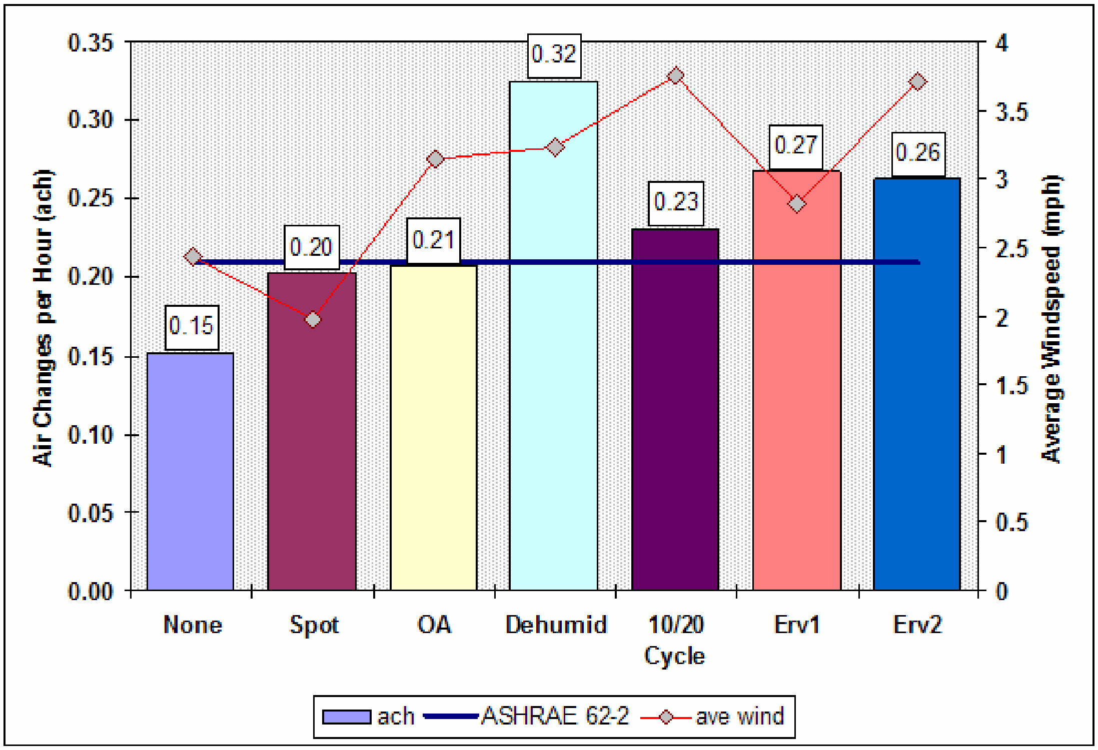


Figure 60 Results of tracer gas decay testing indicating operational infiltration (house not under test pressure) rates measured for each ventilation strategy. ASHRAE Standard 62.2 was the target ventilation rate, not met by *Spot* or *OA* strategies. *Note: Wind speed averaged over 2 hour infiltration test.*

Whole House and Duct Air Tightness: The average whole house air leakage (CFM50) was 1224 (ACH50 of 5.4). The target normalized duct leakage is Qn#6%, where Qn=CFM25/conditioned area, this is the same as the duct leakage target in the Manufactured Home Energy Star program. The total duct system leakage in the MHLab Qn_{total}=5% ($CFM25_{total}$ = 75) with leakage to the outside measured to be $Qn_{(out)}$=3% ($CFM25_{out}$ = 45), well under the leakage target.

Interior temperature and relative humidity: A digital thermostat maintained interior temperature at 75 degrees Fahrenheit. Interior temperature and relative humidity sensors are located on the same wall as the thermostat, at approximately the same height from the floor. Dedicated interior relative humidity control was only available with the dehumidifier strategy, and was a byproduct of cooling coil operation in the other strategies.

Cooling/ventilation power usage

With all mechanical ventilation systems, additional energy use from both increased conditioning loads and fan (if present) power is expected. The split system with the floor duct system is a 12 SEER system with a rated cooling capacity of 30.2 kBtu. The ventilation strategies that required the use of the air handler fan, an energy recovery ventilator, or the dehumidifier had the energy use added to the cooling energy. The dehumidifier strategy did use the most energy for cooling; however, it should be noted that this test occurred during the hottest ambient conditions.

Table 33 Average Ambient and Building Conditions

	Case 1 None	Case 2 Spot	Case 3 OA	**Case 4 Dehumid**	Case 5 10/20	Case 6 ERV1	Case 6 ERV2	Case 7 Hstat
Indoor Temp (°F)	74.5°	74.5°	74.7°	**74.9**°	74.0°	74.1°	74.4°	74.8°
Indoor Temp Max (°F)	75.0°	75.2°	75.5°	**76.0**°	75.0°	74.9°	75.4°	76.0°
Indoor RH (%)	49.2%	45.7%	49.5%	**47.9%**	49.1%	47.8%	47.2%	45.7%
Indoor Dewpoint (°F)	52.4°	54.2	54.5	**53.9**	53.7	53.1	53.0	52.4
Outside Temp (°F)	78.6°	78.6°	78.4°	**82.1**°	79.8°	79.3°	80.8°	79.2°
Outside RH (%)	89.2%	79.5%	87.7%	**83.4%**	87.0%	90.0%	86.9%	88.1%
Δ Temp (°F)	4.3°	4.0°	3.7°	**7.1**°	5.8°	5.1°	6.5	4.4
Δ Dewpoint (°F)	18.6°	20.7°	19.5°	**22.4**°	21.4°	22.7°	23.3°	22.6°
Solar Rad. (kWh/m^2)	53.5	107.3	68.9	**76.3**	86.8	66.3	101.9°	77.1°
Rainfall (Inches)	3.6	0.5	4.7	**0.1**	4.0	5.1	3.2	4.9
Condensate (lbs)	617	905	920	**1131**	1118	1034	1685	1282
Δ P WRT Out (Pa)	-0.2	0	0.1	**0.4**	0	-0.2	-0.2	0.1
Minimum RH	42.1%	38.8%	45.8%	**46.2**%	46.3%	44.2%	39.3%	39.7%
Maximum RH	53.3%	55.2%	53.2%	**51.0**%	58.4%	64.8%	53.0%	61.4%
Mean RH	46.1%	49.2%	49.5%	**47.9**%	49.0%	47.8%	47.2%	45.7%
RH Standard Deviation	1.272	1.471	1.673	**0.845**	1.231	2.194	2.108	3.07
RH Range	*11.2%*	*16.3%*	*7.4%*	***4.8**%*	*12.1%*	*20.6%*	*13.7%*	*21.7%*

Findings

The cooling energy required to maintain the 75°F interior set-point appeared to vary as a result of the temperature difference across the envelope *(Table 33).* A linear regression analysis was performed to compare energy use of the ventilation strategies as a function of temperature difference across the envelope *(Table 34).* The power use at the average temperature difference of five degrees Fahrenheit is shown in bold.

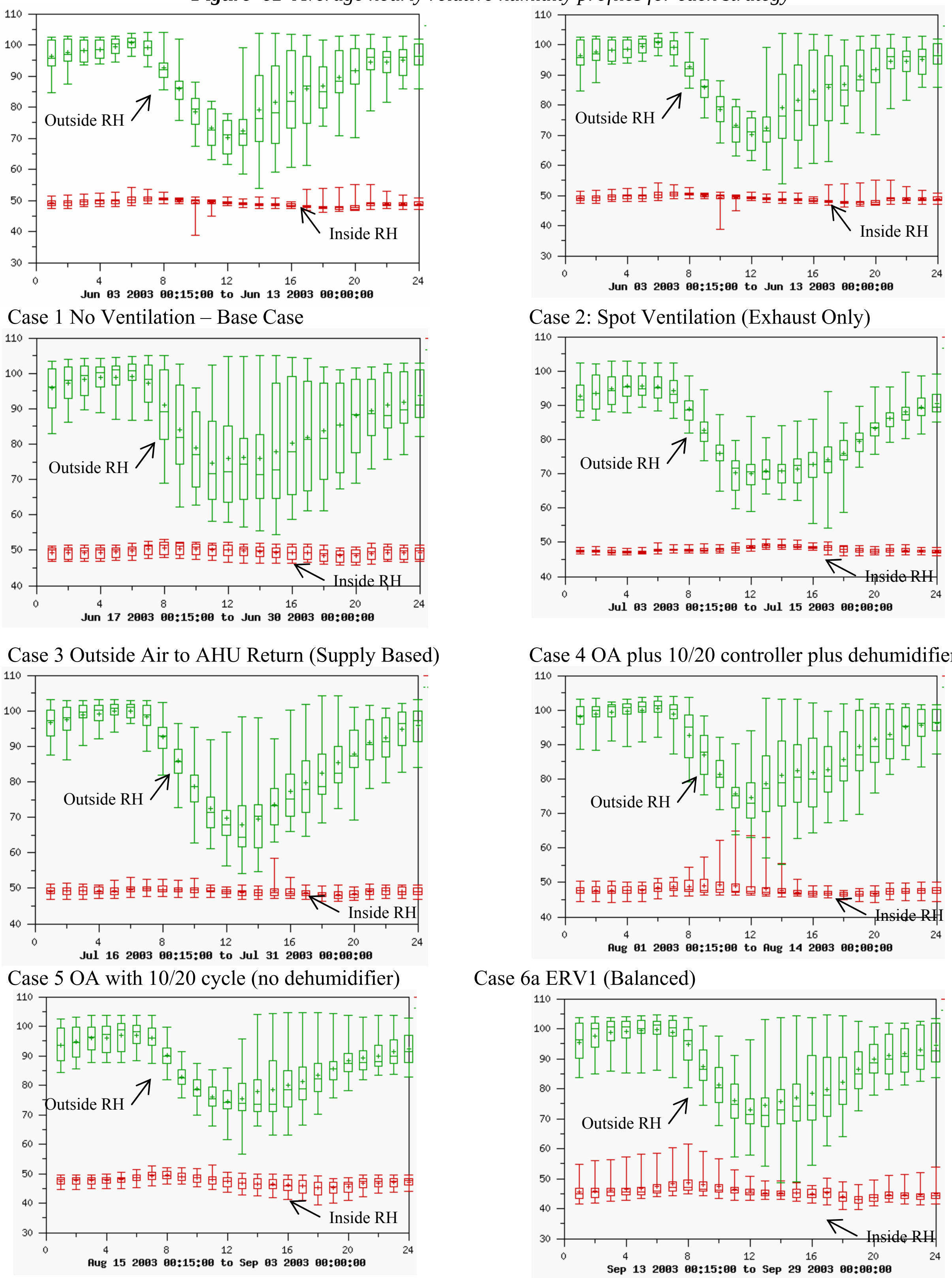
- Case 4, the dehumidifier system, has the highest average power at 1592 watts.
- Case 7 (humidistat controlled fan speed or Hstat) is second highest at 1485 watts.
- Case 5 (10/20 cycle controller) used the least power at 1315 watts.

As might be expected, interior relative humidity had the least variance with the dehumidification system with a low of 46% and a high of 51% (*Table 33 and Figure 61*). The best performing system, Case 4 (10/20 cycle plus dehumidifier), was able to maintain the relative humidity at a nearly constant level for almost 80% of the test period. The next best performer was Case 2 (spot ventilation). Humidity levels during the test period are graphed in *Figure 61*.

Table 34 Cooling and ventilation power (watts) usage as a function of temperature difference across the building envelope

ΔTemp (°F)	Case 1 None	Case 2 Spot	Case 3 OA	Case 4 Dehumid	Case 5 10/20	Case 6 ERV1	Case 6 ERV2	Case 7 Hstat
-5	487	499	475	499	411	459	367	526
0	924	911	949	1046	863	915	880	1006
5	**1361**	**1324**	**1424**	**1592**	**1315**	**1370**	**1393**	**1485**
15	2236	2150	2372	2685	2219	2280	2418	2443

Figure 61 *Average hourly relative humidity profiles for each strategy*



Case 1 No Ventilation – Base Case

Case 2: Spot Ventilation (Exhaust Only)

Case 3 Outside Air to AHU Return (Supply Based)

Case 4 OA plus 10/20 controller plus dehumidifier

Case 5 OA with 10/20 cycle (no dehumidifier)

Case 6a ERV1 (Balanced)

Case 6b ERV1 (Balanced)

Case 7 OA with humidistat controller (Supply Based)

Conclusions

The operation of a correctly sized air conditioning system with a supplemental dehumidification system to pre-condition the outside air and provide additional dehumidification of the space appears to provide the best interior humidity control (*Table 33*, in bold) with only a slight increase in energy usage – about 200 watts *(Table 34).* This is represented by Case 4 of this study. Only this strategy was able to maintain the interior humidity conditions in a range of less than 5% (*Table 34*, in italics).

Though all of the strategies did provide some humidity control over the test period, it is most likely a result of the run time afforded by the correctly sized air conditioning system and the consistent simulated interior sensible load. When an air conditioning system operates for extended periods of time, the removal of moisture from the air stream is enhanced (Khattar, Swami & Ramanan 1987).

Additional testing with other ventilation strategies in the MHLab will be undertaken in the next budget period.

Manufactured Housing Energy Use Study, North Carolina A&T

Paper: *W. Mark McGinley, Alaina Jones, Carolyn Turner, Subrato Chandra, David Beal, Danny Parker, Neil Moyer, and Janet McIlvaine. Optimizing Manufactured Housing Energy Use. Symposium on Improving Building Systems in Hot and Humid Climates, Richardson, Texas, May 17-19, 2004.*

Side-by-side monitoring of two manufactured homes at North Carolina Agricultural and Technical State University (NCA&TSU), evaluated the value of a variety of energy saving technologies and techniques. *(Figure 62 and Table 35)* Home instrumentation measured energy consumption as well as interior and exterior climatic conditions. The "standard home," designed and built to basic HUD code requirements, represented the control home. Modified to use at least 50% less energy, the "energy home" met Building America standards. Cooperating researchers at NCA&TSU and FSEC investigated energy feature performance and compared actual energy used to energy modeling program predictions. In-situ energy performance data provided researchers with interesting information on both issues.

Figure 62 *Side-by-side monitoring of manufactured homes at NCA&TSU.*

Each model contained 1,528 ft^2 of living area with nearly identical floor plans. Though the homes were unoccupied during the testing, home lighting and water heating use was simulated with timers. A datalogger in each home recorded: (1) the interior and exterior temperature and humidity along with solar radiation and wind speed, (2) the home's total power consumption, (3) the air conditioning/heat pump compressor, air handler fan, and electric resistance heater use (primary heater in the standard house, backup or emergency heater for the energy house), and (4) water heating and water usage data.

The energy house features combined higher insulation values, improved windows, centralized and airtight duct design, high efficiency heat pump, and a solar water heater. Feature-by-feature construction differences are highlighted in *Table 35*.

Table 35 Specifications of Standard and Energy Construction

Characteristic	*Standard House*	*Building America House*
square footage	1528	1528
floor insulation	R-11	R-22
wall insulation	R-11	R-13
ceiling insulation	R-20	R-33 + roof deck radiant barrier
windows	single pane with interior storm	low-E double pane
exterior doors	storm door on front	storm door on all
marriage wall seal	fiberglass pad	SOF-SEAL® gasket
heating system	resistance electric	heat pump HSPF 7.5
cooling system	central air conditioning SEER10	central heat pump SEER12
system size	3 tons	2 tons
water heating	electric water heater – 40 gallon	solar water heater – 66 gallon
duct joints	industry standard	sealed with mastic
duct leakage	*CFM5out = 145	CFM25out = 83
house leakage	**ACH50 = 10	ACH50 = 9
**Cubic feet per minute*	***Air changes per hour*	

Data collection on the two homes began in early January 2001 and continued through this reporting period. Palm Harbor Homes in Siler City manufactured both homes, the results for program year three and four are detailed below.

Year 4 Side-by-Side Monitoring Results
During Phase 2, modifications were made to the solar water heating system in the energy efficient housing unit to help improve the performance this system. Further, a number of the incandescent light bulbs in the energy unit were replaced with compact fluorescent bulbs. These changes were staged to allow an evaluation of the effect of each measure on the home's energy use.

Based on investigative results, it can be concluded that:

- Changes in the building envelope, HVAC and duct systems, and fenestrations in the energy home met researchers' 50% energy use reduction goal. Measured annual energy savings for heating and cooling energy was 58%, and 53% for heating, cooling, and hot water production.

- Care should be exercised in the manufactured housing unit setup or relatively minor construction deficiencies can significantly reduce a home's energy efficiency. Many of these items are invisible to the homeowner; therefore procedures must be developed to ensure that deficiencies do not occur during setup.
- The Energy Gauge energy analysis program appears to give a reasonably accurate prediction for expected energy use reduction in a typical manufactured housing configuration. The predicted energy savings for the housing units evaluated in this investigation ranged from 54% to 63%, while the measured values ranged from 53% to 58%. Version 2.0 of the Energy Gauge Program provided a more accurate energy savings prediction than the older software versions.
- An increase in pipe and tank insulation can increase not only the energy efficiency of a solar water heater by reducing stand-by losses, but also can reduce the cooling load in a manufactured housing unit and increase the overall energy efficiency of the water heating unit. Even small amounts of exposed piping can significantly affect the energy efficiency of the water heating system.
- While providing essentially the same lighting levels, replacing incandescent lamps with compact fluorescent bulbs not only reduces lighting energy use, but also reduces the home cooling load.

The total measured energy used by each of the housing units for cooling and heating are shown in tables below. *Table 36* shows the energy used for heating and cooling the standard housing unit from January through August of 2002. The standard home datalogger was struck by lighting in mid-August 2002. Data after this point was not included since only partial data is available and performance comparisons were not possible. *Table 37* shows a summary of the cooling and heating energy used by the energy housing unit. *Tables 38 and 39* list the energy use for hot water production for the standard and energy units, respectively.

Table 36 Cooling and Heating Energy Use, Standard House *Actual Values (kWh)*

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Phase 1	492.4	447.6	648.6	1741.1	2495.3	849.6	628.8	384	566.3	990.8	852.9	1066
Phase 2					2120.2	1717.1	1227.6	502.0	438.0	939.4	1079.4	511.2

Table 37 Cooling and Heating Energy Use, Energy Star House

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Phase 1	337.3	205.7	150.8	452.8	1087.3	472.8	426.9	184.8	528.3	891.5	850.9	671.6
Phase 2					680.7	537.1	378.1	241.9	311.8	603.0	668	626.6

Table 38 Domestic Hot Water Use, Standard House

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Phase 1	197.8	267.7	250.2	212.6	0	0	217.6	244.9	258.1	227.5	207.9	213.5
Phase 2					294.6	280.9	283.2	264.9	280.2	192.2	200.3	85.2

Table 39 Domestic Hot Water Use, Energy Star House

	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Phase 1	133.4	176.2	204.2	189.9	0	0	245.5	184.4	183.0	141.2	152.3	126.6
Phase 2					251.1	212.0	202.8	145.9	157.3	74.8	80.3	83.0

Also listed in each table are the monthly energy use values measured during the first phase of this investigation, January through August 2001. Please note that the energy housing unit data prior to August 2001 is suspect due to duct and HVAC system problems later corrected. The entire data set, including, temperature, relative humidity, solar radiation, and power use is listed on the FSEC web site www.infomonitors.com.

The total energy used for water heating and central cooling over the period of August 1 through August 15 was 363.5 kWh for the energy home and 596 kWh for the standard home. This represents a 40 % reduction in energy use between the two homes.

The total energy used over the period of August 1 through August 15 for water heating was 7.13 kWh for the energy house and 85.18 kWh for the standard home. This represents a 68% reduction in energy use with the solar water heating system and compares well with the June and July reductions of 63% and 60%, respectively. Consistent findings indicate that the tank and piping insulation has reduced the standby tank losses and improved the solar water system efficiency.

In the energy housing unit, three of the 100 watt incandescent lamps that were on the evening four-hour timed duration were exchanged for 25 watt compact fluorescent lamps on June 4th. This change did appear to have a small effect on the cooling load in the energy housing unit. The relative cooling energy used by each of the housing units from June, 2002 through August 2002 showed a small change. The percentage reduction in cooling energy used by the energy housing unit increased from about 30% to 38%. However, it is difficult to isolate the effects of the improvements in the solar water heating system insulation and the effects of the compact fluorescent bulbs. In any event, these effects appear to be much smaller than that produced by the hot water system changes.

Year 3 Side-by-Side Monitoring Results:
Heating system savings (2001 to 2002) were a remarkable 70% during Phase 1. Cooling energy season savings were 36%, less than heating but still very substantial. The combined heating, cooling, and water heating savings were 52% for a 9-month period. *(Figure 63)*
In addition to the energy monitoring effort, NCA&TSU researchers investigated the feasibility of replacing the conventional framing/envelope used in manufactured/industrial housing with alternative systems. Included in this evaluation, was an analysis of the energy impact of using aerated autoclaved concrete (AAC) flooring systems and structural insulated

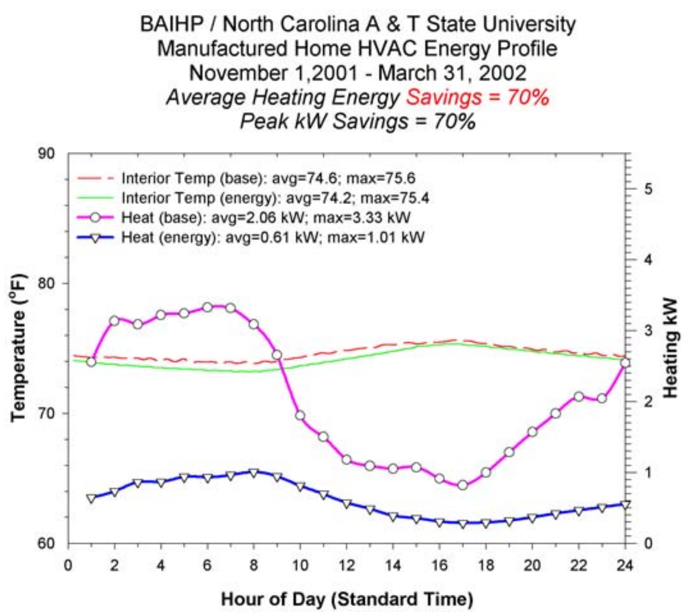


Figure 63 *Heating season consumption and savings for side by side study of Energy Star Manufactured Housing.*

panels (SIP) to supplant traditional wall and roofing systems. The economic viability of using AAC blocks for structural skirting/foundation around the model units also was evaluated.

Analysis' results determined:

- The best manufactured home energy performance can be achieved using the SIP wall and roof systems with the AAC plank. This performance can be further enhanced with an R-8 unvented crawl space. Though a manufactured home performs best with these alternative systems, the cost to include them may not make economic sense.
- AAC planks can be designed to replace both the steel frame and flooring systems for HUD code manufactured housing units and modular units. These planks also can be modified to incorporate built-in insulated ducts.
- AAC planks are pre-manufactured and require less assembly labor than a typical stick framed unit, but including the plank flooring would increase framing costs by 28%. The heavier weight of an AAC system might exacerbate high framing costs. Similarly, comparative analysis results found that replacing a conventional framing system with a SIP system would increase framing costs by 66%.
- At the current prices for energy and wood products, neither the AAC plank system nor the SIP systems are as economically effective as improvements in the current conventional HVAC systems, steel and wood framing, sheathing systems, and air barriers with respect to improving energy performance.
- The use of AAC planks has the potential to be economically viable in the modular housing market, especially if used with sealed crawl space foundation systems, where their improved resistance to moisture degradation would be very important.
- SIP wall and roof systems also could prove to be economically viable if the price of wood energy increases, and the SIP manufacturing costs decrease through large volume purchases.
- The proposed AAC planking system presents a system that is significantly less affected by water and moisture degradation and may be effective in reducing manufactured housing units' susceptibility to flood damage. These systems also are not susceptible to termite attack.
- The savings from reduced transportation damage from greater durability and increased floor system stiffness were not addressed in this investigation. It wouldn't take many days of damage repair (at about $300/person-day for personnel costs related to transportation) to vastly improve the economics of these alternative systems.

Portable Classrooms

Portland, OR; Boise, ID; Marysville, WA

<u>Project Overview</u>

This is primarily a WSU (with subcontractors Oregon and Idaho) and Pacific Northwest National Lab (PNNL) task. Other partners include FSEC, UCFIE, the State Energy Offices of Oregon and Idaho, school districts in Portland, Oregon, in Boise, Idaho and Marysville, Washington, regional utilities, manufacturers, and other stakeholders in the Pacific Northwest.

The objective of this task is to promote the adoption of energy efficient portable classrooms in the Pacific Northwest that provide an enhanced learning environment, high indoor air quality, and both substantial and cost-effective energy savings. BAIHP staff focus on four main goals: (1) offering technical assistance to portable classroom manufacturers, school districts, and related organizations, (2) field assessment, monitoring, and analysis of innovative building technologies and energy saving features to determine their value, (3) facilitation of collaborative agreements among regional utilities, northwestern portable classroom manufacturers and materials and equipment suppliers, as well as school districts, and state education departments and their affiliates, and (4) conducting and creating educational opportunities to advance the widespread adoption of energy efficient portable classrooms in school districts nationwide.

The experiences working on the energy efficient portable were instructive, particularly in the identification of flaws in portable classroom design. The difficulties that BAIHP staff encountered demonstrate the importance of well-defined commissioning protocols, documentation, and coordination among all personnel that service and install HVAC equipment.

Findings:

- Portable classrooms in the Pacific Northwest are occupied about 1225 hours per year, or about 14% of the total hours in a year.
- The average number of occupants in the standard 28' x 32' portable classroom provide an internal heat of about 480 kWh/year, or 8% to10% of space heating requirements.
- Most of the heat loss in portable classrooms manufactured after 1990 occurs by air leaking through the T-Bar dropped ceilings, because they have no sealed air/vapor barrier. This newly created phenomenon occurred with the incorporation of the less expensive dropped T-Bar ceiling in place of the more expensive sheet rock used in older portables. Air leakage also is increased because of unsealed marriage lines - now used as a low cost method of meeting the state attic ventilation requirements.
- Since all portables tested in the project used a simple seven-day programmable thermostat, the HVAC systems operate during vacations and holidays.
- Energy codes in Washington, Oregon, and Idaho are high enough to make beyond-code envelope measures non cost-effective.
- Older portable classrooms under removal consideration could be retrofitted with new energy efficiency measures at much less cost than purchasing a new portable classroom. Installing low-E, vinyl framed windows, insulated doors, T-8 light fixtures, and caulking and sealing air leaks can all be cost-effective when refurbishing older portable classrooms. HVAC system replacement in older portable classrooms will be the biggest single cost item, ranging from $4500 to $6500.
- CO_2 sensors appear to be unreliable as a control strategy. Those installed by field crews and monitored by dataloggers in this study did not match the readings shown by the CO_2 sensors which controlled the ventilation systems.

Based on data analysis from years one through four, the following measures were recommended. New portable classroom procurement, setup, and commissioning as well as existing classroom retrofit guidelines produced by the BAIHP study can all be found in Appendix A.

Recommendations:

- Install 365 day programmable thermostats in all existing portables and specify these thermostats for new construction.

- In portable classrooms constructed with T-Bar dropped ceilings, install an air/vapor barrier above the T-Bar system on the warm side of the insulation. Completely seal all edges and overlaps.
- If roof rafter insulation is used, seal the marriage line at the roof rafter joint with approved sealant such as silicon caulk or foam. Make sure there is adequate ventilation between the insulation and the roof.
- Conduct an audit of older portables scheduled for disposal to determine if retrofitting would be more cost effective than purchasing a new unit.
- Install occupancy sensors to control the ventilation system.
- Specify that new portables contain windows on opposing walls.
- Specify that new portable units contain exhaust fans on the opposite side of the classroom from the fresh air supply.

School Partnerships

Washington Schools - Pinewood Elementary

An 895 ft^2 portable classroom (P5) was sited at the Pinewood Elementary School in Marysville Washington in August 2000. This unit exceeded current Washington State Energy Code standards with upgraded insulation in the floor, roof and walls, low-E windows, and a sensor-driven ventilation system that detects volatile organic compounds (VOCs). A second portable, built in 1985, and also located at Pinewood Elementary (P2), served as the control unit. (*Figure 64)*

Figure 64 *64 Energy efficient portable classroom at Pinewood Elementary School in Marysville, Washington*

Energy use comparisons of the two classrooms show that the energy efficient portable used considerably more energy than the control portable. This was attributable to several factors:

- Incorrect wiring of the exhaust fan, causing it to run continually. The fan was rewired in 2000 during the summer break. Once corrected, energy use in the portable declined.
- Incorrect programmable thermostat settings which were not programmed to turn the heating and cooling system off during holidays and vacations. Though energy use was reduced when the portable was unoccupied, use was still excessive (*Figure 65*).

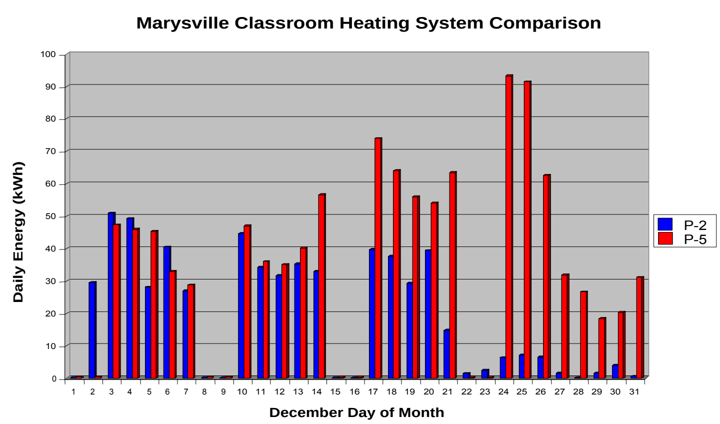


Figure 65 *Graph comparing heating system use of the Pinewood control portable (P2-Blue) with the energy efficient portable (P5-Red). Note the energy efficient portable's high energy use during the Christmas holidays due to incorrectly configured heating system controls.*

- Higher air leakage in the energy efficient portable than the control portable. Blower door testing found 19 ACH at 50 Pa in the energy efficient classroom compared to nine ACH at 50 Pa in the control classroom. Follow-up blower door, smoke stick, and APT pressure tests indicated that the predominant leakage path tracked through the T-bar ceiling and into the vented attic due to an ineffective air barrier in the energy efficient portable. The control portable contains taped ceiling drywall.
- No initial HVAC commissioning by the HVAC supplier or the school district.
- Significant HVAC system alterations (including rewiring, ventilation system VOC sensor replacement with a CO_2 sensor, and modifications to other aspects of the HVAC control system) during 2001 by maintenance staff and the HVAC supplier, unbeknownst to BAIHP staff. Calibration testing done by scientists at the Florida Solar Energy Center on the CO_2 sensors showed significant drift in output results. This made data collected virtually unusable.
- The use of plug-in electric heaters during the winter of 2001 by the resident teacher because of room comfort problems. This led to significant room temperature variations and monitoring data showed high plug-load energy use.

Figure 66 *Ventilation system testing at North Thurston School District.*

- Poor fresh air flow design with the fresh air intake and exhaust fan positioned so they create a "short circuit" of fresh air, bypassing the students and teacher.

BAIHP staff proposed the following recommendations to Pinewood Elementary:

- Well-defined commissioning protocols, documentation, and coordination among all personnel that service and install the HVAC equipment. This is a critical component of efficient and healthy classroom operation and should include outside airflow rate measurements to assess adequate ventilation and control testing to insure correct system operation.
- Design changes to the portable classroom manufacturer, including the use of a structural insulated panel system (SIPS), tighter ceiling barrier and sheetrock ceilings, elimination of the vented attic, and relocation of the exhaust fan to the wall opposite the supply air vent.
- Removal of current HVAC controls and replacement with both an occupancy sensor-driven control for the ventilation system and a heating system programmable thermostat. Staff also proposed a classroom on/off switch to simplify the system turnoff during unoccupied summer and school vacations.
- Location of exhaust fans in future portables on the wall opposite the supply air vent.
- Window installation on opposing sides of the classroom to increase daylight penetration and to assist in passive cross-ventilation.

Based on the above recommendations, WSU researchers worked with Marysville school facility manager and customer representatives from Snohomish Public Utility District to assist them in setting new construction specifications for 13 portable classrooms they will procure during the next reporting period. Marysville School District will specify a completely sealed ceiling barrier, a new model heating/ventilation system, a 365 day programmable thermostat, window placement on opposite sides of the classroom, and exhaust fan placement on an opposite wall from the fresh air supply.

Washington Schools - North Thurston School District
BAIHP staff also worked with the North Thurston School District to troubleshoot a portable classroom in Lacey, Washington. *(Figure 66)* The classroom was experiencing high energy use and poor indoor air quality. BAIHP staff tested the classroom, made recommendations including opening the supply dampers, installing a wall side vent to better ventilate the classroom and discussed the specification development process with district staff. The North Thurston School District now is including most of the measures listed in the new procurement guidelines for their future portable classroom purchases. The school district will investigate the feasibility of installing an air/vapor above the T-bar dropped ceiling and will record costs for making these improvements.

Idaho Schools - Boise School District Retrofit
BAIHP staff located a portable classroom at the West Boise Junior High School in the Boise Idaho School District, occupied by a teacher who was interested in having the classroom monitored and retrofitted. The teacher also is an Idaho State legislator active in education issues, which staff members believe will increase the chances of implementing the final recommendations. (*Figure 67)*

Figure 67 *Weather monitoring system installation in the Boise portable classroom.*

BAIHP staff performed a baseline audit, and installed monitoring equipment to track the classroom's energy use during 2000. In 2001, the classroom was retrofitted with an efficient HVAC system (controlled by CO_2 sensors), lighting, and envelope measures. The classroom was then reaudited, and monitored for the remainder of the year.

BAIHP staff worked with Pacific Northwest National Laboratories (PNNL) on the pre- and post-retrofit audits, and installation of the monitoring equipment. In their capacity of providing energy management services to the school district, the local utility Avista Corporation, collected lighting and occupancy data.

Monitoring data indicates a 58% reduction in energy usage post-retrofit. Blower door tests indicate a reduction in air leakage from nine ACH at 50 Pa to five ACH at 50 Pa. Data also revealed that heating use actually increased on weekends and holidays because of lack of internal heat gain and because the HVAC control systems are not programmed to shut off on weekends and holidays. The total retrofit cost was $9,892.

Monitored data suggests that the CO_2 sensor that controls the HVAC system is not correctly configured. The system does seem to react to an increase in CO_2 levels early in the day, but does not remain on; CO_2 levels only begin to significantly dissipate after one o'clock PM. BAIHP researchers have noted the difficulty of correctly configuring these sensors in other monitored classrooms.

Oregon Schools

Oregon BAIHP staff worked with the Portland Public School District to procure two energy efficient classrooms. These were constructed to BAIHP staff specifications and included increased insulation, high efficiency windows, transom windows for increased daylighting, a high efficiency heat pump, and efficient lighting. Staff videotaped the construction of one classroom.

Monitoring equipment was installed by PNNL staff. Estimates using the software Energy-10 indicated a total energy consumption of 9200 kWh, or $583 per year at Portland energy rates. Measured results showed the Oregon portable used about 6600 kWh for the monitored period.

Incremental costs for the energy efficiency measures were $6,705 over Oregon commercial code, including approximately $2,500 for the HVAC system. This suggests a simple payback of 10 to12 years.

Initial blower door tests found air leakage rates of 11.3 ACH at 50 Pa. BAIHP staff also identified significant leakage through the T-bar dropped ceiling and up through the ridge vents. Other monitoring results indicated that the same HVAC control problems exist with the Oregon classroom as with the others studied in this project.

The Energy Efficient model outperformed code level models in the Portland area. The older the classroom, the more energy consumed. Even when compared with new code level models from the same year, the Energy Efficient model used 35% less energy. Conventional code level classrooms do not include energy efficient measures which greatly increases the unit's operating costs. Classrooms built more than 10 years ago, use twice as much energy as the efficient model. Those older than 20 years consume more than three times the amount of energy. From this study, researches determined that high performance classrooms can save anywhere from $200 to $1000 dollars a year in energy costs compared to older, less efficient portables.

A survey sent to teachers and maintenance staff indicates a high degree of satisfaction with the efficient portables; the teachers were most impressed with the improved indoor air quality and increased light levels due to the daylighting windows.

Historical Data Collection

In Idaho, Oregon, and Washington, BAIHP staff worked with local utilities and school districts to obtain historic energy use data on portable classrooms. This data will be used to compare energy usage from the energy efficient portables monitored in this study.

In Idaho, BAIHP staff worked with Avista Corporation's energy manager to collect historic data on 14 portable classrooms in the Boise School District. The classrooms each were equipped with discrete energy meters; as a result, BAIHP staff was able to obtain energy usage data for the past three to four years. A procedure was developed to collect information on portables at each school in cooperation with the physical facilities manager and each school lead. Historic data collection continues. Site visits and walk-through audits are planned for these 14 buildings. WSU will continue to coordinate with PNNL and FSEC on instrumented data collection on the portable classrooms being monitored in Boise, Idaho, Marysville, Washington, and in Portland, Oregon. WSU will work with Idaho to potentially procure and test one prototype classroom with

SIPS. Evaluate and analyze the collected data and prepare articles for presentation and publications.

Duct Testing Data from Manufactured Housing Factory Visits

Paper: *McIlvaine, Janet, David Beal, Neil Moyer, Dave Chasar, Subrato Chandra. Achieving Airtight Ducts in Manufactured Housing. Report No. FSEC-CR-1323-03.*

Over the past 10 years, researchers at FSEC have worked with the Manufactured Housing industry under the auspices of the U.S. Department of Energy (DOE) funded Energy Efficient Industrialized Housing Program and the Building America (BA) Program (www.buildingamerica.gov). FSEC serves as the prime contractor for DOE's fifth Building America Team: the Building America Industrialized Housing Partnership (BAIHP) which can be found online at: www.baihp.org.

Data and findings presented here were gathered between 1996 and 2003 during 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.

BAIHP and others recommend keeping duct system leakage to the outside ($CFM25_{out}$) equal to or less than 3% of the conditioned floor area, termed Qn_{out}. However, most homes seen in a factory setting cannot be sealed well enough to perform a $CFM25_{out}$ test. Results of many field tests suggest that $CFM25_{out}$ will be roughly 50% of total leakage ($CFM25_{total}$). Thus, to achieve a Qnout of less than 3%, manufacturers should strive for a $CFM25_{total}$ of less than 6% of the conditioned area (Qn_{total}).

Researchers measured total duct leakage and/or duct leakage to the outside in 101 houses representing 190 floors (single wide equals one floor, double wide equals two floors, etc.). Ducts systems observed in these tests were installed either in the attic (ceiling systems) or in the belly (floor systems). Researchers tested 132 floors with mastic sealed duct systems and 58 floors with taped duct systems.

Of the 190 floors tested by BAIHP, the results break down thus:

For mastic sealed systems (n=132):

- Average Qn_{total} = 5.1% (n=124); 85 systems (68%) achieved the $Qn_{total} \leq 6\%$ target.
- Average Qn_{out} = 2.4% (n=86); 73 systems (85%) reached the $Qn_{out} \leq 3\%$ goal.

For taped systems (n=58)

- Average Qn_{total} = 8.2% (n=56); 19 systems (34%) reached the $Qn_{total} \leq 6\%$ target.
- Average Qn_{out} = 5.7% (n=30), more than twice as leaky as the mastic average; 5 systems (17%) reached the $Qn_{out} \leq 3\%$ goal.

The results show that, while it is possible to achieve the BAIHP Qn goals by using tape to seal duct work, it is far easier to meet the goal using mastic. What isn't illustrated by the results is the longevity of a mastic sealed system. The adhesive in tape can't stand up to the surface temperature differences and changes or the material movement at the joints and often fails. Mastic provides a much more durable seal.

Typical factory visits consist of meeting with key personnel at the factory, factory observations, and air tightness testing of duct systems and house shells. A comprehensive trip report is generated reporting observations and test results, and pointing out opportunities for improvement. This is shared with factory personnel, both corporate and locally. Often, a factory is revisited to verify results or assist in the implementation of the recommendations.

The most commonly encountered challenges observed in the factories include:

- Leaky supply and return plenums
- Misalignment of components.
- Free-hand cutting of holes in duct board and sheet metal.
- Insufficient connection area at joints.
- Mastic applied to dirty (sawdust) surfaces.
- Insufficient mastic coverage.
- Mastic applied to some joints and not others.
- Loose strapping on flex duct connections.
- Incomplete tabbing of fittings.
- Improperly applied tape

Duct system recommendations discussed in this report include:

- Set duct tightness target Qn equal to or less than 6% total and 3% to outside.
- Achieve duct tightness by properly applying tapes and sealing joints with mastic
- Accurately cut holes for duct connections
- Fully bend all tabs on collar and boot connections
- Trim and tighten zip ties with a strapping tool
- Provide return air pathways from bedrooms to main living areas

Summary of BAIHP Approach to Achieving Tight Ducts in Manufactured Housing:

- Set goal with factory management of achieving Qnout<=3% using Qntotal<=6% as a surrogate measurement while houses are in production.
- Evaluate current practice by testing a random sample of units
- Report Qntotal and Qnout findings; make recommendations for reaching goals
- Assist with implementation and problem solving as needed
- Evaluate results and make further recommendations until goal is met
- Assist with development of quality control procedures to ensure continued success

Finally, duct tightness goals can be achieved with minimal added cost. Reported costs range from $4 to $8. These costs include in-plant quality control procedures critical to meeting duct tightness goals.

Achieving duct tightness goals provides benefits to multiple stakeholders. Improving duct tightness diminishes uncontrolled air (and moisture) flow, including infiltration of outside air, loss of conditioned air from supply ducts, and introduction of outside air into the mechanical system. Uncontrolled air flow is an invisible and damaging force that can affect the durability of houses, efficiency and life of mechanical equipment, and sometimes occupant health. With improved duct tightness, manufacturers enjoy reduced service claims and higher customer satisfaction, while homeowners pay lower utility bills, breathe cleaner air, and have reduced home maintenance.

Crawl Space Moisture Research for HUD Code Homes
Research led by David Beal
Manufactured Home Merchandiser, July 2005

When BAIHP started to respond to HUD code manufactures' floor damage complaints, the diagnosis often pointed to air distribution system leaks which created negative pressure in the house pulling hot, humid, outside air into air conditioned spaces and unconditioned interstitial spaces such as wall and floor cavities.

Figure 68 *The test units in place. Note white ground cover under unit on left, exposed dirt under unit on right.*

In some cases this led to condensation and rot. From this research and the resultant recommendations, HUD Code Home manufactures have learned to prevent such occurrences and have dramatically improved distribution system air tightness practically eliminating such problems For background on this matter, see these sections of this report:

- *Building Science and Moisture Problems in Manufactured Housing*
- *BAIHP Field Visits to Moisture Problem Homes*
- *Manufacturers Participating in Building Science Research*
- *Duct Testing Data from Manufactured Housing Factory Visits*

Successfully sealing HUD code home crawlspaces may be the last piece of the solution for preventing floor failures plaguing homes in hot, humid climates. Merely curing the duct leakage has proven not to enough to keep all floors intact. Proper techniques to seal these crawlspaces need to be developed. The research reported here and BAIHP's research plan for 2005 addresses this need.

Field Experience

BAIHP researchers have observed that some houses with rotting floors have acceptably tight ductwork, suggesting that factors other than distribution system dynamics are influencing moisture flow. The rot manifests primarily under vinyl flooring which acts a vapor barrier between the conditioned space and floor substrate, which suggests an external source of moisture. BAIHP researchers further observed that the crawlspaces in these homes are damp and musty, often showing signs of standing or running water in the crawlspace.

FSEC concluded that the only uncontrolled moisture source is the humid air in the crawl space of the home driven by vapor pressure toward the cool conditioned space. Several manufacturers address this potential moisture source by requiring a vapor retarder to be placed over the dirt in the crawl space prior to the installation of the house. However, a further exacerbation of the problem stems from the current trend toward extending the siding of the house all the way down to the grade level, in place of the traditional vented skirting. This tends to reduce ventilation, the primary mechanism for dissipating moisture leaching from the ground into the crawls

Other researchers (www.crawlspaces.org) have reported on sealed crawl spaces, and recommended them as a solution to the crawl space moisture problem. The findings from those studies indicate that merely covering the ground without truly sealing the crawl space is not sufficient to solve the problem of high crawl space humidity. The joints and penetrations in the crawl space must be seal to prevent air infiltration as well.

To determine if sealed crawl space solution could be achieved in HUD Code Homes, research needed to be done to address the unique building techniques in that industry, namely the use of vinyl skirting to enclose the crawl space. To that end, in 2004, BAIHP conducted research utilizing two single-wide manufactured houses at FSEC's auxiliary test site in Cocoa, FL.

The crawl space research plan involved two unconditioned, singlewide manufactured homes sited side-by-side, one home with a ground cover under it, the other without a ground cover (only exposed dirt.). A third identical home was available, however, it was not called into use in this experiment. In each of the two experiment houses, three different skirting (crawl space enclosure) options were evaluated: open or no skirting, perforated skirting, and solid skirting. The solid skirting mimics the effect achieved by extending siding down to the ground instead of stopping it at the band joist, described above. Additional evaluations were planned, however, the Florida's four hurricanes dramatically curtailed the testing schedule.

The homes (all three) were instrumented with temperature and humidity sensors, two in the crawl space and one in the interior. The site has a weather station, recording ambient conditions. The temperature and relative humidity was used to calculate the dewpoint at the measurement location.

Data Analysis, Interpretation, and Conclusions

The presented data is the ambient dewpoint, the dewpoint of the two crawl spaces. The ambient readings are subtracted from the average of the two crawl space readings to show the temperature difference or)T. The final column of the table ("Difference") is the difference between the ground cover and the non-ground cover crawl space, showing how much dryer a crawl space with a ground cover is; negative numbers indicating that the ground covered crawl space was dryer.

Table 40 Dewpoint Temperatures

	Ambient Dewpoint	Dewpoint with Ground Cover	)T T_{amb}-T_{cwl}	Dewpoint with No Ground Cover	)T T_{amb}-T_{cwl}	Difference
No Skirting 06/09 – 07/08	73.3^0F	73.3^0F	0.0^0F	73.3^0F	0.0^0F	0.0^0F
Perforated Skirting 07/18 – 07/30	73.5^0F	73.7^0F	0.2^0F	75.4^0F	1.9^0F	-1.7^0F
Solid Skirting 08/23 – 09/03	74.3^0F	76.3^0F	2.0^0F	78.6^0F	4.3^0F	-2.3^0F

This data clearly illustrate a potential problem for manufactured houses, or any home on a crawl space. As can be seen, the average crawlspace dewpoint with skirting and no ground cover was over 75^0F. Both crawlspaces with solid skirting were above 76^0F. Any surface in the crawl space that is at or below the dewpoint will condense moisture. Surfaces that could be problematic are exposed floors, A/C ductwork, and plumbing. Also, note that these numbers are averages gathered over at least one week of measurements. The maximums are much higher in all cases, but of a short duration.

The research shows that if a ground cover and perforated skirting are used, the dewpoint in the crawl space will stay near the ambient dewpoint, on average. Often, this is sufficient to avoid problems in homes with crawl spaces. However, if overly cool conditions are maintained in the house (interior temperatures below the ambient dewpoint), problems can still occur.

Research (www.crawlspaces.org) into site built housing with block stem walls has shown that unvented crawlspaces with a ground cover are significantly dryer than vented crawlspaces if they start out as a dry crawlspace or provisions were made to dry them out after completion, such as a dehumidifier or supply air provided to the space. However, the BAIHP data from the "solid skirting and a ground cover" condition do not support this conclusion.

The conclusion is that the solid skirting did not create an adequate seal of the crawl space, allowing significant moisture into the crawlspace. Suspected entry paths for the moisture intrusion were along the joint behind the skirting starter strip, as well as under the molding used to hold the skirting in place at the ground.

HUD code homes (and older site built homes) placed on piers and skirted pose unique challenges to executing the sealed crawl spaces detail. To overcome the air infiltration points associated with skirting described above (at the top and bottom of the skirting) a continuous vapor barrier is needed from the band joist down to and covering the ground. This however would interfere with visual inspect for termite mud tunnels, possibly voiding the termite protection company's bond. The problem is overcome in crawlspaces with a block walls by stopping the vapor barrier a few inches below the band joist, to allow for inspection.

<u>Planned Research for Summer of 2005</u>

To further research into finding a successful way to seal the crawlspaces of HUD code housing, BAIHP installed a vapor retarder in our on-site, well instrumented, manufactured housing laboratory (MHLab) in March of 2005. The experiment will investigate ways to allow for insect inspection, as well as sealing around penetrations such as piers, anchors, plumbing, and A/C duct work (to package units). The research will also address ways to dry the crawlspace, both from ambient moisture and potential flood problems. This may include a dedicated sump pump and dehumidifier, or the house's own A/C system.

Air tightness testing of the "sealed" crawl space showed that although the crawl space is much tighter than that provided by solid skirting, it is still too leaky. Further attempts will be made to seal the crawl space by June 2005. When the space is sealed satisfactorily, conditioned air from the house will be introduced into the crawl space and its affect on the humidity level will be monitored.

This BAIHP research has been accepted by the trade journal "Manufactured Home Merchandiser" in an effort to get the information to the people in the manufactured home industry that can alter installation requirements. The anticipated publication date is the July 2005 issue.

B. Site Built Housing Research

BAIHP continues to foster the research the implementation of the systems engineering approach with site builders which includes the incorporation of multiple concepts toward achieving the Building America program goals of saving 40% of total energy use while improving durability, indoor air quality, and comfort. Industry Partners in this area of BAIHP rise above "business as usual" production to strive toward this goal. BAIHP assists the builders, much as described in Section II, Technical Assistance, but goes on to instrument and collect relevant data from the house in an effort to validate the approach taken by the builder and add to our knowledge base of how to achieve the Building America goals.

BAIHP conducted research for site built housing which is reported in the following summaries:

- Building America Prototype, Cambridge Homes
- Unvented Attic Study, Rey Homes
- Sharpless Construction, Hoak Residence Energy and Moisture Studies
- Eastern Dakota Housing Alliance (EDHA), Applegren Construction
- Zero Energy Affordable Housing, ORNL and Loudon County Habitat for Humanity
- Hurricane Retrofit Research

Building America Prototype, Cambridge Homes
Orlando, Florida
Category B
Research led by BAIHP Researcher Eric Martin

The partnership between BAIHP and production builder Cambridge Homes began late in 2001. Cambridge Homes had recently signed on with the EPA Energy Star Homes Program as a 100% Energy Star builder and expressed interest in increasing energy efficiency even further, as well as adding some "healthy home" features to their product. Also, Cambridge Homes expressed interest in BAIHP helping them design and build in a way that would prevent moisture related problems and call backs.
BAIHP began by conducting analysis on several typical home designs and presenting results and strategies in a number of meetings with the builder. BAIHP also arranged a special meeting with the American Lung Association of Central Florida to discuss achieving the ALA Health House designation on the showcase model. However, the builder decided not to pursue the health house designation at that time.

Figure 69 *The Augusta, Cambridge Homes Building America Prototype.*

To implement Building America strategies outlined by FSEC researchers, Cambridge Homes constructed a "prototype house" (*Figure 69*) to ensure that the strategies mate well with their current building practices (*Table 41*). A variety of home plans were reviewed to select an appropriate demonstration home, as well as a standard-practice counterpart. During construction, both homes were outfitted with dataloggers and associated monitoring equipment.

The homes were built in Baldwin Park, a new Orlando subdivision being developed on land that was once home to the Orlando Naval Training Center. The development will be 30% larger than New York's Central Park, totaling approximately 1100 acres. Four hundred acres have been set aside for parks and open space, while 700 acres will be used for the construction of 3,000 homes, one million square feet of office space, and 200,000 square feet of retail space. Cambridge Homes is one of ten builders constructing homes in the community and plans to build 700 homes in Baldwin Park over the next five years.

Table 41 Cambridge Homes Specifications

Component	Base Case (Covington)	Prototype (Augusta)
Conditioned Area	2446 ft2	2672 ft2
Envelope		
Above-Grade Wall Structure	CMU first floor 2X4 Frame second floor	Same
Above-Grade Wall Insulation	R-3.5 rigid foam R-13 Fiberglass Batt	R-3.5 rigid foam R-13
Above-Grade Wall	OSB	Same

Table 41 Cambridge Homes Specifications

Sheathing		
Attic	Vented r-30 batt	Unvented r-19 Icynene
Roof	Owens corning shingle	Elk architectural shingle
Windows	Single pane, clear Metal frame	Double pane, low-e Metal frame
Infiltration (ACH50)	Not tested by FSEC	3.0
Equipment		
# Of Systems	2	1
Heating	Heat pump HSPF = 8.65	Same
Cooling	2.5 ton, 13 SEER 2 ton, 13 SEER	5 ton, 13 SEER
Thermostat	Programmable Standard	Programmable
Ventilation	None	Thermastor Ultra-Aire
Water Heater	50gallon Electric EF 0.88	Same
Lighting	10% fluorescent	100% fluorescent
Appliances	Standard	Energy Star
Hers Score	87	87.6

The demonstration home gave the builder firsthand experience with unfamiliar design elements, some of which have been incorporated into their standard practices. Such unfamiliar design elements included vapor permeable wall insulation, low-e windows, whole house dehumidifiers, unvented attics, and compact fluorescent lighting. FSEC researchers closely monitored the construction of the prototype and standard practice home, which was built to the Energy Star level. A duct test was performed in the prototype house during mechanical rough in to ensure leakage specs were met. Meetings also were held with the builder's HVAC contractor to discuss installation of the whole-house high efficiency dehumidification, filtration, and ventilation unit in the prototype model.

Upon completion of the home, duct testing was repeated to include inspection of the whole house dehumidification unit, and infrared camera analysis was conducted on the home. Data (*Figures 70 and 71*) collected from the two homes showed marked improvement in attic temperature (a primary cooling load) and indoor relative humidity control.

BAIHP performed training for Cambridge Homes' sales staff in March 2003. The training took place within the completed “prototype” model. Training focused on the advanced features of the Building America showcase model which Cambridge Homes began offering in April 2003.

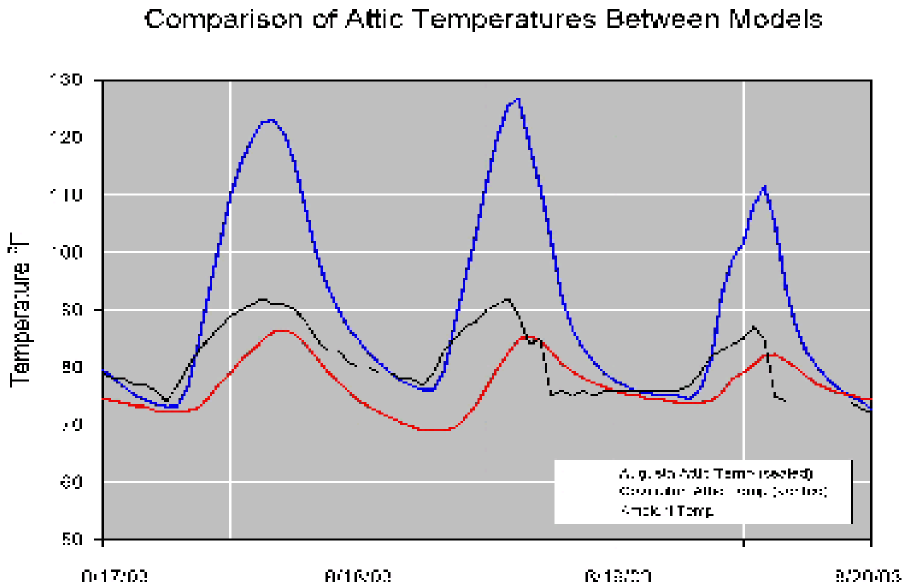


Figure 70 Comparison of attic temperatures between Cambridge Homes BA Prototype (Augusta) and Standard Cambridge Homes construction (Covington). Graph shows how sealed attic construction in Augusta results in lower attic temperatures than vented attic

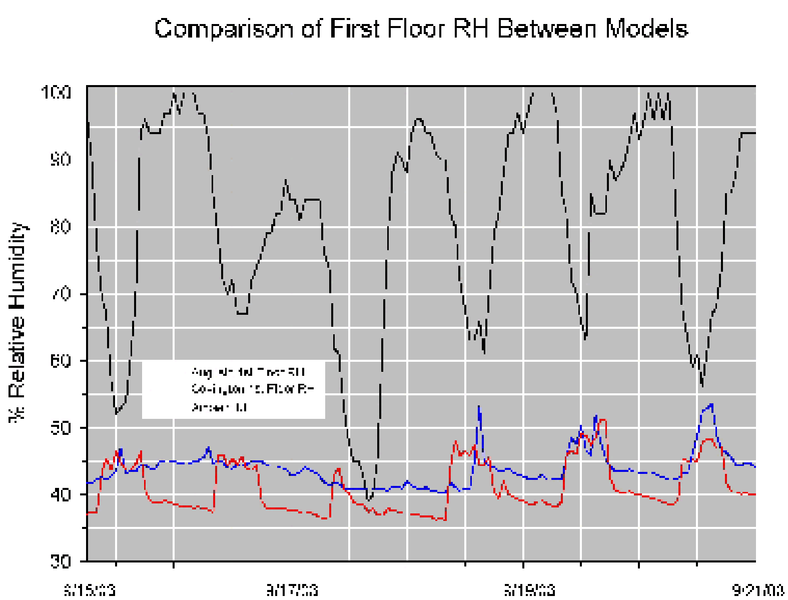


Figure 71 *BA Prototype (Augusta) contains whole house dehumidification system. Plot shows daily cycling of the system resulting in a lower relative humidity in the prototype home than in the standard Cambridge Homes construction.*

Late in 2003, Cambridge Homes began construction of a second home similar to the “prototype” model, which was purchased by a customer impressed with its attributes. FSEC staff conducted training for builder and sales staff in December 2003 to review design methodologies and lessons learned from the prototype model. A second meeting was held in January 2004 inspect progress of the home. Upon moving into the home, Cambridge Homes reports that the new homeowner is extremely happy with the home.

To assist Cambridge Homes with reducing callbacks and moisture reduction problems, FSEC researchers have also conducted “total” and to “out” duct tests on six other Cambridge homes to determine why the total duct leakage numbers were high (>10% of fan flow) despite low to “out” duct leakage. “Out” is defined as outside the conditioned space, including buffer spaces like an attic or garage. Consistent leakage was found around the boot to register grill connections. FSEC worked with Cambridge Homes and their HVAC contractor, DEL-AIR, to specify air tight register grills.

In May 2004 additional instrumentation was installed in the prototype and base case homes to collect more detailed data on the different attic designs of the two instrumented homes (unvented vs. vented). Data collection continued until October 2004, and data is currently being analyzed.

Unvented Attic Study, Rey Homes
Orlando, Florida
Technical Assistance by BAIHP Researchers Eric Martin and Neil Moyer

Rey Homes, a production builder in Orlando, in 2001 pledged to build a community of 200 homes that meet both Energy Star standards (HERS = 86) and the Florida Green Home Designation Standard. Rey’s partnership with FSEC began in October 2001 when researchers analyzed Rey’s standard home designs and construction and made recommendations for complying with these standards.

In the fourth budget period, Rey built 2 homes in their Villa Sol community for side by side comparison of unvented attic construction, a BAIHP recommended strategy. FSEC installed monitoring equipment in both homes, one with an unvented attic and one with a standard vented attic including a set of moisture pins in each house to monitor the moisture content of roof trusses in addition to the usual complement of temperature, humidity, and energy use meters. Instrumentation was complete early in the fifth budget period; however, data collection was not successful due to equipment and site complications. Monitoring equipment was removed during the sixth budget period and relocated to an active monitoring project.

Sharpless Construction, Hoak Residence Energy and Moisture Studies
Longwood, Florida
Category A
Technical Assistance led by BAIHP Researchers Subrato Chandra and Dave Chasar

This three-story, 4,250 square foot home was completed in February 2001 by Mr. David Hoak and Sharpless Construction in Longwood, Florida near Orlando. (*Figure 72*) FSEC assisted the owner and builder by recommending a package of features that produced an exceptionally energy efficient design at a reasonable cost. Because the building envelope design and mechanical equipment selection work together as a system, the home can be cooled with a much smaller air conditioner than is needed by most homes of this size in this climate.

Figure 72 *Hoak residence in Longwood, Florida.*

Envelope Features:

High Performance Windows

Roughly 25% of the annual cooling load in a typical Central Florida home is introduced through the windows. Recent advances in window technology allow this load to be greatly reduced. The windows in this residence are particularly useful in Florida because they have a very low Solar Heat Gain Coefficient (SHGC) to reduce direct solar gains, and a relatively high Visible Transmittance (VT) for natural daylighting.

Unvented Attic

Most Florida homes have vented attics with batt or blown insulation applied just above the ceiling. This exposes the air conditioning ductwork to very high temperatures and magnifies duct leakage problems. Sealing the attic envelope and insulating at the roof deck, as shown in *Figure 73*, provided a semi-conditioned space for the ductwork. This reduced conductive heat gain and minimized the detrimental impact of duct leakage.

Figure 73 *semi-conditioned space for the ductwork.*

Expanding Foam Insulation

A layer of expanding foam insulation *(Figure 73)* was applied to the underside of the roof deck to create an unvented, semi-conditioned attic (R-22). The same insulation was applied to all above-grade walls (R-11). While the insulation R-values were standard, the foam created a nearly airtight seal and greatly reduced outside air infiltration.

Continuous Air Barrier
Infiltration of Florida's hot and humid outside air can have a big impact on energy use, building durability, and occupant health. The continuous air barrier, placed toward the outside of the building envelope, reduces this infiltration. Indoor air quality concerns were addressed by installing an energy recovery ventilator to introduce outside air.

The air barrier consists of a tightly taped housewrap installed over the exterior sheathing on all above-grade frame walls, and extruded polyurethane foam boards glued to the interior of the below-grade block walls. Expanding foam insulation provided an extra measure of airtightness at all above-grade exterior surfaces including the roof deck. Special care was taken to seal wall details such as corners, floor interfaces, and the roof junction. Blower door performance tests verified the home's level of airtightness (ACH50 = 2.0).

<u>Equipment Features:</u>
2-Speed, Zoned Heat Pump
The building envelope design features described above greatly reduced the required air conditioner size. Manual-J HVAC equipment-sizing calculations showed the need for only 2½ tons of heating and cooling capacity. In this case the owner opted for a two-speed compressor, which provides either 2½ or 5 tons of cooling or heating depending on the need.

The Hoak home air conditioning unit typically operated in the 2½-ton mode until the late afternoon when it switched to the 5-ton mode for a few brief periods. In this home, energy use stays low because the low compressor speed operates the majority of the time. But, when quick cool-down or excessive loads require more capacity, the high speed compressor can meet the need.

Figure 74 *Heat pump water heater*

Measured data indicated that the 5-ton mode operated about one in every four days during the three hottest summer months (June to August), usually for periods of 15 minutes or less. Even these short periods of high-speed compressor operation might have been avoided with proper use of a programmable thermostat. These results verify the Manual J sizing calculations and indicate that if a single speed HVAC system were installed, the optimum size would be 2½ to 3 tons.

Variable-speed Air Handler
Two benefits of using a variable-speed motor for air distribution are better moisture removal and energy efficiency. During the cooling season, slower airflow across a cold coil allows for more moisture removal. Wintertime comfort also is enhanced with this operation, since the coil has more time to warm before the air is brought to full flow.

Indoor relative humidity tends to increase during the fall and winter months when air conditioning activity declines. Without a dedicated dehumidifier, the air conditioner is the only means of reducing indoor relative humidity. When there is a call for cooling - the low-speed compressor in a variable speed system operates more consistently than a larger system and keeps relative humidity from rising to unhealthy levels.

Heat Pump Water Heater
Solar water heating would have been the first choice for this home, but poor orientation and too many shade trees forced a search for other options. (*Figure 72*) Natural gas also was unavailable in the area. To avoid the inefficiency of electric resistance water heating, a 6,000 BTU/hour heat pump water heater (*Figure 74*). Heat pump water heater produced all the hot water needs for a four-person household from April to September.

The water heater was connected to a standard 80-gallon electric water heater. By locating the heat pump inside the home, homeowners gained a summertime benefit of additional cooling and year 'round dehumidification because the system removes moisture each time it operates.

Energy Recovery Ventilator
The energy recovery ventilator acts as a conduit to flush out stale indoor air and replace it with outdoor air. As the indoor air is expelled, a heat exchanger recovers up to 80% of the energy used to heat or cool the air and transfers it to the incoming air stream. This unit also transfers a portion of the moisture between the airstreams, which is useful during periods of high outdoor humidity.

Airtight Ducts
Attic and duct heat gain contribute to about 22% of the cooling needs of a typical Central Florida home when are ducts located in a vented attic above the insulation. While some home efficiency is lost by direct heat-gain through the duct insulation, a great deal more efficiency can be lost from unintended duct leakage from the ductwork into the vented attic. Duct leakage test results showed only 50 CFM of air was lost at 25 Pa of pressure differential in the Hoak residence. This leakage equates to 1.2% leakage per square foot of conditioned floor area - far below the leakage normally found in new Florida homes.

<u>Energy Monitoring:</u>
Monitors on the Hoak residence include 11 attic temperature and relative humidity sensors, three indoor sensors, a Hobo event logger to record the dehumidifier cycling time, and a tipping bucket rain gauge with Hobo logger to monitor the combined condensate of the air conditioner, dehumidifier, and heat pump water heater. In 2002, Alten Design also assembled a new logger monitoring computer with the capability of reading data from two Campbell 21X loggers. This computer was configured with remote monitoring and control capacity so that Partners can program and maintain the system without traveling to the site.

<u>Findings</u>
Duct Leakage
Duct leakage test results showed the Hoak home air loss was only 50 CFM at 25 Pa or 1.2% leakage per square foot of conditioned floor area – far below the amount of leakage normally found in new Florida homes.

Total duct leakage is less than 10% of air handler flow (200 CFM). Blower door performance tests verified the home's level of airtightness at two air changes per hour at 50 Pa (ACH50 = 2.0). When including leakage around the supply grills, house leakage increased about 30%. Slightly more than half of the house leakage (1479 CFM at 50 Pa) is located in the sealed attic space (760 CFM at 50 Pa).

Cooling Energy
Initial data comparisons were made against data collected from a Lakeland, Florida residence (PVRes), designed by FSEC and monitored for more than a year. The PVRes home contained the most energy-efficient provisions researchers could devise, including a 5 kW photovoltaic system. Data collected at the Hoak home shows the cooling energy is nearly on par with the PVRes Home on a per square foot basis.

Envelope
Weekly data logs of the Hoak home provided by Alten Design from the 14 Hobo temperature and relative humidity sensors and pressure tests through March 2003, confirm that air pathways between the unvented attic and outdoors still exist. Researchers suspect that these pathways may be the primary source of moisture intrusion into the unvented attic space. Several whole house pressure tests (smoke tests) were performed by Alten Design and FSEC to isolate these external sources of air infiltration. Identified leaks were sealed, though actions have shown some benefit moisture levels are still higher than desired.

In order to isolate areas of leakage, barriers will be placed in the house splitting the areas under test into easier to monitor individual zones.

New Features in 6th Budget Period
An EnergyViewer to monitor whole house power use and the ERV control was modified to respond in tandem with bathroom vents. The ERV runs for a 15 min period of time. Also, new anticipating thermostats by Honeywell were installed.

Eastern Dakota Housing Alliance (EDHA), Applegren Construction
Grand Forks, North Dakota
Category A, 10 Homes
Category B, 13 Homes
Technical Support by BAIHP Researcher, Dave Chasar
Awards: *North Dakota Housing Finance Agency's Champion of Affordable Housing Production Award*
Paper: *Chasar, D., Moyer, N., Chandra, S., Rotvold, L., Applegren, R., "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.*

The Eastern Dakota Housing Alliance plans to build 20 multi-family and single-family dwellings on Selkirk Circle in Grand Forks, North Dakota. Twelve homes have been completed to date and four more are currently under construction.

Table 42 Completed Selkirk Homes

	Phase I	Phase II	Phase III
Number of Homes	4	4	4
Completion Date	Mar-03	Jan-04	Aug-04
HERS range	88 – 90	92.5	88 – 89.5
BA Benchmark range	25 – 30%	40%	TBD

Four Phase I units completed in March of 2003 had HERS ratings between 88 and 90 with whole-house savings of 25 to 30% against the Building America benchmark. Four Phase II units completed in January 2004 had HERS of about 92.5 and whole-house savings of 40%. The Phase II efficiency boost comes from the addition of a whole-house tankless gas water heater and R10 sheathing on exterior walls. Lower HERS scores (88.3 – 89.5) on the Phase III units was primarily due to electric resistance water heating and higher overall duct and envelope leakage. All units have ventilation air brought to the air handler return plenum with 10 of 12 units utilizing heat recovery ventilators (HRVs).

Phase III Testing

A new floor plan was used on the Phase III homes featuring a split level design instead of a full, below grade basement and attached rather than detached garages. Another major difference between these units and previous designs was the location of the air handler in a utility room that opens into the garage. As with previously tested homes, total leakage was very high and concentrated mostly on the return side where duct pathways were partially constructed from building cavity spaces. Duct leakage to out, which was nearly zero in previously tested homes, was substantially higher in the Phase III units. Duct tester results showed that the ratio of duct leakage to out (at 25 Pascals) to conditioned floor area (or Qn) ranged from 0.05 to 0.09. As with previous phases, all Phase III units had high efficiency, sealed combustion gas furnaces.

Figure 75 *Two completed Phase III units (Dec 2004)*

Table 43 Selkirk Split-level Twin Home Specifications – Phase III

Conditioned Area	1850 sq. ft. (including basement)
Above-grade Walls	Wood Frame (R15+R10 sheath)
Sub-grade Basement Walls	R22 Insulated Concrete Forms
Ventilated Attic	R-49
IG Vinyl Windows	U-0.34, SHGC-0.33
Sealed Combust. Gas Furnace	60kBtu, AFUE-92.6
Strait-cool AC	2-ton, 10 SEER
50 Gal Electric Water Heater	EF 0.86
Thermostat	Programmable
Lighting	85% Fluorescent
Ventilation	70% HRV

Each Phase III unit was tested individually for envelope tightness. Leakage was higher overall compared to Phases I and II, but this was expected due to the greater exterior surface area created by the attached garage design.

Table 44 HERS Scores and Envelope Leakage Test Results

Unit	HERS	CFM50	ACH50	ACH	C	n	R
1002	89.5	779	3.12	0.11	22.7	0.90	0.98
1010	88.3	970	3.85	0.32	100.4	0.58	0.97
1018	89.0	999	4.00	0.24	64.2	0.70	0.99
1026	89.1	783	3.14	0.16	38.9	0.77	0.99
Notes: - ACH50 calculation includes area of conditioned basement							

Discussion on Next Set of Homes

Four Phase IV homes are currently under construction utilizing the same floor plan and envelope design as Phase III. Plans include the use of high efficiency gas water heaters (probably tankless) and a central return duct system designed to reduce duct leakage (both total and to out). Return air relief for bedrooms will be incorporated into hallway walls with either a high-low grill system or pass-through grills with sound and light baffles. Plans also include relocating air handlers within the conditioned space instead of in a room attached to the garage. This should substantially reduce duct leakage to out.

Recommendations include:

- Central return located near thermostat in center of home
- Sealed ductwork from central return to air handler
- Avoid use of building cavities as air pathways

Building Science Issues:

- Combining space heating and hot water with a central gas boiler. Since air conditioning is still a requirement, an air handler with an hydronic heating coil will be required.\
- If only 2 of 4 units are fitted with a combined system it offers the opportunity to compare the efficiency of this system over another unit with separate space and water heating through monitoring.
- David Duly of Pilkington glass has offered to work with FSEC to determine the benefit of high solar gain glass which could provide substantial savings on space heating. Window orientation and shading are important factors that may work favorably with the remaining south-facing home sites on Selkirk Circle.

Figure 76 *East side of Selkirk Circle, Phases III & IV*

BAIHP will be conducting Building America benchmarking analysis of these homes and producing Energy Star ratings of the four Phase III homes as well as the Phase IV units upon completion in spring/summer of 2005.

Zero Energy Affordable Housing, ORNL and Loudon County Habitat for Humanity
Lenoir City, Tennessee
Category A
Research by ORNL with BAIHP Support

In partnership with Oak Ridge, BAIHP has instrumented two a zero energy homes (ZEH) built by Loudon County (TN) HFH in partnership with Oak Ridge National Laboratory. *(Figure 77)* See description in the *Technical Assistance* section of this report under *Habitat for Humanity, Tennessee, Loudon County.*

Figure 77 *Local sponsors in front of 2nd ZEH built by Loudon County HFH in partnership with ORNL. FSEC provided monitoring for the 1st and 4th ZEHs.*

Data is available on-line at www.infomonitors.com. A paper on the study was submitted to the Buildings IX conference by Jeff Christian (ORNL) and David Beal (BAIHP-FSEC).

Federation of American Scientists' Rasbach Provident Home

BAIHP is assisting FAS and builder Joe Ecrette with envelope and mechanical system design on this home built with cementitious faced SIP panels. The home serves as a demonstration of an affordable, efficient home that is also well-suited for areas prone to seismic disturbance. A preliminary HERS score of 89 is estimated.

BAIHP will provide data monitoring design assistance, equipment and installation to document energy savings. Data collection, processing and archiving will be provided through FSEC's Infomonitors service, online at www.infomonitors.com.

Hurricane Retrofit Research

Many homes in east central Florida suffered serious damages in 2004 as a result of the hurricanes. We have identified four families who would be willing partners for a U.S. DOE funded project to showcase cost effective energy efficient retrofits. All homes are within 30 miles of FSEC and none are "luxury" homes.

All four homes have undergone a pre retrofit analysis and testing to determine the current energy usage profile and expected energy savings, enhanced comfort, indoor air quality and related benefits. Pre retrofit tests included blower door, duct blaster, pressure mapping and air conditioner system performance measurement. In addition, lighting and water heater and other opportunities will be assessed. All homes will be analyzed by the Energy Gauge USA software to quantify the expected energy savings. Pre and post utility bills will be documented for all homes. The owners have agreed to keep track of the costs and share them publicly.

Post retrofit, Energy Gauge USA analysis will be conducted on all homes and energy savings computed relative to the Building America benchmark. This will require blower door and duct testing of the home post retrofit. A one to two page case study will be prepared for all four homes. Some homes will be monitored in more detail to examine key performance areas. The four homes offer a range of retrofit options and will provide good data on the costs and benefits of effective retrofit strategies in hot-humid climates.

Apartment Ventilation and Humidity Study with Sandspur Housing
Gainesville, Florida

In April and May of 2003, four of 111 newly built apartments at the Brookside Apartment Complex were evaluated for potential moisture problems. Characteristics of the four apartments are summarized in *Table XX1.* The ventilation strategy introduced untempreed outside air to the return side of a central air handler.

Table XX1 Apartment Characteristics						
Apt ID	Floor	Occupants	RH Control	Outside Air Flow	Infiltration (ACH50)	Thermostat Setting
1	1st	1	AC only	25cfm	2.8	Variable
2	2nd	2	AC only	17cfm	2.5	Variable
3	2nd	0	AC only	27cfm	3.2	76º
4	1st	0	AC only	28cfm	3.9	76º

Sensors were installed in four apartments that monitored Temperature and RH in three locations: the air handler cabinet, the kitchen, and the master bedroom closet. The readings from *Apartment 2* were within recommended guidelines in all living spaces monitored, with no changes recommended.

Table XX2 Apartment Results				
	Kitchen		MB CLoset	
Apt ID	Temp Av.	RH Av.	Temp Av.	RH Av.
1	71.9º	54.3%	71.7º	62.0%
2	76.0º	47.6%	76.9 º	53.5%
3	*Invalid data (See Figure XX3)*		N/A	N/A
4	71.4º	50.2	N/A	N/A
Note: Data from the AirHandler senors were similar for all four apartments (reflecting the extremes expected in this locations with RH as high as 90% and 100%), and was not pertinent to the living space temperature and RH.				

The temperature in *Apartment 1* was lower than Apartment 2, the other occupied unit. The readings were within the acceptable level for comfort and mold control, but because the air conditioner ran longer, it also had a longer period to remove moisture. Inspection found that the windows were opened about 1 1/2". When the occupant (the maintenance man for the complex) was asked why, he indicated that it was being done for "health purposes".

The master bedroom closet reflected the lower temperatures of the kitchen but with a slightly higher RH level. The higher RH level in this space was likely due to the closet door being closed which would slow the passage of the dryer kitchen air into the closet space.

The remaining apartments tested varied a large amount over the period of test. *Apartment 4* had wide swings in temperature readings. With no significant period of time in which the temperature was stable, it is assumed that the AC was not running properly in this unit. *Apartment 3* is notable because this unit was vacant and its temperature should have stayed stable within three degrees. The good RH levels were likely due to the longer Air Conditioner run times required to maintain the low temperature.

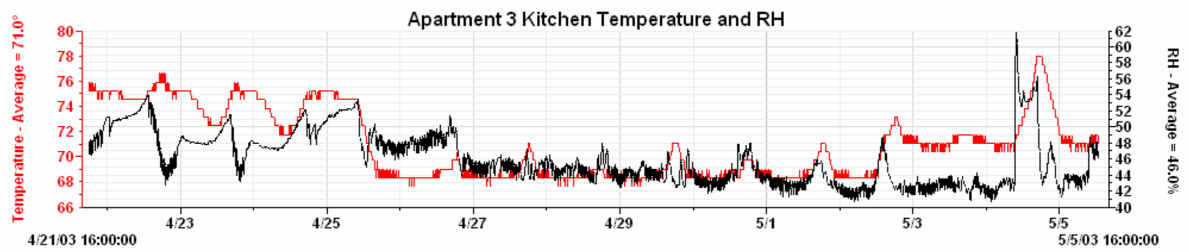


Figure XX3   *Apartment 3 Kitchen Temperature and RH*

Outside Temperature and RH: The test period was during the beginning of Florida summer temperature and RH trends. Daytime high temperatures reach into the low 90's with associated high RH levels in the afternoon. These cycles are reflected in the data collected, the most obvious of these being the apartment 2 closet *(Figure XX5)* where daily outdoor temperature peaks mimic those of the indoor temperature peaks.

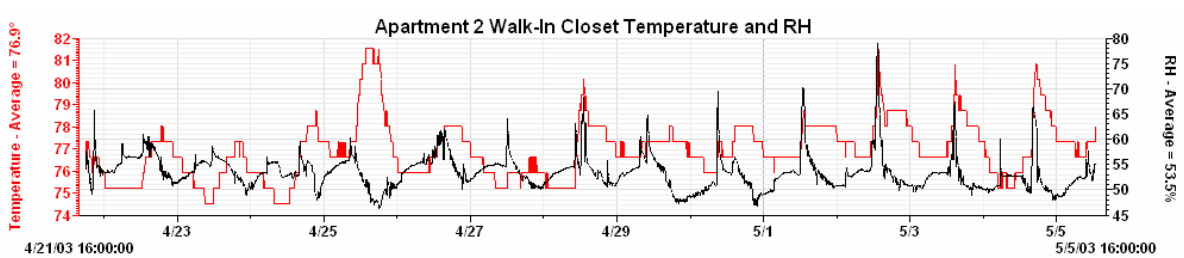


Figure XX5 *Apartment 2 Walk-In Closet Temperature and RH*

Final observations: If all of the apartments have similar characteristics to those of Apartment 1 and Apartment 2, then no changes to lower interior RH levels are required at this time. RH level averages are well within the acceptable range – even in spaces where RH levels tend to get rather high (i.e. – closet) validating, at least preliminary the adequacy of the design principle of using outside ventilation air as has been implemented in these units.

Recommendations

- Educate those involved in the care and maintenance of apartment complexes in basic principles of building science.
- In future apartments locate a supply register in the closet to provide better humidity control for this area.
- Check Apartment 3 & 4 equipment for proper operation, and calibration of thermostat.

C. Field and Laboratory Building Science Research

BAIHP builds on a 20 year foundation of basic building science research at the Florida Solar Energy Center. This research generally focuses on issues important in hot-humid climates similar to Florida's but is relevant to our understanding of building science concepts manifest in all climatic regions. BAIHP has conducted field and laboratory building science research in these areas:

- Air Handler Air Tightness Study
- Air Conditioning Condenser Fan Efficiency
- Fenestration Research
- Reflective Roofing Research
- Return Air Pathway Study
- Heat Pump Water Heater Evaluation
- NightCool - Building Integrated Cooling System
- Ventialtion and Humidity Research, Sandspur Housing

Air Handler Air Tightness Study
Central Florida
Research by FSEC Researchers Chuck Withers, Jim Cummings, and Janet McIlvaine

To determine the impact of air handler location on heating and cooling energy use, researchers measured the amount of air leakage in air handler cabinets, and between the air handler cabinet and the return and supply plenums. To assess this leakage, testing was performed on 69 air conditioning systems. Thirty systems were tested in the 2001 and 39 in 2002. The 69 systems were tested in 63 Florida houses (in six cases, two air handlers were tested in a single house) located in seven counties across the state - four in Leon County in or near Tallahassee, 17 in Polk County, three in Lake County, 13 in Orange County, one in Osceola County, two in Sumter County, and 29 in Brevard County. All except those in Leon County are located in central Florida. Construction on all houses was completed after January 1, 2001, and most homes were tested within four months of occupancy.

In each case, air leakage (Q_{25}) at the air handler and two adjacent connections was measured. Q_{25} is the amount of air leakage which occurs when the ductwork or air handler is placed under 25 Pa of pressure with respect to its surrounding environment. Q_{25} also can be considered a measurement of ductwork perforation.

To obtain actual air leakage while the system operated, it was necessary to measure the operating pressure differential between the inside and outside of the air handler and adjacent connections. In other words, it was necessary to know the perforation or hole size and the pressure differential operating across that hole. By determining both Q_{25} and operating pressure differentials, actual air leakage into or out of the system was calculated.

Field Testing Leakage Parameters
Testing was performed on 69 air conditioning systems to determine the extent of air leakage from air handlers and adjacent connections. Testing and inspection was performed to obtain:

- Q_{25} in the air handler, Q_{25} at the connection to the return plenum, and Q_{25} at the connection to the supply plenum.
- Operating pressure at four locations - the return plenum connection, in the air handler before the coil, in the air handler after the coil, and at the supply plenum connection.
- Return and supply air flows were measured with a flow hood. Air handler flow rates were measured with an air handler flow plate device (per ASHRAE Standard 152P methodology).
- Overall duct system and house airtightness in 20 of the 69 homes.
- Cooling and heating system capacity based on air handler and outdoor unit model numbers.
- The location and type of filter.
- Dimensions and surface area of the air handler cabinet.
- The fractions of the air handler under negative pressure and under positive pressure.
- The types of sealants used at air handler connections.
- Estimated portion of the air handler leak area that was sealed “as found.”

Air Handler Leakage

Leakage in the air handler cabinet averaged 20.4 Q_{25} in 69 air conditioning systems. Leakage at the return and supply plenum connections averaged 3.9 and 1.6 Q_{25}, respectively. Using the operating pressures in the air handler and at the plenum connections, these Q_{25} results convert to actual air leakage of 58.8 CFM on the return side (negative pressure side) and 9.3 CFM on the supply side (positive pressure side). The combined return and supply air leakage in the air handler and adjacent connections represents 5.3% of the system air flow (4.6% on the return side and 0.7% on the supply side). This is a concern, when considering that a 4.6% return leak from a hot attic (peak conditions; 120°F and 30% RH) can produce a 16% reduction in cooling output and 20% increase in cooling energy use (Cummings and Tooley, 1989), and this was only from the air handler and adjacent connections. *(Figure 78)*

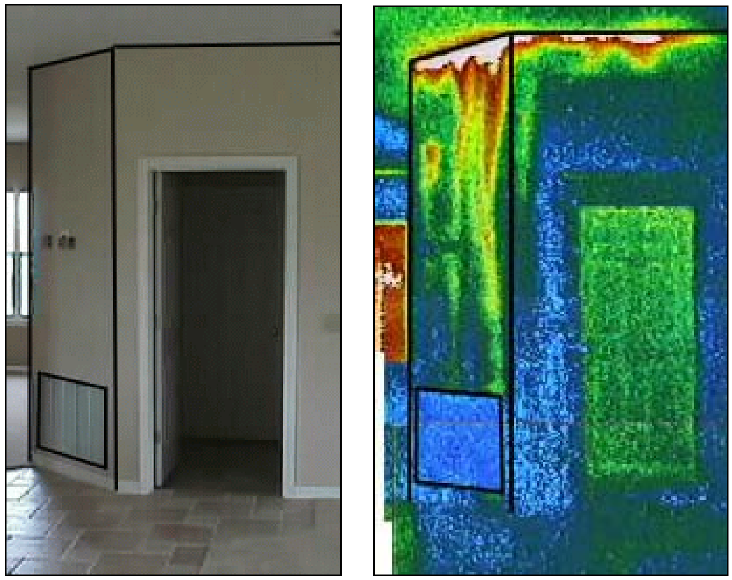


Figure 78 *Thermograph of air being drawn from the attic to the air handler in a Florida house*

"Total" Duct Leakage

Some important observations were made from the extended test data in 20 houses. Total leakage on the return side of the system (including the air handler and return connection) was 53 cfm with weighted operating pressure on the return side of about -100 Pa (including the air handler), operating return leakage was calculated to be 122 CFM, or 9.7% of the rated system air flow.

Total leakage on the supply side of the system ($Q_{25s,total}$) was very large, at 134. The ASHRAE 152P method suggests using half of the supply plenum pressure as an estimate of the overall supply ductwork operating pressure, if the actual duct pressures are not known. For the 20 systems with extended testing, supply plenum pressure was 73.3 Pa. Based on a pressure of 37 Pa, actual leakage should be 167 CFM or about 13.3% of the rated air flow. To test the ASHRAE divide-by-two method, supply duct operating pressure measurements were taken from 14 representative systems. These averaged 35.9 Pa, compared to 65.7 Pa for the supply plenums for those same 14 systems. For these systems, the duct pressure was 55% of the supply plenum pressure - making the ASHRAE method a reasonable method for estimating central Florida home's supply ductwork operating pressures.

However, the ASHRAE method wasn't reasonable for estimating central Florida home's return ductwork operating pressures. For these 20 systems, 38% of the $Q_{25r,total}$ was in the air handler and 62% of the $Q_{25r,total}$ was in the return ductwork. Given an air handler pressure of -133 Pa, a return plenum pressure of -81.5 Pa, and return duct pressure of approximately -70 Pa, the weighted return side pressure was approximately -95 Pa. By contrast, the ASHRAE method predicted -41 Pa. Clearly, in systems with a single, short return duct plenum like those commonly found in Florida, the actual operating pressure should be greater than the return plenum, maybe by as much as 1.2 times the plenum pressure.

Return side leakage is available on 58 of the 69 systems. Return leak air flow ($Q_{r,total}$) combined for the air handler, return connection, and the return ductwork was found to be 152.4 CFM, or 11.8% of total rated system air flow for this group. For this larger sample, $Q_{r,total}$ is considerably greater than for the 20 houses with extended testing. These alarming results show that even in these newly constructed homes about 12% of return air and 13% of supply air duct systems are leaking.

Duct Leakage to “Out”:

In 20 homes, duct leakage to “out” was measured. *(Table 45)* On average, 56% of the leakage of the return ductwork and supply ductwork was to “out.” “Out” is defined as outside the conditioned space, including buffer spaces like an attic or garage. The fraction of leakage that was to “out” varied by air handler location. For return ductwork, the proportion of total leakage to “out” is 81.4% for attic systems, 67.6% for garage, and 28.0% for indoors. For supply ductwork, the proportion of total leakage to “out” was in the range of 52% to 56% for all three locations.

Table 45 Portion of duct leakage to outdoors [($Q_{25,out}$/$Q_{25,total}$) * 100]

Air Handler Location	Return	Supply	Entire Duct System
Attic	81.4%	56.5%	63.2%
Garage	67.6%	51.7%	56.0%
Indoors	28.0%	52.6%	37.1%

The attic return ductwork was the most predictive variable to “out” leakage findings. All of the return ductwork for attic units was located in the attic. Much of the return ductwork for other units was located in the house. As a consequence, the energy penalty associated with locating the air handler in the attic was greater than indicated in the computer modeling results in *Table 46*, since the modeling only considered the leakage of the air handler cabinet and the adjacent connections, and not the return ductwork leakage.

Table 46 Duct leakage “total” and to “out” for three locations, for both 25 Pa test pressure and for actual system operating pressure. Sample size is in [brackets]

	Attic (cfm)		**Garage (cfm)**		**Indoors (cfm)**		**Combined (cfm)**	
Test	*Total*	*Out*	*Total*	*Out*	*Total*	*Out*	*Total*	*Out*
$Q_{25,r}$ [58]	61.9	50.4	93.3	63.1	67.8	19.0	75.7	44.9
$Q_{25,s}$ [20]	109.1	61.6	170.6	88.2	119.5	62.9	134.3	71.4
Q_r [58]	118.1	96.1	194.4	131.4	134.6	37.7	152.4	90.4
Q_s [20]	135.6	76.6	212.0	109.6	148.5	78.1	166.9	88.7

Table 46 shows that the operating supply leakage to "out" was large for all three air handler locations, averaging 89 CFM. The average operating return leakage to "out" was slightly larger, at 90 CFM. However, there was a large variation between air handler locations; 96 CFM for attic systems, 131 CFM for garage systems, but only 38 CFM for indoor systems. From an energy perspective, the attic systems experienced the greatest "real" energy penalties, because all of the return ductwork and air handlers were located in the attic. *(Table 45)* By contrast, a majority of the return leakage for the garage systems likely came from the garage (which is considerably cooler than the attic). For indoor systems, the return leakage to "out" most likely originated from the attic. However, since the return leakage was so much smaller, the energy impact was likely considerably less than both the attic and the garage systems.

Correlation of Supply Duct Leaks with Number of Registers: When analyzing the supply leakage in the extended test data, a surprising correlation was observed. This correlation indicated a systematic and consistent duct fabrication problem across a wide range of air conditioning contractors. *Figure 79* illustrates this correlation, showing that each supply duct has a remarkably predictable total duct leakage. The coefficient of determination is 0.86, indicating that 86% of the variability in total supply duct leakage was explainable by the number of supply registers. *Figure 80* shows a similar relationship between supply leakage to "out" and the number of supply registers. In this case the coefficient of determination was 0.69, indicating that 69% of the variability in total supply duct leakage was explainable by the number of supply registers.

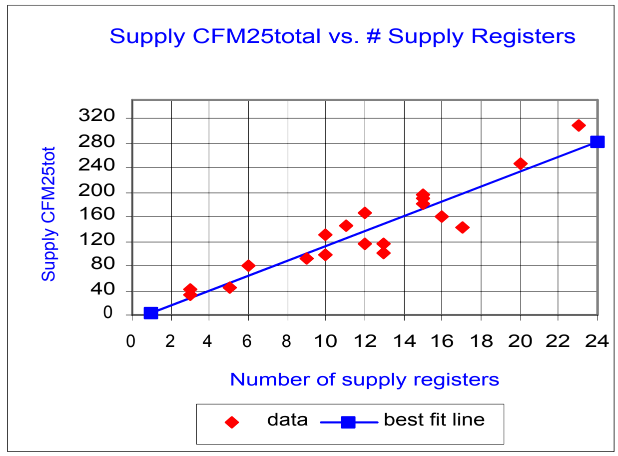


Figure 79 *Supply CFM25 "total" leakage versus the number of supply registers.*

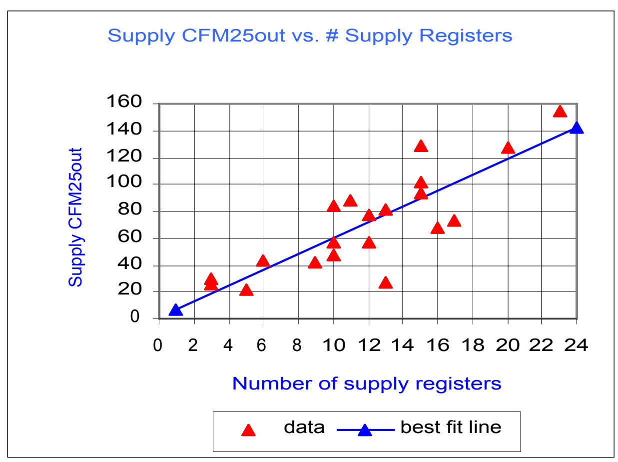


Figure 80 *Supply CFM25 "out" leakage versus the number of supply registers.*

Note that one of the two houses with 13 registers showed considerably less leakage than expected. In this case, supply ducts were located in the interstitial space between floors. When the house was taken to -25 Pa, it is probable (though not measured) that the interstitial spaces were substantially depressurized as well, so leaks in those supply ducts would show less air flow (i.e., less pressure differential = less leakage air flow) and therefore be under-represented.

The data suggest that a duct leakage problem occurs in nearly all new homes. Researchers identified three issues that create most of the leakage: (1) the connection of the supply register or return grill *(Figure 82)*, (2) the boot (supply box) to sheet rock connection *(Figure 81)*, and (3) the flex duct to collar connection. The supply register or return grill leakage typically shows as supply leakage in the "total" test. It usually occurs when the register or grill does not fit snugly to the ceiling or wallboard. Issues two and three show up as leakage to both "out" and "total."

Figure 81 shows how flexible duct connections typically are made. In some cases metal tape is used, but the tape wrinkles when applied to complex angles and over bumps associated with these connection types. Although small in size, these cumulative wrinkles at each connection allow air to pass through.

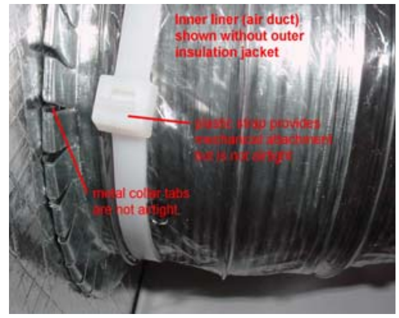


Figure 81 *Flexible duct to metal collar connection.*

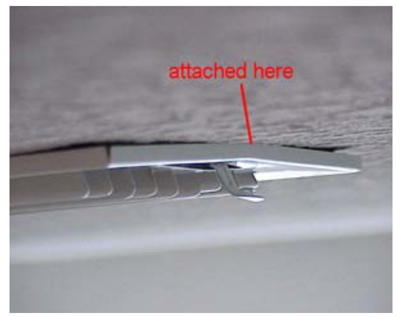


Figure 82 *Gaps at the supply register to drywall joint*

<u>Computer Modeling for Florida Energy Code Air Handler Multipliers:</u>

FSEC researchers performed simulations and developed air handler multipliers for the Florida Energy Code using this study's simulation results. Researcher used the FSEC 3.0 model, a general building simulation program developed in 1992. This program provided simultaneous detailed simulations of a whole building system, including energy, moisture, multi-zone air flows, and air distribution systems.

In 2001, modeling had been performed to develop initial air handler multipliers. These multipliers were based on estimated Q_{25} and duct operating pressures. At the time of the 2001 modeling, there was essentially no data on air handler and connection leakage. Modeling for this project was performed again, but this time using the results of the 69 field tested homes.

The modeling inputs used in 2001 and those from the current study are shown below. (*Table 47*) Note that the same Q_{25} and operating depressurization (dP) values was used for all air handler locations, since there was essentially no difference between the Q_{25} values for attic, garage, and indoor air handler locations when gas furnace units were removed from the analysis.

Table 47 Air Handler (AH) And Connection Inputs For 2001 And Current Project Computer Modeling

	2001 Q_{25}	**AH Study Q_{25}**	**2001 dP**	**AH Study dP**
Return connection	8.7	3.9	-40	-86.1
AH – depressurized portion	48.5	17.6	-42	-139.1
AH – pressurized portion	9.6	2.8	43	106.5
Supply connection	7.8	1.6	32	58.2
Total	**74.6**	**25.9**		

While the Q_{25} leakage for the air handler and connections was about 65% less than earlier estimates, operating pressures were much higher. The air handler multipliers based on the current computer modeling results are presented in *Tables 48, 49, and 50*. Modeling of air handler energy use also was performed for the air handlers located outdoors, despite the fact that no field data was collected for outdoor units. The modeling input parameters were the same as the other air handler locations as shown in *Table 47*. Note also that the air handler multipliers for the attic, indoors, and outdoors are normalized to the garage, since this location was considered the baseline. The final report for this study can be viewed online at: http://www.fsec.ucf.edu/bldg/pubs/cr1357/index.htm.

Table 48 Florida Energy Code AH Multipliers for South Florida

AH Location	**Winter**			**Summer**		
	Old	*2001*	*new*	*old*	*2001*	*new*
Attic	1.04	1.15	1.12	1.04	1.09	1.06
Garage	1.00	1.00	1.00	1.00	1.00	1.00
Indoors	0.93	0.91	0.94	0.93	0.91	0.92
Outdoors	1.03	1.08	1.06	1.03	1.03	1.01

Table 49 Florida Energy Code AH Multipliers for Central Florida

AH Location	**Winter**			**Summer**		
	Old	*2001*	*new*	*old*	*2001*	*new*
Attic	1.04	1.11	1.08	1.04	1.10	1.08
Garage	1.00	1.00	1.00	1.00	1.00	1.00
Indoors	0.93	0.92	0.94	0.93	0.90	0.92
Outdoors	1.03	1.09	1.05	1.03	1.02	1.01

Table 50 Florida Energy Code AH Multipliers for North Florida

AH Location	**Winter**			**Summer**		
	Old	*2001*	*new*	*old*	*2001*	*new*
Attic	1.04	1.10	1.03	1.04	1.11	1.08
Garage	1.00	1.00	1.00	1.00	1.00	1.00
Indoors	0.93	0.93	0.94	0.93	0.91	0.92
Outdoors	1.03	1.07	1.02	1.03	1.02	1.01

Air Conditioning Condenser Fan Efficiency
Florida Solar Energy Center, Laboratory Facilities
Cocoa, Florida
Research by BAIHP Researchers Danny Parker and John Sherwin

Figure 83 *Air conditioning condenser fan and diffuser.*

Purpose
The purpose of this study is to develop an air conditioner condenser fan that reduces the electric energy use of the condensing unit (*Figure 83*). To accomplish this, researchers are designing and producing more aerodynamic fan blades and substituting smaller horsepower (HP) motors which achieve the same air flow rates as the larger, less efficient motors typically used.

4th Budget Period
During the 4th budget period, researchers developed baseline data for the fan power use in a standard condensing unit (Trane 2TTR2036) and tested a new prototype design: “Design A5” with five asymmetrical blades

Baseline data included condenser airflow, motor power, sound levels, and condenser cabinet pressures. Test results favorably compared with the manufacturer’s test data. An experimental set of fan blades, “Design-A5,” designed for a 1/8 hp motor at 850 rpm was numerically created and then successfully produced using rapid prototyping. These prototype blades were substituted on the original condenser, and all test measurements were redone. Design-A5 was found to reduce power use by 20% (40 watts) with approximately equivalent airflow to the original condensing blade design.

5th Budget Period
During the 5th budget period, activities included re-calibration and improvement of the test equipment configuration, refinement of various designs, and patent filing.

Re-calibration and Improvement of Test Equipment Configuration
The air flow measurement equipment was re-calibrated by the Energy Conservatory in Minneapolis in accordance with ANSI/ASHRAE 51-1985 ("Laboratory Methods of Testing Fans for Rating."). Testing determined that the "flow cube" could be modified with settling screens and a flow straightener to yield a 5% absolute flow accuracy and a 2% relative accuracy from the test equipment. Also, the test configuration was moved indoors in order to better measure sound and also to reduce test variability from wind-related effects. Noise measurement protocol improved to comply with procedures used by the air conditioning industry.

Continued Testing to Refine the Identified Condenser Fan and Condenser Top Design
All fans were re-evaluated after bringing the test apparatus into compliance with ANSI/ASHRAE 51-1985 ("Laboratory Methods of Testing Fans for Rating.") New fan prototypes “Design-D” and “Design E” were tested as well as a diffuser for a 27" fan and a specially prepared Electronically Commutated Motor (ECM) provided by General Electric.

All designs were also tested with the conical diffuser with 20-27% increases in measured flow from the low rpm designs, which use 8-pole motors. Sound measurements *(Table 51)* also showed large advantages with as much as a 4 dB reduction in fan sound level over the standard fan. The final test prototype with diffuser and fan is shown in *Figure 84.*

Table 51 Sound Measurements For Various Fan And Housing Designs

Top	Fan	Motor	Flow	Power	Sound
OEM/ Starburst	OEM	6-pole	2170 cfm	197 W	63.0 dB
OEM-Foam	OEM	6-pole	2230 cfm	198 W	63.0 db
Wire top	OEM	6-pole	2180 cfm	188 W	62.0 dB
Wire-Foam	OEM	6-pole	2250 cfm	190 W	62.0 db
OEM-foam	A5	8-pole	1945 cfm	145 W	62.0 dB
Wire-foam	A5	8-pole	2110 cfm	146 W	60.0 dB
WhisperGuard w/foam	A5	8-pole	2300 cfm	143 W	58.5 dB

Presentation and Commercialization

In January, BAIHP researcher Danny Parker made a presentation at the DOE Expert meeting on HVAC and Fans in Anaheim, California and participated in productive meetings with Trane Corporation in May 2004 to discuss licensing of the technology under an existing non-disclosure agreement.

Figure 84 *Final test prototype with diffuser and fan.*

Patents Pending

U.S. Application Serial No. 10/400,888, Provisional applications 60/369,050 / 60/438,035 & UCF-449CIP; WhisperGuard (UCF-Docket No. UCF-458)

Key Improvements from WhisperGuard Technology

Tested Performance with Trane TTR2036 Condenser:

- Provides 46 Watt reduction in fan power (144 W vs. 190 Watts)
- Increases condenser air flow by 130 cfm (6% increase in fan flow)
- Provides 102 W power reduction with ECM 142 motor
- Reduce ambient fan-only sound level by 4-5 dB
- ECM motor allows lower fan speeds for ultra-quiet night operation, higher flows for maximum capacity during very hot periods (temperature based control)
- Attractive hi-tech diffuser appearance

Key Technologies Employed

- High efficiency 5-bladed asymmetrical fan moves air quietly at lower fan speeds
- Diffuser top for effective pressure recovery increasing air flow at slow speed ranges
- Conical center body reduces exhaust swirl
- Acoustic sound control strip to reduce tip losses and control tip vortex shedding

Fenestration Research
Florida Solar Energy Center, Laboratory Facilities
Cocoa, Florida
Research by BAIHP Researcher Ross McCluney

Fenestration: Windows & Daylighting Website
In the 6th budget period major revisions and additions were made to this website, located at http://www.fsec.ucf.edu/bldg/active/fen/index.htm.

Website
The website is now an effective education tool, and will help the consumer make informed, quality decisions concerning the technologies available for existing and new windows.

Work continues on the web site's Decision Tree, which, when complete, will be an interactive process to guide the consumer through a number of questions, providing the specifics for a particular application. At the end, a report will be prepared giving recommendations for the specifications to be used in selecting the correct combination of windows and/or shades for the windows in the home. An Oracle Forms runtime file has been completed and illustrations readied.

AWNSHADE 3.0 Software Revision
AWNSHADE was given an extensive revision, making it a fully Windows-compatible computer program. It is available online as a beta version. The program facilitates the calculation of solar heat gain through vertical windows having exterior shading surfaces, using overhangs, awnings, sidewalls, or a combination.

ASAP Ray Tracing

The focus of this work is toward quantifying edge and other effects associated with Dr. McCluney's previously published model for solar heat gain through planar interior shades attached to single and double pane glazing systems. Other assumptions used to create the model will also be analyzed. In this way, the magnitude of the errors in those assumptions can be quantified, and perhaps the model improved.

A Visual Basic program to calculate the transmittance of a parallel plate of glass as a function of incidence angle was completed and used to generate glass transmittance data for comparison with results of ASAP ray trace calculations of this same quantity. The ray traces were completed and the Fresnel calculations and ray trace results were compared. The two different methods of calculation yielded plots that are indistinguishable, providing confirmation that the ray tracing methodology is completely equivalent to the results of exact calculations using the Fresnel Equations.

ASAP ray trace simulations of both specular and diffuse reflection from a planar shade behind a single pane glazing at any angle of incidence were made. Considerable effort was expended to get the traces of both the specular and diffuse shade cases running properly and plotting results as a function of the ratio of shade width to spacing from the glazing.

Measured data from David Tait will be compared with the model predictions and with the ray trace results. This data is the result of some calorimeter measurements of the solar heat gain coefficient for various glazings plus interior planar shade combinations, as well as the properties of the glazings and shades needed to perform the calculations of McCluney/Mills interior shade solar heat gain algorithm.

We continued ray tracing work on the solar transmittance through a glazing and interior shade and succeeded in setting up a loop over the aspect ratio (shade width divided by the glass-to-shade gap spacing) for a given reflectance. This was repeated for different reflectances. The results of these and additional ray traces will be used to assess the assumptions used in the original model and to improve the model where needed.

The diffuse and specular shade files were run for a range of reflectances from 0.9 down to 0.2. The results show that the specular model is not as terrible as its over-simplifications might indicate, as long as the aspect ratio is above a certain set of values.

Future work includes searching for ways to improve the model, especially at high shade reflectance values. We will look at the edge effects more closely and improve the analytical model at smaller aspect ratios. The results will be presented in a technical paper to be submitted to ASHRAE for publication later this year or early 2006. The timing of this additional work was extended, due to Dr. McCluney's semi-retirement from the university.

<u>American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Technical Committee</u>

In 2002, BAIHP researchers wrote a statement of work for the development of a methodology to calculate solar spectral distributions incident on windows for various sun positions and atmospheric conditions. ASHRAE approved the project and sent it out for bid. Completion of this work project should make it much easier to determine the true solar heat gain through spectrally selective fenestration systems for varying atmospheric conditions and solar altitude angles.

<u>Calorimetric Measurements of Complex Fenestration Systems</u>

FSEC's research calorimeter will be used both indoors with the FSEC Vortek solar simulator and outside under natural solar radiation, on its Sagebrush solar tracker, for window solar heat gain experiments. The results of this testing will offer a way to test the solar gain properties of complex and other non-standard fenestration options for industrialized housing, such as exterior and interior shades and shutters, and those placed between the panes of double pane windows.

Sagebrush Solar Tracker

The computer program running the calorimeter, the Sagebrush tracker, and both together is complete. It contains a user-friendly graphic interface and offers a wide variety of experimental opportunities. There are many channels for adding additional temperature sensors and the calorimeter/tracker can be operated with either the sun as a source - in a variety of tracking modes - or with FSEC's Vortek solar simulator.

To conduct outdoor testing, the Neslab chiller must be connected to the flow meter, the temperature sensors to the calorimeter, and the calorimeter mounted on the tracker. The Sagebrush tracker now is functional, responding properly to commands sent from the computer, rotating in altitude, and azimuth and stopping when the limit switches are encountered. A telescopic sight and level for positioning it outdoors in the proper orientation for accurate solar tracking has been designed and is near fabrication completion.
The Neslab chiller and remote controller have been connected to a Gateway laptop computer and a RS-485 serial interface card necessary to operate the calorimeter has been installed. Researchers can now send commands and receive data from the chiller. Although the calorimeter is designed to work directly with the existing FSEC hydronic loop used for testing solar collectors, the Neslab will give an independent, standalone capability to the calorimeter. *(Figure 83)*

The water flow meter purchased for measuring the flow into the calorimeter has been successfully connected to the Agilent (HP) 34970A data acquisition system and its measurements were incorporated into the calorimeter operating program. Temperature sensors also successfully connected to the data acquisition system, are reading properly, and have been incorporated into the calorimeter program. The program has coding to include a number of additional temperature channels once the temperature probes have been received and installed in the calorimeter. Another 20-channel input card is being purchased for the Agilent, to permit additional temperature readings. Knowing the flow rate and temperature difference, the heat delivered to the water by the calorimeter can now be accurately determined.

Now that all portions of the system are operational, researchers will configure the outdoor system, verify, and begin testing in Year 5.

Vortek Solar Simulator
In 2003, the Vortek Simulator was fired up and operated reliably on the calorimeter testing with FSEC's solar collector test apparatus. As expected, a few computer and other problems delayed initial data collection by a couple of days. However, these problems were corrected and testing proceeded normally.

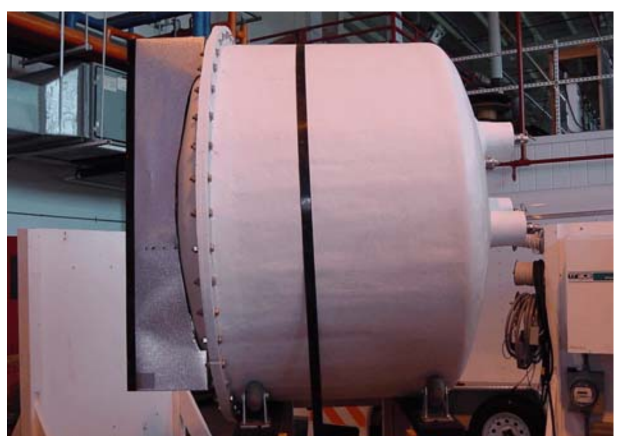


Figure 85 *Side view of calorimeter before it was mounted on the Sagebrush Tracker.*

During testing, the calorimeter was connected to the existing facility's hydronic loop, which was developed over a period of years to a temperature stability of 0.01 degrees centigrade. The irradiance level measured about 820 watts per square meter over an aperture of 0.557 square meters. The calorimeter was tested as though it were a flat plate collector, to obtain its efficiency curve. This was used to infer the thermal losses and solar heat gain coefficient of the eighth inch clear single pane of glass used for the test. The nominal wind speed was set by the laminar blower to five miles per hour. The coolant flow was run at levels of 0.2, 0.5, and 1.0 gallons per minute (GPM), and at varying inlet temperatures.

For all test runs, steady state conditions were established by observing the outlet temperature in a real-time plot as equilibrium was approached. During periods of non-equilibrium, the recorded data was used to measure the first-order system time constant, a function of the flow rate. The calorimeter time constant varied from 1.5 minutes at 1.0 GPM to 6.9 minutes at 0.2 GPM. These time constants were obtained by blocking the incident beam and watching the decay in outlet temperature.

Skylight Dome Transmittance
Researchers completed work on the skylight dome transmittance, adding a spherical shape to the cylindrical one previously used. The ray tracing programming was changed to eliminate reflection of rays approaching the dome from the inside, for comparison with the analytical model, which does not yet include internal reflections. The difference between the two computational approaches, at a 30E solar zenith angle is 1.7%, considered acceptable for rating skylight performance.

With both cylindrical and spherical dome models, transmittance at large solar zenith angles above 60 is substantially greater than for a horizontal flat plate. This is because most of the rays incident on the dome and entering the skylight are incident on the dome close to perpendicular, where dome transmittance is highest.

Energy Gauge USA and Energy Gauge FlaRes
BAIHP mapped a table of window and shade characteristic simulations that could be run with these two programs. These runs will be used to determine the energy use of various fenestration options for Florida residences and to guide the preparation of instructional materials.

Florida Market Transformation
From the beginning of the BAIHP program, researchers have provided technical background information and support to the Alliance to Save Energy and the Efficient Windows Collaborative to promote the sale and installation of energy efficient fenestration in hot climates (such as Florida) and other areas for both conventional and industrialized homes. BAIHP also provides advice, technical information, and educational information to energy companies regarding window energy performance.

National Fenestration Rating Council (NFRC) Technical Committee
In 2002, BAIHP presented a final report at a Task Group meeting in Houston, on the NFRC-funded work to develop a draft standard practice for the rating of tubular daylighting devices. That project is now complete.

In 2001, BAIHP researchers performed a number of ray traces on a highly reflective cylinder of varying lengths, using the trace results to determine the cylinder's transmittances for different interior surface reflectivities (from 90% to 100%). These results generated a "default table" for determining the transmittance of this tubular daylighting component. Using simplified assumptions, and then multiplying the tube transmittance by the top and bottom dome transmittance results, researchers determined the total transmittance for a chosen sun angle. Based on the findings, BAIHP provided NFRC and the industry with a list of suggested research projects to test and develop this methodology further. One of these submitted projects was sent out for bid by ASHRAE in Year 4 and is expected to begin in Year 5.

Tubular Daylighting Device SHGC and VT Value Calculations
Following a request from the TDD industry, a sequence of operations and a new computer program were written to access the Window 5 glazing database and obtain from it the spectral transmittance and front and back reflectance data for any sheet of glazing in that database which might be used in making the top dome of a tubular daylighting device. This permits determination of the input parameters needed to run TDDTrans. The computer program was posted for free download and is available by clicking on http://fsec.ucf.edu/download/br/fenestration/software/TddTrans-Beta/TDDTrans.exe.

Access sequence:
- Download and run the Optics 5 program.
- Select the glazing to be used in the tubular daylighting device.
- Export its spectral data file as a standard ASCII text file.

Reflective Roofing Research
Florida Solar Energy Center, Laboratory Facilities
Cocoa, Florida
Research by BAIHP Researchers Danny Parker and John Sherwin

Improving attic thermal performance is fundamental to controlling residential cooling loads in hot climates. Research shows that the influence of attics on space cooling is not only due to the change in ceiling heat flux, but often due to the conditions within the attic, and their influence on duct system heat gain and building air infiltration. *(Figure 86)* The importance of ceiling heat flux has long been recognized, with insulation a proven means of controlling excessive gains. However when ducts are present in the attic, the magnitude of heat gain to the thermal distribution system can be much greater than the ceiling heat flux. This influence may be exacerbated by the location of the air handler within the attic space - a common practice in much of the southern US. Typically an air handler is poorly insulated and has the greatest temperature difference at the evaporator of any location in the cooling system. It also has the greatest negative pressure just before the fan so that some leakage into the unit is inevitable.

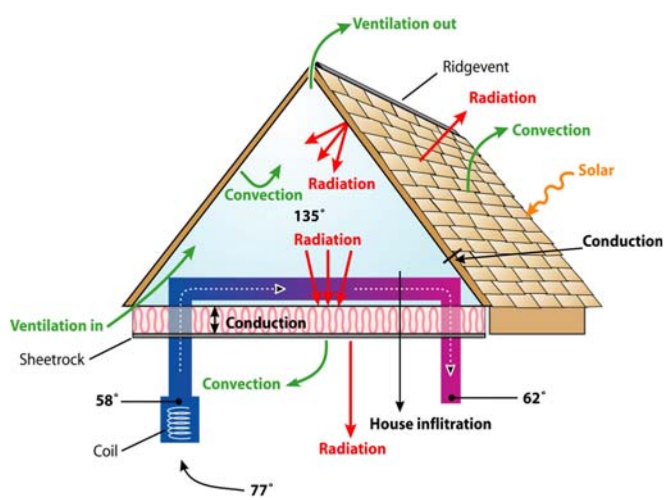


Figure 86 *Vented attic thermal processes.*

The Flexible Roof Facility (FRF) is an FSEC test facility designed to evaluate five roofing systems at a time against a control roof with black shingles and vented attic *(Figure 87).* The testing evaluates how roofing systems impact summer residential cooling energy use and peak demand.

Figure 87 *Flexible Roof Facility in summer of 2003 configuration.*

6th Budget Period Experiments

In the summer of 2004, the following roofing systems were tested (*Table 52).* Cell numbering is from left to right.

Table 52 Roofing systems tested at the FSEC Flexible Roofing Facility, Summer of 2004

Cell #	Description
1	Galvalume®* unfinished (unpainted) 5-vee metal with vented attic (3rd year of exposure)
2	Proprietary test cell
3	Proprietary test cell
4	Galvanized unfinished 5-vee metal with vented attic (3rd year of exposure)
5	Black shingles with standard attic ventilation (Control Test Cell)
6	White standing seam metal with vented attic (3rd year of exposure after cleaning)

** Galvalume is a quality cold-rolled sheet to which is applied a highly corrosion-resistant hot-dip metallic coating consisting of 55% aluminum 43.4% zinc, and 1.6% silicon, nominal percentages by weight. This results in a sheet that offers the best protective features characteristic of aluminum and zinc: the barrier protection and long life of aluminum and the sacrificial or galvanic protection of zinc at cut or sheared edges. According to Bethlehem Steel, twenty-four years of actual outdoor exposure tests in a variety of atmospheric environments demonstrate that bare Galvalume sheet exhibits superior corrosion-resistance properties.*

All had R-19 insulation installed on the attic floor. The measured thermal impacts include ceiling heat flux, unintended attic air leakage and duct heat gain. Test Cells #2 and #3 had proprietary test configurations that are not further described in this report.

The white metal roof results in the coolest attic over the summer, with an average day peak air temperature of only 95.7°F – 22.2° cooler than the peak in the control attic with dark shingles.

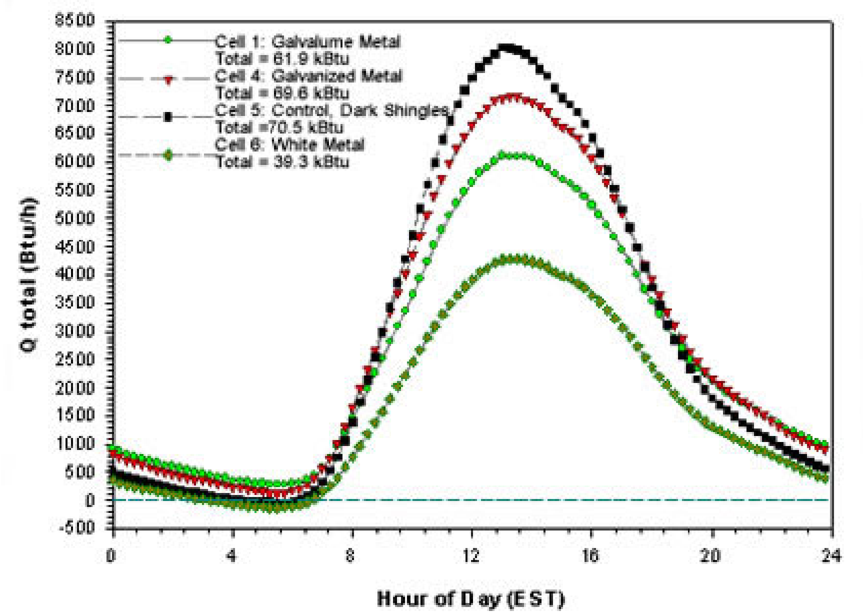


Figure 88 2004 Results *Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling heat flux on space cooling needs on an average summer day in a 2,000 ft2 home.*

This was the third year of comparative testing metal roofing (galvanized and Galvalume®) under long term conditions. Galvalume® roofs are reported to better maintain their higher solar reflectance than galvanized types. Average daily mid-attic maximum temperatures for the Galvalume® and galvanized metal roof systems showed significantly better performance for Galvalume® product (10.9°F and 2.1°F cooler than the control dark shingle respectively). However, both unfinished metal roofs showed significant degradation in their performance over the three year period compared to the white metal roof.

We also estimated the combined impact of ceiling heat flux, duct heat gain and unintended attic air leakage from the various roof constructions. The alternative constructions produced lower estimated cooling energy loads than the standard vented attic with dark shingles. The Galvalume® roof clearly provided greater reductions to cooling energy use than the galvanized roof after three summers of exposure, although both suffered significant degradation relative to the first year's performance. More specifically, the Galvalume® and Galvanized roof system provided a 32% and 22% savings in the first year of exposure, but only 12% and 1% respectively after three years of exposure.

One important fact from our testing is that nighttime attic temperature and reverse ceiling heat flux have a significant impact on the total daily heat gain, particularly for the metal roofs. The rank order below shows the percentage reduction of roof/attic related heat gain and approximate overall building cooling energy savings (which reflect the overall contribution of the roof/attic to total cooling needs):

Table 53 Cooling Load Reduction and Savings

Rank	Description	Roof Cooling Load Reduction	Overall Cooling Savings
1	White Metal with vented attic (Cell #6)	44%	15%
2	Galvalume® unfinished metal with vented attic (Cell #1)	12%	4%
3	Galvanized unfinished metal roof with vented attic (Cell #4)	1%	0%

The relative reductions are consistent with the whole-house testing recently completed for FPL in Ft. Myers (Parker et al., 2001). This testing showed white metal roofing having the largest reductions, followed by darker constructions. After long-term exposure, test results indicate that galvanized metal roofing is no better than a standard asphalt shingle roof after three years of exposure. On the other hand, the Galvalume roof does maintain some advantage although not nearly so great as the white metal type.

5th Budget Period Experiments

The roofing systems tested in the summer of 2003 are listed in *Table 54.* Cell numbering is from left to right beginning with the second cell in from the left.

Table 54 Roofing systems tested at the FSEC Flexible Roofing Facility, Summer of 2003

Cell #	Description
1	Galvalume®* unfinished 5-vee metal with vented attic (2nd year of exposure)
2	Sealed attic with proprietary configuration
3	High reflectance brown metal shingle with vented attic
4	Galvanized unfinished 5-vee metal with vented attic (2nd year of exposure)
5	Black shingles with standard attic ventilation (Control Test Cell)
6	Standing seam metal with vented attic (2nd year of exposure after cleaning)
** See note Table 52*	

All had R-19 insulation installed on the attic floor except in the configuration with the sealed attic (Cell #2) which had R-19 of open cell foam sprayed onto the bottom of the roof decking. The measured thermal impacts include ceiling heat flux, unintended attic air leakage and duct heat gain. Cell #2 had a proprietary configuration which is not reported upon in this report.

A major thrust of the testing for 2003 was comparative testing of metal roofing under long term exposure. Given the popularity of unfinished metal roofs, we tested both galvanized and Galvalume® roofs in their second year of exposure.. Average daily mid-attic maximum temperatures for the Galvalume® and galvanized metal roof systems showed significantly better performance for Galvalume® product (17.5°F and 13.1°F cooler than the control dark shingle respectively).

Other than the sealed attic case, the white metal roof results in the coolest attic over the summer, with an average peak of only 94.6°F – 22.1° cooler than the peak in the control attic with dark shingles. The highly reflective brown metal shingle roof (Cell #3) provided the next coolest peak attic temperature. Its average maximum daily mid-attic temperature was 101.5°F (15.2°F lower than the control dark shingle cell). While the brown metal shingle roof's reflectance was lower than the two metal roofs and white metal roof we observed evidence that the air space under the metal shingles provides additional effective thermal insulation.

We also estimated the combined impact of ceiling heat flux, duct heat gain and unintended attic air leakage from the various roof constructions. All of the alternative constructions produced lower estimated cooling energy loads than the standard vented attic with dark shingles *(Figure 89)*. The Galvalume® roof clearly provided greater reductions to cooling energy use than the galvanized roof after two summers of exposure.

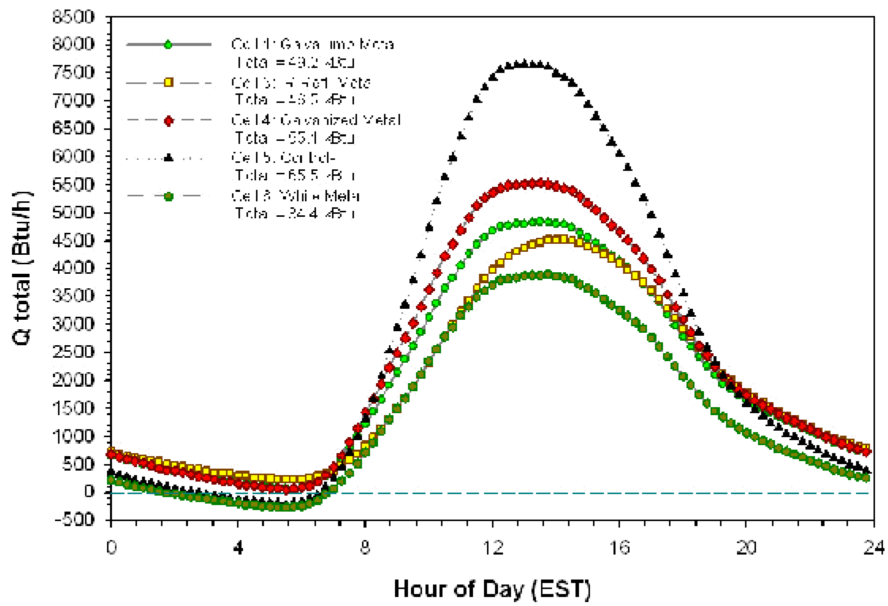


Figure 89 *Estimated combined impact of duct heat gain, air leakage from the attic to conditioned space and ceiling heat flux on space cooling needs on an average summer day in a 2,000 ft² home.*

Nighttime attic temperature and reverse ceiling heat flux have a significant impact on the total daily heat gain, particularly for the metal roofs. The rank order in Table 55 shows the percentage reduction of roof/attic related heat gain and approximate overall building cooling energy savings (which reflect the overall contribution of the roof/attic to total cooling needs):

Table 55 Roof cooling load reduction and overall cooling savings, Summer 2003

Rank	Description	Roof Cooling Load Reduction	Overall Cooling Savings
1	White metal with vented attic (Cell #6)	47%	15%
2	High reflectance brown metal shingle with vented attic (Cell #3)	29%	10%
3	Galvalume® unfinished metal with vented attic (Cell #1)	25%	8%
4	Galvanized unfinished metal roof with vented attic (Cell #4)	16%	5%

4th Budget Period Experiments

In the summer of 2002, six roofing systems were evaluated as described in *Table 56*, *Figure 90.*

Table 56 Roofing systems tested and associated energy savings at the FSEC Flexible Roofing Facility, Summer of 2002

Cell #	Roof Material	Venti-lation	Roof Cooling Load Reduction	Overall Cooling Savings
#1	Galvalume® unfinished 5-vee metal	vented	32%	11%
#2	double roof with radiant barrier (ins roof deck)	sealed	7%	2%
#3	high reflectance ivory metal shingle	vented	38%	12%
#4	galvanized unfinished 5-vee metal	vented	22%	7%
#5	black shingles (control cell)	vented	control	control
#6	white standing seam metal	vented	7%	2%

All roof cells had R-19 insulation installed on the attic floor, except the double roof configuration (Cell #2) which had a level of R-19 open cell foam sprayed onto the bottom of the roof decking. Measured thermal impacts included ceiling heat flux, unintended attic air leakage, and duct heat gain.

Figure 90 *Flexible Roof Facility in summer 2002 configuration. Cells are numbered from left to right starting with the second cell in from the left.*

The sealed attic double roof system (Cell #2) provided the coolest attic space of all systems tested (average maximum mid-attic temperature was 81.1°F), and therefore had the lowest estimated impact due to return air leakage and duct conduction heat gains. However this cell also had the highest ceiling heat flux of all strategies tested, and recorded the most modest space cooling reduction (7%), relative to the control roof.

Metal roof testing was given more emphasis in 2002 due to the popularity of these products. Researchers tested both galvanized and Galvalume® roofs. Galvalume is a cold-rolled sheet with a highly corrosion-resistant hot-dip metallic coating application of 55% aluminum 43.4% zinc, and 1.6% silicon. These roofs are reported to better maintain solar reflectance than galvanized roofing systems. Average daily mid-attic maximum temperatures for the Galvalume® and galvanized metal roof systems were roughly similar (19.6°F and 17.3°F cooler than the control roof, respectively). The estimated total heat gain for these roof cells also was relatively close.

The highly reflective ivory metal shingle roof (Cell #3) provided the coolest peak attic temperature of all the cells without roof deck insulation. Its average maximum daily mid-attic temperature was 93.3°F (23.4°F lower than the control dark shingle cell). While the ivory metal shingle roof's reflectance was slightly lower than the two metal roofs and white metal roof, researchers noted that the air space under the metal shingles provided additional effective thermal insulation.

Researchers also estimated the combined impact of ceiling heat flux, duct heat gain, and unintended attic air leakage from the various roof constructions. All of the alternative roofing treatments produced lower estimated cooling energy loads than the standard vented attic with dark shingles. *(Figure 91)* The Galvalume® roof clearly provided a greater cooling energy use reduction than the galvanized roof. This also was true during the 2001 study. Nighttime attic temperatures and reverse ceiling heat flux have a significant impact on the total daily heat gain, particularly for metal roofs.

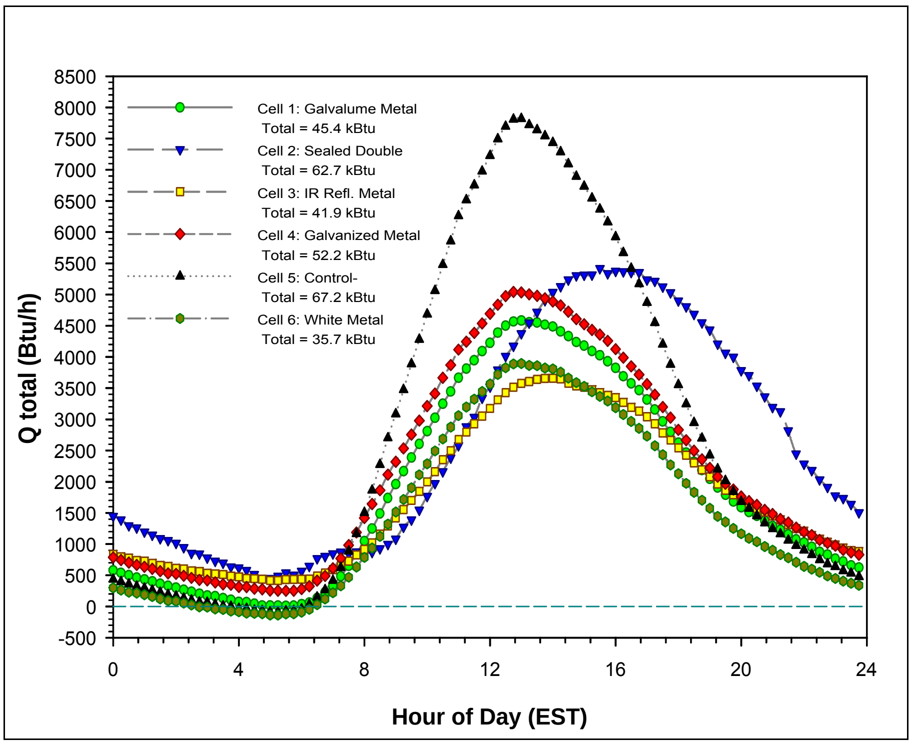


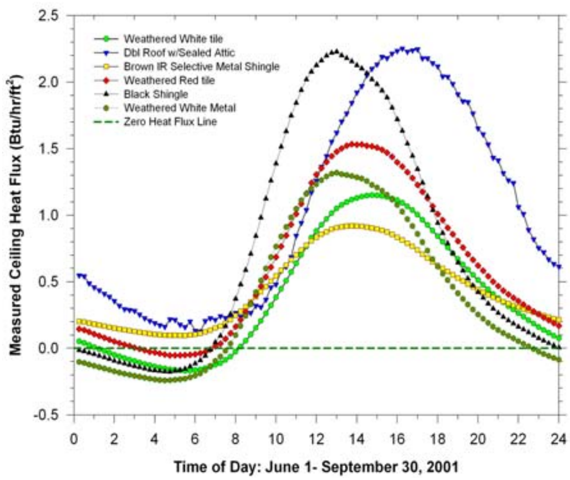
Figure 91 *2002 estimated combined impact of duct heat gain, air leakage from the attic to conditioned space, and ceiling heat flux on space cooling needs on an average summer day in a 2,000 ft² home.*

<u>3rd Budget Period</u>

In the 2001 testing *(Figure 92)*, Cell #2 with the double roof/sealed attic showed the lowest attic temperatures and narrowest temperature range. *(Table 57; Figures 93 and 94)* Peak attic temperatures in Cell #2 were 5°F to 6°F lower than this same sealed cell

Figure 92 *2001 Experimental roof cell. Cells are numbered from left to right starting with the cell second in from the left.*

the year before, without the double roof. This indicates that the double roof did provide a substantial benefit. Since there is no insulation on the attic floor though, there still is a significant heat gain across the ceiling. In fact, the ceiling heat fluctuation actually is higher than the reference Cell #5. *(Figure 93)*



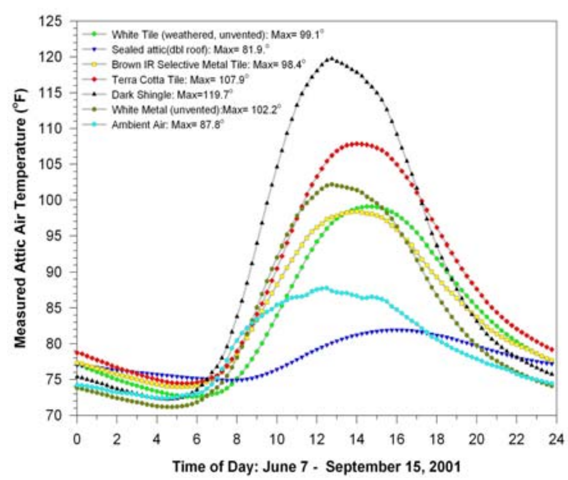


Figure 93 *(left) 2001 heat flux measurements across attic.* ***Figure 94*** *(right) 2001 mid-attic temperatures.*

The true impact of the double roof construction of Cell #2 is most likely a combination of the benefits of a cooler attic space that reduces duct heat gain and minimizes the effects of air leakage from the attic into the house, and the drawback of the higher ceiling heat flux.
Cell #3 with its spectrally selective dark brown metal shingles, produced lower attic temperatures at night, but higher roof deck temperatures (which were most likely due to the insulating quality of the shingles which have an air space underneath them).

Table 57 Roofing systems tested and attic temperatures at The FSEC Flexible Roofing Facility, Summer of 2001

Cell #	Roof Material	Venti-lation	Avg Attic Temp	Max Attic Temp
#1	white tile (weathered)	sealed	84.6	111.2
#2	double roof with radiant barrier (ins roof deck)	sealed	78.4	85.4
#3	brown IR selective metal shingle	vented	85.0	110.8
#4	terra cotta tile (weathered)	vented	89.0	124.3
#5	dark shingles (control)	vented	91.0	143.4
#6	white standing seam metal (weathered)	sealed	84.0	115.5

<u>Roofing Experiment with Habitat for Humanity in Fort Myers, Florida</u>
In July 2000, FSEC and Florida Power and Light instrumented six side-by-side Habitat for Humanity homes in Ft. Myers with identical floor plans, orientation, and ceiling insulation, but with different roofing systems as described in *Table 58*. A seventh monitored house contained an unvented attic with insulation on the underside of the roof deck rather than on the ceiling.

Each unoccupied home was monitored from July 8 through July 31, 2001 to collect building thermal and air conditioning power data. *Table 59* presents the cooling performance of the roofing systems clearly showing the energy-saving benefits of reflective roofing systems in Florida, especially the tile and metal roofs with solar reflectance between 65% and 75%.

Table 58 Roofing systems tested at side-by-side Habitat for Humanity homes in Ft. Myers Summer of 2000

Code	Description	Code	Description
RGS	Standard dark shingles (control)	RTB	Terra cotta "barrel" S-tile roof
RWS	Light colored shingles	RWB	White "barrel" S-tile roof
RWM	White metal roof	RWF	White flat tile roof
RSL	Standard dark shingles with sealed attic & R-19 roof deck insulation		

Table 59 Energy use and savings from roofing systems in Habitat for Humanity roofing study, summer of 2000

Site	Total kWh	Savings kWh	Saved Percent	Demand kW	Savings kW	Saved Percent
RGS	17.03	----	----	1.63	----	----
RWS	15.29	1.74	10.2%	1.44	0.19	11.80%
RSL	14.73	2.30	13.05%	1.63	0.01	0.30%
RTB	16.02	1.01	5.9%	1.57	0.06	3.70%
RWB	13.32	3.71	21.8%	1.07	0.56	34.20%
RWF	13.20	3.83	22.5%	1.02	0.61	37.50%
RWM	12.03	5.00	29.4%	0.98	0.65	39.70%

Significant findings: Reflective roofing materials represent one of the most significant energy-saving options available to homeowners and builders. These materials also reduce cooling demand during utility coincident peak periods, and are potentially one of the most effective methods for controlling demand.

- Based on comparative data from August of 2000, the maximum decking temperatures in the sealed attic home were 23EF higher than the control home (177E versus 154E). After the installation of white shingles in midsummer, the highest deck temperature from the sealed attic home measured only 7E higher than the control in August of 2001 (161E versus 154E).
- An additional month's data was collected with the homes occupied and thermostat set points kept constant. Average cooling energy use for the homes rose by 36%, but there was no decrease in the highly reflective roofing system savings. Additional heat gained from the occupants and their appliance use increased the cooling system runtime and introduced more hot air into the air conditioning duct system.
- In 2001, the average maximum attic air temperature in the terra cotta barrel tile roof home was 15EF hotter than the maximum ambient. After installing a radiant barrier the average difference in August was +9EF. A similar evaluation with the light colored

shingles showed that peak attic air temperatures dropped from + 29E to +20EF after installing a radiant barrier.

- Household interior temperature settings varied from one year to the next, making direct energy saving comparisons impossible. Still, the collected data did show that attic air temperatures were reduced by the radiant barrier. On the other hand, measured maximum plywood decking temperatures rose by 11E to 13EF.
- Based on previously evaluated roof buckling problems on the decking of the sealed attic home, researchers decided to install white shingles similar to those on the RWS roof. It was thought that buckling problems likely were caused by excessive heat buildup in this roofing system. White shingles replaced the dark shingles to see if this would drop the roof decking temperature spikes.

Return Air Pathway Study

Research by BAIHP Researcher Neil Moyer with BAIHP Industry Partner Tamarack

Scope

In effect since March 2003, Section 601.4 of the Florida Building Code applies to *residential* and *commercial* buildings having interior doors and one, centrally located return air intake per heating and cooling system.

Objective Of The New Florida HVAC Code Requirement

Reduce pressure difference in closed rooms with respect to (wrt) the space where the central return is located to 0.01" water column (wc) or 2.5 pascal (Pa) or less. Pressure imbalances created by restricted return air flow from rooms isolated from the central return by closed interior doors create uncontrolled air flow patterns.

Technical Background

Ideally, forced-air heating and cooling systems circulate an equal volume of return air and supply air through the conditioning system, keeping air pressure throughout the building neutral. Each conditioned space in the building should, ideally, be at neutral air pressure at all times.

Figure 95 *Return Air Flow Test Chamber*

When a space is under a positive air pressure, indoor air will be pushed outward in the walls, floor and ceiling. When a space is under a negative pressure, air will be pulled inward through the walls, floor and ceiling. Negative and positive air pressures in buildings result from uncontrolled air flow patterns.

Section 601.4 of the Florida Building Code specifically deals with the uncontrolled air flow pattern when interior doors are closed thereby reducing return air flow from the closed room, while maintaining the same supply air flow to the room. This imbalance of supply and return air has been addressed conventionally by the common practice of undercutting interior doors to allow return air to flow from the room. This research quantifies the volume of air flow provided by this and other methods of return air egress from closed rooms.

Section 601.4 limits the air pressure imbalance in closed rooms to 0.01" wc or 2.5 pascals when compared to, or with respect to (wrt), the main body of the building where the return is located. With door undercuts, researchers have regularly observed room pressures with respect to the main body of the house (wrt$_{mainbody}$) of +7 pascals (pa) or more. A room with this level of air pressure (+7pa, wrt$_{mainbody}$) is trapping air, starving the heating/cooling system of return air. As the heating/cooling system struggles to pull in the designed amount of air, the resulting negative pressure pulls air into the main body of the building along the path(s) of least resistance. Usually this means that air is flowing through the walls, floor and ceiling from unconditioned spaces or outside environment to makeup for the trapped air in the closed room.

In the closed room, positive pressure builds up when return air is trapped. Conversely, the space with the central return gets depressurized because extra return air is being removed to make up for the air trapped in the closed room. More air is leaving the space (return air) than is entering the space (supply air). The positive pressure in the closed rooms *pushes* air into unconditioned spaces, such as the attic and wall cavities. The negative pressure in the main body of the building *pulls* air from unconditioned spaces. In Florida, the air brings heat and moisture with it that become an extra cooling load. This air is referred to as "mechanically induced infiltration" since the negative pressure drawing infiltration air in was created by the mechanical system.

<u>Styles of Pressure Relief</u>
When return air flow is restricted by closed doors, it creates pressure differences between parts of the building. This can be prevented by installing a fully ducted return system, by creating a passive return air pathway such as a louvered transoms, door undercut, "jump duct", through-wall grilles, or a baffled through-wall grill.

A "jump duct" is simply a piece of flex duct attached to a ceiling register in the closed room and another ceiling register in the main body of the house. A jumper duct provides some noise control while providing a clear air flow path.

A through-wall grille is the simplest and least expensive approach to pressure relief for closed rooms. Holes opposite each other on either side of the wall within the same stud bay are covered with a return air grilles. The downside of this approach is a severe compromise the privacy of the closed room. An improvement on this theme would be to locate one of the grilles high on the wall and the opposing opening low on the wall. Also, such openings in interior wall cavities introduce conditioned air into what is typically an unconditioned space possibly contributing to other building problems.

Figure 96 *Installing sound baffled return air flow through wall insert made by Tamarack.*

However, connecting the two openings with a sleeve of rigid ducting forms an enclosed air flow path that limits introduction of conditioned air into the wall cavity but doesn't solve the visual and sound privacy issues. To address this problem, BAIHP Industry

Partner Tamarack developed a sleeve with a baffle that can reduce the transfer of light and sound but still provide adequate air flow to minimize pressure differences. The product is called a Return Air Path (RAP).

To validate the effectiveness of this product and other approaches to providing return air pathways, Tamarack and BAIHP researchers devised a test apparatus and conducted experiments in FSEC's Building Science Laboratory.

Figure 97 *Installing unbaffled return air flow through wall grille*

Testing Protocol

In May of 2003, a chamber was constructed at FSEC *(Figures 95-98)* that simulated a frame construction room with an 8 foot high ceiling. A "Minneapolis Duct Blaster" was connected to one end of the room with a flexible duct connection leading out of the room to provide control over pressure in test chamber.

In the middle of the chamber, on a stool, a radio was tuned "off station" to effectively create a standardized level of "white noise" at 57 dBA inside the chamber with the "door" closed. The temperature at the start of the tests was 80°F at 40%RH. A sound meter was located outside the chamber on a stand 4 feet above the floor and 20 inches from the middle of the chamber wall surface.

The sound level in the test facility outside the chamber with the "white noise" turned off was 36.4 dBA and with the "white noise" turned on was 41.5 dBA, an average, sampled over a 30 second period. A series of tests on 31 different set-ups were performed, measuring the flow at 3 different pressure levels and recording a 30 second sound sample with the "Duct Blaster" deactivated.

Tests were made for 6" and 8" jump ducts, five different sized wall openings *(Figure 97)* in different configurations including straight through with and without sleeves, straight through with sleeve and privacy baffle *(Figure 96)*, and high/low offset using the wall cavity as a duct, and three different slots simulating three different size undercut doors.

Results

Table 60 summarizes the results of these tests arranged in ascending air flow order based on the results at 2.5 Pascals (0.01" wc), the maximum allowable pressure in a closed room under new requirement in Florida Building Code, Section 601.4.

Table 60 Air Flow Resulting from Various Return Air Path Configurations at Controlled Room Pressure Difference (ΔP) with respect to Return Zone

Dim.	Air Flow (cfm) at ΔP=1 pa	ΔP=2.5 pa	ΔP=5 pa	Area	Air Flow to Area Ratio	Return Air Path Configuration	Extra
6 dia	22	**36**	52	**28**	**1.29**	Jumper Duct	
4x12	26	**41**	60	**48**	**0.85**	Wall Cavity	
4x12	25	**42**	61	**48**	**0.88**	Wall Sleeve	RAP Insert
4x12	28	**45**	65	**48**	**0.94**	No Sleeve	
4x12	29	**46**	68	**48**	**0.96**	Wall Sleeve	
8x8	31	**49**	72	**64**	**0.77**	Wall Cavity	
12x6	32	**52**	75	**72**	**0.72**	Wall Cavity	
12x6	33	**56**	82	**72**	**0.78**	Wall Sleeve	RAP Insert
8x8	35	**57**	81	**64**	**0.89**	No Sleeve	
8x8	34	**58**	83	**64**	**0.91**	Wall Sleeve	RAP Insert
8x8	36	**59**	85	**64**	**0.92**	Wall Sleeve	
12x6	36	**60**	88	**72**	**0.83**	No Sleeve	
12x6	37	**60**	88	**72**	**0.83**	Wall Sleeve	
1 x 30	39	**61**	88	**30**	**2.03**	Slot	
8 dia	38	**62**	90	**50**	**1.24**	Jumper Duct	
1 x 32	42	**65**	92	**32**	**2.03**	Slot	
8x8	40	**67**	95	**64**	**1.05**	Wall Cavity	Two Inside Holes
8x14	44	**70**	100	**112**	**0.63**	Wall Cavity	
12x12	45	**72**	103	**144**	**0.50**	Wall Cavity	
1 x 36	49	**73**	103	**36**	**2.03**	Slot	
8x14	61	**101**	146	**112**	**0.90**	Wall Sleeve	RAP Insert
8x14	68	**107**	153	**112**	**0.96**	No Sleeve	
8x14	68	**110**	154	**112**	**0.98**	Wall Sleeve	
12x12	75	**119**	170	**144**	**0.83**	No Sleeve	
12x12	74	**120**	169	**144**	**0.83**	Wall Sleeve	
12x12	74	**120**	174	**144**	**0.83**	Wall Sleeve	RAP Insert

By comparing the air flow of the slots (door undercut) to the openings with grilles, the detrimental effect of the grille becomes clear. The ratio of air flow (cfm) to the surface area of the slot (in^2) is more than 2 to 1 (for example; 30 in^2 to 61 cfm), whereas with grilles in place the ratio of air flow to area averages 0.83 to 1 (for example; 72 in^2 to 60 cfm). Similarly, the jump duct *(Figure 98)* assemblies' air flow to area ratios average 1.19 to 1. In any calculation for the size of the through wall assembly, the resistance of the grille becomes the critical factor in determining the size of the opening for achieving the desired flow.

Figure 98 *Return air flow path provided by jumper duct*

The following formulas account for the grille resistance and maybe used to size return air path openings.

- Door undercuts: Area Sq. In. = CFM/2
- Wall opening with grilles: Area Sq. In. = CFM/.83
- Flexible jumper duct with grilles: Diameter = √CFM

Although there does not appear to be significant flow improvement when a sleeve is used, such an assembly will reduce the possibility of inadvertent air flow from the wall cavity itself.

The high/low grilles using the wall cavity reach maximum flow at 72 cfm because of the dimensional limitations of the wall cavity itself. Increasing the opening of each grille beyond 112 square inches does not significantly increase the flow of air through the wall cavity.

The accompanying bar chart *(Figure 99)* can be used to select the best method at various air flows while maintaining the room-to-building pressure difference at .01" wc. The strategies are ranked by air flow allowance (cfm) on equivalent to supply air delivered to the room. For example, an 8" jumper duct could be used to maintain 0.01 wc in rooms with supply air up to 60 cfm. Note that these transfer methods are additive so that, for example, combining a 6" transfer duct with a 1" undercut a 30" door, will provide a flow of 95 cfm to be delivered at .01" wc (*Figure 99*) or combining a R.A.P. 12.12 with a 1" undercut would allow up to 175 cfm to be delivered . It should be noted that door undercuts are under builder not HVAC control and that the actual dimensions are greatly affected by the thickness of the floor coverings.

<u>Summary</u>

Ideally buildings with forced air heating/cooling systems are pressure neutral. The same amount of air is removed from the building (and each room) as is supplied to it. However, this balance can be disturbed in homes that have one, centrally located return intake when interior doors are closed, blocking return of air supplied to private rooms. Other factors outside the scope of this study may also result in household pressure imbalances.

These research results are relevant to homes with forced air heating and cooling systems having a single, centrally located return air inlet with no engineered path for return air to exit closed rooms. Such systems pull return air from the whole house as long as interior doors are open.

When an interior door is closed, more air is supplied to the closed room than can be removed, or returned, from the room.

Positive pressure builds up in the closed room while a negative pressure occurs in the connected spaces. Positive pressure presses outward on all surfaces and may eventually reduce supply air flow into the closed room and while pushing conditioned air through small breaks in the room's air barrier.

To overcome house pressure imbalances caused by door closure, a variety of passive return path strategies are studied including a product produced by BAIHP Industry Partner Tamarack that overcomes privacy issues associated with through-wall grills. Achievable air flows for jump ducts, through-wall grilles, sleeved through-wall grilles, and the Tamarack baffled through-wall grille are presented.

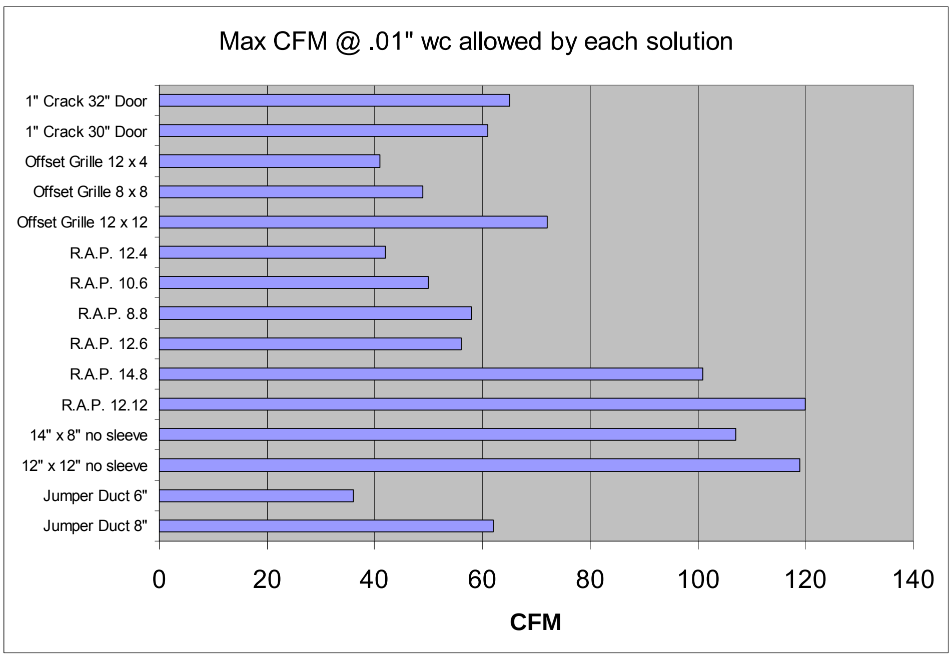


Figure 99 *Maximum air flow achievable using various return air paths from closed rooms for a give supply at a room pressure of 2.5 pa or 0.1" wc with respect to the return zone. For example, an 8" jumper duct could be used to maintain 0.01 wc in rooms with supply air up to 60 cfm.*

Heat Pump Water Heater Evaluation
Research by BAIHP Researcher Carlos Colon

BAIHP researcher tested the efficiency of a heat pump water heater manufactured by EMI, a division of ECR International. The unit features a compressor (R-134A refrigerant) with a wrap-around heat exchanger mounted on top of a 50-gallon storage tank. The latest controller board model #AK 4001 was installed during the test.

The temperature regulation of the unit is achieved by an adjustable potentiometer which sets a resistance that is measured by the controller board and translated into the corresponding temperatures. The set temperature is stored in the controller's memory.

Figure 100 *Airflow measurements using a Duct tester on heat pump cold air discharge*

The controller logic is designed to operate the heat pump when the temperature in the bottom of the tank drops below the effective dead band temperature of 30°F (20°F deadband + assumed stratification of 10°F). The heat pump shuts off when the temperature in the bottom of the tank has reached 10°F below the set point temperature. The upper element of the tank operates only when the temperature in the upper tank reaches 27°F below the set point temperature.

During laboratory testing the controller's performance was evaluated by measuring inlet and outlet water temperatures using thermocouples mounted to the copper inlet and outlet pipes as well as a Fluke hand-held thermometer inserted into the hot water outlet stream. One minute average measurements during draws were in agreement with the 10°F stratification logic utilized by EMI.

Also, following a series of hot water draws during the efficiency test (described below), the compressed refrigerant heat was able to replenish the tank to the 130 °F temperature level. However, following the heating recovery, neither compressor or resistance element were activated during standby until three days later when bottom tank temperatures dropped below 95°F. The compressor was called into operation when the tank was submitted to a hot water draw which triggered the ON compressor event in less than a minute.

Table 61 is a summary of electrical efficiency results generated from three tests performed in the laboratory. Tank pre-heating for test #1 and #2 were performed in a similar way, by forcing the compressor to turn "ON". The tank was allowed to loose heat on standby (1-2 days) and then purged with a draw of at least 30 gallons of new water. The purge forced the compressor to operate. Preheating for the test #3 was performed with the tank relatively hot and only twelve gallons of hot water were purged. This might explain the higher outlet temperatures read during test 3. For all three tests, we attempted to heat water so that initial hot water draws were near 130 °F (+/- 5 °F). However, we noticed that temperatures at the top of the tank (upper level) increased slightly with each purge (i.e., 10.7 gallon draw). During the third test shown in *Table 52* for example, outlet temperatures during the first draw averaged 129.2 °F, but during the last draw temperatures reached an average of 143.4 °F. The values shown for test #3 shows an overall hot water delivery temperature (T_{outlet}) of 136.6 °F. The controller never called for compressor or auxiliary energy when left on standby during the completion of the test (24-hr.).

Table 61 Electrical Efficiency Results from Laboratory Tests

Test	Total Gallons Drawn	Average T_{inlet} (°F)	Average T_{outlet} (°F)	Total Qout kWh	Total Qin kWh	COP
#1	63	82.3 °F	133.2 °F	7.756	3.974	1.95
#2	53.5	82.1 °F	131.2 °F	6.533	3.516	1.86
#3	65.9	82.0 °F	136.4 °F	8.789	4.254	2.06

Conclusions

The WattSaver™ heat pump water heater is rated with an energy factor (EF) of 2.45 and clearly demonstrates that heating water can be accomplished at a relative higher efficiency when compared to conventional electric water heaters. Installed in a conditioned space, and under operation with inlet water temperatures above 80 °F (e.g., Central Florida summer water mains temperatures), an average electrical (COP) efficiency of 2.0 was attained. Other measurements and performance indicators are summarized in *Table 62*.

Two caveats to the heat pump water heater's performance was first the delayed recovery during standby which would present larger hot water temperature variation to the residential user. This also leads to diminished hot water capacity during long periods of no hot water use activity. Second, because the compressor's discharge refrigerant (i.e., hottest temperatures) enter the wrap-around heat exchanger at the top of the tank, the unit demonstrated larger hot temperature variations at the tank's upper levels when the top portion was already pre-heated. These stratified tank temperature levels differ from those obtained when heating is started with the tank filled up with mains (colder) water conditions.

Table 62 Summary of Other Measurements and Performance Overview

Typical Cooling Air Flow rate: 87 CFM *(Figure 87)* Top cavity/Fan operating : -6.4 pa Evaporator Air temp: 73 °F (63%RH entering) / 53.1 °F (leaving) Condensate: 502.6 g/hr. (1.1 lb/hr) Sensible: 1900 Btu/hr. Latent: 957 Btu/hr Total Capacity : 2,857 Btu/hr	*Current consumption (208 VAC)* Compressor2.9 amps Fans (2) : 0.08 Amps/each Total 3.08 amps

NightCool - Building Integrated Cooling System
Study led by BAIHP Researcher Danny Parker

Technical Background
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. This is because a typical roof at 75° F will radiate at about 55-60 W/m^2 to clear night sky and about 25 W/m2 to a cloudy sky. For a typical roof (250 square meters), 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 characteristics (differential approach temperature, fan power, convection and conductance) limit what can be actually achieved, 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 typical homes experience cooling loads averaging 33 kWh per day from June - September with roughly 9.2 kWh (28%) of this air conditioning coming between the hours of 9 PM and 7 AM when night sky radiation could greatly reduce space cooling.

A big problem with night sky radiation cooling concepts has been that they have typically required exotic building configurations. These have included very expensive "roof ponds" or, at the very least, movable roof insulation with massive roofs so that heat is not gained during daytime hours. The key element of our new configuration is that rather than using movable insulation with a massive roof or roof ponds, the insulation is installed conventionally on the ceiling. The operation of the system is detailed in the attached schematic.

During the day, the building is de-coupled from the roof and heat gain to the attic space is minimized by a white reflective metal roof. During this time the space is conventionally cooled with a small air conditioner. However, at night as the interior surface of the metal roof in the attic space falls two degrees below the desired interior thermostat setpoint, the return air for the air conditioner is channeled through the attic space by way of electrically controlled louvers with the variable speed. The warm air from the interior then goes to the attic and warms the interior side 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 interior air temperature does not cool sufficiently or the relative humidity is not kept within bounds (<55% RH) the compressor is energized to supplement the sky radiation cooling. A dehumidifier is used when temperature conditions are favorable, but moisture conditions are not. The massive construction of the building interior (tile floor and concrete interior walls) will store sensible cooling to reduce space conditioning needs during the following day.


Figure 101 *Groundbreaking for the Nightcool instrumented experimental buildings, Florida Solar Energy Center*

Experimental Design

To verify the potential of the concept, the radiative cooling system will be tested in two 10 x 16' test structures. These highly instrumented buildings are located just south of the Building Science Lab *(Figure 101)* at the Florida Solar Energy Center (FSEC). Design and siting issues were resolved in 2004, and construction began in 2005.

One of the test sheds will be the control structure with a standard attic with R-19 ceiling insulation and an asphalt shingle roof with 1:300 ventilation. The experimental unit will have a white metal roof on metal battens and a sealed attic, which can be convectively linked to the main zone by a powered circulation fan. Both units will have slab floors, frame walls and solar control small double glazed windows.

A day/night monitoring protocol is being established with detailed instrumentation. This would involve measuring air mass flow with leaving and entering temperatures to the sealed attic space under the radiatively coupled roof. Weather parameters including a pyroheliometer would be used to determine potential night cooling along with nighttime heat dissipated to the integral night sky radiator system. Small room air conditioners would be used to supply supplemental cooling. Internal loads would be simulated by switching on and off interior lamps. A schematic of the test case and a similar drawing of the concept in a real home are shown in *Figures 102 and 103* (on pages 172 and 173).

<u>6th Budget Period: Detailed Simulation Model</u>

During the 6th budget period a detailed simulation model was created. Once the simulation model was validated against known solutions (Givoni, 1994 and Santamouris and Asimakopolous, 1996), the model was then mated to TMY2 hourly weather data to predict performance around the year under realistically changing weather conditions. For the calculations we use Tampa, Florida TMY2 data adjusting the weather data wind speed to account for the greatly diminished velocity seen over roof tops in experiments done at the Flexible Roof Facility (Parker and Sherwin, 1998). Florida weather is less advantageous for the analysis than many other locations since high summer dew points will often limit cooling potential. However, this allows evaluation of the concept under difficult environmental conditions

The seasonal analysis for Tampa from June - September showed that the nocturnal system would operate an average of 8.6 hours per day, producing an average of 15.2 kWh of cooling per day for a home with a consumption of fan energy of 1.4 kWh. In a typical Florida house using 33 kWh/day this could offset about 46% of required space cooling if all could be effectively utilized. The system average operating energy efficiency ratio (EER) was 37.1 compared too 10-15 for common vapor compression air conditioners. The average daily profile of performance is shown in *Figure 103* which shows the system performance.

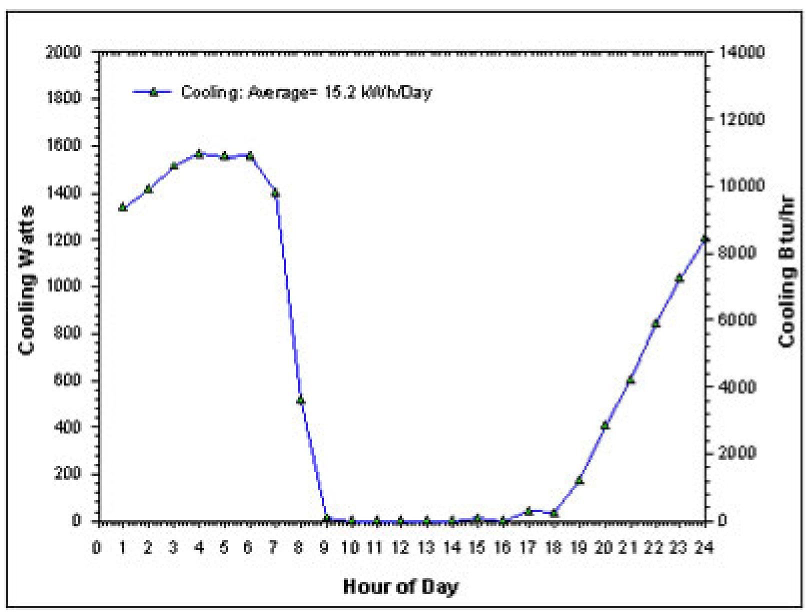


Figure 103 *Average hourly predicted cooling performance NightCool system*

Simulation in Other Climates

To examine concept performance elsewhere, we conducted the same simulation in three additional climates which we expected to evidence substantially different potentials. These were Atlanta, Georgia, reflecting a more moderate cooling dominated climate, Baltimore, Maryland with a mixed heating and cooling climate and Phoenix, Arizona with an arid, very hot climate.

Results are shown in *Table 63*. For comparison, performance indicated from the simulation for June - September are provided alongside those for Tampa, Florida. We also provide the results for the month of July in parentheses to illustrate how the cooling potential varies during the hottest conditions in each location.

Table 63 NightCool Simulation Results for Other Climates June - September and (July Only)

Parameter	Tampa, FL	Atlanta, GA	Baltimore, MD	Phoenix, AZ
Avg Daily Cooling kWh	15.2 (10.8)	50.3 (42.4)	62.4 (45.4)	23.2 (11.2)
Avg Hrs per Night	8.6 (7.6)	14.3 (13.9)	14.6 (13.6)	7.9 (5.3)
Fan kWh	1.4 (1.3)	2.4 (2.3)	2.4 (2.3)	1.3 (0.9)
COP	10.9 (8.3)	21.0 (18.4)	26.0 (19.7)	17.8 (12.4)
SEER (Btu/Whr)	37.1 (28.4)	71.5 (62.9)	88.7 (67.4)	60.9 (42.5)

Note that each climate other than Tampa shows better performance for the concept, both in absolute cooling and in overall cooling efficiency. Atlanta and Baltimore clearly indicate the concept to produce more cooling during evening hours than could be effectively utilized. For these locations, this would suggest both interior thermal storage and nighttime dehumidification to further offset daytime cooling needs.

The very hot climate of Phoenix, however, shows that like Tampa, the concept would only be able to offset 20 - 30% of daily cooling needs, although seemingly with the potential to essentially eliminate air conditioning loads during the swing months of April - May and October. Although Phoenix has less cloud cover, and greater diurnal temperature swing, the ambient evening temperatures tend to be hotter. Consequently, in this location, the NightCool system often does not start operation until after midnight. Even so, the concept showed efficient operation in all climates along with substantial ability to offset cooling needs in more temperate locations.

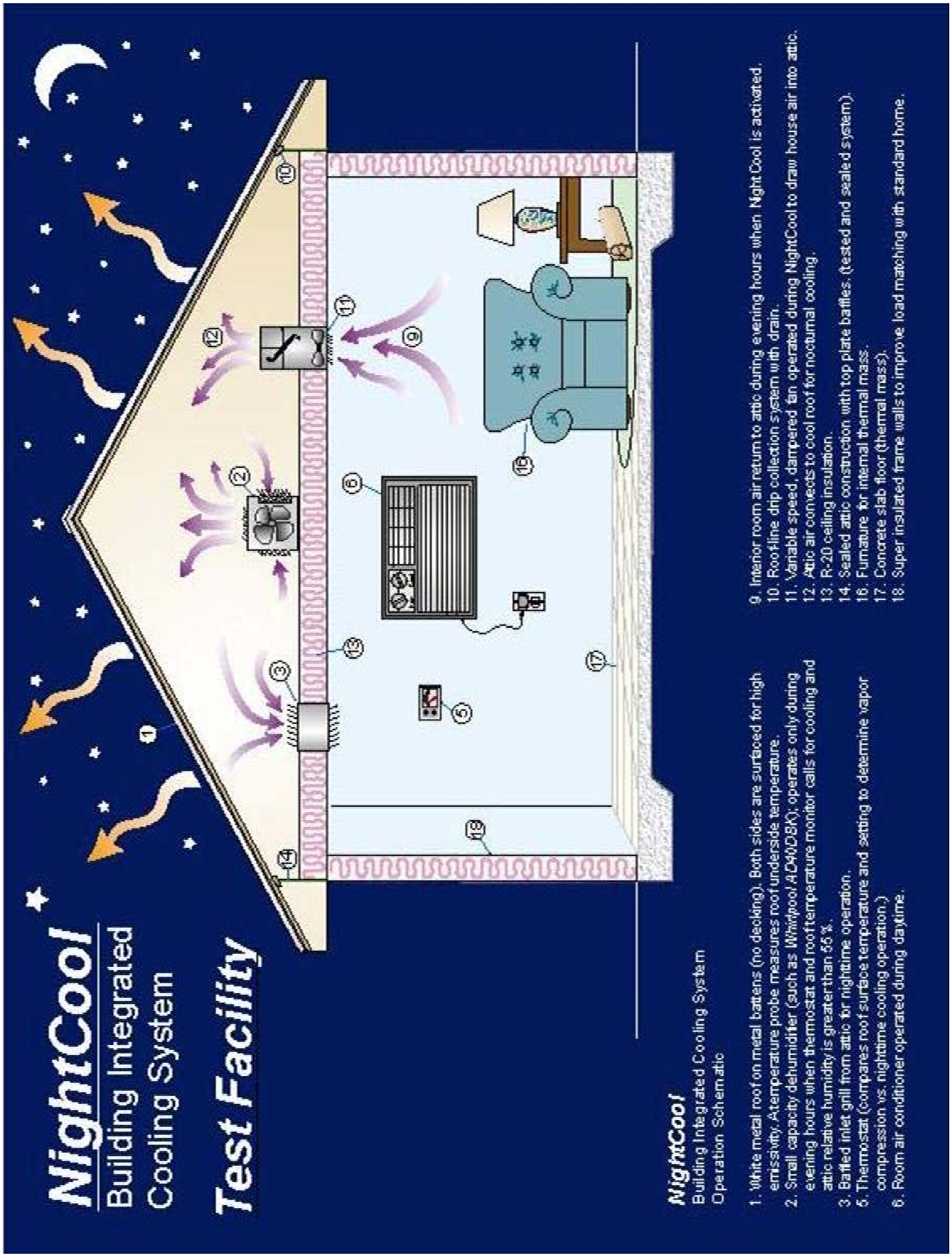


Figure 103 *-Scehmatic design for NightCool test facility.*

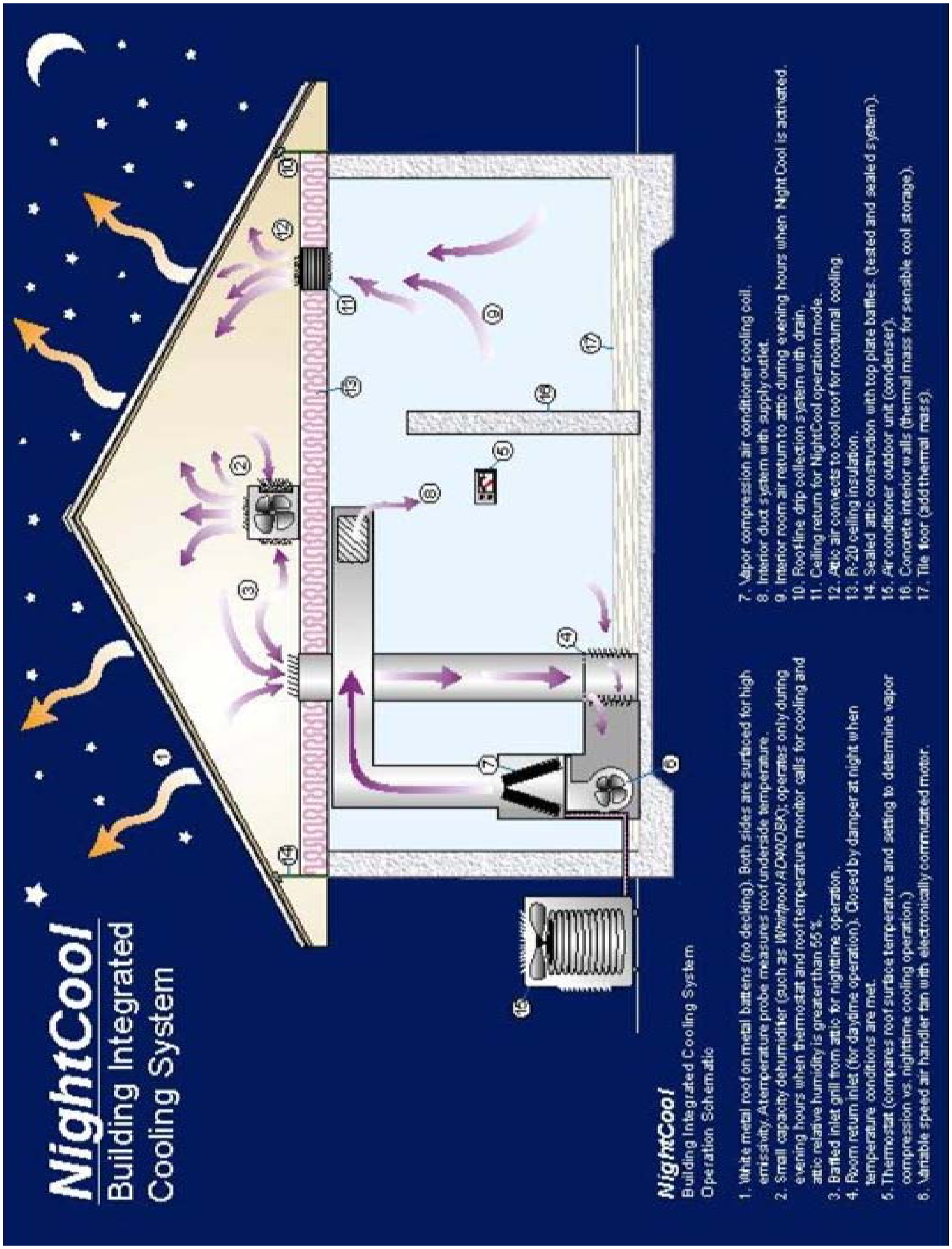


Figure 104 *Schematic of NightCool concept in typical residential building.*

IV

BAIHP WEB PAGE, TRAINING and PUBLICATIONS

BAIHP WEB PAGE, TRAINING, and PUBLICATIONS

BAIHP Web Page

The BAIHP web page at www.baihp.org *(Figure 105)* includes an Overview of the project, a summary of the types of Activities that BAIHP researchers are engaged in, the names and links for BAIHP Partners, and the names and brief bios for BAIHP Researchers.

Figure 105 *BAIHP Home Page at www.baihp.org*

Periodic updates are made to the web page in Case Studies of our Partners' BA projects, Current Data from BAIHP experiments, and BAIHP Publications. In addition to those current case studies, experiments, and publications listed in *Table 64*, 44 BAIHP press items are included in *Media Recognition* and 13 Pre-2000 Publications are listed separately in "Publications". *(See also BAIHP Publications 09/99-03/04 in this document following the BAIHP Training section.)*

Contact Us information is given for a variety of project staff, DOE officers, and sub-contractors. The web page has been visited approximately 20,000 times since August of 2000.

Table 64 – BAIHP Web Page Contents for Case Studies, Publications and Current Data

BAIHP Case Studies	Publications
▪ Metal Roof Retrofit on a Hurricane Damaged Home ▪ Building America Partners with Habitat for Humanity ▪ City of Orlando, Florida ▪ Cold Climate Case Study: High Efficiency North Dakota Twin Homes ▪ WCI Communities at Evergrene ▪ Show Me the Money: Selling Builders on Systems Engineering ▪ Pet House Project ▪ Cambridge Homes at Baldwin Park ▪ Zero Energy Manufactured Home ▪ Six Moisture Home Case Studies ▪ Making the DREAM Home a Reality ▪ Highly Efficient Central Florida Home ▪ Habitat for Humanity - Energy Star Examples ▪ Side-by-side Comparison of Manufactured Homes (Palm Harbor Homes – NCATU Campus) ▪ Super Good Cents/Natural Choice Program ▪ Portable Classrooms ▪ Side-by-side comparison of Manufactured Homes (Stylecrest Sales and Fleetwood Homes) ▪ Palm Harbor Homes – 16 Factories in 8 States ▪ Habitat for Humanity – Plains, GA ▪ The Entry Level Homes Study – Orlando, FL ▪ Health House® 1997 – Orlando, FL ▪ Health House® 1996 – New Orleans, LA **Current Data (BAIHP Research)** ▪ Manufactured Housing Lab ▪ Highly Efficient Central Florida Home ▪ Side by Side Comparison of Manufactured Housing (Palm Harbor – NCATU) ▪ Portable Classrooms ▪ Filter Back Grill Experiment	▪ BAIHP Annual Report – Fifth Budget Period ▪ Development of High Efficiency Air Conditioner Condenser Fans ▪ Effect of Residential Ventilation Techniques for Hot and Humid Climates on Indoor Concentrations of Volatile Organic Compounds (02/05) ▪ Manufactured Home Performance Case Study: A Preliminary Comparison of Zero Energy and Energy Star ▪ Assessing Six Residential Ventilation Techiniques in Hot and Humid Climates (08/04) ▪ Geographic Variation in Potential of Rooftop Residential Photovoltaic Electric Power Production in the United States (08/04) ▪ Cold Climate Case Study; High Efficiency North Dakota Twin Homes (08/04/ ▪ Energy Star Manufactured Homes: The Plant Certification Process (08/04) ▪ Optimizing Manufactured Housing Energy Use (05/04) ▪ Standards for Clean Air Florida Homes (03/04) ▪ Alleviating Moisture Problems in Hot, Humid Climate Housing (01/04) ▪ BAIHP Annual Report – Fourth Budget Period (12 03) ▪ Achieving Airtight Ducts in Manufactured Housing (09/03) ▪ Show Me the Money: Selling Builders on Systems Engineering (04/03) ▪ Technical services provided to the HUD Code and modular home industry. (04/03) ▪ Measured and Simulated Cooling Performance Comparison; Insulated Concrete Form Versus Frame Construction (08/02) ▪ The Building America Industrialized Housing Partnership (05/02) ▪ Performance and Impact from Duct Repair and Ventilation Modifications in Two Newly Constructed Manufactured Houses Located in a Hot and Humid Climate (05/02) ▪ Moisture Problems in Manufactured Housing: Probable Causes and Cures (11/01) ▪ Preventing House Dust Mite Allergens in New Housing (11/01) ▪ Design and Construction of Interior Duct Systems (04/01) ▪ Energy Efficiency and Moisture Retention Data Report (2001) ▪ Ventilation in US Manufactured Homes (09/00) ▪ Evaluation of EnergyGauge® USA, A Residential Energy Design Software, Against Monitored Data (08/00)

BAIHP Training

BAIHP research is communicated to public and industry audiences through the BAIHP web page, conference papers and presentations, and various media coverage. *Table 65* shows training events in reverse chronological order and is divided by budget period. Following the table are summaries of training events organized by audience and a summary of BAIHP web page and media coverage.

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Mar 2005	'05 SIPA National Mtg	Benefits and Challenges of SIPS, a Building America, Systems Engineering Perspective	McIlvaine	SIP Industry/~130
Feb 2005	Sarasota FL	Florida Green Home Certification Course	Martin	27 students including 15 builder's reps.
Jan 2005	ASHRAE Technical Program – Orlando, FL	Presentation: Ventilation Strategies in Hot and Humid Climates	Moyer	ASHRAE Engineers/HVAC Industry
Jan 2005	ASHRAE Technical Program – Orlando, FL	Presentation: Whole Buildings: Why Everything Interacts	Moyer	ASHRAE Engineers/HVAC Industry
Dec 2004	Performance of Exterior Envelopes of Whole Buildings IX, Clearwater (FL)	Accepted Paper on Side by Side Monitoring of Energy Star and Standard HUD Code Home.	McGinley	Energy Efficiency Industry
Dec 2004	Performance of Exterior Envelopes of Whole Buildings IX, Clearwater (FL)	Accepted Paper: Cold Climate Case Study of North Dakota Twin Homes for Performance of Exterior Envelopes	Chasar	Energy Efficiency Industry
Dec 2004	Performance of Exterior Envelopes of Whole Buildings IX, Clearwater (FL)	Accepted Paper: Residential Ventilation Techniques	Moyer	Energy Efficiency Industry
Nov 2004	ASHRAE Puget Sound Chapter Annual Meeting, Seattle (WA)	Invited speaker Presentation on ASHRAE TC6.3 Activities	Lubliner	ASHRAE Engineers/HVAC Industry
Nov 2004	Ft. Walton Beach	Greening Our Growth: Using Green Standards to Guide Our Growth.	Martin	Local Government / Utilities ~ 10
Nov 2004	Ft. Walton Beach	Florida Green Home Certification Course	Martin	Builders/consultants ~ 10

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Nov 2004	USGBC GreenBuild Conference – Portland, OR	Impact of Roofing Systems on Residential Cooling Energy Demand.	Martin	Green Industry
Oct 2004	FSEC	Training: Green Home Construction Practices	E. Martin	WSI Architects – 13
Oct 2004	FSEC	Presentation: High Performance Homes	S. Chandra	FSEC Policy Advisory Board
Oct 2004	FSEC	EnergyGauge Class 1 Rating Course	N. Moyer	2 students
Oct 2004	WCI Communities – Bonita Springs, FL	Florida Green Home Certification Course	Martin	Architects ~ 15
Oct 2004	WCI Communities – Bonita Springs, FL	Overview of Home Building Programs in Florida: Getting to Zero Energy.	Martin	Architects ~ 25
Oct 2004	MHI Annual Meeting, Energy Roadmap session Palm Springs (CA)	Invited speaker Presentation on BAIHP in the PNW	Lubliner	MHI-HUD Code Industry
Oct 2004	EEBA, Dallas, TX	Presentation: Producing Airtight Ducts	Moyer	Energy Efficiency Industry
Oct 2004	EEBA, Dallas, TX	Presentation: Ventilation in Humid Climates Data from Field Experiments	Moyer	Energy Efficiency Industry
Sept 2004	AIVC Conference Prague, (CZ)	Invited paper Performance and Application of Gossamer Wind Solar Powered Ceiling Fans	Lubliner, Parker, Chaser	International Building Science Community
Aug 2004	FSEC	EnergyGauge Class 1 Rating Course	N. Moyer	8 students
Aug 2004	Solar Energy Society of Canada, Waterloo	Invited paper: Justification for Energy Efficient and Renewable Energy Systems	McCluney	Energy Efficiency Industry
Aug 2004	Florida Pollution Prevention Conference – Gainesville, FL	Creating a Green and Profitable Work Environment.	Martin	Local Governments, researchers, industry
Aug 2004	SE Builder Conference – Orlando, FL	Presentation: Health House Design and Construction	Moyer, Chandra	Builders

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Aug 2004	SE Builder conference – Orlando, FL	Presentation: Indoor Air Quality – Positioning Yourself for This Growing Market	Moyer, Chandra	Builders
Aug 2004	ACEEE Summer Study, Pacific Grove (CA)	Accepted Paper: Six Residential Ventilation Techniques in Hot and Humid Climates	Chasar for Moyer	Energy Efficiency Industry
Aug 2004	ACEEE Summer Study, Pacific Grove (CA)	Accepted Paper: Energy Star Manufactured Homes: The Plant Certification Process	Chasar	Energy Efficiency Industry
Aug 2004	ACEEE Summer Study, Pacific Grove (CA)	Accepted Paper: Revision to the Energy-Efficiency Requirements in MHCSS	Lubliner, Conner, Dillon, Lucas	Energy Efficiency Industry
Aug 2004	ACEEE Summer Study, Pacific Grove (CA)	Panel Moderators: Residential Technologies 24 papers	Lubliner, Parker	Energy Efficiency Industry
July 2004	American Lung Association	Energy Efficiency and IAQ seminar	S. Chandra	American Lung Association staff
July 2004	FSEC	RHVAC Manual J Software and Manual J8 Instruction	FSEC staff	10 Building Scientists
Jul 2004	American Solar Energy Society Conference	Invited Paper: Introducing Solar Ready Manufactured Housing	Lubliner, Hadley, and Gordon	Solar Energy Industry
Jun 2004	Sarasota, FL	Florida Green Homes Certification Course	McIlvane	23 students
Jun 2004	ASHRAE Annual Meeting, Nashville, (TN)	Invited Author ASHRAE 2004 HVAC and Equipment Handbook Chapter 9 Residential HVAC Systems	Lubliner, Andrews, et. al	ASHRAE Engineers/HVAC Industry
Jun 2004	ASHRAE Annual Meeting, Nashville, (TN)	Invited symposium Abstract – HVAC Systems and Performance in Building America Homes	Lubliner, Vorha	ASHRAE Engineers/HVAC Industry

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Jun 2004	Lakewood Ranch Polo Club – Sarasota, FL	Florida Green Home Certification Course	Martin	Builders/consultants ~ 25
May 2004	Seaside Institute – Seaside, FL	Building Science and Home Building Programs in Florida (w/ Southface)	Vieira	Builders ~35
May 2004	Florida GreenTrends Conference	Green Building at the Municipality Level: Developing a Standard for Florida Local Governments.	Martin	Green Industry
Apr 2004	FSEC – Cocoa, FL	Florida Green Home Certification Course	Martin	Builders/consultants ~ 25
Apr 2004	14th Symposium on Improving Building Systems in Hot and Humid Climates, Dallas TX	Presentation: Achieving Airtight Ducts in Manufactured Housing	McIlvaine	Energy Efficiency Industry
Apr 2004	14th Symposium on Improving Building Systems in Hot and Humid Climates, Dallas TX	Presented Referred Paper: Optimizing Manufactured Housing Energy Use	McGinley	Energy Efficiency Industry
Apr 2004	14th Symposium on Improving Building Systems in Hot and Humid Climates, Dallas TX	Presented Referred Paper: An Overview of Experimental Research on Houses by the Building America Industrialized Housing Partnership	Chandra	Energy Efficiency Industry
Apr 2004	14th Symposium on Improving Building Systems in Hot and Humid Climates.	Presented Referred Paper: Air Duct Tightness in Manufactured Housing	McIlvaine	Energy Efficiency Industry
Apr 2004	HFH National Leadership Conference	Presentation, 1.5 hours: Advanced Building Science and Moisture Control	McIlvaine	HFH Construction Managers and Leaders
Apr 2004	SPIE Defense and Security Symposium, Orlando FL	Presentations: Introduction to Radiometry and Photometry	McCLuney	Optical engineers

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Apr 2004	Affordable Comfort Conference, Minneapolis	Presentation: Summertime Humidity Control: High Performance Home Challenges	Moyer	Energy Efficiency Industry
Apr 2004	Affordable Comfort Conference, Minneapolis	Presentation: Vented & Unvented Roof Assemblies: What Not To Do	Moyer	Energy Efficiency Industry
Mar 2004	IBACOS/FSEC Monitoring Workshop Meeting	FSEC co-hosted 1-day workshop session with IBACOS. Presentations by researchers from NREL, Davis Energy Group, IBACOS and FSEC as well as reps from Campbell (dataloggers) and Data Taker.	Chasar, Kalaghchy (FSEC Computer Resources Manager), BAIHP Staff	BA Researchers
Mar 2004	GreenPrints Conference, Atlanta	Presentation: Techniques You Should Incorporate In Your New Home or How to Star in the High Hurdles,	Vieira	Builders, Energy Efficiency Industry ~75 attendees
Mar 2004	www.baihp.org	Posted Standards for Clean Air Florida Homes	Chandra	Builders, Manufacturers, Building Scientists, Public
Feb 2004	Central Atlantic Coast HFH Conference	Presentation, 2 hours: Advanced Building Science and Moisture Control	McIlvaine	~100 HFH Construction Managers/Staff
Feb 2004	www.baihp.org	Posted Achieving Airtight Ducts in Manufactured Housing	McIlvaine	Builders, Manufacturers, Building Scientists, Public
Feb 2004	www.baihp.org	Posted Alleviating Moisture Problems Hot, Humid Climate Housing	Moyer	Builders, Manufacturers, Building Scientists, Public
Feb 2004	www.baihp.org	Posted Case Study: WCI Communities at Evergrene	Martin	Builders, Manufacturers, Building Scientists, Public

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Feb 2004	FSEC, Cocoa (FL)	Workshop, 3 day course: Class 1 Florida Home Energy Rater Training. Included Certification exam	Moyer	Energy Raters
Jan 2004	USDOE Expert Meeting, Anaheim (CA)	Expert meeting co-developed with ASHRAE: Residential HVAC Fans and Systems		Building Scientists
Jan 2004	Southeastern Habitat for Humanity Conference, Jekyll Island (GA)	Short Course: Advanced Building Science and Moisture Control	McIlvaine	~60 HFH Construction Managers/Staff
Jan 2004	BAIHP Task Meeting, Cocoa, FL	Moisture in Housing	Moyer	BA Team members
Jan 2004	BAIHP Task Meeting, Cocoa, FL	Ventilation & Moisture Research	Moyer	BA Team members
Jan 2004	International Builders' Show/NAHB Conference, Las Vegas	Represented BAIHP at DOE booth	Chandra	Builders
Jan 2004	NAHB International Builder Show, Las Vegas (NV)	Presentation at Energy Value Housing Awards Workshop	Lubliner	Energy Efficiency Industry
Jan 2004	ASHRAE Winter Meeting, Anaheim, CA	Presentation: Ventilation in Hot-Humid Climates	Moyer	HVAC Industry
Jan 2004	ASHRAE Winter Meeting, Anaheim, (CA)	Symposium Session Chairman – "Factors Influencing Energy Performance of Residential HVAC"	Lubliner, Parker, et. al	ASHRAE Engineers/HVAC Industry
Jan 2004	ASHRAE Winter Meeting, Anaheim, CA	Moderator/Coordinator for USDOE Building America Fan Energy Expert Meeting	Lubliner	ASHRAE Engineers/HVAC Industry
Dec 2003	FSEC, Cocoa (FL)	Workshop, 1 day course: Green Home Certifying Agents for Florida Green Building Coalition	Martin	Green Home Certifying Agents, Candidates

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Nov 2003	GreenBuild Conference and Expo, Pittsburgh (PA)	Presented Paper: Complying with Florida's Green Land Development Standard: Case Studies and Lessons Learned		Builders, Public, Building Scientists and Related Specialists
Nov 2003	www.baihp.org	Revised Partner contact information and maps for each region		Builders, Manufacturers, Building Scientists, Public
Oct 2003	Workshop with ALACF, Orlando	Workshop, 2 day, Building Health Houses	Chandra and Hutchinson	14 Builders and Suppliers
Oct 2003	AIVC Conference, Washington	Presented Referred Paper: Building Envelope, Duct Leakage and HVAC System Performance in HUD-Code Manufactured Homes	Lubliner	Building Scientists
Oct 2003	AIVC Conference Washington, DC	Accepted Paper: Building Envelope, Duct Leakage and HVAC System Performance In HUD-Code Manufactured Homes		Lubliner, Moyer
Oct 2003	FSEC, Cocoa (FL)	BAIHP staff hosted a full day meeting for 4 person team from India. Topics: codes and standards, tools, training, voluntary green building programs, Florida regulatory and voluntary house building programs		4 person team from India
Oct 2003	International Conference for Enhanced Building Operations, Berkeley, California	Accepted Paper: An Assessment of Six Residential Ventilation Techniques in Hot and Humid Climates	Moyer, Parker, Chandra	Energy Efficiency Industry
Oct 2003	EEBA, Lincolnshire, IL	Presentation: Thermal & Moisture Control of Wall Surfaces – Hot & Humid Climate Perspective	Moyer	Energy Efficiency Industry
Sept 2003	Florida Housing Coalition Conference, Miami	Presentation: BAIHP benefits and applicability to affordable housing	Martin	~25 Affordable Housing Providers

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
Sept 2003	Sierra Club, Melbourne (FL)	Green Buildings	Martin	Environmental ~30 attendees
Sept 2003	www.baihp.org	Created Infomonitors data page for Zero-Energy Manufactured Home www.infomonitors.com/zmh Created Infomonitors data page for Zero Energy Habitat House (with ORNL) http://www.infomonitors.com/onl		Building Scientists
Aug 2003	FSEC, Cocoa (FL)	Workshop, ½ day course: Why the Ceiling Fell In	Moyer	Public, Construction Industry
Aug 2003	FSEC, Cocoa (FL)	Workshop, 1 day course: Diagnosing Moisture Problems	Moyer	Public, Construction Industry
Aug 2003	FSEC, Cocoa (FL)	Workshop, 3 day course: Class 1 Florida Home Energy Rater Training includes certification exam	Moyer	Energy Raters
Aug 2003	FSEC, Cocoa (FL)	Workshop, 1 day: Green Home Certifying Agents for the Florida	Martin	9 Attendees seeking certification
Aug 2003	www.baihp.org	MHLab Ventilation Study	Moyer	Builders, Manufacturers, Building Scientists, Public
Jul 2003	American Lung Association: Mid-Florida, Builder Training, Orlando	Presentation: Health House Builder Training (1.5 days)	Chandra, Moyer	Potential ALA Health House Builders
July 2003	Southeast Builders Show, Orlando (FL)	Short Course, 3 Hour: Health House Builder Guidelines	Chandra, Hutchinson, Tim Kensok (Honeywell)	100+ attendees, 90 builders attended all or part of course. 19 builders indicated desire to be certified Health House Builders
July 2003	www.baihp.org	Brookside Apartment testing	Chandra	Builders, Manufacturers, Building Scientists, Public

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
July 2003	www.baihp.org	Palm Harbor Energy Star Plan certification	Chasar	Builders, Manufacturers, Building Scientists, Public
July 2003	Florida Local Environmental Resource Agencies Conference, Jupiter Beach (FL)	Green-home elements and Florida standards; How local governments can foster green building within their community.	Martin	Local Government Staff ~15 attendees
July 2003	World Resources Institute Bell Conference, Ft. Lauderdale (FL)	Panel Session: The Business of Green Construction	Martin	Business, local government, state regulatory agencies ~20 attendees
June 2003	Recycle Florida Today Conference, St. Petersburg Beach (FL)	Presentation, 30 minutes: Green-home elements and Florida standards	Martin	~35 attendees, government (local and state), solid waste management /recycling industry
June 2003	U.S. - Spain Construction Forum, Miami (FL)	Presentation: Florida Green Building Coalition	Chandra	~20 attendees
June 2003	ASHRAE Summer Meeting, Kansas City (KS)	Presentation: Duct Leakage in New Washington State Residences: Findings and Conclusions	Lubliner	Energy Efficiency Industry
May 2003	Energy Efficiency + Solar Energy = Zero Energy Homes, Orlando (FL)	Presentation: Florida Green Home Designation; Panel included 3 BAIHP builder partners	Martin	~30 attendees eligible for 2 CEUs
May 2003	www.baihp.org	Posted Case Study: Show Me the Money: Selling Builders on Systems Engineering.	Fonorow	Builders, Manufacturers, Building Scientists, Public
May 2003	www.baihp.org	Posted Technical Services Provided to the HUD Code and Modular Industry	Chandra	Builders, Manufacturers, Building Scientists, Public

Table 65 Training and Presentations by BAIHP Staff January 2002 – March 2005

Month	Venue	Description	Researcher	Audience/Attendees
April 2003	2003 MHI Conference, Las Vegas (NV)	Presentations: Use of innovative crossover-duct system; Duct mastic riser system Exhibit: BAIHP booth	Chandra, Mullens	BAIHP partners and conference attendees
April 2003	Puyallup Manufactured Home Show, Puyallup, (WA)	Exhibit: Technical and marketing assistance, worked with utility representatives to promote incentives	Lubliner	General public, MH dealers, home manufacturers and other industry representatives
Apr 2003	Affordable Comfort Conference, Kansas City	Presentation: Dehumidification-Principles and Strategies	Moyer	Energy Efficiency Industry
Apr 2003	Affordable Comfort Conference, Kansas City	Presentation: Cooling, Ventilation, & Dehumidification in Energy Efficient Homes	Moyer	Energy Efficiency Industry
Nov 2002	The Quality Modular Building Task Force	Presentation: Research Results: Energy Benchmarking	Moyer, Mullens	Modular Builders & Suppliers
Oct 2002	EEBA, Phoenix, AZ	Presentation: BAIHP Updates	Moyer	Energy Efficiency Industry
Apr 2002	Affordable Comfort Conference, Cincinnati (OH)	Presentation: BA: New Buildings that Last	Moyer	Energy Efficiency Industry
Mar 2002	2002 RESNET Conference, Cocoa, FL	Presentation: Moisture “Opportunities” For Manufactured Housing	Moyer	Energy Efficiency Industry

BAIHP Training Events by Audience

BAIHP has presented research findings and Building America concepts to a variety of audiences including architects, builders, HUD Code home manufacturers, and housing decision makers; construction trades and realtors; attendees at building science conferences; portable classroom producers and decision makers; energy raters and green home certifiers, and college students in academic venues.

<u>Audience: Architects in 6th Budget Period</u>

WCI Communities: Gave an overview of “Home Building Programs in Florida: Getting to Zero Energy, October 2004.

Audience: Architects Prior to 6th Budget Period
North Florida AIA Chapter: Introduced the Building America program, Florida Green Building Standards, and related issues during a presentation at a monthly meeting. 23 registered architects attended.

Evans Group: In 2002, researchers gave a presentation to the Evans Group in their Orlando office. Presentation and discussion issues included: mechanical system right-sizing, dehumidification strategies, mechanical system sensible heat ratios, importance of and methods to provide outside air and associated pressurization issues, and the impact of spectrally selective low-E windows on equipment sizing and occupant comfort. This presentation led to BA involvement in the 2003 SEBC Southern Showplace Home.

Audience: Builders, HUD Code Home Manufacturers, and Housing Decision Makers during 6th Budget Period
Green Building Seminars: BAIHP staff green building concepts" to
- Utilities and local government in Ft. Walton Beach, November 2004
- Florida Pollution Prevention Conference, August 2004
- Florida GreenTrends Conference, May 2004.

SE Builder Conference: BAIHP researchers presented Health House House Design and Construction, and Indoor Air Quality – Positioning Yourself for This Growing Market", August 2004.

Building Science
- Seaside Institute: presented building science and home building programs to approximately 35 builders, May 2004.
- HFH National Conference: presented advanced building science and moisture control to construction managers and leaders, April 2004.

Manufactured Housing Institute Annual Meeting, Energy Roadmap session: BAIHP staff presented information about BAIHP activities in the Pacific Northwest, October 2004.

Audience: Builders, HUD Code Home Manufacturers, and Housing Decision Makers during 5th Budget Period
American Lung Association: Presented by BAIHP and ALACF Building Health Houses, 2-day course for 14 builders.

Florida Housing Coalition Conference: BAIHP staff presented benefits and applicability of Building America concepts to affordable housing in September of 2003 to approximately 25 affordable housing providers.

Green Building Seminars: BAIHP staff presented green building concepts including the Florida Green Home Standard at:
- Energy Efficiency + Solar Energy = Zero Energy Homes in Orlando, May 2003
- Recycle Florida Today Conference in St Petersburg Beach (FL), June 2003
- U.S.-Spain Construction Form in Miami, June 2003
- Florida Local Environmental Resource Agencies Conf. in Jupiter Beach (FL), July2003
- Sierra Club members in Melbourne (FL), September 2003

Habitat for Humanity Construction Managers: FSEC presented an advanced building science course for construction managers at two HFH conferences with one presentation planned for April:

- 2004 Southeastern Habitat Conference (GA): 4 hour session, ~60 attendees January
- 2004 Central Atlantic Conference (NC); 2 hour session, ~100 attendees February
- 2004 National Leadership Conference (TX): 1.5 hour session,, April

Most participants had attended a basic building science course taught by FSEC or HFHI's Green Team at a previous conference. Discussion sprang from case studies and covered moisture detailing, air flow and pressure dynamics, return air pathways, reaching beyond Energy Star, new water heating options, and foundation detailing. An enthusiastic crowd with informed questions showed a tremendous increase in building science awareness among Habitat construction managers compared to the attendees in the early days Building America's involvement with Habitat.

A two-hour version of the course was presented at the Central Atlantic Conference to approximately 100 attendees with similar response. FSEC has been asked to present the material again at the National HFH Leadership Conference in April and the Central States HFH Conference in October 2004.

Habitat for Humanity Construction Volunteers: FSEC spearheaded energy efficiency training at the 2003 Jimmy Carter Work Project sites in Anniston (AL) and LaGrange (GA) *(Figure 106)*. FSEC worked with volunteer Energy Monitors at both sites prior to the blitz build to train project staff and supervisory volunteers regarding the elements of the energy packages and to assist with material and equipment specs and procurement. During the initial orientation sessions, volunteers got an overview of the energy features of the houses. During the week-long blitz build, FSEC and HFHI staff held training sessions each morning to discuss and demonstrate the energy details of the day.

Figure 106 *Volunteers follow energy efficiency guidelines for building Energy Star houses during Habitat for Humanity 2003 Jimmy Carter Work Project*

Volunteers learned and practiced how to seal the whole house air barrier and interior air handler/furnace closets, install insulation, install exterior rigid insulation, and install flashing around windows and doors. Since the weather was rainy all week, volunteers, homeowners, and project managers were concerned with moisture issues which led to moisture discussions regarding vapor diffusion, material drying dynamics, and moisture flow in assemblies. Approximately 500 volunteers in LaGrange (22 Energy Team Volunteers) and 800 volunteers in Anniston (~35 Energy Team Volunteers) received a hands-on education in energy efficiency, indoor air quality, moisture details, and (in Anniston) combustion safety. An Alabama environmental group installed radon mitigation systems in all 35 Anniston homes.

Volunteers participated in testing the homes they had built in LaGrange. In the end, the volunteers built 22 Energy Star Homes in LaGrange and 35 near Energy Star homes in Anniston. Due to a lapse in communication, the air conditioners procured for the Anniston site were SEER 10 instead of SEER 12, narrowly missing the Energy Star mark for all 35 homes.

Health House Workshop (Orlando): In July 2003 FSEC researchers conducted a Health House builder workshop with the American Lung Association of Central Florida (ALACF) at the Southeast Builders Show. Approximately 90 builders attended. The team conducted a 3 hour short course on the Health House Standard in October 2003, with 14 builders and suppliers attending.

International Builders' Show: BAIHP staff assisted at the BA booth, speaking with potential Partners and interested parties.

2003 MHI Conference (Las Vegas, NV): BAIHP presented Use of an Innovative Crossover Duct System and Duct Mastic Riser System and helped staff the Building America Booth.

Moisture Issues Seminars: BAIHP staff presented a 1 day course titled *Diagnosing Moisture Problems* and a ½ day course *Why the Ceiling Fell In* at FSEC in August 2003.

Puyallup Manufactured Home Show (WA): BAIHP staff provided technical and marketing assistance and worked with utility representatives to promote energy efficiency incentives.

2003 Southeast Builders Show (Orlando, FL): 3 hour short course: Health House Builder Guidelines, 100+ attendees with 90 builders attending part of or the entire course. 19 builders indicated desire to be certified Health House Builders.

<u>Audience: Builders, HUD Code Home Manufacturers, and Housing Decision Makers during prior to 5th Budget Period</u>
Home Builders: Courtland Homes, Habitat for Humanity, Ashton Woods, Engle Homes, Beazer Homes, and Golden Heritage Homes.

Habitat for Humanity Workshops: From April 2001 to March 2003, BAIHP conducted: (1) a one-hour session on Energy Code changes and energy efficiency concepts for Florida Habitat for Humanity construction managers at the Spring Construction Round Table, (2) training for City of Lubbock personnel, city builders and Habitat personnel, (3) mechanical contractor and duct installer training for Calhoun County Alabama affiliate, and (4) HFHI workshop for 60 Ohio affiliates on the home energy rating process, the house as a system concept, best improvements for Ohio affiliates and house pressure and combustion safety.

Duct Systems Workshop: In 2000, workshops in Oregon and Washington focused on improved duct installation and inspection oversight, particularly on the use of mastic as a sealing strategy for ductwork joists. Manufacturers Palm Harbor Homes, Fleetwood Homes (Washington and Oregon) and Valley Manufactured Housing participated. In 2001, these same manufacturers participated along with Fuqua Homes, Marlette, and all of the Idaho manufacturers. In 2002, BAIHP staff continued to provide these workshops, working in partnership with BAIHP partner Flexible Technologies to demonstrate the added value of their innovative duct sealing technologies

Energy Seminar: In 2002, BAIHP participated in an energy seminar held in Gainesville, FL., entitled *"Responsible Buying, Building, or Retrofitting for Higher Energy Efficiency and Comfort in Homes."* 80 - 100 people attended the seminar.

Fenestration Short Course: Researchers presented a half-day short course to about 25 attendees on windows at the Fenestration Manufacturers of Florida meeting in Ft. Lauderdale. The session was completed in approximately three hours, followed by about a half hour discussion. A broader presentation has been planned to include the entire United States.

Fleetwood Homes: Researchers made a presentation to Fleetwood corporate representatives on BAIHP research efforts - concentrating on Energy Star and the use of a crossover duct system with a flex flow elbow.

Health House Workshops: In 2002, FSEC researchers conducted a Health House builder workshop for the American Lung Association of Central Florida (ALACF). This workshop helped the National Health House group determine the best format for presenting National Health House guidelines to builders.

MHRA Energy Star Committee: Assisted MHRA on a request for on Quality Assurance procedures for Energy Star manufactured homes in a joint effort with the US EPA.

Mid Florida Builders Association: BAIHP held a seminar in August 2002 in Maitland (FL) on building healthy, energy efficient homes in central Florida. More than 60 builders attended the program and many were still asking questions more than two hours after the seminar formally ended. Researchers also provided a building science seminar for Shea Active Adult sales and construction personnel and for the general public.

Audience: Trades and Realtors
In 2002, BAIHP provided training for Trane Air Conditioning Company and developed a certified New Home Professional Realtor Course attended by 22 real estate professionals

<u>Audience: Papers and Presentations at Building Science Conferences in 6th Budget Period</u>
Conference Name (number of papers accepted/presented, date)

- '05 SIPA National Meeting (1, March 2005)_
- ASHRAE Technical Program (2, Jan 2005)
- Performance of Exterior Envelopes of Whole Buildings IX (3, December 2004)
- USGBC GreenBuild Conference (1, November 2004)
- ASHRAE Puget Sound Annual Meeting (1, November 2004)
- Energy Efficient Building Association Conference (2, October 2004)
- 25th Conference of the Air Infiltration and Ventilation Centre (1, September 2004)
- 29th Annual Conference of the Solar Energy Society of Canada Inc (1, August 2004)
- American Council on an Energy Efficient Economy (ACE3) Summer Study (3, August 2004)
- American Solar Energy Society (ASES) Conference (1, July 2004)

- ASHRAE Annual Meeting (2, June 2004)
- 14th Symposium on Improving Building Systems in Hot and Humid Climates (3, April 2004)
- SPIE Defense and Security Symposium (1, April 2004)
- Affordable Comfort Conference (2, April 2004)

Audience: Papers and Presentations at Building Science Conferences prior to 6th Budget Period

- GreenPrints Conference (1, March 2004)
- US DOE Expert Meeting, Residential HVAC Fans and Systems, Co produced with ASHRAE at Winter Meeting in Anaheim.
- GreenBuild Conference and Expo (1, November 2003)
- Air Infiltration and Ventilation Centre (AIVC) Conference (1, October 2003)
- American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Summer Meeting (1, June 2003)2002 American Council on an Energy Efficient Economy (ACE3) Summer Study: four papers presented:
- Pushing the Envelope: A Case Study of Building the First Manufactured Home Using Structural Insulated Panels
- Washington State Residential Ventilation and Indoor Air Quality Code (VIAQ) - Whole House Ventilation Systems Field Research Report
- Measured and Simulated Cooling Performance Comparison: Insulated Concrete Form Versus Frame Construction.
- Do Energy Star Homes Live Up to Their Promoted Energy Savings? A Comparison of Utility Bill Data for Recently Built Energy Star and Control Homes in Alachua County, Florida, and co-presented a paper on Structural Insulated Panels with PNNL.
- 1st Annual USGBC International Green Building Conference and Exposition, Austin
- Energy and Environmental Integration Through a Green Municipality Designation" Florida Annual Pollution Prevention Conference in Miami Beach, presenting details of the sustainable design approach planned for the Miami-Dade HOPE VI Project
- Manufactured Housing Institute Convention on healthy homes and cool roofs
- National Institute of Standards and Technologies (NIST) Annual Meeting in Gaithersburg, Maryland, presenting a program on manufactured home testing to HUD, DOE, and EPA staff
- ASHRAE Summer Meeting on uncontrolled air flow in small commercial buildings
- Quality Modular Building Task Force in Charlottesville, Virginia summarizing 2002 research results for members including modular industry energy benchmark study results, a proposed plan for adding quality metrics to employee incentive programs, and advancements in lean manufacturing in the modular industry
- Central Florida Simulation Users Group Conference in Orlando, FL. on the role of simulation in a homebuilding productivity suite
- Southwest Chapter of the Washington Association of Maintenance Operations Administrators Conference on the results, findings, and recommendations of the portable classroom study
- Washington State Manufactured Housing Coordination Conference with the Washington Departments of Labor and Industries, Licensing, Community Development and Office of Manufactured Housing, The Attorney General's Office, and the Washington Manufactured Housing Association, presenting results of the BAIHP/Energy Star for manufactured housing efforts.
- EEBA Conference in Phoenix (3 presentations)

- 2002 ACEEE Summer Study on Energy Efficiency in Buildings Conference on Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida
- 13th Symposium on Improving Building Systems in Hot and Humid Climates in Houston (TX)
- Measured Cooling Performance of Two-story Homes in Dallas, Texas: Insulated Concrete Form Versus Frame Construction
- Performance and Impact from Duct Repair and Ventilation Modifications of Two Newly Constructed Manufactured Houses Located in a Hot and Humid Climate
- The Building America Industrialized Housing Partnership (BAIHP)
- Mid West Energy Alliance meeting in Chicago
- 2nd Annual Interagency Conference on Tribal Affairs in Orlando, Florida on Building America, building science, and energy efficiency concepts for Native America housing providers HUD, PATH, and Pennsylvania State University
- DOE's 25th Annual Weatherization Conference on Interior Duct Study
- Affordable Comfort Conference Buildings that Last in a Hot-Humid climate
- Weatherization Conference, Tampa.
- Daylighting Class: In 2001, staff taught a two-hour class in Orlando on daylighting calculations, as part of a continuing education series sponsored by the Central Florida Chapter of the Illuminating Engineering Society of North America.

Conference and Training Attendance prior to 5th Budget Period

Year 4 (April 2002 to March 2003)

- NAHB International Builders Show in Las Vegas, NV.
- Southeastern Regional Habitat for Humanity Conference, exhibiting and providing information on Florida's new Energy Code, building science, energy efficiency details for hot-humid climates, and the Building America program during educational sessions
- Idaho Energy Conference (IEEC 2002 commercial code training)
- RESNET Conference in San Diego, CA.
- Basement, Crawlspace, Slab Insulation & Moisture Control Seminar in Westford, MS. (a Building Science Corporation expert meeting)
- Salem Home Show in Salem, WA.
- Westford Building Science Seminar
- ACCA Manual J Training Class
- Zero Energy Manufactured House dedication ceremony in Nez Perce tribal fish facility near Lewiston.
- The Health Home Media Tour in Orlando, FL. (covered by local television stations, Channels 2 and 35, and an AM radio station).

Year 3 (April 2001to March 2002)

- Design charette organized by Steven Winter Associates and McStain Enterprises in Boulder, CO.
- National Association of Home Builders Conference in Atlanta, GA.
- 16th Annual National Low-Income Energy Conference in Ft. Lauderdale, FL., introducing Building America and building science principals
- Building VIII Conference in Clearwater Beach, FL.
- NCA&TSU manufactured housing advisory committee meeting in Raleigh (NC)
- Zero Energy Buildings workshop in Orlando, FL.

- Mold seminar put together by the Mid-Florida Home Builder Association
- Seminar on WUFI, a moisture analysis software developed by ORNL
- Council of State Administrative Agencies' Spring Workshop in San Antonio, TX, representing BAIHP and sharing Building America research.

Tours
In 2002, BAIHP conducted a tour of the National Institute of Standards and Technologies (NIST) facilities in Gaithersburg, Maryland to HUD, DOE, and EPA staff. BAIHP also led a Beaverton Classroom tour for DOE, WSU, and PNNL staff.

Audience: Energy Raters and Green Home Certifiers in 6th Budget Period
Florida Green Home Certification Course: BAIHP staff worked with the FGBC to provide training to those seeking to become Green Home Certification Agents in April, June, October and November 2004, and February 2005. The 1 day course ended with the certification exam.

Audience: Energy Raters and Green Home Certifiers prior to 6th Budget Period:
Class I Florida Home Energy Rater Training and Certification: BAIHP staff worked with the Florida Energy Gauge Office to provide training to energy raters seeking Class I certification in August 2003 and February 2004. The 3 day course ended with the certification exam.

Green Home Certifying Agents for Florida Green Building Coalition: BAIHP staff worked with the FGBC to provide training to those seeking to become Green Home Certification Agents in August and December (2003). The 1 day course ended with the certification exam.

Pulmonary Symposium: In 2003, researchers conducted two one-hour pulmonary symposiums in Lake Mary, Florida for 86 health professionals. Symposium topics covered building science and lung health components.

Audience: Portable Classroom Producers and Decision Makers Prior to 5th budget period *Energy Optimization for Universities and School Districts Workshop (Seattle, WA.):* In 2002, BAIHP presented findings and recommendations of the three-year Pacific Northwest Portable Classroom Study. Facility managers from across the state attended the workshop.

Portable Classroom Presentations/Training: In 2001, BAIHP staff conducted four installer certification training sessions in WA, involving more than 200 onsite setup crew personnel. During 2002, 100 set-up crew personnel received the training and certification.

Smart Portable Classroom Collaborative Workshop (Portland, OR): In 2000, BAIHP staff hosted this workshop which was the first opportunity for national experts in portable classroom design, construction, siting, and end-use to come together and discuss energy-related issues. Outreach to other school districts included numerous meetings like the Oregon School Facilities Managers' annual meeting, and the Oregon Association of School Business Officials annual meeting.

Academic Venues prior to 5th Budget Period
Arizona State University: Del E. Webb School of Construction and Scottsdale Community College.

University of Florida: Director of School of Building Construction and Environment, 22 post-graduate students at the Cobblefield subdivision on techniques and methodologies incorporated at this "Green" subdivision.

BAIHP Publications List – All Budget Periods (09/99-03/05)

Papers

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.

Broadway, R. and M. Mullens (2004). "Shop Floor Information Systems for Industrialized Housing Production," Industrial Engineering Research '04 Conference Proceedings, Houston, May, 2004.

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.

Chasar, D., Moyer, N., Rudd, A. F., Parker, D., & Chandra, S. (2002). "Measured Cooling Performance of Two-story Homes in Dallas, Texas: Insulated Concrete Form Versus Frame Construction." Thirteenth Symposium of Improving Building Systems in Hot and Humid Climates, Houston, TX.

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. Peer reviewed

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. Peer reviewed

Chasar, D., Moyer, D., Rudd, A. F., Parker, D. K., & Chandra, S. (2002). "Measured and Simulated Cooling Performance Comparison; Insulated Concrete Form Versus Frame Construction." 2002 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA.

Chandra, Subrato, Danny Parker, David Beal, David Chasar, Eric Martin, Janet McIlvaine, Neil Moyer (2004). Alleviating Moisture Problems in Hot, Humid Climate Housing. Position Paper for NSF Housing Research Agenda Workshop, UCF Feb. 12-14, 2004.

Chandra, Subrato, Fonorow, Ken, McCloud, Matthew, Moyer, Neil, Beal, David, Chasar, David, McIlvaine, Janet, Parker, Danny, Sherwin, John, Martin, Eric, Mullens, Michael, Lubliner, Michael, McSorley, Michael (2002). "The Building America Industrialized Housing Partnership" Symposium on Improving Building Systems in Hot, Humid Climates - Houston, Texas, May 20-22, 2002.

Chandra, S., & Beal, D. (2001). “Preventing House Dust Mite Allergens in New Housing.’ In ASHRAE IAQ Conference Proceedings, San Francisco, CA.

Chandra, S., Moyer, N., Beal, D., Chasar, D., McIlvaine, J., & Withers, C. (2001). “The Building America Industrialized Housing Partnership (BAIHP): Enhancing Energy Efficiency, Durability and Indoor Air Quality of Industrialized Housing.” In XXIX IAHS World Congress on Housing Conference Proceedings, Ljubljana.

Christian, J.E., D. Beal, and P. Kerrigan (2004). “Toward Simple Affordable Zero Energy Houses.” Proceedings of Performance of Exterior Envelopes of Whole Buildings IX, Clearwater, Florida, December 5-10, 2004.

Cummings, J., C. Withers, J. McIlvaine, J. Sonne, M. Lombardi (2003). Air Handler Leakage: Field Testing Results in Residences. ASHRAE Transactions V.109 pt.1 February 2003. To be published in ASHRAE Journal.

Elshennawy, A., M. Mullens, and I Nahmens (2004). “Quality-Based Compensation Schemes for Modular Homebuilding,” Industrial Engineering Research ’04 Conference Proceedings, Houston, May, 2004.

Elshennawy, A., Mullens, M., & Nahmens, I. (2002). “Quality Improvement in the Modular Housing Industry.” In Industrial Engineering Research ‘02 Conference Proceedings, Orlando, FL.

Fuehrlein, B., Chandra, S., Beal, D., Parker, D.K., & Vieira, R. (2000). “Evaluation of EnergyGauge® USA, a Residential Energy Design Software Against Monitored Data.” In ACEEE Summer Study Proceedings, Pacific Grove, CA.

Hales, D; M. Lubliner, A. Gordon (2003). “Duct Leakage in New Washington State Residences: Findings and Conclusions” – Proceedings of the 2003 ASHRAE Summer Meeting.

Hodgson, A.T., Apte, M.G., Shendell, D.G., Beal, D. and McIlvaine, J.E.R. (2002). Implementation of VOC source reduction practices in a manufactured house and in school classrooms. In Levin, H. (Ed.), Proceedings of the 9th International Conference on Indoor Air Quality and Climate. Indoor Air 2002, Santa Cruz, CA, Vol. 3. pp. 576-581.

Hodgson, A.T., Moyer, N., and Beal, D. (2005). “Effect of residential ventilation techniques for hot and humid climates on indoor concentrations and emission rates of volatile organic compounds.” February 2005, LBNL-57030, Lawrence Berkeley National Laboratory, Berkeley, CA.

Hodgson, A.T., D. Beal and J.E.R. McIlvaine. 2002. Sources of formaldehyde, other aldehydes and terpenes in a new manufactured house. *Indoor Air* **12**: 235-242.

Hodgson, A.T., A.F. Rudd, D. Beal and S. Chandra. 2000. Volatile organic compound concentrations and emission rates in new manufactured and site-built houses. *Indoor Air* **10**: 178-192.

Lombardi, M., D. Parker, R. Vieira, P. Fairey (2004). “Geographic Variation in Potential of Rooftop Residential Photovoltaic Electric Power Productions in the United States,” Proceedings of ACEEE 2004 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, D.C, August 2004.

Lubliner, M., A. Hadley, A. Gordon. “Introducing Solar Ready Manufactured Housing.” Proceedings of the 2004 National Solar Energy Conference, pp. 1151-1155. July 2004.

Lubliner, M., A. Gordon, A. Hadley. “Manufactured Home Performance; Comparing Zero Energy and Energy Star.” Proceeding of Performances of Exterior Envelopes of Whole Buildings IX International Conference, Clearwater Beach, FL, December 2004.

Lubliner, M, Nelson, M, & Parker, D. (2003). “Gossamer Wind Solar Power Ceiling Fan.” In 2003 ASES Conference Proceedings, Austin, TX.

Lubliner, M, Kunkle, R, Devine, J, & Gordon, A. (2002). “Washington State Residential

Ventilation and Indoor Air Quality Code (VIAQ) - Whole House Ventilation Systems Field Research Report." 2002 ACEEE Summer Study on Energy Efficiency in Buildings Conference, Pacific Grove, CA.

Lubliner, M.; Gordon, A.; Persily, A.; Moyer, N.; Richins, W.; Blakeley, J (2003). "Building Envelope, Duct Leakage and HVAC System Performance in HUD-Code Manufactured Homes" 23rd Annual AIVC Conference Proceedings.

Lubliner, M., & Gordon, A. (2000). "Ventilation in US Manufactured Homes: Requirements, Issues and Recommendations." 21st Annual AIVC Conference Proceedings, The Hague.

Martin, E. "Making the right choices: Finding green products is now easier than ever, but a systems approach must be employed to select the right products for a green project." Guest editorial for Florida Real Estate Journal, March 2005.

McCluney, R. (2003). "Methodologies for Determining the SHGC of Complex Fenestration Systems." Paper presented at the 2003 National Fenestration Rating Council Meeting, Houston, TX.

McIlvaine, J., Beal, D., Moyer, N., Chasar, D., Chandra, S. (2004). Achieving Airtight Ducts in Manufactured Housing. Symposium on Improving Building Systems in Hot and Humid Climates, Richardson, Texas, May 17-19, 2004.Report No. FSEC-CR-1323-03.

McGinley, W. Mark, Jones, A., Turner, C., Subrato C., Beal, D., Parker, D., Moyer, N., McIlvaine, J. (2004). Optimizing Manufactured Housing Energy Use. Symposium on Improving Building Systems in Hot and Humid Climates, Richardson, Texas, May 17-19, 2004.

Moyer, N., Chasar, D., Hoak, D., Chandra, S. (2004). "Assessing Six Residential Ventilation Techniques in Hot and Humid Climates," Proceedings of ACEEE 2004 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC, August 2004. Peer reviewed.

Moyer, N., Beal, D., Chasar, D., McIlvaine, J., Withers, C, & Chandra, S. (2001). "Moisture Problems in Manufactured Housing: Probable Causes and Cures." ASHRAE - IAQ 2001 Conference Proceedings, San Francisco, CA.

Mullens, Michael A. and Mark E. Kelley III. 2004. "Lean Homebuilding Using Modular Technology." Housing and Society. January 31, 2004 pp.41-54.

Mullens, M. and M. Hastak (2004). "Defining a National Housing Research Agenda: Construction Management and Production" Proceedings of the NSF Housing Research Agenda Workshop, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M. and Hastak, M. Vol 2.

Mullens, M. (2004). "Production flow and shop floor control: Structuring the modular factory for custom homebuilding" Proceedings of the NSF Housing Research Agenda Workshop, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M. and Hastak, M. Vol 2.

Mullens, M., & Kelley, M. (2003, January). "Lean Homebuilding Using Modular Technology." NAHB International Builders Show Conference Proceedings, Las Vegas, NV.

Mullens, M., & Kelley, M. (2002). "Introducing Revolutionary Change in the Modular Housing Construction Process Using a Kaizen Blitz." In Industrial Engineering Research '02 Conference Proceedings, Orlando, FL.

Nasereddin, M., Mullens, M., & Cope, D. (2002). "The Development of a Reusable Simulation Model for the Modular Housing Industry Using Promodel and Visual Basic." In Industrial Engineering Research '02 Conference Proceedings, Orlando, FL.

Withers, C., Moyer, N., Chasar, D., & Chandra, S. (2001). "Performance and Impact from Duct Repair and Ventilation Modifications of Two Newly Constructed Manufactured Houses

Located in a Hot and Humid Climate." Paper presented at the 13th Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX.

Contract Reports

Chandra S, N. Moyer, D. Parker, D. Beal,. et al. "Building America Industrialized Housing Partnership (BAIHP) Final Technical Report - Fourth Budget Period", December 2003

Chandra S, N. Moyer N, D. Parker, D. Beal, et al. "Building America Industrialized Housing Partnership (BAIHP) Final Technical Report - Third Budget Period", March , 2003

Chandra S, N. Moyer, D. Parker, D. Beal, et al. "Building America Industrialized Housing Partnership (BAIHP) Final Technical Report - Second Budget Period", Dec. 2001

Chandra S, D. Chasar, N. Moyer, et al. "Building America Industrialized Housing Partnership (BAIHP) Final Technical Report - First Budget Period" FSEC-CR-1239-01 March 2001

Cummings, J., Withers, C., Gu, L., McIlvane, J., Sonne, J. K., & Lombardi, M. (2002). "Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage." Florida Solar Energy Center Contract Report # FSEC-CR-1357-02, Cocoa, FL.

Florida Solar Energy Center, & York Unitary Products Group. (2000). "The Coleman® Pressure Control System: A Comprehensive and Proactive Process to Eliminating Pressure Driven Moisture Damage in Manufactured Housing." Florida Solar Energy Center Contract Report, Cocoa, FL.

Hodgson, A.T., N. Moyer and D. Beal (2005). "Effect of residential ventilation techniques for hot and humid climates on indoor concentrations and emission rates of volatile organic compounds." February 2005, LBNL-57030, Lawrence Berkeley National Laboratory, Berkeley, CA.

McCluney, R., L. Mills (2003).The Benefits of Using Window Shades " Florida Solar Energy Center Nov. 01, 2003.

McCluney, R., N. Dhere (2002). "Industry Guide to Selecting the Best Residential Window Options for the Florida Climate " Florida Solar Energy Center , Pf-358-00, Dec. 01, 2002.

McGinley, M. (2002). "Study of Innovative Manufactured Housing Envelope Materials." BAIHP Subcontract Report, Greensboro, NC.

McIlvaine, J., S. Chandra, N. Moyer, D. Parker , D. Beal, et al. "Building America Industrialized Housing Partnership (BAIHP) Final Technical Report - Fifth Budget Period", March 2005.

McIlvaine, Janet, David Beal, Philip Fairey (2001). Design and Construction of Interior Duct Systems. FSEC PF-365-01. Florida Solar Energy Center. Cocoa, Florida, May 2001.

Mullens, M., & Burdick, J. (2003). "Energy Test Results and Recommendations for Avis America Homes." University of Central Florida Housing Constructability Lab BAIHP Report, Cocoa, FL.

Mullens, M., Gallas, K., & Moyer, N. (2002). "Energy Test Results and Recommendations for General Homes Corporation." University of Central Florida Housing Constructability Lab BAIHP Report, Cocoa, FL.

Mullens, M., Gallas, K., Chasar, D. (2002). "Energy Test Results and Recommendations for Nationwide Homes." University of Central Florida Housing Constructability Lab BAIHP Report, Cocoa, FL.

Mullens, M., & Chasar, D. (2002). "Energy Test Results and Recommendations for Cardinal Homes." University of Central Florida Housing Constructability Lab BAIHP Report, Cocoa, FL.

Parker, D., J. Sonne, J. Sherwin (2004). "Flexible Roofing Facility: 2003 Summer Test Results", Prepared for U.S. Department of Energy Building Technologies Program, July 2004.

Parker, D., Sonne, J., Sherwin, J. (2003). Flexible Roofing Facility: 2002 Summer Test Results, Prepared for: U.S. Department of Energy Building Technologies Program, July 2003.

Parker, D. K., Sonne, J. K., Sherwin, J. R., & Moyer, N. (2000). “Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand.” Florida Solar Energy Center Contract Report #FSEC-CR-1220-00, Cocoa, FL.

Sonne, J K, D S Parker and J R Sherwin (2002). Flexible Roofing Facility: 2001 Summer Test Results. FSEC-CR-1336-02. Florida Solar Energy Center, Cocoa, FL.

Articles in Trade Press, Popular Press, and DOE Program Newsletters

Automated Builder Magazine. “WSU Energy House.” October 2000.

Automated Builder Magazine “Northwest Portable Classroom Study.” August 2003.

Automated Builder Magazine. “Zero Energy Manufactured Home.” October 2003.

Builder/Architect. G.W. Robinson, Builder/Founder of Cobblefield, “Healthy Homes for a Healthy Bottom Line”. August/September 2004.

Building Edge Magazine. “Environmental Perspective: Innovation in Home Building. December 2004.

Building Edge Magazine. “Tommy Williams Homes, Building From the Heart.. December 2004.

Buildings for the 21st Century. “Genesis Homes Showcases Innovative, High-performance Home.” Spring 2002, p. 2.

Energy Design Update. “Transforming Manufactured Housing: The Building America Way.” January 2002, pp. 11-13.

Energy Design Update. “Palm Harbor's Prototype Home Scores Impressive Energy Savings.” December 2001, pp. 7-8.

Energy Design Update. “Field Tests Commence on the World's Most Energy-efficient Manufactured Home,” December 2000, p.3.

Energy Design Update. “New Building America Consortium to Focus on Industrialized Housing.” March 2000, pp. 3-4.

Energy Design Update. “Energy Savings (and Unsolved Mysteries) Draw Attention to Georgia Habitat Project.” Vol. 20 Number 4. April 2000.

Energy Design Update. “Ventilation System Decision Flow Chart.” February 1999, p.16.

FlaSEIA Industry News. “SunBuilt and Building America Partnership.” Spring 2002, Vol. 23, N.1 pp.5-8.

Florida Home Builder. “Today's Home Buyers Seeking Resource-efficient New Homes.” May/June 2002, p.25.

Florida Home Builder (Ad). “Their Lifestyle Demands Quality and Comfort: Their Values Dictate a Healthy House.” May/June 2002, p.25.

Gainesville Sun - Issues & Trends Section. “The Good News on Solar Homes.” April 14, 2002, pp. G1 & G3.

Home Energy. “ICFs in North Texas.” Nov/Dec 2002, pp. 39-40.

Home Energy. “Energy-efficient Manufactured Homes.” May/June 2002, pp. 16-17.

Home Energy. “Chasing Interior Ducts.” May/June 2002, Vol. 19.3.

Home Energy. “Building America: Seven Years of Progress.” May/June 2002, p.2.

Home Energy. “Allergy Relief in Humid Climates.” March/April 2002, pp. 30-33.

Home Energy. “Moisture Problems in Manufactured Housing.” March/April 2002, pp. 24-29.

Indoor Environment Business. “Center Finds IAQ Problem from Leaky Air Handlers, Ducts in Florida.” April 2002, p.4.

Orlando Sentinel - Home Section. “A Clean Sweep: Simple Steps Can Improve a Home's Indoor Air.” September 22, 2001 (OrlandoSentinel.com)

Orlando Sentinel - Home Section. “In the Name of Energy.” September 2, 2001. (OrlandoSentinel.com)
Pendleton Times. "Simpson Home Is First of Its Kind in WV." March 17, 2005. Vol. 92, N. 11, pg. 5.
Rebuild America - Building America Partner Update. “Portable Classrooms: An Efficiency Challenge.” March/April) 2002, p. 7.
Rebuild America - Building America Partner Update. “Building America: Solving Problems with Energy Efficiency.” January/February 2002, p. 10.
Solar Today. “Home Energy Use Halved.” November/December 2001, pp. 54-55.
Washington Post "Susanka's Signatures -- and Surprises -- Fill Demo Home in Orlando", Saturday, March 12, 2005; Page F05

One Page Fact Sheets
Building America Industrialized Housing Partnership,
Transforming the Market: Super-Efficient Manufactured Housing.
Manufactured Housing Laboratory: A Research and Training Facility.
Durable, Resource-Efficient Achievable Model (DREAM) Home.
Habitat for Humanity Collaborations: Affordable Energy Efficiency.

BAIHP Web Page Contents:
Manufactured Housing*:*
- Technical services provided to the HUD Code and modular industry. Chandra, Subrato, Michael Mullens, Mike Lubliner. http://www.fsec.ucf.edu/bldg/baihp/pubs/techserv/index.htm
- Palm Harbor Homes Partnership, Case Study, http://www.fsec.ucf.edu/bldg/baihp/casestud/PALM/INDEX.HTM
- Plains Habitat Structural Insulated Panel Field Project, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/casestud/PLAINSHABITAT/index.htm
- Portable Classrooms, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/data/Portables/index.htm
- Side by side Comparison of Manufactured Homes, Case Study, http://www.fsec.ucf.edu/bldg/baihp/casestud/Bossier/index.htm
- Super Good Cents/Natural Choice Program, http://www.fsec.ucf.edu/bldg/baihp/casestud/WSU/index.htm
- WCI Communities, Inc. Evergrene Community, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/casestud/wci/index.htm
- WSU Energy House, Case Studies page. (www.fsec.ucf.edu/bldg/baihp/casestud/wsu/wsuhouse.htm). (www.fsec.ucf.edu/bldg/baihp/pubs/media/index.htm).
- Zero Energy Manufactured Home, Case Studies page. http://www.bpa.gov/Energy/N/tech/zemh/

Site Built Housing:

- Cambridge Homes at Baldwin Park, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/casestud/cambridge/index.htm
- Central Florida DREAM Home, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/casestud/DREAM/index.htm
- Entry Level Homes, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/casestud/ELH/index.htm
- Habitat for Humanity Energy Star Home Examples. http://www.fsec.ucf.edu/bldg/baihp/casestud/HfH_EStar/index.htm
- High Efficiency Florida Home, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/data/CFRes/index.htm
- Orlando House, Florida's Future, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/casestud/orlando/index.htm

Building Science and Design:

- About Window Films. McCluney, Ross. http://www.fsec.ucf.edu/bldg/active/fenestration/ResOptions/films.htm
- Advice to Florida Homeowners on Windows, Shades, and Film Selection. Ross McCluney. www.fsec.ucf.edu/bldg/active/fen/w_select.htm.
- Industry Guide to Choosing the Best Residential Window Options for the Florida Climate. Ross McCluney. www.fsec.ucf.edu/bldg/active/fen/industry16.pdf.
- Filter Back Grill Experiment, Current Data page. http://www.fsec.ucf.edu/bldg/baihp/data/filter/index.htm
- Fenestration Research. http://www.fsec.ucf.edu/bldg/active/fen/index.htm
- Pet House Project, Case Studies page. http://www.fsec.ucf.edu/bldg/baihp/casestud/pethouse/index.htm
- Six Moisture Damaged Homes, Case Studies. http://www.fsec.ucf.edu/bldg/baihp/casestud/moisture/index.htm

V

BAIHP COLLABORATIONS

BAIHP COLLABORATIONS

BAIHP researchers collaborate with a variety of entities in the homebuilding industry and the energy efficiency and research realm. *Table 66* lists collaborators in the following categories:

- DOE National Labs (e.g. NREL, LBNL, ORNL)
- Code and Standards Bodies (e.g. RESNET, NFPA)
- Industry and Professional Organizations, Universities, and Suppliers

Table 66 BAIHP Collaborations

Collaborators	Description/Subject of Collaboration	Month
DOE National Labs		
DOE-ATLANTA & Pacific Northwest National Lab (PNNL)	Hosted Traci Leath (DOE Atlanta Regional Office) and Michael Baechler (PNNL) for a tour of BAIHP facilities (FSEC in Cocoa) and BAIHP partners and projects in Florida (Orlando, Plant City, and Gainesville.)	JULY 03
NIST and BA Partner The Energy Conservatory	NIST test home in Gaithersburg, Maryland.	JULY 03 on-going
PNNL	Technical Assistance for PNNL's efforts to evaluate HUD Uo value.	JULY 03 on-going
PNNL	Finalized efforts with PNNL and DOE on BAIHP cost data and duct research efforts.	AUG 03
LBLN	Hosted Al Hodgson at FSEC and participated with Al on VOC sampling at the MHLab	JUNE 03
ORNL	Participated in ORNL partnership with Loudon County (TN) Habitat for Humanity. Instrumentation, data collection, and web hosting of data.	APR 03 - MAR 04
NREL	Philip Fairey and Danny Parker assisted with the BA benchmark development and review process.	APR 03 - MAR 04
Code and Standards Bodies		
NFPA	Integrated BAIHP research and cost information into 5 proposals for the NFPA501 standards committee	JULY 03 completed
NFPA	Presented BAIHP cost and duct research efforts which resulted in adoption of a new standard on duct air tightness and testing protocol.	SEPT 03 completed
HUD – NFPA	Supported HUD's John Steven proposals to NPFA-501 committee. Proposals regard ducts and ventilation systems. Reflected in HUD 2004 federal register.	JAN, FEB 04 - DEC 04 completed
RESNET	BA Benchmark Support, Philip Fairey.	APR 03 - MAR 04
Industry and Professional Organizations, Universities, and Suppliers		
ASHRAE	Submitted draft of revised Chapter 9 of ASHRAE Handbook for HVAC Systems and Equipment Systems to Building America partners.	APR 03 completed
ASHRAE	Submitted draft of revised Chapter 43 of ASHRAE Applications Handbook - Thermal Envelopes.	JAN 04 on-going

Table 66 BAIHP Collaborations

Collaborators	Description/Subject of Collaboration	Month
ASHRAE	Chapter 9 appoved by ASHRAE TC6.3 with revisions suggested by TC 6.3 members.	MAY 03 completed
ASHRAE	Submitted Chapter 9 to ASHRAE for publication.	MAY 03 completed
ASHRAE	Chapter 9 published in 2004 Systems and Equipment Handbook	JUNE 04
ASHRAE	As part of ASHRAE Technical Committee 6.3 (TC6.3): worked with committee members to develop a program plan and research plan.	JUNE, JULY 03
ASHRAE	Worked with TC6.3 members and BAIHP partners to coordinate committee activities for 2004 ASHRAE Symposium in Anaheim, CA.	JUNE, JULY 03 on-going
ASHRAE	For 2004 Symposium, review of papers on HVAC performance.	MAY, JUNE, JULY 03 completed
Enterprise Foundation	Meeting and follow on discussions to provide technical assistance to the Green Communities program in Florida.	March 05-April 05
MHRA	Met in DC and Las Vegas, NV to discuss potential collaborations.	APR 03
MHRA	M. Mullens and S. Chandra participated in MHRA planning conference for 2005	APR 03
MHRA	At MHRA request, Neil Moyer assisted MHRA staff in testing single a wide home in Alabama for the MHRA moisture study.	MAY 03
MHRA	Provided feedback to MHRA on their moisture research plan. MHRA attended *BAIHP Project Review Meeting*	JAN 04
MHRA	Continued collaborations with MHRA on testing houses for their moisture study. Written and oral feedback provided.	MAR 04
Southface	Participated in building science/green builder training in the Florida Panhandle.	May 2004
ACEEE	As Residential Buildings Panel Chair, Danny Parker and Mike Lubliner conducted a preliminary review of 99 abstracts for ACEEE 2004 Summer Study.	NOV 03 completed
ACEEE	Followed up on issues from ACEEE 2004 Summer Study.	JAN, FEB 03 completed
ACEEE	Began peer review on papers submitted to ACEEE Residential Building's panel; followed up on issues for ACEEE 2004 Summer Study.	MAR 04 completed

Table 66 BAIHP Collaborations

Collaborators	Description/Subject of Collaboration	Month
HONEYWELL	Organized a meeting with Honeywell to exchange information on Indoor Air Quality research and products.	MAY 03 completed
HONEYWELL	Honeywell joined BAIHP team.	JULY 03
HONEYWELL	Monthly/periodic conference calls to exchange information.	SEPT 03-MAR 04
NAHB	Participated in the NAHB Building Systems Councils plant tour. Networked with D. Kaufman , exec director and began a dialogue to significantly participate in BSC activities.	MAY 03
NAHB	Mike Lubliner participated in Energy Value Housing Award judging at NAHB Research Center.	OCT 03 on-going
NOMACO	Continued collaborations with Mike Schroeder, Nomaco representative on potential new product. Non disclosure agreement was finalized.	APR 03 - MAR 04
SSHC, Inc.	Met with SSCI, manufacturer of ENERJOY radiant heating panels, on continued BAIHP research efforts.	JUNE 03 on-going
USGBC	Bi-monthly conference calls with core committee, additional for TSAC committees	APR 03 - April 05
AUBURN UNIVERSITY	Department of Architecture, Design, and Construction on DESIGNhabitat, a sustainability and energy efficiency project - Worked with undergraduate fellowship winner to draft a monitoring plan and select HOBO sensors.	JUNE 03
AUBURN UNIVERSITY	HOBOs installed in, and data collected from 2 DESIGNhabitat homes and 1 conventional Habitat home (~3 yrs old).	JULY, AUG 03
AUBURN UNIVERSITY	Data from HOBO monitoring sensors posted online and utility bill analysis completed. Review of data and refinement of utility bill analysis.	SEPT 03-NOV 04
AUBURN UNIVERSITY	Fellow completed study and presented paper to senior thesis committee. Student took and passed USGBC's LEED certification test as result of fellowship experience.	DEC 03
CITY OF SANTA MONICA, CA	City began planning a community of Green manufactured homes.	JUNE 03
IBACOS	Support IBACOS technical assistance to the New American Home to be displayed during the International Builders Show in Orlando, FL. in 2005 and again in 2006. Site Work (testing and inspections), photos, and Florida Energy Star rating. Photo/video of the stages of construction provided on a weekly basis.	SEPT 03-MAR 06 MAR 04

Table 66 BAIHP Collaborations

Collaborators	Description/Subject of Collaboration	Month
NSF/PATH	Participated in NSF/PATH Housing Research Workshop (Feb 12-14) and presented paper.	FEB 03
UCF	1 hour lecture to about 250 students as part of UCF Life activities on improving residential energy efficiency and indoor air quality	MAR 04
BPA	Demonstration, Research analysis and publications on Zero Energy Mfg Home.	On-going
NEEM	Implementation of PNW Energy Star/BAIHP Program Including factory and site inspections, specification improvements, tracking and certification of homes.	On-going
NEEA	Technical Assistance to Northwest Energy Star Site Built Program.	On-going
Fleetwood & Pal Harbor Homes	Collaboration on Solar Ready Specifications and Testing.	On-going
Fleetwood	Collaboration on new technologies evaluations.	On-going
Champion Homes	Collaborations on Fort Lewis Modular Homes Project.	On-going
WA Mfg Housing Working Group	Provide technical assistance on state-level HUD-code housing issues.	On-going
AFC	Planning and coordination for 2005 Conference Workshop.	On-going
ABSN	Coordinate with Alaska BAIHP stakeholder.	On-going
Energy Trust of OR	Technical assistance on mfg housing incentive program.	On-going

VI

BAIHP PROJECT MANAGEMENT

PROJECT MANAGEMENT

BAIHP project management includes participating in Building America program reviews/meetings and preparing monthly and yearly reports for project activities as well as managing all project tasks (see Sections 1-6) and subcontracts. In the 6th Budget Period BAIHP participated in the Peer Review conducted by DOE. A list of project management activities is included in *Table 67.*

Note that only project management activities for the 6th budget period are available here; if activities from previous budget periods are desired, please contact BAIHP project manager Subrato Chandra at subrato@fsec.ucf.edu or review previous year's final reports on the BAIHP web page at www.baihp.org.

Table 67 BAIHP Project Management Activities for the 6th Budget Period

BAIHP Task/Staff	Description/Subject
Task: Participation in BA Quarterly Review Meetings	
Chandra, Fairey, Vieira, McIlvaine, Parker	Participation in BA Quarterly Review Meetings
Participation in other BA Meetings	
WSU	Met with WSDUE and PNNL to discuss BAIHP research support for NFPA-501 future. (April 04))
WSU	Attended MHI Congress, representing Building America. Met with BAIHP industry partners and submitted ideas for 2 papers for 2005 International conference. (April 04
Chandra, Mullens	MHRA pre conference to define agenda for the 2005 International Conference on factory built housing (April 2004)
WSU	Attended ASHRAE conference and chaired TC 6.3 (June 04)
Martin, Chandra	BA all teams meeting in Washington D.C (June 04)
Lubliner, Moyer	Annual NEEM meeting with special focus on integrating NEEM and BAIHP efforts.
Chandra, Vieira	BA quarterly meeting (August 2004)
FSEC	Teleconference call organized byt the DOE Seattle regional office to discuss Building America approach with Hawaii state energy personnel. (September 2004)
WSU	Met with USDOE staff in Washington, focus on BAIHP activites. (September 2004)
WSU	Conference calls on BAIHP activities with USDOE regional office. (Septemeber 2004)
Chandra	Meeting, DOE-Atlanta to discuss FY05 solicitation for BA tech transfer activities. (October, 2004)
WSU	Met with USDOE staff in Washingtin, focus on BAIHP activites. (October 2004)
Fairey, Parker	BA quarterly review in Washington, D.C. (November 204)
FSEC	Met with Robin Pharo – Aprilaire (discusiion on BAIHP and FSEC collaboration). (February 2005)

Chandra, Moyer, Parker	Pre peer review meeting in Washington, D.C. (March 2004)
Prepare 5th Budget Period Progress Report	
Chandra, All Researchers	Compiled and summarized results from 5th Budget Period
Prepare Monthly Reports	
Chandra, Alidina, All	Compiled and summarized monthly results from research, implementation research, presentations, and publications.
Manage Project and Subcontracts and Perform Related Activities	
Chandra	BAIHP subcontracts issued and scope of work developed..
Chandra	Continued meetings and discussion with Sam Taylor regarding Building America deployment through Energy Extension services.
Chandra	Prepared response to DOE solicitaion # DE-FC2699GO10478
Chandra	Preparation of FY06 AOP proposal submission to DOE.
Peer Review Meeting at DOE	
Chandra, all BA Researchers	Prepared documentation.
Chandra, Mulles, McILvane, Moyer, Parker, Fairey	BAIHP presentations at DOE Peer Review sessions on Whole House and Component Research.

Appendix A: BAIHP Media Coverage

BAIHP Media Coverage

5th Budget Period:

During the fifth budget period, BAIHP research received media attention in a variety of publications and television shows.

- Orlando Sentinel, Sunday, February 8, 2004. "The Green Revolution: A Florida First. Part 1 of a 4-part series." "Blueprints for the home planet." *(Figures A1-A3)*
- Orlando Sentinel, Sunday, February 15, 2004. "The Green Revolution: Interior Motives. Part 2 of a 4-part series." "Health worries hit home." *(Figures A4-A6)*
- Orlando Sentinel, Sunday, February 22, 2004. "The Green Revolution: Applying Principles. Part 4 of a 4-part series." "Pioneer spirit." *(Figure A7-A9)*

Prior to 5th Budget Period:

- "Tricks of the Trade" radio show and "Build It Green" pilot television program. BAIHP provided training and presentation.
- *FlaSEIA Industry News,* "SunBuilt and Building America Partnership," Spring 2002, Vol.23, Number 1, pp.5-8.
- *Florida Home Builder*, "Today's Home Buyers Seeking Resource-Efficient New Homes," May/June 2002, p.25.
- *Home Energy Magazine*, "Chasing Interior Ducts," May/June 2002, pp.24-28.
- *Home Energy Magazine*, "Energy-Efficient Manufactured Homes," May/June 2002, pp.16-17.
- *Energy Design Update*, "Building America: Seven Years of Progress," May 2002, p.2.
- Indoor Environment Business, "Center Finds IAQ Problem from Leaky Air Handlers, Ducts in Florida," April 2002, p.4.
- *The Gainesville Sun* - Issues & Trends Section, "The Good News on Solar Homes," April 14, 2002
- *Buildings for the 21st Century*, "Genesis Homes Showcases Innovative, High-Performance Home," Spring 2002, p.2.
- *Home Energy Magazine*, "Allergy Relief in Humid Climates," March/April 2002, pp. 30-33.
- *Home Energy Magazine*, "Moisture Problems in Manufactured Housing," March/April 2002, pp. 24-29.
- *Partner Update (Rebuild America - Building America),* "Portable Classrooms: An Efficiency Challenge," March/April 2002, p.7.
- *Partner Update (Rebuild America - Building America),* "Building America: Solving Problems with Energy Efficiency," January/February 2002, p.10.
- *Energy Design Update*, "Transforming Manufactured Housing (the Building America Way)," January 2002, pp.11-13.
- *Energy Design Update*, "Palm Harbor's Prototype Home Scores Impressive Energy Savings," December 2001, pp. 7-8.
- *Solar Today*, "Home Energy Use Halved," November/December 2001, pp. 54-55.

Listing continued on page A11.

Homes

Orlando Sentinel • OrlandoSentinel.com

SUNDAY, FEBRUARY 8, 2004 • SECTION J

REAL ESTATE CLASSIFIED
INSIDE AND ONLINE
orlandosentinel.com/realestate/

NSW

STEPHEN M. DOWELL/ORLANDO SENTINEL

Green with energy. Larry and Vivian VanCleave didn't know much about the green-building movement when they bought their Lake County home. Now they are enthusiastic about its energy-efficient features.

The Green Revolution: A Florida First

PART 1 OF A 4-PART SERIES

Blueprints for the home planet

A growing number of builders and homeowners are making the environment their business as eco-friendly houses gain ground.

By CARRIE ALEXANDER
SENTINEL STAFF WRITER

CLERMONT

Paul Fallman stretches out in a deck chair on his screened back porch with a yellow notepad, a sharp pencil and a chunk of eraser.

To keep cool, he flips the ceiling fan on high and pours a glass of cold water. To clear his mind, he swivels around to pop in a CD by a fellow environmentalist, Jimmy Buffett.

The music starts to build. Fallman starts to draw.

A crop of connecting circles materializes on the lined paper. He changes his mind about the location of one and erases it, adds another. Erases. Adds another.

The Lake County builder is sketching a floor plan for a home that represents a growing trend in the national housing market known as green building. Fallman belongs to the Florida Green Building Coalition, a nonprofit organization that sets standards for environmentally friendly home construction in the Sunshine State. Florida's coalition joins 20 other regional programs throughout the country, with more on the way.

"My niche is energy-efficient custom homes," says Fallman, 40. "I do it because I think it's the right thing to do. Green building is the next step."

Although the definition continues to evolve, proponents generally describe green building as designing, constructing and operating homes in an environmentally friendly, healthful and resource-efficient manner.

To do this, builders combine age-old practices with emerging technologies. They build homes that take advantage of natural breezes and sunlight in an effort to use less air conditioning and electricity, and they use

PLEASE SEE GREEN, J4

TOM BENITEZ/ORLANDO SENTINEL

A new kind of builder. Paul Fallman drafts a floor plan on the back porch of his Clermont home, which is certified by the Florida Green Building Coalition.

WHY GREEN BUILDING MATTERS

Experts cite these reasons, among others, for why this growing trend matters:

- Fossil fuels such as coal, oil and natural gas are being depleted at a rate that is 100,000 times faster than they are being formed, according to the American Solar Energy Society, a grass-roots organization in Boulder, Colo., that promotes solar technology. Green building reduces the need for fossil fuels by creating energy-efficient homes and by using renewable resources such as solar power when possible.
- Heating and cooling costs account for about 44 percent of a homeowner's energy bill, according to the U.S. Department of Energy. Energy Star, a program managed by the Environmental Protection Agency and the U.S. Department of Energy, qualifies homes that incorporate savings in design and construction, and use 30 percent less energy for heating, cooling and water heating than a standard home does. This allows homeowners to save from $200 to $400 annually on their utility bills, according to the EPA.
- About 15 percent of the population experiences some sensitivity to chemicals, according to the National Academy of Sciences. Green building calls for the use of natural, nontoxic materials that don't emit harmful fumes.
- Building demolition, construction and renovation account for about 40 percent of the raw materials used and about 40 percent of materials sent to landfills, according to the Worldwatch Institute, an environmental research organization in Washington, D.C. Green homes are built with recycled and recyclable materials, which conserve natural resources and save landfill space.

— CARRIE ALEXANDER

ABOUT THE SERIES

Today in Homes: A Florida First
A trend is emerging that may be one of the most significant in home building for the 21st century. It's the green revolution, and it's been catching on in Florida since the state certified its first green home three years ago. Industry experts discuss the principles of building green and the hurdles builders face.

Feb. 15 in Homes: Interior Motives
Energy efficiency and environmental issues drove the green-building movement early on, but health concerns are beginning to play a larger role, as research indicates a correlation between chemicals in modern building materials and illness. Also, designers are demonstrating that interiors can be eco-friendly as well as stylish.

Feb. 21 in Garden & Home: Botanical Benefits
The green movement's efforts to protect natural resources extend to a home's landscaping where extravagant gardening practices are changing. The design, plant selection and maintenance techniques are key to saving water and energy, and protecting the environment from harmful chemicals.

Feb. 22 in Homes: Applying Principles
A retired couple in South Florida live the green life daily, as experts debate which up-and-coming products and materials are the most environmentally sound and energy efficient. Plus, whole communities devoted to the concept are cropping up in Florida, and a number of resources are available to help consumers get greener homes.

Story Gallery Online: The stories in this series are being posted on OrlandoSentinel.com/green

INSIDE

Win a home
A $1 million house on the Georgia coast may not be your dream home, but what if someone were to hand you the keys?
PAGE J13

ONLINE

Looking to build?
Check out the new communities in Central Florida, and also review floor plans of homes, prices and elevations.
ORLANDOSENTINEL.COM/REALESTATE/

Figure A1 Page J1 of Orlando Sentinel, Sunday, February 8, 2004. "The Green Revolution: A Florida First. Part 1 of a 4-part series." "Blueprints for the home planet."

Anatomy of a green home

This cutaway shows some of the features that make a home energy efficient and environmentally sensitive while they preserve indoor air quality.

Budget or luxury — any price range can be green

GREEN FROM J1

natural, nontoxic, recyclable materials that don't pollute the air or clog landfills.

This trend, many industry professionals believe, will prove to be one of the most significant in home building in the 21st century.

Orlando architect John Henry describes green building as the "ideal and ethical" way to build. But he says most builders aren't doing it because it requires extra effort and expense, and consumers would rather spend money on luxury items than green features.

These reasons make green building a more comfortable fit for custom builders than for production builders, says Henry, who has designed starter homes from 1,200 square feet to luxury estates with 60,000 square feet.

"All initial costs are more expensive," says Henry, who heads up his namesake design firm. "A lot of builders aren't used to doing this, and any time you introduce a new technology, it's hard to get it through the pipeline. If you add any glitch into the system, then you're bound to increase costs and have longer delays."

Homeowners can recoup the extra costs over time through lower energy bills, he says, "but you have to live in the house long enough to gain the benefits. If we don't plan to stay in that house long enough, then we won't get the benefits."

Setting the standards

Four years ago, representatives from several state universities and construction-industry professionals established the Florida Green Building Coalition to produce guidelines on how to build green. The group created standards by which a home can be evaluated for how well it uses natural resources during construction and in the home's lifetime of operation.

The Florida program judges homes by criteria such as site orientation, energy and water efficiency, building materials, indoor air quality, landscaping and disaster mitigation.

The first home in Florida to be certified as green was a 2,410-square-foot home built in 2001 by Fallman Design and Construction in Clermont. The energy- and water-efficient home functioned so well the builder constructed one for his own family last year using many of the same methods and materials. This home, too, is certified.

Eco-friendly homes such as those Fallman built are still rare, but industry professionals are seeing signs of a quiet revolution. Between 1990 and 2001, fewer than 19,000 homes nationwide were built to green guidelines, according to the research center for the National Association of Home Builders. In 2002 alone, more than 13,000 green homes were built. Figures for 2003 are expected to be significantly higher, but details won't be released until later this month.

The builders group and its research center are planning to develop voluntary green guidelines that can be used by home builders across the country. The plan was announced last month at the International Builders Show in Las Vegas. The guidelines will contain criteria to set the industry bar for land development, site planning, resource efficiency, water conservation, indoor air quality, energy efficiency, operations maintenance and homeowner education.

If membership in the Florida coalition is any indication, more green homes are on the way. From eight members in 2000, the coalition has grown to 112 today.

Florida developments feature green houses in a wide range of prices. For example, homes at The Estates at Twin Eagles in Naples start at $1.2 million, while homes at Celebration Oaks, a Habitat for Humanity community near Gainesville, are expected to be priced between $48,000 and $54,000.

Fallman says the demand for green homes isn't strong locally yet. But as consumers and builders learn about the benefits, he expects the movement to transform the housing market.

"There are people who will demand building green in the name of saving the planet," he says. "But most people don't know about it. As people become more educated and aware, especially about situations such as our drought, it becomes more and more important to build houses like this. If people only knew the benefits, they would demand these things."

The need to educate

Green-building concepts may be fine in theory, but in practice it's not always feasible for builders suddenly to make the leap from conventional building to green standards, say some industry professionals.

"Education is one of the primary reasons why it's not the de facto way in which building is done," says Rich Dooley, environmental analyst/land use planner at the research center for the National Association of Home Builders. "Consumers drive the train in the home-building industry. From the conversations that I've had [with builders] across the country, it's primarily because the consumers aren't asking for it."

Architects, builders and other construction-industry professionals unfamiliar with green-building practices also may need time to learn how to integrate new methods into design and construction, and how to work together as a team.

"It requires extra effort on everybody's part," Henry says.

Educating builders and consumers, though, isn't enough if eco-friendly products are unavailable, too costly or inferior as they have been in the past.

"Getting materials in a timely manner is one of the drawbacks," Dooley says.

For example, he says, builders have reported delays in receiving wood with the stamp of approval from the Forest Stewardship Council, an organization that verifies wood products come from environmentally responsible forests.

Such problems are to be expected in any industry as it moves forward, Dooley says. Builders who already meet green standards have been willing to tackle and overcome obstacles to pioneer construction techniques. As the bumpy road grows smoother, he says, more builders will join the green movement.

"Can a builder build a quality house without it being green? Yes," Dooley says. But "I don't see a reason why anyone wouldn't want to build green or why any consumer wouldn't want a green house. That's my perspective. It's a win-win situation for the environment, a win-win situation for the consumer and a win-win situation for the builder, as well."

Many builders already are incorporating some greener features as new building codes require more energy-efficient measures, says Tom Lagomarsino, former executive director of the Home Builders Association of Metro Orlando.

"The [changing] building code calls for houses to be tighter and tighter," he says. "They [builders] all have to comply with government regulations, and they are. Compared to 15 years ago, are we building green? Yes, we are."

Building on past experience

For decades, eco-friendly home builders have attempted to save natural resources by choosing alternative materials such as rammed earth, straw-bale and even used car tires, but these unusual approaches weren't widely accepted. The green homes built today bear little resemblance to those constructed during the 1960s and '70s.

Austin, Texas, is credited as the birthplace of the modern green-building movement because it was the first city to adopt a residential green-building program in 1991. Green building also has gained a foothold in such environmentally conscious cities as Denver and Portland, Ore.

Current green-building efforts include mainstream design and construction techniques, as well as materials that offer environmental benefits without being out of step with surrounding homes.

For example, Florida's first certified green home fits nicely into its Clermont subdivision. Most onlookers wouldn't notice many of its health-conscious, resource-efficient features: maintenance-free solar water heating, insulated French doors, a digital programmable thermostat, a central dehumidification and ventilation system, and heavy-duty attic insulation.

Green concepts extend to the home's landscape plan, which uses drought-tolerant plants, a water-saving irrigation system with separate plant and turf zones, and a rain-sensor shut-off valve.

To homeowners Larry and Vivian VanCleave, the features mean lower utility bills and less time spent on household upkeep.

"I think people need to see what energy efficiency can do," says Larry VanCleave who describes himself as "not really an environmentalist." "Sooner or later our water and [other] resources are going to reduce themselves and become more costly."

Payback for consumers

Energy efficiency plays an important role in the mainstream appeal of green, because it provides the biggest payback in terms of dollars, says Eric Martin, research engineer with the Florida Solar Energy Center, a research institute of the University of Central Florida in Cocoa.

"Other green features provide less quantifiable, but equally important, payoffs such as health, durability and natural-resource efficiency," Martin says.

Lower utility bills and a cleaner environment may have been the impetus for building green early on, but health concerns likely will keep the movement spreading.

Although outdoor air pollution has been a concern for decades, the Environmental Protection Agency has identified indoor air quality as one of the top five most-urgent environmental risks to public health.

Indoor air pollution comes from chemicals found in common building materials inside the home, according to the government agency. Carpet, paint, glue and cabinet materials, for example, can emit fumes for years after installation that can cause headaches or irritation to the skin, eyes, nose and throat, according to the EPA.

Green-building programs offer guidelines on how to create less-polluted indoor environments.

Durability figures into green-building's allure because a house that's designed to be more wind-resistant and built with long-lasting materials creates a safer environment in storm-prone areas, and saves the homeowner maintenance costs.

A durable concrete tile roof such as the VanCleaves' may cost about three times more to install than heavyweight asphalt shingles — a common home covering — but it outlasts most other roofing materials.

A concrete roof typically lasts at least 50 years; the average asphalt roof lasts 17 years and the material is difficult to recycle. Concrete's longer life span means less waste at the landfill.

Higher cost to build

The main stumbling block to a greener future in the construction industry has been the extra up-front costs to consumers, experts say.

"It's a little more expensive. That's the only drawback to it," says Lagomarsino.

For example, builder Fallman estimates the green upgrades added about $10,000 to the price of the VanCleave house, which sold for $294,000.

But Fallman points out that a house's real cost is not the listing price but what it costs the owner to operate over time, including utility bills and household maintenance expenses. He estimates that the VanCleaves' green features save the couple about $75 a month in reduced energy and water bills.

Although building codes are greener than they used to be, fewer builders are willing to go beyond those requirements unless they know buyers will pay any extra costs associated with green building.

Recent surveys suggest they are. A poll by the Cahners Residential Group, which includes *Professional Builder* magazine, found that 96 percent of nearly 300 respondents said they are willing to pay more for green building features. More than two-thirds said they would pay $2,500 to $5,000 for green features, and an additional 20 percent of respondents said they would pay $10,000 for a package of green features in a new home.

Still, builders say survey answers don't always manifest when construction starts. When the budget forces buyers to choose, they aren't always willing to give up status items such as whirlpool tubs to pay for environmentally sensitive upgrades, Lagomarsino says.

The VanCleaves hadn't heard of the green-building movement when they stumbled upon their green home. But now that they've lived there long enough to experience the benefits, they say they would ask for many of the features in any future house.

"I have nothing but praise for how Paul [Fallman] built this house," says Larry VanCleave.

"I think that most of the people now in our subdivision have so much respect for the quality that went into our house. We've had people drive by and say, 'Can we look at it?' We let them. People need to see the quality construction."

Carrie Alexander can be reached at calexander@orlandosentinel.com or 407-420-5499.

HOW GREEN IS YOUR HOME?

If your home is sensitive to the environment, is energy efficient and uses nontoxic materials, then you'll agree with each of these statements. Tally your points, and find out how green your home really is.

Statement	Agreement YES	NO
My yard is less than 50% grass.		
My appliances carry the Energy Star label for energy efficiency.		
The south and west sides of my house are shaded by trees or porches.		
The Seasonal Energy Efficiency Rating (SEER) of my air conditioner is 13 or higher.		
The air filters in my house are more than 1 inch thick.		
Less than 50% of my house is carpeted.		
The planted areas of my yard use drip irrigation.		
There are 3 to 4 inches of mulch applied to planted areas.		
The exhaust fan comes on automatically when I turn on the bathroom light.		
My insulation is an energy-efficient type such as Icynene.		
Total points from YES column		

Ranking:
0-3 points: My house is in need of a green renovation.
4-7 points: My house is average.
8-10 points: My house has good indoor air quality and efficient features.

SOURCE: Trifecta Construction Solutions Inc.

LISA A. FRASIER / ORLANDO SENTINEL

Figure A2 Page J4 of Orlando Sentinel, Sunday, February 8, 2004. "The Green Revolution: A Florida First. Part 1 of a 4-part series." "Blueprints for the home planet."

Orlando Sentinel

The Green Revolution: A Florida First

SUNDAY, FEBRUARY 8, 2004 J5

Solar-power technology costs are expected to fall as use rises

By CARRIE ALEXANDER
SENTINEL STAFF WRITER

The sun's power has been harnessed throughout history, but modern applications of solar energy didn't flourish until the energy crisis in the 1970s. Since then, solar-power technology has grown more efficient and has steadily worked its way into the mainstream market.

Today, homes and businesses with solar panels can generate their own electricity while connected directly to the existing power grid. A photovoltaic system is a solar electric system that converts some of the energy in sunlight directly into electricity, which can be used immediately or stored in large batteries.

The main obstacle to residential use of photovoltaic systems is its higher cost. For example, a 1 kilowatt photovoltaic system on a typical home might cost about $10,000 to install and maintain over the life of the system, according to the Florida Solar Energy Center in Cocoa. That system would produce about 30,000 kilowatt-hours of power at about 33 cents per kwh. The average cost of electricity in Florida is about 9 cents per kilowatt-hour.

Some states such as California subsidize the cost of the systems almost by half, lowering the price to about 16 cents per kwh. As the cost continues to decrease, the use of photovoltaics is expected to increase.

Other energy-efficient building methods and technologies — both ancient and cutting-edge — are enjoying increased popularity in regions where the climate is suited to their use. Here are a few:

Straw bale — Straw is an inexpensive, renewable resource that is considered energy efficient when used as a building material. Straw bale construction uses the waste product from harvested grain. Straw bales are skewered on reinforcing steel bars and are stacked bricklike on top of one another. The exterior walls are covered by stucco, giving the home an adobe look.

Rammed earth — Plywood forms are erected, and a soil-cement mixture is pressed into the forms. When the forms are removed, solid-earth walls remain. Their strength rivals concrete.

Cordwood — Cordwood construction uses short logs placed horizontally in the wall within a special mortar mix. These houses are considered low-cost, fire-resistant and energy efficient.

Green roof — Also known as a living roof, it is covered with a waterproof membrane and a layer of soil planted with vegetation. Already popular in Europe, green roofs are appearing in American cities because of their many benefits. Rooftop gardens keep buildings cooler, soak up rainwater which helps reduce storm runoff, and filter air and water pollution.

Insulated concrete forms — Made of an insulating material such as foam, these forms resemble Lego building blocks. Steel rod reinforcements are set in the forms, which are stacked, and concrete is poured in them to create walls.

Zero-energy home — A home built to use less energy than standard homes combines energy-efficient construction and appliances with renewable energy systems such as solar and wind. The home is connected to the utility grid, but it can produce as much energy as it consumes and may even produce more energy than it needs. The excess energy can be sold back to the utility company.

Carrie Alexander can be reached at calexander@orlandosentinel.com or 407-420-5499.

These homes show off green concepts

Demonstration projects throughout the United States serve as catalysts in the transition to more environmentally sustainable practices. Here are three in Florida:

• Orlando House showcases environmentally friendly products and methods. The two-story house, constructed of recycled and durable materials, was designed to Florida Green Building Coalition standards and Energy Star requirements.

The landscape promotes drought-tolerant, water-wise practices to conserve water and reduce the need for chemicals, fertilizers and pesticides. House details include steel framing, a metal roof with a lifetime warranty, drywall made of 98 percent recycled material, termite-resistant fiber-cement plank siding and bamboo flooring, a solar water-heating system, Icynene insulation and double-pane, insulated windows.

Joe Sandley, rehabilitation supervisor for the city's housing department, served as project manager, and Robb & Stucky Furniture and Design Studio in Altamonte Springs coordinated the interior design.

Where: 2516 E. Church St.

When: 11 a.m. to 3 p.m. Saturdays and 1 to 4 p.m. Sundays through March 14. Group tours are available during the week by appointment.

Admission: Free.

Details: 407-898-4860 or cityoforlando.net.

• The Florida House Learning Center at Sarasota County Technical Institute is an "earth-friendly" demonstration of green building design strategies and technologies. The project demonstrates energy efficiency, water conservation, healthy house concepts and recycled products.

Building details include compact fluorescent lights with a timer, carpeting made of recycled plastic bottles, floor tile made of recycled glass, a water-purification system and solar cells on the roof.

The landscape exhibits green principles such as the use of native and edible plants, compost and drought-tolerant plants. There is also a cistern water-collection system. The center is open to the public, and the extension service conducts classes on subjects such as decking alternatives and termites.

Where: Sarasota County Technical Institute campus, 4600 Beneva Road S., Sarasota.

When: 10 a.m. to 4 p.m. Tuesdays through Fridays and 1 to 4 p.m. Saturdays.

Admission: Free.

Details: 941-316-1200; sarasota.extension.ufl.edu.

• The WCI Green Building Demonstration and Learning Center is under construction at Florida Gulf Coast University in Fort Myers. The center will foster environmentally sustainable and healthy building and landscaping practices, with a focus on such principles as health, water and energy conservation, hurricane protection and solar-energy applications.

The building is expected to be certified under the U.S. Green Building Council Leadership in Energy and Environmental Design program.

Where: On the Florida Gulf Coast University campus, 10501 FGCU Blvd. S., Fort Myers.

When: Programs are ongoing at other locations while the center is under construction. Call for times and locations.

Details: 239-229-3177; www.fgcu.edu/greenbuilding.

— CARRIE ALEXANDER

FLORIDA HOUSE LEARNING CENTER

A greener shade. The Orlando House (right) on Church Street has steel framing and drywall made of 98 percent recycled material. The Florida House Learning Center at Sarasota County Technical Institute (above) has building details such as carpeting made of recycled plastic bottles and floor tile made of recycled glass.

RED HUBER/ORLANDO SENTINEL

SOURCES

Florida Green Building Coalition, floridagreenbuilding.org. Lists Florida construction industry professionals involved in green building and provides copies of the green home and land development standards.

U.S. Environmental Protection Agency and **U.S. Department of Energy**, www.energystar.gov; 1-888-782-7937. Maintain a joint Web site that provides information about the Energy Star program and energy-efficient products.

U.S. Green Building Council, usgbc.org; 202-828-7422. Works to promote buildings that are environmentally responsible, profitable and healthy places to live and work.

Florida Solar Energy Center, a research institute of the University of Central Florida in Cocoa, fsec.ucf.edu; 321-638-1000. Maintains a Web site that discusses energy efficiency and green-building standards.

U.S. Department of Energy's Smart Communities Network, www.sustainable.doe.gov. Has case studies on green buildings, as well as information on funding, programs and rating systems.

Figure A3 Page J5 of Orlando Sentinel, Sunday, February 8, 2004. "The Green Revolution: A Florida First. Part 1 of a 4-part series." "Blueprints for the home planet."

Homes

NSW

Orlando Sentinel • OrlandoSentinel.com
SUNDAY, FEBRUARY 15, 2004 • SECTION J

REAL ESTATE CLASSIFIED INSIDE AND ONLINE
orlandosentinel.com/realestate/

A fresh angle. Health concerns about the chemicals used in manmade products make salvaged materials an attractive option. This neoclassic wood pediment from a circa-1905 home in Upstate New York is available at Florida Victorian Antiques in DeLand.

PHYLLIS REDMAN/SPECIAL TO THE SENTINEL

Switch on the ingenuity. This chandelier, featuring oak timbers with iron straps, chains and amber glass in copper-and-tin fixtures, was salvaged from the now-defunct Bonefish Billy's restaurant in Winter Park. The circa-1960 fixture is on display at the DeLand salvage shop.

PHYLLIS REDMAN/SPECIAL TO THE SENTINEL

ORLANDO SENTINEL

Reflections of the past. Stacia Hollman used salvaged wood flooring, created wainscoting from restored doors and blended old columns into her DeLand home. Such materials create a cozy atmosphere the homeowners find desirable.

The Green Revolution: Interior Motives

PART 2 OF A 4-PART SERIES

Health worries hit home

Forget plain: You can save the planet with panache

By CARRIE ALEXANDER
SENTINEL STAFF WRITER

Actress Amy Smart does it. So does Backstreet Boy Kevin Richardson.

In fact, it's all the rage in Hollywood. Celebrities are "greening" their homes, says Danny Seo, lifestyle consultant to the stars.

The longtime environmentalist advises celebrities on eco-styling. He says no one is likely to make good environmental choices if they have to sacrifice style, so his message is this: It's possible to save the planet and be stylish.

Eco-friendly interior design is an element of the green building movement that is sweeping the country.

"It's being embraced in Hollywood," Seo says. "They [celebrities] finally realize they can have the beautiful home in Hollywood Hills, and it can be environmentally friendly."

Seo, who is sometimes called the Martha Stewart of the organic set, offers many suggestions not just for stars but for anyone trying to create an elegant living space that shows environmental sensitivity.

Waste not, want not

First, Seo says, think like MacGyver, the 1980s television secret agent who saved the day by creating something useful

PLEASE SEE DECOR, J4

JOHN RAOUX/ORLANDO SENTINEL

Home sick. Dee Smith uses air purifiers at her home in Palm Bay, which is free of chemicals. In a previous home, Smith complained of ailments that a doctor said probably were caused by formaldehyde.

ABOUT THIS SERIES

Feb. 8 in Homes: A Florida First
A trend is emerging that may be one of the most significant in home building for the 21st century. It's the green revolution, and it's been catching on in Florida since the state certified its first green home three years ago. Industry experts discuss the principles of building green and the hurdles builders face.

Today in Homes: Interior Motives
Energy efficiency and environmental issues drove the green-building movement early on, but health concerns are beginning to play a larger role, as research indicates a correlation between chemicals in modern building materials and illness. Also, designers are demonstrating that interiors can be eco-friendly as well as stylish.

Saturday in Garden & Home: Botanical Benefits
The green movement's efforts to protect natural resources extend to a home's landscaping where extravagant gardening practices are changing. The design, plant selection and maintenance techniques are key to saving water and energy, and protecting the environment from harmful chemicals.

Feb. 22 in Homes: Applying Principles
A couple in South Florida live the green life daily, as experts debate which up-and-coming products and materials are the most environmentally sound and energy efficient. Plus, whole communities devoted to the concept are cropping up in Florida, and a number of resources are available to help consumers get greener homes.

Story Gallery Online: The stories in this series are being posted on OrlandoSentinel.com/green

Attention is turning to green-building practices and products that protect inhabitants and the environment as some chemicals used in modern houses prove to have harmful effects.

By CARRIE ALEXANDER
SENTINEL STAFF WRITER

PALM BAY

Hopelessness.

Dee Smith, 57, has felt it before, and she is feeling it again as she snatches a bottle of vitamins off the counter and throws it across the room.

Seven months before, Smith recalls, she had been in good health. She and her new husband, Ron, had set up house in a manufactured home in Lakeland in August 1996. Within three weeks she began experiencing a variety of health problems, from painful muscle spasms to arthritislike aches in her toes. Her nasal passages became congested, and her eyes felt dry and irritated. Her skin developed extreme sensitivity, and at times she couldn't bear to be touched.

Dee Smith says she felt as though her muscles wouldn't stretch. She found it nearly impossible to bend down to pick up things off the floor.

During the next 11 months, a battery of medical tests ruled out lupus, arthritis, leukemia and thyroid problems. But the tests did not reveal what was wrong.

Then she took a trip to Kentucky. Some of her strength returned almost immediately, and she was able to reach down and touch the floor again. Her husband began to wonder how that could be possible.

"The change was so dramatic," he says. "I said, 'I know what's wrong with you: You're allergic to the house.'"

Ron Smith, it turns out, was on to something.

Many construction professionals say chemicals used in modern building materials are proving to have harmful effects on humans. They say it's time to turn the industry's focus to building homes that are healthier for the occupants while protecting the environment and its natural resources.

This concept, called green building, will be among the most significant trends in home building in the 21st century, many industry professionals say.

Ron Smith's suspicions about his wife's illness and their new home led him to search his files for a health notice he remembered being taped to the countertop when they moved in. Printed in capital letters, the notice read: "Some of the building materials used in this home emit formaldehyde. Eye, nose and throat irritation, headache, nausea and a variety of asthma-like symptoms, including shortness of breath, have been reported as a result of formalde-

PLEASE SEE GREEN, J5

• How to find details about chemical hazards. | Page J5

INSIDE

Antiques Show & Sale
Antiques lovers will find wares of vendors from 12 states at the Orlando Museum of Art's annual Antiques Show & Sale, opening Friday.
PAGE J9

ONLINE

Virtual tours
Take virtual tours of homes that are for sale to experience how the interiors are laid out, and you'll also get to see "around back."
ORLANDOSENTINEL.COM/REALESTATE/

Figure A4 Page J1 of Orlando Sentinel, Sunday, February 15, 2004. "The Green Revolution Interior Motives. Part 2 of a 4-part series." "Health worries hit home."

J4 Orlando Sentinel — The Green Revolution: Interior Motives — SUNDAY, FEBRUARY 15, 2004

Salvaged materials help add warmth

DECOR FROM J1

out of ordinary objects such as chewing gum and paper clips.

Seo encourages that same resourcefulness when it comes to decorating. Reuse common items for other purposes in your home, he says, instead of relegating them to the landfill.

For example, in Seo's New York apartment, tree branches found new lives as curtain rods, and an old church podium became his television stand. He painted a wall with nontoxic chalkboard paint where he created his own "art" by scribbling messages in chalk.

Another suggestion: Instead of buying new furniture and tossing the old, give pieces a face-lift by painting, reupholstering or refinishing. Seo upholstered a chair with an Old Navy jumper.

Seo offers many other ideas for eco-design in his book *Conscious Style Home: Eco-Friendly Living for the 21st Century* (St. Martin's Press, $29.95).

Green scene

Just as green construction is making inroads with builders and developers, green interiors slowly are catching on among designers. In 1999 the International Interior Design Association listed sustainable design issues among its priorities.

Some design professionals, including DeLand designer Beverly Weiter, focus on environmental concepts and materials in their work. Weiter's firm, Environs Interiors, also works with clients who have environmental illnesses such as asthma and multiple chemical sensitivity, a disorder that makes one increasingly intolerant to chemicals.

The principles are the same in any design, but the products should reflect concern for the health of the environment and the people, she says. Green interiors should focus on natural materials, such as natural-fiber carpeting, as much as possible.

Green materials, she says, are "not difficult to find. You're seeing major companies come on board. Benjamin Moore, DuPont and others are coming out with [green] products."

Today's explosion of choices — thanks to the addition of more-healthful paints and finishes, natural-fiber fabrics with no coatings and sustainable wood — gives designers a diverse menu of options for dressing a home that is environmentally sound.

Weiter says such a design can be achieved without a room appearing much different than a conventionally designed room.

Home and Condo's 2003 Dream Home in Naples was evidence of that. The $3.3 million home in The Estates at TwinEagles was designed as a model of green building, from its environmentally conscious architecture to its interior design.

Romanza Interior Design, which has an office in Orlando, created a welcoming space using green alternatives to conventional materials.

Green interior materials are chosen for energy and resource efficiency, durability, nontoxicity and recycled content or ability to recycle.

These green alternatives were chosen for the dream home:

• Floor and ceiling choices include bamboo, cork, granite and wool carpeting. Bamboo, a fast-growing grass, is often used in place of hardwood flooring because it is a more renewable resource than hardwoods, which can be a healthful option for homeowners with allergies. Cork, a product that won't rot and cushions the feet, is harvested from the bark of the cork tree. Natural-fiber carpeting such as the wool used in the master suite reduces dust mites and doesn't emit noxious fumes as synthetic carpeting can.

• For indoor air quality, wall coverings and paint were chosen with low volatile organic compounds to diminish the amount of fumes they emit.

• Upholstery and window treatments are from natural-fiber fabrics — including linen, cotton and silk — that don't emit fumes.

• Tile made from recycled glass was used for the master bath shower and backsplash.

• Granite kitchen countertops and flooring are natural, durable choices that won't emit toxic fumes.

• Reclaimed wood from a sunken barge was used for beams in the kitchen and flooring in the club room.

What's old is new again

Using reclaimed wood and other salvage materials gives homeowners a chance to blend the past and the present with materials that offer unique character and craftsmanship, says Mark Shuttleworth, owner of Florida Victorian Architectural Antiques, a salvage retail shop in DeLand.

When buildings are hand demolished to salvage components, savings are twofold: "The materials are reused so they don't go in the landfill," Shuttleworth says. "Plus, you don't use the energy that's required to create new products."

The materials evoke the spirit of another time, he says, and add warmth to the interior of a newly built home, which can sometimes seem cold and even sterile.

"Some people really like the history — to know the house it came out of, where it was, what it was used for," Shuttleworth says.

"A lot of people use older materials simply because they have personality. Older woods have a nice rich patina, so it gives kind of a warmer look."

Locally salvaged materials at Shuttleworth's shop have included brick from a 1923 Sanford building, tin and display cases from former Church Street Station structures and windows from Rollins College.

"We tend to be really eclectic in our buying," Shuttleworth says, which is why the shop's assortment can also include staircases, stained glass windows, movie props, antique counters and sinks.

Many of Shuttleworth's customers display the ingenuity that Seo discusses in his book.

Stacia Hollman, for example, recycled old beadboard molding into frames for family photos in her DeLand home. She incorporated a kitchen cabinet unit from a 1900s farmhouse and installed wood flooring that had been salvaged from several other houses. Wainscoting in her home was made from old doors.

Similar items can be found at salvage shops run by Habitat for Humanity, an organization that builds housing for low-income families. Often called ReStores, Habitat shops can be found in many cities including Orlando, Leesburg and Gainesville. They sell used and surplus building materials, such as wood, hardware, doors and fireplace mantels that have been donated, often from contractors and demolition crews. Proceeds fund the construction of Habitat houses in the store's respective communities.

Green greenery

Another green design principle is the use of plants, which not only add aesthetic appeal but can improve indoor air quality, according to several studies.

Bill Wolverton was a senior research scientist with NASA in 1984 when he tested houseplants in sealed chambers to see if they would maintain clean air for future space habitats. Wolverton discovered that philodendrons and golden pothos were excellent at controlling formaldehyde while gerbera daisies and chrysanthemums were impressive benzene purgers.

Another NASA study in 1989 concluded that some houseplants removed up to 87 percent of toxic indoor air within 24 hours.

Wolverton says plants are nature's living air filters, and he lists top pollutant controllers in his book, *How to Grow Fresh Air: 50 Houseplants That Purify Your Home or Office* (Penguin Books, $16.95).

Plants might brighten corners and help to purify the air, but most homeowners will want other elements to jazz up their interiors, too. Hollywood stylist Seo likes to keep things natural when he's choosing accessories. He suggests displaying pieces of driftwood found when strolling along the beach or using attractive rocks as paperweights and bookends.

He's also designing a collection of eco-friendly housewares and accessories that he says will be just as stylish as conventional products.

Environmental concerns "can never serve as the main reason somebody is going to buy something," Seo says. "Products that are solely green will not do well, but if you can offer a product that is designed in a clever way and is priced right and is green, then you've got something."

Carrie Alexander can be reached at calexander@orlandosentinel.com or 407-420-5499.

Elements of green living

The Home & Condo 2003 Dream Home in Naples was designed as a model of green living, with environmentally conscious architecture, materials, landscaping and interior design. These five rooms showcase several green elements.

A. **Air vents** filter out particles through a HEPA filtration system.

B. **Lighting fixtures** are sealed to prevent infiltration of outdoor air.

C. **Plants** improve indoor air quality.

D. **Natural flooring materials** such as stone, marble, granite, wood and wool carpeting preserve indoor air quality.

E. **All-wood cabinetry** helps maintain a pollutant-free environment.

F. **Recycled wood** saves natural resources.

G. **Nontoxic paint** emits fewer fumes.

H. **Natural countertop materials** help maintain indoor air quality.

I. **Energy-efficient appliances** lower utility bills.

J. **Natural-fiber curtains** are made of fabric not treated with chemicals.

K. **Ceiling fans** allow thermostats to be set higher, saving cooling costs.

L. **Timer-controlled** exhaust fans help control moisture.

M. **Plantation shutters** are easier to keep free of dust and pet dander than other window coverings.

N. **Recycled-glass tiles** are durable; using recycled materials saves landfill space.

SOURCE: Sentinel research
PHOTOS BY LAURENCE TAYLOR, PHOTO ILLUSTRATION BY LISA A. FRASIER / ORLANDO SENTINEL

ON THE SHELF

• *New Old House: Designing With Reclaimed Materials* by Ed Knapp; Gibbs Smith, $39.95, hardcover, 160 pages.

• *The Healthy Home: Beautiful Interiors That Enhance the Environment and Your Well Being* by Jackie Craven, Rockport, $25, hardcover, 159 pages.

• *Conscious Style Home: Eco-friendly Living for the 21st Century* by Danny Seo; St. Martin's Press, $29.95, hardcover, 160 pages.

• *Chemical-Free Kids: How to Safeguard Your Child's Diet and Environment* by Allan Magaziner, Linda Bonvie and Anthony Zolezzi; Kensington, $15, paperback, 304 pages.

• *Good Green Homes: Creating Better Homes for a Healthier Planet* by Jennifer Roberts; Gibbs Smith, $39.95, hardcover, 160 pages.

SOURCES FOR GREEN PRODUCTS

Co-op America, environmental organization, greenpages.org. Provides a directory of businesses that sell eco-friendly products.

Habitat for Humanity International, habitat.org/env/restore.html. Provides a directory of ReStores, including several in Florida, that sell salvaged items such as doors, hardware, mantles and wood flooring.

Figure A5 Page J4 of Orlando Sentinel, Sunday, February 15, 2004. "The Green Revolution: Interior Motives. Part 2 of a 4-part series." Health worries hit home."

Builders seek out less-toxic materials

GREEN FROM J1

hyde exposure."

The notice went on to read that research is examining the long-term effects of exposure to formaldehyde, and, "If you have any questions regarding the health effects of formaldehyde, consult your doctor or local health department."

The Smiths did both. They called the Florida Department of Health to have their home tested for formaldehyde exposure. The level measured in the kitchen was 0.23 parts per million, and in the bedroom, 0.12 ppm. Both levels exceeded the recommended maximum of 0.10 ppm, according to the health department report.

Dee Smith consulted with Dr. Albert Robbins, a physician in Boca Raton who specializes in environmental medicine. The formaldehyde exposure was deemed the most likely cause of her subsequent diagnosis of multiple chemical sensitivity, a disorder that makes one increasingly intolerant of chemicals.

The Smiths eventually received an out-of-court settlement in a lawsuit, but as part of the settlement agreement, the couple say, they cannot discuss it.

Dee Smith's symptoms grew worse and the couple moved several times before they purchased a house in Palm Bay. That home had been modified by the previous owner, who also suffered from chemical sensitivities. Dee Smith says living in the pollutant-free environment eased her symptoms.

Formaldehyde is common

Anecdotal evidence suggests that the number of those affected by multiple chemical sensitivity is steadily rising, says Robbins. Specific numbers are difficult to come by because the illness is not easily diagnosed and is not accepted by all medical practitioners. About 15 percent of Americans experience sensitivity to chemicals, according to National Academy of Sciences estimates.

Formaldehyde is one of the most likely culprits. It belongs to a family of chemicals — called volatile organic compounds — that vaporize at room temperature. The chemical has been classified as a probable human carcinogen by the U.S. Environmental Protection Agency. Yet it is used in finishes, plywood and particleboard, as well as other household products.

Chemicals are added to building materials to help preserve them, increase their durability or flexibility, keep insects at bay or make colors more vibrant. To keep the indoor environment as free of pollutants as possible, green builders try to use fewer chemical-laden building materials.

"You'd be very surprised to learn about the chemicals you're being exposed to on a regular basis, especially in new homes and renovation," says Bill Walsh, national coordinator for the Healthy Building Network, a consumer advocacy group in Washington, D.C.

"When you trace the life cycle of building materials, you see enormous amounts of chemicals that find their way in our homes. The exposure we have to toxic chemicals in the built environment is very high. You hear about [outdoor] air pollution, but actually people breathe more toxic air in the home."

'You hear about [outdoor] air pollution, but actually people breathe more toxic air in the home.'
— BILL WALSH
HEALTHY BUILDING NETWORK

Walsh says many homeowners report feeling ill after moving into a new home. Some find their symptoms intolerable and leave the home.

The green method

Green-building advocates say any possible harmful effects from construction can be lessened by changing practices and products. Programs such as the Florida Green Building Coalition's Green Standard and the American Lung Association's Health House create guidelines by which homes can be judged for health value.

Green-design specifications call for sealing the home to keep out air pollution, eliminating toxic materials and furnishings, providing ventilation systems to allow for healthy exchange of air and to prevent moisture buildup, and scheduling construction steps in an order that will produce the cleanest air.

Proper ventilation can protect the home from excess moisture and heat, which can lead to mold. Ventilation also brings in fresh air to dilute indoor pollutants and irritants including chemicals, dust and pet dander. Heat-recovery ventilators bring in fresh air and direct most of the energy back into the system, increasing comfort and lowering energy bills.

More homeowners are filing lawsuits claiming that mold is making them sick. To keep moisture out and prevent future mold problems, green builders install foundation waterproofing, seal doors and windows, and use roof flashing.

To remove moisture inside the home, green builders suggest installing exhaust fans that are vented to the outdoors in kitchens and bathrooms. The fans keep moisture from penetrating cracks and crevices, plaster and drywall, and other places where dampness can cause damage.

Many materials routinely used in new homes don't fare well by green-building program standards. For example, most guidelines steer homeowners away from synthetic carpeting and cabinets made of particleboard because they can emit formaldehyde or other harmful fumes.

Instead, to meet green standards, home buyers should look for formaldehyde-free cabinets, and have their builders attach countertop materials with mechanical fasteners rather than toxic adhesives. Buyers also should choose paints and sealants with low volatile organic compounds and select natural-fiber carpeting.

Green-building guidelines often specify the order in which materials should be installed. For example, construction steps such as painting and caulking, which release fumes in the air, should be done before installing absorbent materials such as carpeting and ceiling tiles.

Changes are being seen

Ideally, the house also would be built away from industrial sites, in a community with plenty of green space, says Melbourne Beach builder Ed Harrison, who designs and builds homes with a focus on health.

"Start with more green area to allow trees and shrubbery and grass to give off more oxygen," he says.

Harrison chooses natural, nontoxic building materials, and he designs houses with detached garages to keep noxious fumes from entering the living space. He also places the kitchen and laundry areas away from sleeping areas to avoid exhaust fumes.

"I take a holistic approach to architecture," he says. "We're not living in an ideal world, so we have to do the best we can, try to ease the load."

He says constructing a healthier home doesn't have to cost more than a conventionally built house. The reason many builders don't switch from traditional practices to greener methods is that they don't have the patience to learn healthier construction technique, he says. But, he adds, "the industry is starting to change because it affects their bottom line."

Manufacturers, too, are beginning to respond to growing health concerns among consumers. Paint companies such as Benjamin Moore now offer paint choices with no or low volatile organic compounds. The carpet industry created a "green label" program to test a sampling of carpets each year for emissions of volatile organic compounds.

"I think they're on the right track," Harrison says. "They've got a long way to go, but at least they're on the right track. It's the educated consumer who has the control over the manufacturing process. The people have the power."

Although the jury is still out on exactly how some chemicals harm humans, Harrison says it just makes sense to build homes with natural alternatives when possible.

Walsh, of the Healthy Building Network, agrees.

"Generally speaking, when it comes to human health, why not live by the age-old adage: better safe than sorry," he says. "If you can buy a product that doesn't contain a toxic chemical, why would you buy one that does?"

Carrie Alexander can be reached at 407-420-5499 or calexander@orlandosentinel.com.

WEB SITES OFFER HELP ON POTENTIAL TOXINS

Several organizations offer information about chemicals — many of which are found in building materials — they deem toxic or potentially toxic to humans. Here are a few Web sites that offer information on potential toxins:

- To find profiles on common chemicals, check with the Agency for Toxic Substances and Disease Registry in Atlanta, Ga.; 1-888-422-8737; www.atsdr.cdc.gov.
- The U.S. Environmental Protection Agency Web site, epa.gov/epahome/topics.html, offers information about toxic chemicals and pollutants and U.S. regulations regarding these materials.
- The Second National Report on Human Exposure to Environmental Chemicals, by Centers for Disease Control and Prevention in Atlanta, provides an ongoing assessment of the exposure of the U.S. population to environmental chemicals. The report can be found at www.cdc.gov/exposurereport/.
- Physicians for Social Responsibility, an environmental health organization, provides a report on the Web site, envirohealthaction.org/bearingtheburden, that includes information about the chemical types included in the 2003 National Exposure Report. The report offers detailed profiles of many of the chemicals, describing potential sources of exposure, health effects, methods for detecting exposure and federal regulations for protecting human health.

— CARRIE ALEXANDER

MORE ON HEALTHY HOMES

The Healthy House Institute, hhinst.com; 812-332-5073. Provides articles on topics such as how your house can make you sick and improving indoor air quality.

Centers for Disease Control and Prevention, National Center for Environmental Health; www.cdc.gov/exposurereport; 1-866-670-6052. Provides a copy of the Second National Report on Human Exposure to Environmental Chemicals.

Agency for Toxic Substances and Disease Registry, www.atsdr.cdc.gov/atsdrhome.html; 1-888-422-8737. Contains profiles of commonly used chemicals.

American Lung Association Health House program, healthhouse.org; 1-877-521-1491. Sets standards for creating healthy indoor environments.

The Healthy Building Network, a project of the Institute for Local Self-Reliance; healthybuilding.net; 202-898-1610. Provides information on more healthful building materials.

The U.S. Environmental Protection Agency, epa.gov. Maintains a Web site that discusses, among other things, indoor air quality. Consumers can order a free booklet, "The Inside Story: A Guide to Indoor Air Quality," on the site or by calling the National Service Center for Environmental Publications at 1-800-490-9198.

Figure A6 Page J5 of Orlando Sentinel, Sunday, February 15, 2004. "The Green Revolution: Interior Motives. Part of a 4-part series." "Health worries hit home."

Homes

NSW

Orlando Sentinel • OrlandoSentinel.com
SUNDAY, FEBRUARY 22, 2004 • SECTION J

REAL ESTATE CLASSIFIED
INSIDE AND ONLINE
orlandosentinel.com/realestate/

PHOTOS BY JULIE FLETCHER/ORLANDO SENTINEL

On line. Colette Corwin hangs clothes in a breezeway that connects the garage to their southwest Florida home. The breezes that blow through help cool the house and save energy by drying laundry naturally.

The Green Revolution: Applying Principles

PART 4 OF A 4-PART SERIES

Pioneer spirit

More and more Florida dwellings harken to yesteryear, as today's homes take advantage of sunlight and shade, and use recycled and energy-efficient materials.

By CARRIE ALEXANDER
SENTINEL STAFF WRITER

When Stan and Colette Corwin walked into an architect's office two years ago, they provided him with a wish list for their new home.

Give us a simple yet flexible design.

Make it energy- and water-efficient.

Disturb the surrounding environment as little as possible.

Provide a system to harvest rainwater and leave a spot to plant a large organic garden.

The Corwins are among an increasing number of consumers who want homes that are built with a focus on protecting natural resources — a trend known as green building.

"They wanted it to be Earth-friendly and to be healthy," recalls Rob Andrys, a South Florida architect who is president of the Florida Green Building Coalition. The nonprofit organization sets standards for environmentally friendly home construction. "They knew about green-building practices, but they didn't know what they should do or what they should look for."

Interest in eco-friendly concepts is growing among consumers, and many industry professionals think green building will prove to be one of the most significant trends in home construction in the 21st century.

"Green building is the natural response for those who recognize that we humans cannot continue to ignore the consequences of the way we live on our planet," says Stan Corwin, 68.

"To those who have not given this a thought, I would simply ask them to consider the consequences of the building decisions they make ... on their children and their grandchildren," says Corwin. "I would ask them to think about where the materials come from, the energy used to process them and to bring the materials to the site, and what are the alternatives that might be a better, cleaner, healthier, more sustainable solution."

Andrys suggested the couple read a book by Sarah Susanka, *The Not So Big House*, which espouses the idea that houses should be smaller and more personal.

The final design of the Corwins' 2,300-square-foot contemporary home in Alva pays tribute to Susanka's ideas, Florida Cracker-style and environmentally sensitive concepts.

The house features an open floor plan with a central "pod" that houses a fireplace, bookshelves and storage. The pod helps to define the foyer,

PLEASE SEE GREEN, J3

At home in the garden. Colette and Stan Corwin prepare the soil to grow organic vegetables. The garden is 1 of the finishing touches on their 9-acre property, which includes a green home.

BOBBY COKER/ORLANDO SENTINEL

COMING NEXT SUNDAY IN HOMES

Planning a pool? The 2004 Central Florida Pool Guide, publishing next Sunday as a special edition of the Homes section, will cover everything from choosing tiles to selecting insurance. Find out how to work with a contractor, plus get advice from three veteran remodelers on redoing your pool. We'll also cover safety issues, spas, aboveground pools and more.

Before you join the parade, map out a strategy

By G.K. SHARMAN
SPECIAL TO THE SENTINEL

The annual parades of homes in Central Florida can help you decide what type of house you would like as well as show you the latest trends in features.

But there are a lot of homes to see in the six counties during the four builder associations' parades of homes from late February through early May. If you count all the new models open daily from Volusia to Osceola, Brevard to Lake and northeast Polk County, you're looking at several hundred abodes and communities.

But at least the four parades are scheduled at different times, with Lake County leading the way Saturday through March 7, followed by Brevard, March 20-28; Volusia, April 17-25; and metropolitan Orlando, April 25-May 9.

"It can be overwhelming when you have all those choices," says Beth McGee, executive director of the Home Builders Association of Metro Orlando. The Orlando parade includes homes in Orange, Seminole and Osceola counties, as well as the northeastern corner of Polk County.

Could you see all the entries, even if you wanted to? Maybe. Should you try? If you have time and a large gas tank, why not.

What works best for most home-seekers is a strategy, a parade plan of attack.

"Make yourself a map," McGee advises.

If you want to buy a home, start by thinking about what you're looking for and where you want to be. Most people live relatively near work, she says, so that's a good place to start.

Next, consider what kind of neighborhood or lifestyle you want or what kinds of

PLEASE SEE PARADE, J9

INSIDE

Design of the Week

Le Chaumont, a French Normandy-style home, has a courtyard entryway, board shutters and other details that give it an Old World feel.
PAGE J18

Index

ONLINE

Where to retire

If you're part of the senior set, check out Where to Retire, featuring interactive maps, lists of agencies and stories about seniors.
ORLANDOSENTINEL.COM/REALESTATE/

Figure A7 Page J1 of Orlando Sentinel, Sunday, February 22, 2004. "The Green Revolution: Applying Principles. Part 4 of a 4-part series." "Pioneer spirit."

Stop to check out builder before giving green light

By CARRIE ALEXANDER
SENTINEL STAFF WRITER

Going green is getting easier.

Buyers can find homes in some Florida communities that already are being built with eco-friendly features. Or, buyers can work with builders who offer a green option package that will bring one of their conventionally built homes up to the Florida Green Building Coalition standard.

But if that's not the case where you're planning to live, how can you get a greener abode?

Clermont builder Paul Fallman says green construction is multifaceted, so it's best if home buyers can find a builder who already is experienced in green concepts. Otherwise, he says, "find someone who builds all their homes to Energy Star standards and have that builder contact the Florida Solar Energy Center for more information and assistance."

Energy Star is a federal program that promotes energy efficiency. Homes built to Energy Star guidelines typically are 30 percent more efficient than conventional homes.

Buyers can work with their builders to achieve a greener home in any price range, says Pierce Jones, director of the Florida Energy Extension Service at the University of Florida in Gainesville. He says guidance is available through Green Advantage, a program that offers certification to professionals who have been trained in green-building techniques.

Consumers can find certifying agents on the program's Web site, greenadvantage.org, and on the Florida Green Building Coalition Web site, floridagreenbuilding.org.

Experts agree that consumers should do their homework and have some idea of what they want before meeting with a builder to discuss plans.

"Consumers need to sit down with builders and express their goals with the project, whether it be energy efficiency, health, resource efficiency or all of the above," says Eric Martin, research engineer for the Florida Solar Energy Center. "A good green builder will work with the client and suggest features that meet the project goals and budget."

> *'A good green builder will work with the client and suggest features that meet the project goals and budget.'*
>
> — ERIC MARTIN
> RESEARCH ENGINEER FOR THE FLORIDA SOLAR ENERGY CENTER

Once a budget is determined, he says, products can be selected.

"There are always trade-offs, and multiple ways to achieve the same goal," he says. "This is good, because no one builder can be an expert in all possible equipment and techniques."

For example, he says, project goals could include building a house that meets Energy Star standards, produces healthy indoor air quality and uses recycled products wherever possible.

"Of course, goals could be more specific than that, or they could even be more general," he says. "Green-building programs come in and help persons meet their goals, and also suggest a flexible bar that they can reach for. This is important, because some people have the simple goal of wanting to build green but don't have the knowledge to go any further than that."

Jones cautions home buyers interested in incorporating green measures into their homes to make sure the builder isn't just marketing himself as a green builder for financial gain but is committed to using green supplies and methods.

"There are standards to measure green," he says. "The best example of that is Energy Star. A second example is Florida green-building standards. Look for programs that are third-party certified."

Experts debate what is, is not green

GREEN FROM J1

dining room, kitchen and living room spaces while allowing shared views. Above the pod, sunlight streams through a cupola, dispersing natural light throughout the main living spaces and reducing the need for electricity.

The single-story home has two bathrooms, a master bedroom and a guest room that connects to an office with French doors so the two spaces can be used as one.

The home was meticulously planned to meld harmoniously with the property's hickory trees, live oaks and cabbage palms, while not disturbing the native hawks, snakes and a wild boar that live nearby.

Before construction began, a site planner and a horticulturist recorded the habits of the native wildlife, the growth patterns of local plants and the natural water flow. Public areas of the house were located to take advantage of creek views, while the barn and garden were placed between the house and the road to mitigate any traffic noise.

A breezeway that connects the garage at an angle to the house takes advantage of summer breezes and provides a place to air-dry laundry.

The home's longest side faces the south, which allows overhangs and strategically placed porches to control harsh sunlight and help alleviate heat buildup inside the home. Carefully positioned windows and doors aid in the cross-ventilation strategy employed by Andrys.

The result? Monthly electric bills hover around $72, half of what the Corwins paid in their previous home.

Durability comes from walls of thin concrete slabs that sandwich insulating foam reinforced by rebar. The low-maintenance white metal roof reflects the sun's heat and directs rainwater to a cistern, then through a filtering process that purifies the water for use in laundering, showering and even drinking.

The homeowners chose sustainable materials that don't use much energy to produce and that are easily replenished. "The carpet is recycled soda-pop bottles, and it wears as well as nylon," says Corwin.

The Corwins planned for the future by building a battery storage room and by wiring the house in preparation to use a solar-powered photovoltaic system when prices drop. Photovoltaic systems, which do not produce air pollution or hazardous waste, convert sunlight into electricity that can be used immediately or stored for later use.

With the Corwins' new dwelling, home building has come full circle in Florida. Early settlers knew to orient their houses to take advantage of prevailing winds, sunlight and shade. They knew to fashion local materials into structures that fit the area's landscape and climate, and to collect rainwater for everyday uses.

Survival required it. Air conditioning didn't exist, and heating and lighting were achieved through more primitive means such as wood-burning fireplaces and oil lamps.

As modern conveniences came into play, builders could shrug off such principles and focus on household amenities.

Now in a quest to slow the depletion of natural resources, reduce pollution and save on monthly utility bills, green-building practitioners are resurrecting ancient construction concepts and combining them with new technologies.

PHOTOS BY JULIE FLETCHER/ORLANDO SENTINEL

A green blueprint. The final design of the Corwins' 2,300-square-foot contemporary home in Alva pays tribute to eco-sensitive concepts.

What is green?

As the Corwins discovered, determining what is green is no easy task.

Sometimes even the experts don't agree. The list of green products is ever evolving in part because the industry is still learning about the health effects of chemicals added to construction materials.

Some products can be green because of what isn't there and others can be green because of what is, says Eric Martin, research engineer for the Florida Solar Energy Center in Cocoa.

"Some are green because they are recycled, recyclable, produce less waste, use less energy to manufacture, etc., while others may be green because they produce a structure that uses less energy, is healthier and is maybe more disaster resistant," Martin says.

"Determining which is more green is difficult. At a minimum, a green product should have at least one green attribute," Martin says. "As an example, you can get points on the Florida standard for selecting a carpet that is recycled. You can also get points for minimizing carpet, and for the carpet you do have, choosing a 'healthy' version that is not recycled but virgin material."

Many industry professionals also consider the life cycle of a product, from raw materials to energy use during manufacturing and distribution, maintenance, then reuse and waste management. But even that is open to debate.

Wood detractors are concerned about harvesting and forest-management practices, while steel opponents worry about the environmental impact of manufacturing steel. Yet both products gain points for being recydable. Some green proponents say those who use wood should choose either reclaimed wood salvaged from existing structures or ecologically harvested wood that is handpicked with consideration given to the effect on the ecosystem.

"Everywhere you turn today people are talking about environmentally friendly or green building materials," says Chicago builder Lou Manfredini, author of home-improvement books including *Mr. Fix-It Introduces You to Your Home*. "Some are seeking less-toxic ways of building houses while others are simply looking for materials that require less energy to produce and can be recycled easily."

Although Manfredini is an advocate of wood, he's not opposed to using other building materials too.

"We need steel, we need concrete, we need all these materials, there's no question about it," he says. "It takes a lot of different materials to build a home."

On guard

Many organizations have developed standards and guidelines to evaluate products and services for their environmental impact. For example, the Washington, D.C., group Green Seal evaluates the environmental impacts of each stage of a product from resource extraction, production, distribution and use to disposal or recycling. The group then offers certification for products it deems environmentally friendly.

Green Guard Environmental Institute, a Washington, D.C., nonprofit group, oversees a program that tests and certifies products as low emitters of chemicals. And the government-backed Energy Star program identifies and promotes energy-efficient products.

Consumers also can learn about Earth-friendly products from local green-building organizations and their members as the Corwins did when they built their home in Alva, near Fort Myers.

Architect Andrys, Fort Myers builder Charles Kingsley and interior designer Barbara Hoey helped the couple choose healthful products that create less strain on the environment. Choices included linoleum flooring made of linseed oil, wood floor and rosin binders, solid-surface bathroom countertops made from waste resin and fence posts made of recycled plastic medicine bottles.

"I believe that the trend of green building is not only important but essential to the survival of our planet," says Colette Corwin, 63.

"To someone not into green building, I would ask them if they have thought of building in ways kinder to themselves and to the planet. And if they want to help make the world a better place, building a sustainable building is a way of doing this."

Carrie Alexander can be reached at calexander@orlandosentinel.com or 407-420-5499.

Water from heavens. Rainwater flows to a cistern, then through a filtering process that purifies the water.

SOURCES

Lists of builders committed to building efficient and/or more healthful homes:

Florida Green Building Coalition, floridagreenbuilding.org.

Energy Star program, www.energystar.gov/.

American Lung Association Health House program, healthhouse.org.

U.S. Department of Energy's Building America program, www.eere.energy.gov/.

Consumer information on green-building products and techniques:

The UF/IFAS Extension Bookstore at the University of Florida, ifasbooks.ufl.edu; 352-392-1764. Offers a guide to energy and water savings; $10.

Eco-Smart, operated by the Florida House Institute for Sustainable Development, ecohouse.com; 1-888-329-2705.

Research Center for the National Association of Home Builders, nahbrc.com, 1-800-638-8556.

ABOUT THIS SERIES

Feb. 8 in Homes: A Florida First

A trend is emerging that may be one of the most significant in home building for the 21st century. It's the green revolution, and it's been catching on in Florida since the state certified its first green home three years ago. Industry experts discuss the principles of building green and the hurdles builders face.

Feb. 15 in Homes: Interior Motives

Energy efficiency and environmental issues drove the green-building movement early on, but health concerns are beginning to play a larger role, as research indicates a correlation between chemicals in modern building materials and illness. Also, designers are demonstrating that interiors can be eco-friendly as well as stylish.

Feb. 21 in Garden & Home: Botanical Benefits

The green movement's efforts to protect natural resources extend to a home's landscaping where extravagant gardening practices are changing. The design, plant selection and maintenance techniques are key to saving water and energy, and protecting the environment from harmful chemicals.

Today in Homes: Applying Principles

A retired couple in South Florida live the green life daily, as experts debate which up-and-coming products and materials are the most environmentally sound and energy efficient. Plus, whole communities devoted to the concept are cropping up in Florida, and a number of resources are available to help consumers get greener homes.

Story Gallery Online: The stories in this series are being posted on OrlandoSentinel.com/green

Figure A8 Page J3 of Orlando Sentinel, Sunday, February 15, 2004. "The Green Revolution: Interior Motives. Part 2 of a 4-part series." "Health worries hit home."

Simpson Home Is First of Its Kind in WV

PLAQUES RECOGNIZING THE partnership of Almost Heaven Habitat for Humanity and Congress Building America for building energy efficient houses, which provide a comfortable environment, were presented to John Reisenweber and Michelle Connor, far right. The certificates were presented by Janet McIlvaine, left, at the house blessing for Bertha Simpson, center.

Last Thursday, Almost Heaven Habitat for Humanity dedicated its 63rd house, built in partnership with Bertha Simpson, and in memory of her late husband, Charles Henry Simpson.

Mrs. Simpson was presented with a bible, gifts and keys to her new house. She then gave her remarks and thanked everyone involved in the project.

Among those attending the ceremony was Trevor Riggen, the Director of Congress Building America (CBA).

The Simpson home is the first Habitat house in West Virginia built under the CBA program in cooperation with Congresswoman Shelley Moore Capito.

The Congresswoman broke ground with the Simpson family in September and was represented at the dedication by John Reisenweber, Capito's district field representative.

CBA is an initiative representing a cooperative effort between Habitat for Humanity International, the US Congress, the department of Housing and Urban Development and national corporate and nonprofit sponsors.

The program is designed to produce new, affordable, single family homes, to strengthen the network of affordable housing supporters by partnering members of Congress with local Habitat for Humanity affiliates and to highlight the importance of volunteerism.

Also attending the house blessing was a representative from the US Department of Energy (DOE), Janet McIlvaine.

The DOE will be providing participating Habitat for Humanity affiliates in the CBA program with technical assistance relating to energy, efficiency, durability, indoor air quality and systems engineering.

Visiting workcamp volunteers were also on hand from St. Joseph's University, Haverford College and Bryn Mawr College to partake in the celebration.

March 17, 2005—The Pendleton Times—Page 5

Figure A9 page 5 of the Pendleton Times (West Virginia), March 17, 2005. "Simpson Home Is First of It's Kind in WV"

- The Pendleton Times - "Simpson Home Is First of Its Kind in WV", March 17, 2005
- *Orlando Sentinel* - Home Section, "A Clean Sweep; Simple Steps Can Improve a Home's Indoor Air," September 22, 2001
- *Orlando Sentinel* - Home Section, "In the Name of Energy," September 2, 2001 OrlandoSentinel.com

- WSU Cougar Football Program, "WSU Energy House Serves as a Technology Test Bed," September 2001, WSU Press Release
- *Energy Design Update*, "Field Tests Commence on the World's Most Energy-Efficient Manufactured Home," December 2000, p.3.
- *Energy Design Update*, "New Building America Consortium to Focus on Industrialized Housing," March 2000, pp. 3-4.
- *Automated Builder Magazine*, "WSU Energy House", October 2000.
- *Energy Design Update*, "Ventilation System Decision Flow Chart," February 1999, pp. 16.
- *Builder*, "Resources: HVAC Electronic Control," October 1998, pp. 296.
- *Air Conditioning, Heating & Refrigeration News*," Fan recycling control offers improved indoor air and comfort for tight houses," September 28, 1998, pp. 30-33.
- *Air Conditioning, Heating & Refrigeration News*," What's New: Blower Control," September 14, 1998, pp. 24.
- *Energy Design Update*, "Computer Simulations Look Good for "Cathedralized" Attics," September 1998, pp. 6-10.
- *Home Energy Magazine*, "Energy Stars Shine on Manufactured Homes," July/August. 98, pp. 9-10.
- *The Home Front News*, "My Favorite New Product," July 1998.
- *Architecture*, "Technology: SIPS, Not Studs," June 1998, pp.148-152.
- *Concrete Home News*, "New $50 Device Controls Ventilation," June 1998.
- *Environmental Design and Construction*, "New HVAC Products," May/June 1998, pp. 41.
- *Builder,* "Space Shot Building Products: In Orbit – FanRecycler," January 1998, pp. 330.
- *Builder*, "Space Shot Building Products: Steel studs with thermal breaks," Jan 98, pp. 324.
- *Solar Collector*, "Smart box a boon to indoor air quality," December 1997, pp. 3.
- *Energy and Housing Report*, "FSEC Develops FanRecycler," December 1997, pp. 206.
- *Energy Design Update*, "Controller Improves the Efficiency of Furnace-Based Ventilation Systems," September 1997, pp. 15.
- *New Building Products*, "Low-Cost Ventilation System," August-September 1997, Vol. 3 No. 5, pp. 2.
- Nisson, J.D. Ned, Don Best, 1997. "Steel Framing for Houses," pp. 47-48, Cutter Information Corp., Arlington, MA.
- The *Building Systems Magazine*, of the National Association of Homebuilders, features a one-half-page add on a regular basis for the Structural Insulated Panel Association which prominently sites a direct quote from Armin Rudd's research report on the 1993 side-by-side testing in Louisville, KY.
- *Popular Science*, "Home Technology, Building Technology: The Panels Prevail," by Judith Anne Gunther, Apr-94.
- *The DSM Letter*, "New Technology: Insulated Panels Could Challenge Fiberglass Batts In Residential Market," Feb-94, pp.5.
- *Progressive Architecture*, "Technics Focus: Building With Panels," by Steven Winter, Nov-93, pp. 88-90
- *Energy and Housing Report*, "Side-By-Side Tests," Mar-93.
- *Energy Design Update*, "Most Practical Research of the Month Award: Foam Core vs. "Stick Built"--Side-by-Side Tests," Jan-93.

Appendix B: UCF Housing Constructability Lab Annual Report

Progress Report: April 2003 – March 2004

Prepared for

The Industrialized Housing Partnership & The Building America Program

Sponsored by
U.S. Department of Energy

Prepared by
UCF Housing Constructability Lab
Dr. Michael A. Mullens, PE

June 15, 2004

Executive Summary

UCF researchers continue to identify and develop prototype applications of computer technology for the modular factory floor. Research efforts this year focused on real time production labor data collection. While labor represents a relatively modest fraction of production cost, typically 10-15%, it has a profound impact on operations, including product quality, cycle time, material waste, and labor productivity. The Status Tracking and Control System (STACS) is a real time shop floor labor data collection and reporting system. Production workers use wireless laser scanners to report their current work assignment. STACS reporting is web based and provides both real time manufacturing status and summaries of historical production performance.

An alpha prototype of STACS was tested in drywall finishing operations at Avis American Homes (Avis, PA) in Summer 2003. Test results demonstrated that production workers could operate the system effectively and that the system accurately captured scanned activity. Large scale plant-wide testing began at Penn Lyon Homes (Selinsgrove, PA) in March 2004 and will continue into Summer 2004. Test results will be used to develop labor models using linear regression and neural nets.

Trinity Construction Corporation is a large shell contractor serving Florida homebuilders. Faced with increasing demands for higher quality, lower cost and more timely delivery, Trinity is actively exploring innovative alternatives to conventional concrete block construction, the predominant homebuilding technology in the central and south Florida market. Trinity operates a pre-cast concrete panel production facility, in South Bay, Florida where concrete panels are pre-cast, transported to the construction site, and quickly assembled using a construction crane. The UCF Housing Constructability Lab (HCL) was asked to assist Trinity in improving the current panelizing process by incorporating lean production principles.

Preliminary research determined that material handling and rework were primary contributors to the 47% of labor consumed by non-value added activities. Once started, the flow of value-added activity was routinely interrupted. Poor access to materials and tools, rework, ill-defined process flows, and workforce/1st line supervision issues were contributing factors. To address these issues, HCL researchers utilized lean production principles - challenging non-value added activities and removing the obstacles to continuous production flow. Recommendations addressed issues of organization/communication, structured procedures and work flow, material handling, and off-line sub-assembly.

To test the recommendations, Trinity allowed HCL researchers to perform a 3-day pilot test. The test involved a single house consisting of 25 wall panels with a gross wall area of 3,119 ft^2. Productivity increased for all observed activities, with an average increase of 68%. Not all recommendations could be realized during the test. Some equipment and personnel issues could not be resolved on a short-term test basis. This suggests that the true potential is significantly greater than that observed during the test – possibly approaching 200% increase in labor productivity. Corresponding cycle time reductions are estimated to be 20-25%. This successful pilot test has given Trinity the opportunity to develop a competitive advantage in the housing construction market and a good foundation to dominate it.

Innovative Applications of Computer Technology on the Factory Floor

UCF researchers continue to identify and develop prototype applications of computer technology for the modular factory floor. Research efforts this year focused on the collection of real time production labor data. While labor represents a relatively modest fraction of production cost, typically 10-15%, it has a profound impact on operations. Except for the slower winter months, experienced labor is a scarce resource. Even if labor is sufficient in the aggregate, it is rarely positioned where it is most needed at a particular moment in time. Competitive market pressures are resulting in an increasing mix of custom home features, increasing the likelihood of "floating bottlenecks" in production. Quality and safety can suffer as undermanned crews rush to complete custom features (i.e., fire-rated walls or a hip roof). If a crew cannot keep pace, the line slows, production rate drops, overtime is required and delivery dates are missed.

In the past, the sheer number of production activities, lengthy cycle times and extensive product customization have discouraged manufacturers from accurately estimating labor needs and using this information to plan and control production. Instead, they have responded by controlling labor at the overall plant level, attempting to maintain labor at a historical target value, which is stated as a percentage of overall production cost or sales revenue. A limitation of this approach is that it seldom reflects the actual labor content in the product, particularly in periods of increasing customization. To address the problem of shifting bottlenecks, many manufacturers use flexible resources termed "utility workers", "flex workers", or expeditors. However, the decision to deploy these workers is often made with minimal planning, after a problem has started to impact the line.

To better understand the true usage of production labor, the UCF research team has developed the Status Tracking and Control System (STACS). STACS is a real time labor data collection and reporting system designed specifically to meet the needs of the industrialized housing industry. A schematic of the STACS system is shown in Figure 1. Production workers use wireless laser scanners to report their current work assignment. Scanned information is transmitted immediately to a base station and then relayed to a local shop floor processor, where it is verified and temporarily staged. Information is periodically transmitted via wireless LAN to a central database server where it is stored and used for reporting. STACS reporting is web based and provides both real time manufacturing status and summaries of historical production performance. Real time production performance can be monitored from the web-based STACS Dashboard (Figure 2). "Clicking" on any item on the Dashboard will display corresponding real-time details. Historical results can be used for a variety of analytical and management purposes:

- The development of analytical labor estimating models. These models can be used to estimate labor requirements for product costing, production scheduling and labor planning.
- As a baseline for continuous improvement efforts.

An alpha prototype of STACS was tested in drywall finishing operations at Avis American Homes (Avis, PA) in Summer 2003. Test results demonstrated that production workers could operate the system effectively and that the system accurately captured scanned activity (Figure 3). Large scale plant-wide testing began at Penn Lyon Homes (Selinsgrove, PA) in March 2004 and will continue into Summer 2004. Test results will be used to develop labor models using linear regression and neural nets.

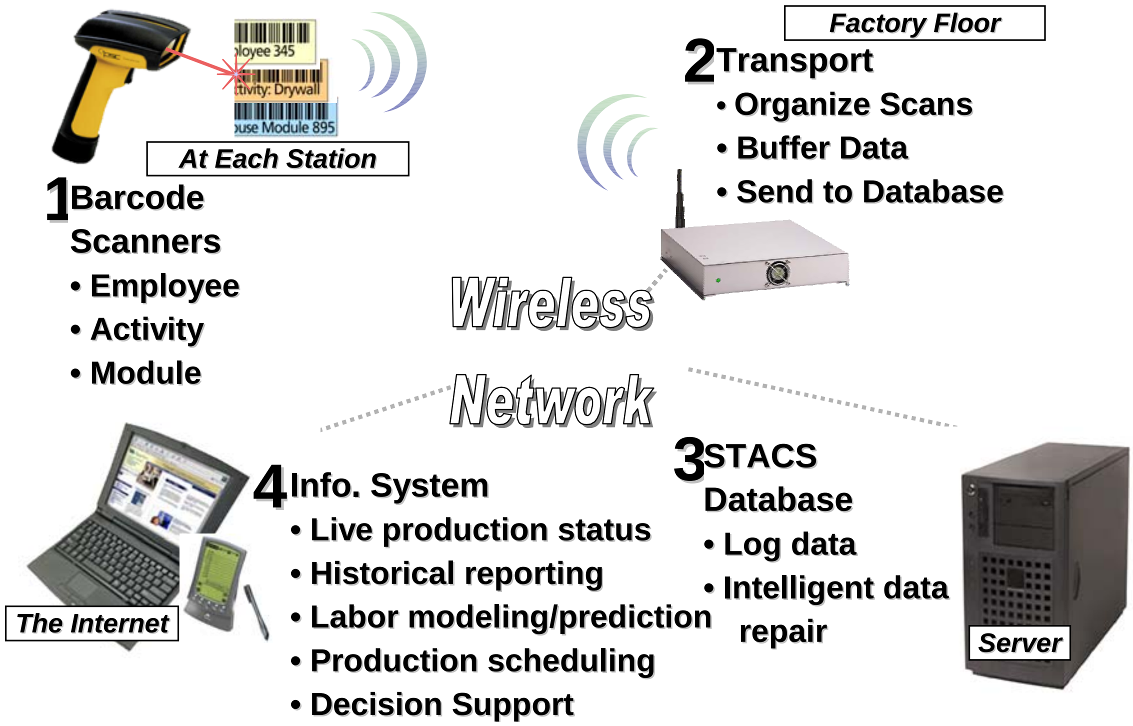
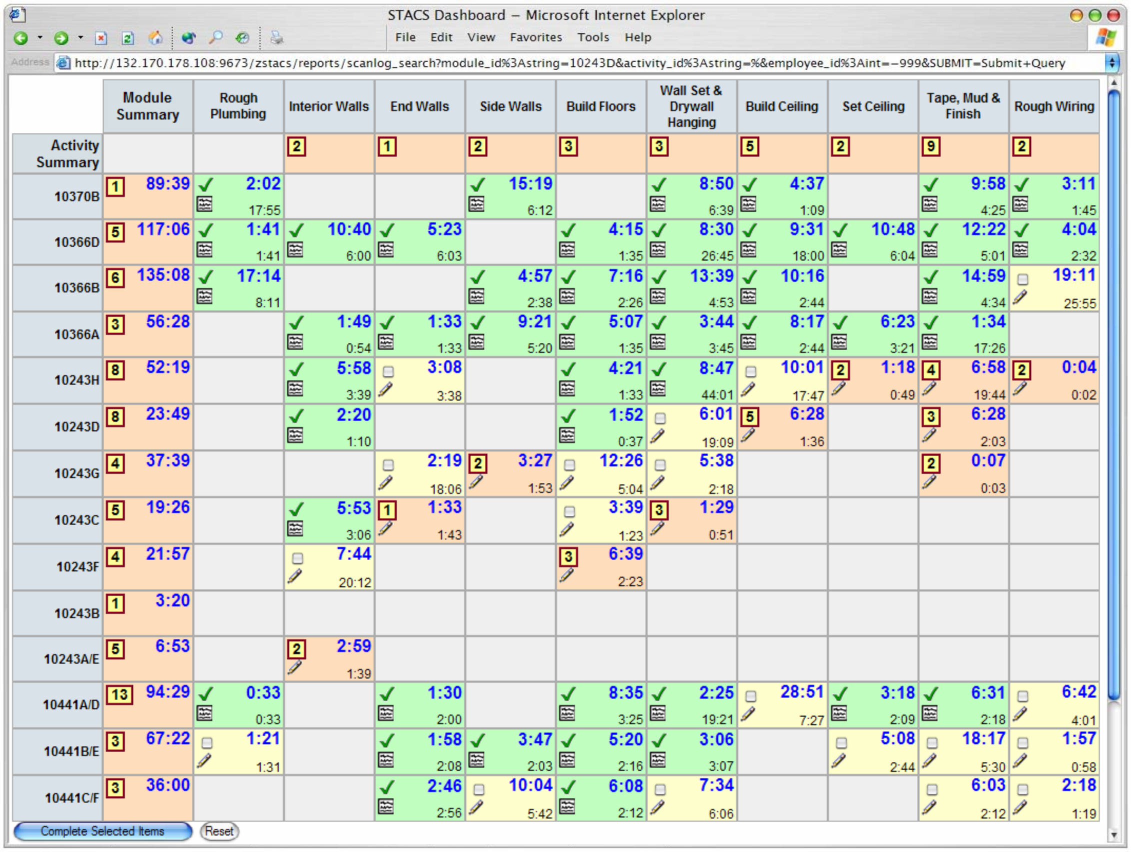


Figure 1. Structure of STACS system



STACS Dashboard – Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://132.170.178.108:9673/zstacs/reports/scanlog_search?module_id%3Astring=10243D&activity_id%3Astring=%&employee_id%3Aint=-999&SUBMIT=Submit+Query

	Module Summary	Rough Plumbing	Interior Walls	End Walls	Side Walls	Build Floors	Wall Set & Drywall Hanging	Build Ceiling	Set Ceiling	Tape, Mud & Finish	Rough Wiring
Activity Summary			2	1	2	3	3	5	2	9	2
10370B	1 89:39	✓ 2:02 17:55			✓ 15:19 6:12		✓ 8:50 6:39	✓ 4:37 1:09		✓ 9:58 4:25	✓ 3:11 1:45
10366D	5 117:06	✓ 1:41 1:41	✓ 10:40 6:00	✓ 5:23 6:03		✓ 4:15 1:35	✓ 8:30 26:45	✓ 9:31 18:00	✓ 10:48 6:04	✓ 12:22 5:01	✓ 4:04 2:32
10366B	6 135:08	✓ 17:14 8:11			✓ 4:57 2:38	✓ 7:16 2:26	✓ 13:39 4:53	✓ 10:16 2:44		✓ 14:59 4:34	19:11 25:55
10366A	3 56:28		✓ 1:49 0:54	✓ 1:33 1:33	✓ 9:21 5:20	✓ 5:07 1:35	✓ 3:44 3:45	✓ 8:17 2:44	✓ 6:23 3:21	✓ 1:34 17:26	
10243H	8 52:19		✓ 5:58 3:39	3:08 3:38		✓ 4:21 1:33	✓ 8:47 44:01	10:01 17:47	2 1:18 0:49	4 6:58 19:44	2 0:04 0:02
10243D	8 23:49		✓ 2:20 1:10			✓ 1:52 0:37	6:01 19:09	5 6:28 1:36		3 6:28 2:03	
10243G	4 37:39			2:19 18:06	2 3:27 1:53	12:26 5:04	5:38 2:18			2 0:07 0:03	
10243C	5 19:26		✓ 5:53 3:06	1 1:33 1:43		3:39 1:23	3 1:29 0:51				
10243F	4 21:57		7:44 20:12			3 6:39 2:23					
10243B	1 3:20										
10243A/E	5 6:53		2 2:59 1:39								
10441A/D	13 94:29	✓ 0:33 0:33		✓ 1:30 2:00		✓ 8:35 3:25	✓ 2:25 19:21	28:51 7:27	✓ 3:18 2:09	✓ 6:31 2:18	6:42 4:01
10441B/E	3 67:22	1:21 1:31		✓ 1:58 2:08	✓ 3:47 2:03	✓ 5:20 2:16	✓ 3:06 3:07		5:08 2:44	18:17 5:30	1:57 0:58
10441C/F	3 36:00			✓ 2:46 2:56	10:04 5:42	✓ 6:08 2:12	7:34 6:06			6:03 2:12	2:18 1:19

Complete Selected Items Reset

Figure 2 STACS real-time dashboard

Figure 4. Scanning drywall activities at Avis America

Lean Production of Precast Concrete Panels

Trinity Construction Corporation is a large shell contractor serving Florida homebuilders. Faced with increasing demands for higher quality, lower cost and more timely delivery, Trinity is actively exploring innovative alternatives to conventional concrete block construction, the predominant homebuilding technology in the central and south Florida market. Trinity operates a pre-cast concrete panel production facility, in South Bay, Florida where concrete panels are pre-cast (Figure 1), transported to the construction site, and quickly assembled using a construction crane (Figure 2). The UCF Housing Constructability Lab (HCL) was asked to assist Trinity in improving the current panelizing process by incorporating lean production principles.

Figure 1 Panel forms on forming bed

Figure 2 Setting pre-cast concrete wall panel

Preliminary research involved extensive observation and analysis. Value stream mapping identified activities that contributed value to the customer as well as activities that added little or no value. Material handling and rework were primary contributors to the 47% of labor consumed by non-value added activities. Once started, the flow of value-added activity was routinely interrupted. Poor access to materials and tools, rework, ill-defined process flows, and workforce/1st line supervision issues were contributing factors. To address these issues, HCL researchers utilized lean production principles - challenging non-value added activities and removing the obstacles to continuous production flow. Recommendations addressed issues of organization/communication, structured procedures and work flow, material handling, and off-line sub-assembly. A typical recommended daily production flow is shown in Figure 3.

To test the recommendations, Trinity allowed HCL researchers to perform a 3-day pilot test. The test involved a single house consisting of 25 panels. The panels had a total of 21 window and door openings and a gross wall area of 3,119 ft^2. The first day was spent organizing and training the test production team and the second and third days were dedicated to production. All 25 panels were produced. Productivity increased (Table 1) for all observed activities. Lifting productivity was not observed. Conservatively assuming that lifting will remain at historical levels, overall labor productivity increased by 47%. If lifting productivity is assumed to increase at the average rate observed for the other activities, overall productivity would increase 68%. Not all recommendations could be realized during the test. Some equipment and personnel issues could not be resolved on a short-term test basis. This suggests that the true potential (Table 1) is significantly greater than that observed during the test – possibly approaching 200% increase in labor productivity. Corresponding cycle time reductions are estimated to be 20-25%.

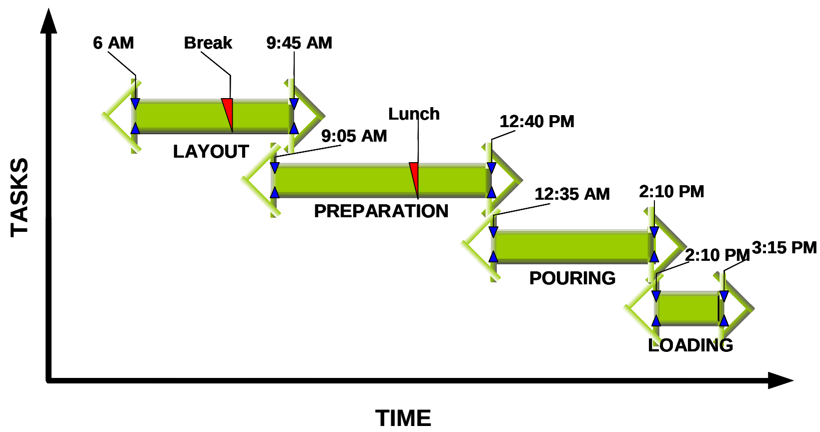


Figure 3. Summary of typical daily production schedule using continuous flow

The HCL research team recommended that Trinity proceed with implementation of the lean production recommendations. In addition to the technical recommendations, the research team also made recommendations involving worker empowerment, dealing with the heat and sun, and material/equipment availability. Potential future research areas include covers for the production area, on-site factories in new home developments, and factory installed wall insulation. This successful pilot test has given Trinity the opportunity to develop a competitive advantage in the housing construction market and a good foundation to dominate it.

Table 1. Productivity - ft^2 of wall/ labor hour

Process Phase	Existing Process	Potential Process Results	Pilot Test Results	Productivity Increase during Test
Layout	53	152	91	72%
Prep	52	149	79	52%
Pouring	146	211	296	103%
Lifting	75	440	75*	0%
Total	17	49	25	47%

Publications and Presentations

Mullens, M. and M. Kelley, "Lean Homebuilding Using Modular Technology," *Housing and Society: Journal of the Housing Education and Research Association*. In Press

Mullens, M. and M. Hastak, "Defining a National Housing Research Agenda: Construction Management and Production" *Proceedings of the NSF Housing Research Agenda Workshop*, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M. and Hastak, M. Vol 2.

Mullens, M. "Production flow and shop floor control: Structuring the modular factory for custom homebuilding" *Proceedings of the NSF Housing Research Agenda Workshop*, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M. and Hastak, M. Vol 2.

Mullens, M. and I. Nahmens, “Lean Principles Applied to Pre-cast Concrete Homebuilding,” *Industrial Engineering Research ‘04 Conference Proceedings*, Houston, May, 2004.

Elshennawy, A., M. Mullens, I. Nahmens, “Quality-Based Compensation Schemes for Modular Homebuilding,” *Industrial Engineering Research ‘04 Conference Proceedings*, Houston, May, 2004.

Nahmens, I., M. Mullens and A. Elshennawy, “The Impact of Demographics on New Homebuyer Satisfaction,” *Industrial Engineering Research ‘04 Conference Proceedings*, Houston, May, 2004.

Broadway, R. and M. Mullens, “Shop Floor Information Systems for Industrialized Housing Production,” *Industrial Engineering Research ‘04 Conference Proceedings*, Houston, May, 2004.

Appendix C: 2005 Annual Report of Washington State University Energy Program (WSU) with Oregon Office of Energy, and Idaho Department of Water Resources, Energy Division

Annual Report

BUILDING AMERICA INDUSTRIALIZED HOUSING PARTNERSHIP
WSU Extension Energy Program, IDWR, ODOE
April 1, 2004 – March 30, 2005

The Washington State University Energy Program (WSU), together with partners Oregon Office of Energy and Idaho Department of Water Resources, Energy Division, continue to provide technical and research support to the Northwest Energy Efficient Manufactured Housing Program (NEEM program in the Pacific Northwest. The NEEM program involves 20 plants in three states, hundreds of retailers and thousands of homebuyers.

The NEEM program includes the brands Super Good Cents and ENERGY STAR, and includes homes heated by electricity and Natural Gas/propane. Prior to Year 5, the NEEM program also included the Natural Choice brand, which was exclusive to homes heated with Natural Gas or propane. In Year 5, the Natural Choice brand was phased out; now, all gas heated homes are branded ENERGY STAR. In Year 6, a new path for ENERGY STAR was developed for Super Good Cents homes with electric furnaces. Homes will be built to this path beginning in year 7.

In Year 6, NEEM staff began to provide technical assistance to Champion Homes on a 700 unit private military modular housing development at Ft. Lewis. In-plant verification, certification and on-site verification of these homes began in year 6 and will continue in year 7 as a major BAIHP effort.

In Year 6, technical assistance by NEEM staff to the Energy Trust of Oregon resulted in the development of a million dollar utility incentive program that promotes the production of a more NEEM homes built to higher benchmarking levels consistent with BAIHP goals. A technical analysis of the ETO program has been provided to FSEC.

Between years 1-6, WSU staff provided technical assistance and guidance to the NAHB Research Center Energy Value Housing Awards, judging submittals, providing de-briefing to builders, and participating on workshops. NEEM builders Fleetwood, Champion, Valley and Marlette have received EVHAs for factory built housing.

Aligning with New Building America Goal

During Year 6, BAIHP staff performed a benchmarking evaluation, (included in the Year 5 annual report) to assess the improvement of NEEM homes over the entire BAIHP project period. The benchmarking was based on a home defined by NREL (built to IECC requirements). The savings over the benchmark home were estimated using version 2.2 of Energy Gauge USA. Evaluations were performed for a typical 1600 ft^2 double wide home with 12% glazing to floor area (the NEEM fleet average) in three Pacific Northwest climate zones: Portland, OR; Spokane, WA; and Missoula MT.

The homes were benchmarked assuming a continuously operating whole house ventilation system, resulting in a significant thermal energy penalty. Additional benchmarking was also conducted using the 164 kWh/year ventilation assumption in the NREL benchmark, in an effort not to penalize the homes for improved IAQ associated with HUD whole house ventilation system requirements and ASHRAE 62.2.

In Years 5 and 6, improvements were made to NEEM HVAC systems and duct specifications as a result of BAIHP research (see Refinement of NEEM Specifications, below.) Additional benchmarking is presented that reflects these improvements.

The results of the benchmarking vary considerably by HVAC type, water heat and climate, as noted in Table 1 below. Some key observations:

- In all climate zones, electric homes result in negative savings if the ventilation penalty is assumed. This is largely the result of the assumption that the benchmark home has a heat pump that performs without installation problems; an assumption that will be evaluated by BAIHP research.
- Gas heated NEEM homes came closest to meeting the overall BAIHP goal of 40% over the NREL benchmark, but only met the goal if gas heat is paired with electric water heat, in cold climates with no ventilation system penalty.
- Eliminating the ventilation system penalty has a higher impact on benchmarking results (9 to 23 percentage points) than improved duct leakage tightness (3 to 11 percentage points).
- It should be noted that Benchmarking these NEEM homes against the HUD-FMCSS requirements (Uo=.079) for manufactured homes rather than the IECC (Uo=0.06) would yield considerably higher savings than current benchmark assumptions.

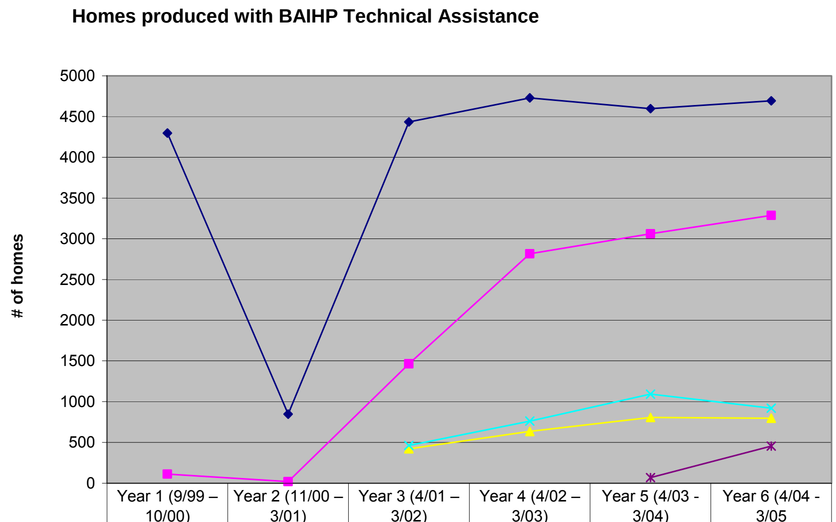
Table 1 Benchmarking Savings Results

Duct Leakage	Pre-2004*	2004**	Pre-2004*	2004**
Ventilation System Penalty	Yes	Yes	No	No
Portland				
Electric Furnace	-31	-20	-8	0
Heat Pump	11	14	20	22
Gas Heat/Elec DHW	16	22	32	37
Gas Heat/Gas DHW	15	20	30	34
Spokane				
Electric Furnace	-18	-9	2	10
Heat Pump	17	21	27	30
Gas Heat/Elec DHW	22	27	36	41
Gas Heat/Gas DHW	21	26	35	39
Missoula				
Electric Furnace	-12	-3	8	15
Heat Pump	17	22	28	32
Gas Heat/Elec DHW	21	26	35	40
Gas Heat/Gas DHW	20	25	34	38

** Pre-2004 – Duct leakage of -132 cfm@25PA*
*** 2004 – Duct leakage of -60 cfm@25PA*

Technical Assistance/Figure 1 shows, by program year, the number of homes produced with technical assistance from BAIHP, as well as the number of homes submitted for ENERGY STAR designation by BAIHP staff and the breakdown of homes by benchmarking score. Please note the following:

- The benchmarking includes the assumption, based on the random study (**see Random Study, below)** that 24% of all homes included after-market heat pumps.
- No benchmarking was performed for Years 1 and 2, due to a lack of accurate regional data.
- In Years 5 and 6, the appearance of homes that achieved a 30+% benchmark is the result of the improvements made to the NEEM HVAC specifications.
- Figure 1 averages benchmarks for Spokane and Missoula for homes in cold climates and uses the Portland benchmark for marine climates. Figure 1 also assumes an average value between ventilation penalty and no ventilation penalty.



	Year 1 (9/99 – 10/00)	Year 2 (11/00 – 3/01)	Year 3 (4/01 – 3/02)	Year 4 (4/02 – 3/03)	Year 5 (4/03 - 3/04)	Year 6 (4/04 - 3/05
Total homes	4296	848	4434	4729	4596	4694
Homes Submitted for Energy Star© Designation	112	18	1465	2816	3061	3286
10-20% over NREL benchmark	*	*	423	635	808	797
20-30% over NREL benchmark	*	*	463	763	1092	921
30+% over NREL benchmark	*	*			69	456

* Homes not benchmarked due to a lack of regional data

Figure 1

The continued success of the program is due to several factors. BAIHP and NEEM staff worked to increase awareness within the manufactured housing industry of the marketing value of energy efficiency, increase participation by utilities in incentive programs, and promote the co-branding of NEEM with ENERGY STAR.

The increase in ENERGY STAR designations is due to refinement of the SGC duct sealing specifications, resolving a discrepancy between the SGC specifications with ENERGY STAR's duct sealing protocols (while this question was being resolved [Years 1-2], BAIHP staff did not submit homes to DOE for ENERGY STAR designation). In year 5, remaining discrepancies with manufacturers in Idaho were further resolved, allowing BAIHP staff to accurately report all qualifying homes.

SGC/E-STAR program activities include:
Refinement of SGC specifications: BAIHP staff continually work to refine the existing SGC specifications, a result in large part to innovative building technologies researched in BAIHP.

In Year 5, BAIHP staff worked with NEEM staff and manufacturers to develop revisions to NEEM specifications, including allowing only mastic for duct sealing, requiring metal flex duct for whole house ventilation fans, and changing the air infiltration specification from 7.0 ACH_{50} to 5.0 ACH_{50}.

The revised specifications were voted on and accepted by the manufacturers; they took effect on January 1, 2004.

In year 6 5 in Oregon, 1 in Idaho plants began testing the ducts in all the NEEM homes they produce, which is expected to result in even tighter duct systems. Field testing of a sub-sample of these homes duct testing began in year 6 and continues in year 7. This field testing is also evaluating homes that employed a “thru-rim” crossover duct system.

BAIHP staff continues to work with EPA and other regional partners on clarifying the equivalency of SGC with ENERGY STAR. In Year 4, BAIHP staff developed a new ENERGY STAR compliance path for climate zone 2 that does not require a heat pump. The non-heat pump path uses a heat recovery ventilation system, a .93 EF hot water heater and tighter ducts and envelope. This path was not utilized due to reluctance by manufacturers to install HRV systems. In year 6, this path was modified to eliminate the HRV, and include options such as set-back T-stats, ENERGY STAR dishwasher, adjusted glazing limits, improved window U-factors, and in-plant tested duct systems.

Revised In-plant Manual: In Year 5, in light of the revisions to the NEEM specifications, BAIHP staff from the Oregon Department of Energy developed an updated in-plant inspection manual, with new graphics, including details on correct installation of heat recovery ventilation. Many of the manual updates are the result of BAIHP research and demonstration efforts, including use of hybrid floor systems and proper duct sealing with mastic. The manual also now includes a regionally consistent problem home inspection protocol.

In-plant QC Training: In year 6, BAIHP staff from the Oregon Department of Energy developed a PowerPoint presentation, based on the revised In-plant manual. In year 6, BAIHP staff began using this presentation to train QA staff at each plant; this effort will continue in year 7, until all NEEM plants have received this training.

SGC Random Home Testing: In 1994-1995 (prior to implementation of BAIHP), SGC staff conducted field testing of 178 SGC homes built in 1992-1993. In BAIHP Year 1, staff in Idaho and Washington field-tested 49 SGC homes built in 1997-98. In Year 2, analysis of field test data confirmed some improvements to home set-up procedures and air leakage control, while highlighting a need to improve duct tightness and ventilation system operation (through homeowner education.) In Year 3, BAIHP staff produced an updated homeowner ventilation brochure.

In Years 4 and 5, BAIHP staff worked with Ecotope to develop a valid sample for the next round of field testing, and began to develop the field testing protocol. In year 5, Ecotope selected 105 homes from the total production for the years 2001-2002. The field testing took place in the summer of Year 5. Findings from the testing include:

- Average house size is 1769 ft^2; double section homes are also getting bigger, on average. The house size is very comparable to the homes built in 1997-1998 but 20% larger than the homes in 1994-1995 study
- Houses are getting tighter, according to the blower door results. The average air leakage rate at 50 Pa is 4.2, which represents a tightening of almost 25% over the original MAP home average. The median equivalent leakage area (ELA) for double-section homes has decreased by about 12% despite a substantial increase in house size.
- Only about 20% of NEEM homes in this study contain intentional outside air inlets. This is the result of BAIHP research indicating that intentional outside air inlets are unnecessary to provide adequate fresh air.
- 2/3 of homes in the study have dedicated whole house fans and a substantial fraction of homeowners are using their whole house fans. However, a significant minority (30%) does not turn them on.
- About half of homes in the study use central cooling, with more than half of these homes using a heat pump.
- Duct systems are about 20% leakier than in the Year 1 study and about 10% leakier than in the 1994-1995 study (when the comparison is normalized by house size).
- The median supply leakage fraction is 11-13% for the homes in this sample. The duct loss translates into a heating system efficiency loss of between 10-20% overall, depending on the location of the home (west side or east side of the mountains) and type of heating equipment (heat pumps perform worse).

In year 6, BAIHP staff conducted a billing analysis on a limited number of random field study homes. The conclusions (although not statistically significant) suggest that temperature related energy use in NEEM homes remains similar to previous larger studies on cost-effectiveness. The analysis attempted to evaluate total and space conditioning energy use by HVAC system types but was limited by small sample size.

In year 6, a sub-sample of homes that are believed to represent the best case for duct tightness were selected for additional field testing. These homes include those with in-plant tested ducts and thru-rim crossover duct systems. The goal of this effort is to establish a "tightest" duct case benchmark. Field testing will be completed in year 7; report will follow.

Problem Homes: In offering technical support to owners of over 100,000 homes built since 1990, the staff answers questions from homeowners, manufacturers, retailers and others. In Year 6, staff from Washington, Oregon and Idaho responded to over 25 phone calls and conducted 10(OR) field visits.

The number of problem home field visits has significantly decreased over the history of the program, in large part because of manufacturer's and installer's increased awareness of the

SGC/E-Star specifications, and the requirement that manufactured home installers be certified in Washington and Oregon. Efforts were made in year 6 to improve regional coordination of problem home tracking and reporting.

BAIHP staff began to utilize Energy Gauge USA as a tool for evaluating high bill complaints in year 6. Specific problem home reports conducted in Washington in year 6 are provided to FSEC. Reports for the other states are available from ID, MT and OR State Energy Offices.

BAIHP staff participated in quarterly meetings of the Washington State Manufactured Housing Technical Working Group, which coordinates the certification of manufactured housing set-up crews.

While butyl duct tape is no longer allowed under current NEEM specifications, a consistent issue in the field continues to be excessive duct leakage, due in large part to failures of duct tape. These findings were brought to the attention of the NFPA-501 Mfg Housing Standards committee, resulting in a successful proposal to revise the duct sealing specifications in the NFPA-501 standard in year 5.

In year 6, further improvements to NFPA-501 were made that focused a variety of energy related improvements, with the potential of increasing consumer comfort and lowering energy bills; high among these was improved procedures involving in-plant testing of ducts.

In-Plant Inspections: On a quarterly basis, BAIHP staff visits each of the manufactured housing plants to verify compliance with SGC/E-Star specifications. Inspections include a plant audit, ventilation system testing, and troubleshooting construction-related problems with plant staff and independent inspectors. Consistent issues in the plant include wall insulation compression or voids due to improper cutting of batts, attention to duct installation and air sealing. Specific in-plant inspection reports conducted in Washington in year 6 are provided to FSEC.

Transition to mastic: As mentioned above, the NEEM program eliminated the use of butyl tape for duct sealing, and required the use of mastic. As of the end of Year 5, ten manufacturers have successfully transitioned to mastic. Testing in-plant has indicated significant improvement in duct leakage rates of homes in these factories– an average 36.8 cfm @ 25 PA (versus 50.1 cfm @ 25 PA pre-mastic), a 27% improvement. This trend continued in year 6.

WSU and ODOE began working with Fleetwood engineers to evaluate a new lower cost duct leakage testing device that Fleetwood is considering using in all of its plants throughout the USA. The preliminary results suggested a need utilize 10 second averaging and set a higher pressure ratio from 86% to 90% to be consistent with NEEM duct leakage targets. This work continues in year 7.

Duct Workshops: In Year 6, BAIHP staff continued to provide workshops focused on improved duct installation and inspection oversight, working in partnership with BAIHP partners. One in-plant duct leakage workshop in year 6 resulted in the identification of significant duct leakage (branch disconnect) which re-enforced the need to consider duct testing of all units at that plant.

Demonstration Homes: In Year 6, technical support was provided for the following demonstration homes:

- *Zero Energy Manufactured Home (ZEMH):* BPA, working with BAIHP staff in Idaho and Washington, provided funding for the most energy efficient manufactured home in the country. The RFP was sent to 18 Northwest manufacturers; Kit Homes of Idaho was selected as the manufacturer of the home. BAIHP staff solicited 24 industry partners to provide energy efficient building components, including Icynene wall, floor and roof insulation, a low-cost HUD-approved solar system, sun-tempered solar design, and ENERGY STAR© windows, appliances and lighting. Partners include Building America Team members such as Flexible Technologies, Icynene and LaSalle.

Figure 2 *Zero Energy Manufactured Home, on site at the Nez Perce Fish Hatchery*

The ZEMH was built in Year 4 along with a control home. The ZEMH was displayed at the 2002 Spokane County Interstate Fair before siting at the Nez Perce tribal fish facility near Lewiston Idaho. Blower door and duct leakage tests at the plant and on-site indicate that this is the tightest home ever tested by BAIHP staff.

Working with FSEC and BPA, BAIHP staff installed monitoring equipment for the ZEMH. Monitoring of the home began in Year 5 and continued in year 6 and 7. Preliminary findings include:

- Measured net energy use of the ZEMH 6% is lower than the base home, not normalized for occupant behavior. This also does not take into account the fact that the ZEMH's PV system was only fully operational for one month.
- The ZEMH required 45% less space heating energy, possibly due to improved building envelope measures, and the lack of consistent HRV operation.
- The measured envelope leakage in the ZEMH was 2.0 ACH_{50}, much lower than the base home (indeed, lower than any other NEEM home tested in the field) and substantially tighter than typical HUD code homes.
- The ZEMH total duct leakage was 46% lower than the base home; leakage to the outside was 405% lower than the base home. BAIHP staff speculate that the unprecedented

low leakage to the outside value is the result of the ducts in the ZEMH being located within the conditioned space, and effectively within the pressure envelope of the home, surrounded as they are by foam insulation.

- The solar water heating system in the ZEMH provides most, if not all of the energy needed during the summer months, and roughly 45% of the overall water heating energy use.
- The PV system with net metering provides 38% of the total ZEMH energy use.

The project highlights the importance of occupant choices and behavior on the performance of energy efficient housing. Based on the preliminary monitoring data and occupant surveys, the behavior patterns of the ZEMH occupants are not themselves "energy efficient". These patterns create the appearance of a less efficient home. On the other hand, the behavior of the ZEMH occupants may shorten the payback for the innovative technologies of the ZEMH.

BAIHP staff also performed a benchmarking analysis on the ZEMH, as part of the overall benchmarking effort. The ZEMH reached a level of 60% above the NREL prototype, which indicates the difficulty of obtaining a high benchmarking score. In year 6 a research paper was presented at BTECC which provided a preliminary evaluation of the ZEMH performance without the full operation of the PV net metering system. By the end of year 7 there will be a full year of ZEMH data, with the PV system operational.

- *NOGI Gardens:*, Nogi Gardens is a 75-home community located in southeast Seattle The project contains the first two-story, HUD code attached "townhouse homes." All the homes have been built by Marlette Homes in Hermiston, Oregon to SGC/E-Star specifications. A blower door test of the building envelope showed 5.0 ACH at 50PA, average for a manufactured home in the Pacific Northwest. Duct leakage is very low, due to Marlette's use of mastic and duct risers. During Year 5, Nogi Gardens was the recipient of the HUD Secretary's Gold Award for Excellence. Marlette was also the winner of the Energy Value Housing Award in Year 5.

Kokanee Creek: In year 6 Marlette was involved with a new 32 home multi-story development called Kokanee Creek. BAIHP staff conducted field evaluation on the first set of homes and provided technical assistance to Marlette and the developer HomeSight, related to the envelope and duct leakage improvements.

Figure 3 *Kokanee Creek HUD-code Multi-Story HID-code housing*

WSU Energy House: This 2600 ft.^{2} home has been built to beyond SGC standards, and incorporates ENERGY STAR lighting and appliances. The home has received significant national exposure through tours, local and trade media, and the BAIHP website, which includes house monitoring data. BAIHP staff use the house to test additional innovative technologies and testing methods. In Year 5, BAIHP staff developed a moisture case study based on research at the WSU Energy House, published under a separate Building America project. In year 6, moisture problems associated with siding and trim details were eliminated using and an improved window flashing system. The adoption of this system is currently under discussion with some manufacturers, and NFPA-501.

Habitat for Humanity: In year 6, WSU staff began providing technical support to BAIHP partner Habitat for Humanity. Support was provided , specifically for two site built projects in Olympia, WA (marine climate) and Grant Co. (cold climate). Technical support on was included; HVAC design, Energy Gauge analysis and field testing assistance. WSU continues to evaluate these homes year 7, when final case studies will be completed.

The Olympia home highlighted the challenges of integrating "green" technologies; such as Icynene insulation, and Rastra block walls. The home also used instant flow gas combo hydronic HVAC and HRV systems, and energy star lighting, appliances and was built "solar ready".

The Grant country home utilized standard construction materials and framing, ENERGY STAR HVAC, lighting and appliances. This home moved 100% of the duct system into the conditioned space; from the attic, crawlspace and garage where it was to be installed, at little or no additional cost.

In addition to the projects listed above, previous highlights from BAIHP research include:

- *Vincent Village:* Vincent Village is a 49 home rental community, located in Richland, WA. All of the homes are small, single section, heated and cooled by Insider heat pumps. Half the homes were built to SGC standards, the other half were not. Metered utility data indicate average yearly savings of $241 for the SGC homes.
- *Fish Facility:* Three SGC homes were built at the Nez Perce tribal fish facility in Cle Elum, Washington. One of these homes is equipped with ENERGY STAR appliances and lighting; all three homes are heated with Insider heat pumps. Testing revealed significant envelope and duct leakage, likely due from failure of butyl duct tape at risers.
- *SIP House:* This home, located in Western Washington and constructed by Champion Homes, is the first stress skin insulated panel manufactured home. House tightness was measured at 3.55 ACH at 50 Pa, well below the average numbers for all previous random home studies. Energy savings are estimated at 50% greater than HUD code minimum.

Field Monitoring: In Year 5, monitoring equipment was installed in the ZEMH and base home. The monitoring equipment collects the following energy use data from each home:

- Total electric use from grid
- Resistance elements in heat pump
- Heat pump compressor and fan motors
- Water heating equipment, including gallons used
- PV energy production (ZEMH)

Sensor data are collected every 15 minutes by data loggers and transmitted daily to the host computer. Summary data reports are available at: http://infomonitors.com/zmh/. Plug-type energy loggers were installed in mid March 2003 to sub-meter the energy use of the refrigerator, freezer and clothes washer in each home, as well as the radiant heat panel and HRV in the ZEMH. Data from these loggers was collected (by occupant readings) in mid-December 2003.

The WSU Energy House data has been monitored since year 1. Monitoring data being collected includes weather, temperature, humidity, CO_2, CO, and 8 differential pressures. Energy use data from water heat, laundry, fireplace, and HVAC are also being collected. Monitoring results from the WSU Energy House have been presented to the building science, IAQ and HVAC research communities at ASHRAE, AIVC, HUD/NIST, NFPA and BETEC. Data is available at http://logger.fsec.ucf.edu/cgi-bin/wg40.exe?user=lubresidence

New Product and Technology Evaluation
Blown Cellulose Floor Insulation: Industry partner Greenstone has been working with BAIHP staff and SGC/E-STAR manufacturers to evaluate a hybrid floor insulation system. These systems, composed of one R-11 belly blanket and R-22 blown cellulose insulation eliminates over-compression and reduces the chance of leakage during transport and set-up, while minimizing material and labor costs. Fleetwood Homes of Washington adopted this system for all of their homes in Year 3. Other manufacturers have adopted the hybrid floor insulations system, which provides less insulation voids and reduces first cost of R33 floor system over 3-R11 fiberglass batts. One potential consequence of using the hybrid system is increased moisture in the belly; in Year 5, BAIHP staff installed data loggers in two homes to determine whether this is a problem; after the data loggers were retrieved in Year 6, BAIHP staff submitted a report to Fleetwood suggesting no dew point problems within the floor system, as shown in *Figure 4*.
High Efficiency Gas Furnaces: Initial evaluations of 90% efficient gas furnaces indicates that

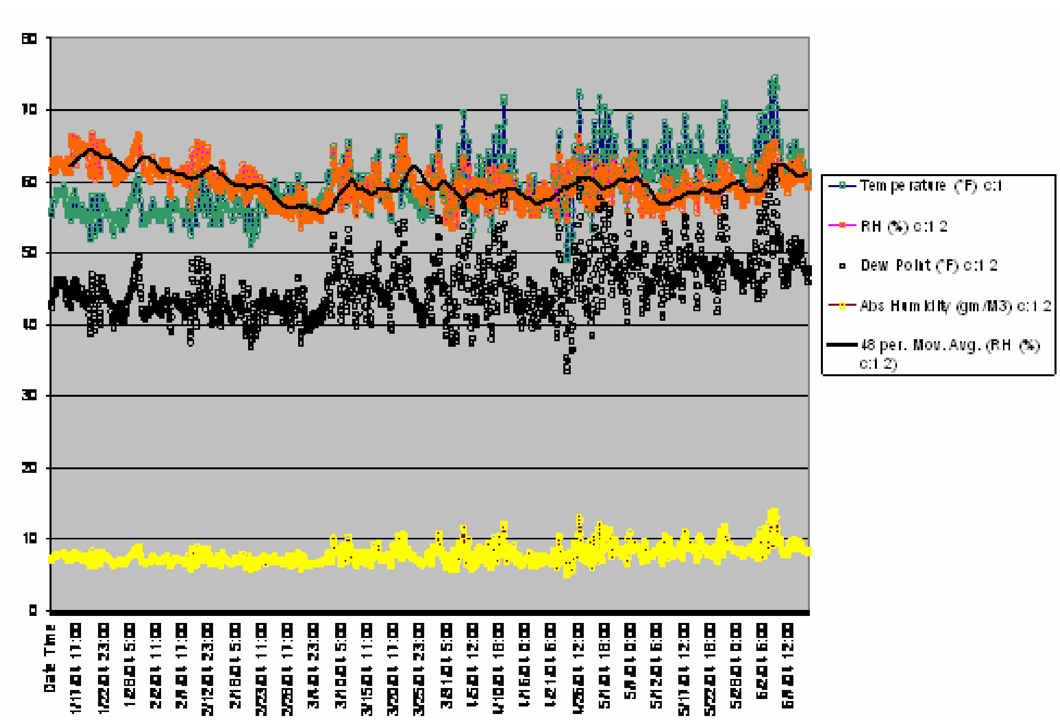


Figure 4 *Temperature and Dew Point Under Hybrid Floor Decking*

there is no incremental installation cost to the use of these furnaces, as no field modifications are required. In Year 5, Nordyne and Evcon came out with furnaces with an appropriate footprint for manufactured housing; Intertherm also continues to offer a 90% efficient model. Discussion with BAIHP home manufacturer partners Fuqua, Marlette, Champion, and Fleetwood, and furnace manufacturer partners Evcon and Nordyne, indicate the that this market is growing quickly, especially in homes with high pitch “tilt-up” roof systems, and multi-story homes such as at Nogi Gardens and Kokanee Creek. The ability to use wall venting instead of roof venting with condensing furnaces makes them more attractive where tilt-up roofs are employed.

Figure 5 *90% AFUE Furnace, as installed at Kokanee Creek*

- *Through the rim crossover duct system:* Three Oregon manufacturers, Marlette, Skyline and Homebuilders Northwest, adopted a crossover duct system that runs through a cut out section of the rim joist, effectively placing the entire crossover system in the heated space. A gasket on the marriage line provides a seal between sections. Challenges with the use of this system include the need for very accurate measurements to insure matching of the duct connection, and careful treatment of the gasket material during set up, so that it doesn’t detach from the rim.

Year 6 evaluations suggest that that further improvement to gasket systems may be needed to ensure set-up that achieves effective duct sealing.

- *La Salle Duct Riser:* BAIHP staff worked with BAIHP partner La Salle Air to design and produce a duct riser for manufactured homes that uses mastic instead of tape. BAIHP staff demonstrated prototype designs of the riser to Northwest manufacturers in Year 3. Most NEEM manufacturers adopted the new risers or equivalent systems in year 6. . BAIHP staff worked with Fleetwood’s national office to promote the use of the riser in all Fleetwood plants. During Years 5 and 6, BAIHP staff promoted the use of this technology at the annual MHI conferences and energy road-mapping meetings.

- *Flexible Technologies:* BAIHP partner Flexible Technologies has developed innovative systems that improves the heat and tear resistance of the duct inner liner, reduces the crimping of ductwork without the use of sheet metal elbows, and an improved system to air seal where the crossover duct penetrates the bottom board. BAIHP staff evaluating the use of this system in the WSU Energy House and ZEMH, and worked with Flexible Technologies staff to promote the use of the new system to the region’s manufacturers. Efforts to gain market adoption of the technology remain challenging due to first cost increases and lack of demonstrated benefits.

- *Insider Heat Pump:* Monitoring of the Insider heat pump at the WSU Energy House was begun in Year 1. Measured flow rate of the indoor unit was good (850 CFM total, 425 CFM per ton), but BAIHP staff identified two performance issues: a too-frequent operation of the defrost cycle and a lower than expected airflow at the outdoor coil. Continued testing of the Insider in Year 3 indicated a 10% increase in COP due to increased airflow at the outdoor coil. At Vincent Village, the property manager indicated a high degree of satisfaction with the Insider heat pumps, with no comfort complaints. Flip flop testing that varies the compressor and electric resistance heat were conducted in the WSU and ZEMH. The results of those tests being analyzed for a ASHRAE paper to be submitted in year 7. The Insider Flip flop test results are presented in figure 6.

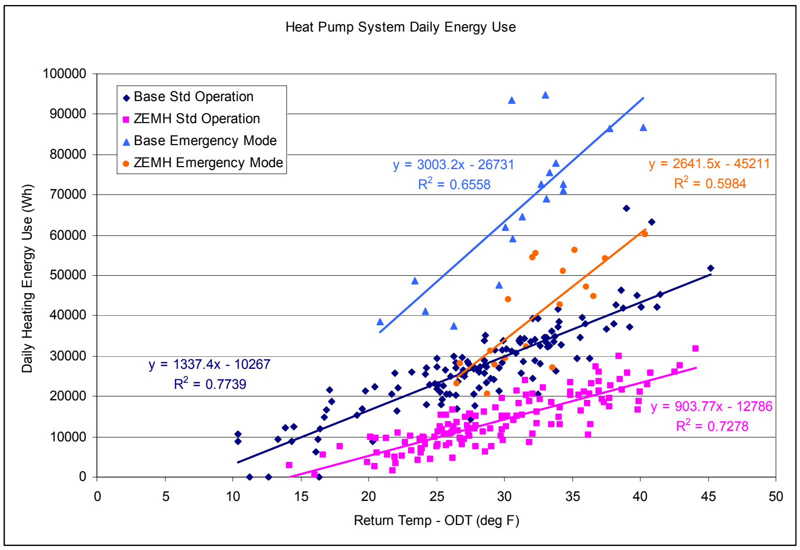


Figure 6 *Insider Heat Pump in ZEMH and Base Home - Operation in HP and Strip Heat Modes*

- *Energy Conservatory:* BAIHP staff work with the Energy Conservancy (EC) to evaluate their new products for measuring air handler and exhaust fan flows. In Year 6, BAIHP staff worked with EC staff to develop an automated test that will provide duct leakage to outside. Discussion with EC indicated significantly increased sales of duct blasters to HUD-code manufacturers as a result of BAIHP efforts. WSU continues to work with EC to develop new building science tools for HUD-code housing.

Other New Technologies: In year 6, BAIHP staff submitted a status report summarizing program efforts to introduce BAIHP manufacturers to new technologies. The report highlights the barriers and successes made regarding:

- 24" OC Wall Framing
- Air-Tight Can Lighting Fixtures
- Solar Ready design
- Improved flashing/drainage systems
- High Efficiency Water Heaters
- Blown Cellulose Hybrid Floor Insulation
- Condensing Gas Furnaces

- Heat Pump Water Heaters – Site built
- Hi-R wall Systems (Foam Sheathing + Icynene) – Site Built

Research Support

ASHRAE: During Year 5, in the capacity of chairing ASHRAE's 6.2 Technical committee, BAIHP staff directed a major effort to revise Chapter 9 of the ASHRAE Systems Handbook, "Design of Small Forced-air Heating and Cooling Systems." The revisions to the chapter, which incorporated BAIHP research, were accepted by the committee, and forwarded to ASHRAE for publication. In year 6 BAIHP staff provided assistance to other BA teams to improve chapter 43 of the ASHRAE Applications Handbook – Envelopes.

BAIHP staff have also participated in ASHRAE research projects, conferences, symposiums, seminars and forums, including:

* Authoring a paper on duct leakage, which was submitted and approved for presentation at ASHRAE summer meeting in Year 5.
* Making a presentation at the ASHRAE summer meeting in Year 4, "Uncontrolled Air Flow in Small Commercial Buildings."
* Moderating a forum on HVAC experiences in HUD code housing at ASHRAE's summer meeting in Year 3. 20 industry and building science professionals participated in the forum.
* Co-chairing ASHRAE's Technical Committee 6.3 – Residential Forced Air Heating and Cooling Equipment, which is responsible for ASHRAE standard 152 – Thermal Distribution Systems.
* Building America research on ductwork and HVAC systems will be included in the next version of the ASHRAE standards. Building America research will also be a part of future efforts in TC 6.3.

NFPA-501: BAIHP continues to support the NFPA standards process. The NFPA standard is typically incorporated into the HUD code, which governs the construction of over 250,000 HUD code homes each year.

* In Year 5, BAIHP staff integrated BAIHP duct leakage and cost data into proposals to the NFPA-501 committee. Based on this data, NFPA approved a new standard on duct tightness, as well as a refined duct testing protocol.
* In Year 4, BAIHP staff cited Building America research and demonstration efforts in support of additional successful proposals for standards revision, including duct testing, and use of mastic in duct sealing.

ACEEE:

* BAIHP staff have co-authored two papers presented at ACEEE Conferences, "Pushing the Envelope: A Case Study of Building the First Manufactured Home Using Structural Insulated Panels," and "Washington State Residential Ventilation and Indoor Air Quality Code (VIAQ) - Whole House Ventilation Systems Field Research Report."
* In year 6, BAIHP staff coordinated 24 peer reviewed papers for the Residential technologies track at the Summer Study and coordinated informal sessions on HUD-code housing.

National Institute of Standards and Technologies (NIST): BAIHP staff continues to work with NIST staff and industry representatives to evaluate ventilation and IAQ issues in HUD code homes.

* BAIHP staff also worked with NIST and the Energy Conservancy to perform tests on a typical HUD code model house on the NIST campus in Gaithersburg, Maryland. Testing indicates low flow rates of the whole house ventilation system and significant duct leakage.
* In Year 6, discussions with NIST, LBL, Ecotope and Energy Conservatory continued on a retrofit research effort with Dupont Tyvek, and development of new ventilation system controls with Panasonic. These discussions will continue in year 7.

National Manufactured Housing Research Alliance (MHRA): BAIHP staff continues to participate on MHRA's ENERGY STAR committee, which is developing Quality Assurance procedures with USEPA on ENERGY STAR manufactured homes. An article on the ZEMH appeared in the MHRA newsletter. WSU worked with MHRA to provide an article on the ZEMH project. WSU continues to provide technical support to MHRA on ENERGY STAR and other building science/energy related efforts such as the MHI roadmap.

PORTABLE CLASSROOMS

During Years 1 through 4, BAIHP staff conducted a major effort to promote the adoption of energy efficient portable classrooms in the Pacific Northwest. BAIHP staff from Washington, Oregon and Idaho studied both new, energy efficient portable classrooms and a retrofitted classroom (originally built in the 1970s).

As a result of these studies and additional computer modeling, project staff developed a series of energy-efficient guidelines for portable classrooms in the Pacific Northwest. These guidelines cover the procurement, set-up and commissioning of new portable classrooms, as well as the retrofitting of existing portable classrooms.

The project final report and guidelines are available on the project website:

http://www.energy.wsu.edu/projects/building/portable_prj.cfm

As part of a separate Building America project, former BAIHP staff are continuing to provide outreach on efficient portable classrooms, based on the BAIHP efforts.

Appendix A

LIST OF PEER REVIEWED PAPERS PRODUCED UNDER BAIHP

ACEEE

Conner, Lubliner, et. al. Invited paper, presented at 2004 ACEEE Summer Study Update of Energy Efficiency Requirements for Manufactured Homes

Baechler, M.; Lubliner, M; Gordon, A. "Pushing the Envelope: A Case Study of Building the First Manufactured Home Using Structural Insulated Panels" – Invited paper, presented at ACEEE Summer Study, Year 3.

Lubliner, M; Kunkle, R; Devine, J; Gordon, A. "Washington State Residential Ventilation and Indoor Air Quality Code (VIAQ) - Whole House Ventilation Systems Field Research Report" – Invited paper, presented at ACEEE Summer Study, Year 3.

AIVC

Lubliner, Douglass, Parker, Chaser, Performance and Application of Gossamer Wind ™ Solar Powered Ceiling Fans, presented at the 25th AIVC conference Year 6

Lubliner, M.; Gordon, A.; Persily, A.; Moyer, N.; Richins, W.; Blakeley, J. "Building Envelope, Duct Leakage and HVAC System Performance in HUD-Code Manufactured Homes" – Invited paper, presented at the 23rd annual AIVC conference, Year 4.

Lubliner, M; Gordon, A."Ventilation in US Manufactured Housing" – Invited paper, presented at the 21st annual AIVC conference, Year 1.

American Solar Energy Society (ASES)

Lubliner, M.; Hadley, A.; Gordon, A. "Introducing Solar ready Manufactured Housing" – invited paper, published and presented at ASES conference, Year 6.

Lubliner, M; Nelson, M; Parker, D. "Gossamer Wind Solar Power Ceiling Fan" – invited paper, presented at ASES conference, Year 5.

ASHRAE

Lubliner, M.; Gordon, A.; Hadley, A. "Manufactured Home Performance; Comparing Zero Energy and ENERGY STAR". Invited paper, submitted to Whole Buildings IX International Conference, published and presented in Year 6.

ASHRAE Std 152 Sub-committee. ASHRAE 2004 Standard 152 - MOT to Determine the Steady State and Seasonal Efficiency of Residential Thermal Distribution Systems. – Year 6

Lubliner, M.; et. al. ASHRAE 2004 Systems and Equipment Handbook chapter 9 – Residential and Small Commercial HVAC Systems. Year 6.

Hales, D; Lubliner, M; Gordon, A. "Duct Leakage in New Washington State Residences: Findings and Conclusions" – Invited paper, presented at ASHRAE Summer Meeting, Year 5.

Automated Builder Magazine

Baechler, M; Gordon, A. “Northwest Portable Classroom Study”, Year 5.

Gordon, A.; Lubliner M. “Zero Energy Manufactured Home”, Year 5.

Manufactured Housing Research Alliance

Lubliner. “Zero Energy Manufactured Home”, Year 5.

National Fire Protection Association

NFPA-501 2004 MEC. Standard on Manufactured Housing – Mechanical Chapter

NFPA-501 2002 MEC. Standard on Manufactured Housing – Mechanical Chapter

NFPA-501 1999 MEC. Standard on Manufactured Housing – Mechanical Chapter

Appendix B
BAIHP Workproducts

Included on separate CD, which includes:

1) Papers – AIVC, BTECC, ASES
2) Example of Problem Home report
3) Example of ¼ inspection report
4) Billing Analysis report
5) Benchmarking Report
6) Power Point Presentations
7) Trip Reports
8) New Technology Summary Report
9) Fleetwood duct leakage "pressure box" test report
10) Fleetwood Belly Moisture Tests data analysis results

Appendix D: Florida H.E.R.O. Standard Technical Specifications

Florida H.E.R.O. Standard Technical Specifications

While it is crucial to work within the context of individual industry partner's designs, budget constraints, and the skill sets of available tradesmen, there are several areas that Florida H.E.R.O. consistently deals with on all projects. The keystone of an energy efficient home begins with a right sized mechanical system, a properly designed air distribution system, and performance testing to insure intended results. To accomplish these goals, a room-by-room ACCA Manual J calculation is performed for each home. In addition, an ACCA Manual D calculation is developed. The use of 13 SEER air conditioning equipment or better, in conjunction with a variable speed air handler is recommended. Ongoing site visits and communication of issues to the various sub-contractors help to insure that problems are minimized.

As windows account for the single greatest source of heat gain/loss, Florida H.E.R.O. encourages the use of double pane, vinyl frame low-e windows with an SHGC of 0.35 or less. As Florida has a rigorous air infiltration control requirement as part of the state Energy Code, most new homes are being built fairly "air-tight," with typical natural infiltration rates of 0.35 or less. Frame homes that use fiberglass batts for wall insulation typically have significantly higher infiltration rates than those insulated with cellulose or expandable foam.

The introduction of outside air for ventilation helps ensure better indoor air quality and when it is introduced to the return side of the plenum, results in a home operating under positive pressure with respect to the outside, ideal for Florida's hot-humid climate. This has become a standard feature in most of the sub-divisions that Florida H.E.R.O. works in. Other Florida H.E.R.O. recommended features include:

- 92+ AFUE gas furnaces
- Electronic thermostat
- Ducts in conditioned space
- Maximizing passive solar heat rejection measures
- Moisture management
- Instant or sealed combustion gas water heating
- Solar water heating
- Hot water pipe insulation
- Energy Star appliances
- Energy Star lighting
- "Air-Loc" style recessed (can) lights
- Ceiling fans
- Radiant barrier or unvented attic

The single most challenging are is the mechanical system. Builders are not adequately educated regarding system design and installation. Mechanical contractors attempt to overcome deficiencies by over-sizing equipment. Consumers pay a higher initial price for systems that often do not perform efficiently. In an attempt to improve this situation, each home that Florida H.E.R.O. works with is fully commissioned. Florida H.E.R.O. measures both total duct leakage and duct leakage "to out" as well as system operating static pressure, temperature drop across the coil, and air flow through each supply register. A pressure map of the house is generated showing pressure differential with respect to outside of each room with interior doors closed.

The ventilation air flow through the outside air intake is measured and adjusted if needed. Problems discovered during commissioning are resolved with the builder and responsible sub-contractors. A completed Home Energy Rating Report is provided to the builder (Sample next page).

florida H.E.R.O. sm

Part of the Solution... One Home at a Time

Home Energy Rating Report

Project Name___________________________ Test Date_____________
Street Address__________________________ Orientation____________
City/State/Zip___________________________

Energy Rating____________HERS

C:______ N:______ R:______ CFM50______ Indoor Temp______ Outdoor Temp_____
CFM25-T: S:______ R:______ AVG:________ Indoor RH________ Outdoor RH _____
CFM-Out: S:______ R:______ AVG:________

Mechanical Characteristics: Make_____________ SEER/AFUE/HSPF_____________
System 1:CU____________________ Tons________ AH_________________________
System 2:CU____________________ Tons________ AH_________________________
Controls: Manual_____ Programmable_____ Zoned/#_____
Outside Air: Type_______________________ Measured Flow ____________
Delta T:___________ Static Pressure:__________
Pressure Characteristics in Pa:
House to out____ MBR____ BR 1____ BR 2____ BR 3____ BR 4____ Other_____

Water Heating Characteristics: Type_________ Size/Input_________ EF__________
Window Characteristics: ____
Stove:________ Dryer:_________ Washer:_________ Frig:_________ Freezer:_______
Radiant Barrier:____________
Special Features/Comments: ____
____
____
____
____

Job #:______________ Technician:____________________________

Florida Home Energy & Resources Organization, Inc.
15220 N.W. 5th Avenue · Newberry, FL 32669 · Phone 352.472.5661 · Fax 352.472.2291