Building High Performance Homes

Janet McIlvaine and David Beal
November 20, 2008
Mobile, Alabama
Welcome and Introductions
Welcome and Introductions

- Janet McIlvaine and David Beal
  - Florida Solar Energy Center, Research Institute of UCF
  - Lead 1 of 6 Department of Energy Building America Teams
  - Building America Industrialized Housing Partnership (BAIHP)
  - Research Analysts

- Brenda C. Lawless and Brian Stanley
  - Mobile County Habitat for Humanity
  - Partners in Building America's Gulf Coast High Performance Demonstration Housing Project

- HBA of Metro Mobile
  - Promotional Partner
DOE Building America Program

- [www.buildingamerica.gov](http://www.buildingamerica.gov)
- Public-Private Research Initiative
- Public: DOE funded teams of researchers
- Private: Home builders across America
- Cost Shared Research:
  - Build high performance houses together
  - Document problems and solutions
  - Conduct training to spread lessons learned
Building America Goals

• Move standard practice toward “High Performance”
• Climate specific solutions
• Work in key markets
• With production builders
• Produce whole communities
• **Systems engineering** approach
  – aka “house as a system” or “whole house” approach
• Transfer “Lessons Learned” to other builders
  – Workshops, documents, case studies
DOE Building America Program

• “High Performance” Goals
  – 30-70% energy savings (Mobile goal ~30% savings)
  – First year positive cash flow
  – While improving indoor air quality, durability, and comfort
  – How is this possible…
BAIHP is estimated to save over $14,000,000/yr in 168,000+ homes
G.W. Robinson Builders, Inc. – Gainesville, FL

- Progressively increased energy efficiency over time
- HERS Index <70 saving ~ 30% on a whole house basis
- 400+ Houses completed and sold
- Lead – Florida H.E.R.O. (Ken Fonorow)
G.W. Robinson Builders, Inc. – Gainesville, FL

- 1st year positive cash flow

<table>
<thead>
<tr>
<th></th>
<th>First Cost</th>
<th>Annual Cost</th>
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<tbody>
<tr>
<td></td>
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<td>(7%, 30 yr mortgage)</td>
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<tr>
<td>Total Incremental Cost</td>
<td>$2,021</td>
<td>$161</td>
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<tr>
<td>(includes 10% mark up)</td>
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<tr>
<td>Estimated Annual Energy Savings (wrt typical)</td>
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<td>$863</td>
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<td>Net 1st Year Cash flow</td>
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G.W. Robinson Builders, Inc. – Gainesville, FL

- **Heating/Cooling Equipment features**
  - SEER 15 Air conditioner, 93% AFUE Gas Furnace
  - ACCA Manual J system sizing
  - Ducts sealed with mastic and tested
  - Interior air handler closet

- **Water Heating Equipment**
  - EF=0.84 Tankless gas water heater

- **Heating/Cooling Load Reduction Features**
  - Energy Star Windows (0.28 SHGC, U=.39 Vinyl Low-e)
  - R-30 with Radiant barrier vented attic
  - 2 x 4 Advanced Framing w/R-13 cellulose
  - Wide Overhangs on Patio doors and windows
  - Passes Energy Star Thermal Bypass Inspection

- **Indoor air quality, durability, and comfort features**
  - Ducted kitchen and bath exhaust fans
  - Passive, positive pressure outside air ventilation
  - Drainage plane and flashing details
  - Passive return air pathways from bedrooms
  - Low VOC paints

- **Verification**
  - Blower door and duct leakage testing
Lakeland Habitat for Humanity – Lakeland, FL

• Goal: Cost Effectively Exceed Energy Star
• Builder Motivation – Reduce total cost of ownership
• Started with Energy Star ’99 in 2001, progressively improved
• HERS Index = ~70 saving about 30% in whole house energy use
• Understand Builder Needs:
  – Volunteer Friendly
  – Proven
  – Readily Available
  – No Maintenance Burdens
• Estimated First Cost Increase: $2000
• Detailed Case Study: www.baihp.org/habitat/pdf/Lakeland-Habitat-Case-Study.pdf
Lakeland Habitat for Humanity – Lakeland, FL

• 1st year positive cash flow

<table>
<thead>
<tr>
<th>Total Incremental Cost</th>
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<th>Annual Cost (0%, 20yr HFH mortgage)</th>
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<tr>
<td>$2,000</td>
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<td>$100</td>
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<tr>
<td>Estimated Annual Savings</td>
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<td>$250</td>
</tr>
<tr>
<td>Net 1st year cash flow to owner</td>
<td></td>
<td>$150</td>
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</table>

• $5000 grant from city for meeting energy standards
Lakeland Habitat for Humanity – Lakeland, FL

• Heating/Cooling Equipment
  – SEER 14, HSPF 8+ Heat Pump sized with ACCA Manual J
  – Duct system sealed with mastic and tested
  – Interior air handler closet, ducted central return
• Heating/Cooling Load Reduction
  – R-30 Ceiling and R-13 Wall Insulation
  – Passes Energy Star Thermal Bypass Inspection
  – Radiant Barrier below roof decking
  – Infiltration control (house wrap air barrier + extensive air sealing)
  – Energy Star Windows shaded by overhangs, Porches & shade trees
• Appliances & Lighting
  – Water heater timer
  – Energy Star Refrigerator
  – 20% CFL Lighting
• Indoor air quality, durability, and comfort features
  – Ducted kitchen and bath exhaust fans
  – Passive, positive pressure outside air ventilation
  – Drainage plane and flashing details
• Verification
  – Blower door and duct leakage testing
“Systems Engineering” Approach to Change

“Lessons learned” Translated into case studies, publications, & “Best Practices” documents
Systems Engineering Approach

• More Case Studies & free BA resources online:
  – www.baihp.org
    • Case studies, publications, and presentations
  – www.baihp.org/habitat
    • Habitat specific information
  – www.baihp.org/gulfcoast
    • Demonstration project summary
  – www.buildingamerica.gov
    • Best practices, program overview, searchable database of publications
Systems Engineering Concepts

• “House as a System” thinking
  – As we make improvements, make sure we aren’t creating new problems
• Involve whole construction team
• Anticipate and solve common problems on paper
• Reduce call backs by evaluating warranty claims
• Work with “off the shelf” products
• Seek first year positive cash flow
• Prototype, evaluate, and refine solutions
Building America Technical Assistance

• Partner steps toward reaching 30% whole house savings goal
  – First – Preliminary Evaluation
    • Combustion Safety
    • Warranty Issues
    • Energy Code Compliance
    • Begin “Systems Engineering” process
  – Next - Energy Star for Homes
    • HERS 85 + prescriptive req’s
    • Ensure no IAQ, durability, comfort problems
  – Next – Exceed Energy Star
    • HERS 70-75
    • Ensure no IAQ, durability, comfort problems
Systems Engineering Process

- Preliminary Evaluation
- Develop a package of improvements
- Work with project team to anticipate and solve problems before implementation. Prototype and refine individual improvements, if necessary
- Build a TEST house
- Refine package as needed
- Integrate into production process

*This is the process we used for GC Demonstration Houses*...
Project Introduction:
Building America’s Gulf Coast High Performance Affordable Housing Demonstration Project
Gulf Coast High Performance Affordable Housing Demonstration Project Goals

• 30% whole house energy savings
  – Proven results in Florida, but in a new market
  – Technical assistance alone did not attract much interest

• Demonstration houses show case…
  – NOT cutting edge technology
  – BUT an achievable, replicable high performance package that most builders can adapt to their houses

• Affordable housing focus to emphasize feasibility
DOE Gulf Coast High Performance Affordable Homes

- [http://www.baihp.org/gulfcoast/](http://www.baihp.org/gulfcoast/)

- **Goals**
  - HERS Index 70-75
  - $2,000 first cost
  - First year positive cash flow
  - Meets Indoor Air Quality, Durability, and Comfort Criteria
  - Conduct local builder training

- **Four Builder Partners**
  - Habitat for Humanity Affiliates
  - Baton Rouge, New Orleans, Slidell, and Mobile
New Orleans Area Habitat

Mobile County Habitat

Habitat of Greater Baton Rouge

East St. Tammany Habitat (Slidell)
First Year Positive Cash Flow

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Gulf Coast High Performance Affordable Homes – Systems Engineering Process

• Preliminary Evaluation
  – IAQ, Durability, Comfort, and Energy (HERS Index)
• Identify “Package” & Develop Strategies
• Build a Trial House (Afternoon Tour)
• Refine Package
• Build Demonstration House
• Conduct Training with Home Building Industry
Systems Engineering Approach

- **Avoidable IAQ, Durability, and Comfort Problems …**
  - Combustion safety issues
    - Flame roll out and exhaust back drafting
  - Asthma/allergy triggers
    - Pollen, roach dander, dust mites
  - Bulk water and humidity issues
    - Biological growth, buckling, bulging, sagging, standing water, rusting, shorting electrical connections, water logged materials and fixtures, wet insulation, condensation
  - Comfort
    - “My bedroom/kitchen/family room never gets cool/warm”

- **Many of these issues are driven by the same dynamics of air, heat, and moisture/water movement**
Building Science
Fundamentals
Building Science Background

- Our building science scope...
  - Energy use and efficiency, indoor air quality (IAQ), durability, and comfort
- Dynamics and management of air, heat, & moisture/water
- Outside our scope...
  - Structural integrity – engineering
  - Life safety (including disaster resistance) – codes
Typical Energy Use Profile

Average Annual Energy Use
Measured in 10 Florida Habitat Homes

- 40.7% Heating & Cooling
- 19.6% Other
- 7.9% Refrigerator
- 8.6% Dryer
- 4.4% Stove
- 18.7% Water Heating

Avg. for ten control houses
Total=43 kWh/day
Typical Energy Use (& Conservation) Profile

- **40% = Heat and Cooling**
  - Efficient Equipment – Mechanical system
  - Load Reduction - Enclosure

- **20% = Water Heating**
  - Efficient Equipment

- **20% = Appliances (stove, dryer, refrigerator)**
  - Energy Star Appliances

- **20% = “Other” including lighting**
  - Efficient Lighting
Building Science Back Ground

• Air, heat, moisture, and water often move together

• By controlling movement, we control
  – Indoor air quality
    • Example: entry of outside pollutants, soil gases
  – Durability
    • Example: path of rain over building materials, indoor humidity levels
  – Comfort and energy efficiency
    • Heat gain and loss, air flow in each room, humidity levels
  – Multiple benefits from individual improvements
    • Example: infiltration control

• Creating a “controlled” environment
Building Science Terms

- **Conditioned space**
  - Controlled environment – inside
- **Unconditioned space**
  - Less controlled environment – attic, crawl spaces
- **Outside**
  - Uncontrolled environment - outside
- **Building enclosure** ("envelope")
- **Mechanical system**
Movement of Air, Heat, Moisture and Water

• Building enclosure ("envelope")
  – Boundary
  – Materials and assemblies
    • Foundation, floor, walls, roof & ceiling
    – Air barrier + thermal barrier + drainage plane
    – Controls air, heat, and water flow  
      – how…?

• Mechanical system
  – Moves air, removes heat and humidity
  – Heating/Cooling + ventilation + exhaust fans
Movement of Air, Heat, Moisture, & Water

• Air, heat, and moisture move in response to differences…temperature or pressure

• Direction of Movement…
  – “High” goes to “Low”
  – Air moves from high pressure or temp toward low
    • Air barrier stops it
  – Heat moves from high temp toward low temp
    • Thermal barrier stops it
  – Water moves from high ground toward lower
    • Drainage plane and flashing direct it
Movement of Air, Heat, Moisture, & Water

• House is full of air
  – 1 cfm “in” = 1 cfm “out”
  – Every 1 cfm exhausted is replaced by 1 cfm

• Example: Box fan in window
Movement of Air, Heat, Moisture, & Water

• To have movement, need three things…
  – Air/heat/moisture + hole + driving force

• Example: Drinking straw
Control Movement of Air, Heat, Moisture, & Water

• To control flow…
  – Minimize source
    • Nearly impossible
  – Minimize holes
    • Continuous boundaries between source & cond. Space
    • Air barrier + thermal barrier + drainage plane
    • At joints and penetrations…ship lap and/or seal
  – Minimize driving forces
    • Can’t eliminate temperature difference
    • Maintain neutral air pressure
Controlling Water, Air, and Heat

Principal Strategies

**Water:**
- Dry Materials
- Continuous Ext. finishes
- Continuous Drainage Plane
- Flashing
- Assemblies that Dry
- Exhaust wet air

**Air:**
- Continuous Air Barrier
- Sealed Duct System
- Neutral Air Pressure

**Heat:**
- Continuous, Even Layer of Insulation
Controlling Water, Air, and Heat

Siding and Shingles are first line of defense against liquid water
Continuous drainage plane behind vented (vinyl, wood, fiber cement) siding.

- Tar Paper/Felt (Ship lapped)
- House Wrap (sealed at edges and seams)
- Rigid Insulation (T&G or sealed at edges and seams)
Controlling Water, Air, and Heat

Principal Strategies

Water:
• Dry Materials
• Exterior finishes
• Continuous Drainage Plane
• Flashing
• Assemblies that Dry
• Exhaust wet air

Air:
• Continuous Air Barrier
• Sealed Duct System
• Neutral Air Pressure

Heat:
• Continuous, Even Layer of Insulation
All these materials are drainage planes. Which are also air barriers?

- Tar Paper/Felt (Ship lapped)
- House Wrap (sealed at edges and seams)
- Rigid Insulation (T&G or sealed at edges and seams)
All these materials are drainage planes. Which are also air barriers?

Tar Paper/Felt (Ship lapped) **Is NOT an Air Barrier**

House Wrap (sealed at edges and seams) **IS an Air Barrier**

Rigid Insulation (T&G or sealed at edges and seams) **IS an Air Barrier**
Continuous Air Barrier

• Controls Air Flow and Air Transported Moisture Flow
  – Separates conditioned space from unconditioned
  – Surrounds and contains “conditioned space”
  – Elements
    • Slab/floor decking
    • Sill seal or equivalent
    • House wrap or
    • Rigid insulation sealed at edges and seams
    • Top plates (exterior AND interior walls)
    • Ceiling drywall
    • Sealant in penetrations of above surfaces
    • Ducts and air handler, if in unconditioned space…
Sealed Duct System

- Duct system in unconditioned spaces is part of the house air barrier
- Each duct surrounds little piece of conditioned space
- Air handler is part of the air distribution system
- Special conditions in ducts
  - Very high pressure in supply
  - Very low pressure in return
  - Both in air handler
  - Very cold/hot air in supply
  - High potential for changing house air pressure
Unbalanced house air pressure

• Duct leakage can lead to uncontrolled air flow
  – From out to in, from in to out, and both at the same time
  – can heighten natural infiltration significantly
  – Can cause whole house depressurization or pressurization
  – Can lead to combustion safety issues, so can other causes of house depressurization such as…
    • Exhaust fans
    • Closed interior doors (without ducted returns)
    • (Demonstration of Air Flow Dynamics after break)
What combustion safety problem?
Water is a byproduct of combustion

- 1 cubic foot natural gas releases 1000 Btus
- 100K Btuh furnace burns about 100 cuft/hr
  - About 200 cuft water vapor per hour
  - Slightly more than 1 gallon water per hour
- Typical Btuhr Input (residential)
  - Furnace 50K-200K
  - Water Heater 30K-75K
  - Ranges 10K-15K
Naturally Aspirated Combustion Equipment
• And now we pause for a demonstration of air flow dynamics…and combustion safety discussion
Combustion safety problems produced by space depressurization

- Normal Draft CAZ wrt Out: 0 pascal
- Spillage CAZ wrt Out: -5 pascals
- Backdraft CAZ wrt Out: -8 pascals
- Incomplete Combustion CAZ wrt Out: -15 pascals
- Flame Rollout CAZ wrt Out: -25 pascals
Prevent combustion safety problems…

• Switch to non-atmospherically vented equipment
• Make combustion “zone” completely connected to unconditioned space or outside AND completely separated from conditioned space by a continuous air barrier and thermal barrier
• Always provide combustion “zone” with adequate (idiot proof) combustion air using the National Gas Code guidelines
80%, mid-efficiency or induced draft furnace
Direct Vent Water Heater
Sealed Combustion Condensing 90%+ AFUE Furnace
Gas Appliances in Confined Space

Confined Space: Volume Less than 50 Cu. Ft. / 1000 Btuh
All Air From Inside the Building

Example:

- Furnace = 100,000 btu/hr input
- Water heater = 34,000 btu/hr input
- Total btu/hr = 134,000 btu/hr input
- 1 square inch per 1,000 btu/hr input required.

- 134,000 / 1,000 = 134 square inches for each opening.
- One within 12 inches of ceiling & one within 12 inches of the floor.

FIGURE 304.3.1
All Air From Outdoors. Method 1a - Vertical

- Example:
  - Furnace = 100,000 btu/hr input
  - Water heater = 34,000 btu/hr input
  - Total btu/hr = 134,000 btu/hr input

- 1 square inch per 4,000 btu/hr input required.

- 134,000 / 4,000 = 33.5 square inches for each opening.
- One within 12 inches of ceiling & one within 12 inches of the floor.
All Air From Outdoors. Method 1b - Horizontal

Example:

- Furnace = 100,000 btu/hr input
- Water heater = 34,000 btu/hr input
- Total btu/hr = 134,000 btu/hr input

- 1 square inch per 2,000 btu/hr input required.
- 134,000 / 4,000 = 67 square inches for each opening.
- One within 12 inches of ceiling & one within 12 inches of the floor.
All Air From Outdoors. Method 2

- Example:
  - Furnace = 100,000 btu/hr input
  - Water heater = 34,000 btu/hr input

- Total btu/hr = 134,000 btu/hr input

- 1 square inch per 3,000 btu/hr input required.

- 134,000 / 4,000 = 44.7 square inches for each opening.

- Within 12 inches of ceiling

Figure M703.2(d)
Whole house air pressure

• For Hot Humid Climate
  – Negative House Pressure – Bad
  – Neutral House Pressure – Good
  – Positive House Pressure – Better

• Causes of negative house air pressure
  – Exhaust fans
  – Closed interior doors
  – Supply duct leakage
  – Supply duct leakage > return duct leakage

• To induce slight positive pressure…
  – Small amount of filtered, controlled outside air
• Air barrier and duct system holes are hard to see, but can be measured with a testing equipment.
Controlling Water, Air, and Heat

**Principal Strategies**

**Water:**
- Dry Materials
- Exterior finishes
- Continuous Drainage Plane
- Flashing
- Assemblies that Dry
- Exhaust wet air

**Air:**
- Continuous Air Barrier
- Sealed Duct System
- Neutral Air Pressure

**Heat:**
- Continuous, Even Layer of Insulation
Controlling Water, Air, and Heat
Thermal Barrier

- Install in a continuous, even layer
- Missing insulation isn’t seen, it’s felt.

- Like a hole in your coat.
Building Science Summary

• Driving Forces
  – Temperature difference
  – Pressure difference

• Control Boundaries
  – Air barrier, sealed duct system, thermal barrier, drainage plane

• Energy Star for New Homes
  – Thermal Bypass Inspection covers air and heat flow!
  – www.energystar.gov
Step 1 – Achieve Energy Star

- Home energy rating system index
- Energy star program overview and technical requirements
- Thermal bypass inspection
- Overview of Afternoon Field Activities
Preliminary Evaluation

- The HERS Index
- HERS=Home Energy Rating System
- Compares a “designed” or “as built” home
- To the HERS “Reference Home”
  - same size, wall areas, structural system, fuel
  - Minimum efficiency equipment
  - Insulation etc to comply with 2004 International Energy Conservation Code (IECC)
Preliminary HERS Index Evaluation for Demonstration House Partners

HERS Index Scale
A house compliant with the International Energy Conservation Code (IECC) scores 100, each point lower = 1% whole house savings compared to IECC

Existing Homes

IECC

Energy Star 85

Building America Demonstration Goal 70-75

Zero Energy Home 0

115 New Orleans

99 Slidell

95 Mobile

90 Baton Rouge

90 Baton Rouge

95 Mobile

99 Slidell

115 New Orleans