Introduction

- 2011 Building America Program
- Evaluation and Testing of Individual Measures for New Homes
- Proposed that Hybrid Assemblies would help meet the U.S. Department of Energy home energy use reductions of 30-50%

Building America

The U.S. Department of Energy’s Building America Program is reengineering the American home for energy efficiency and affordability. Building America works with the residential building industry to develop and implement innovative building processes and technologies – innovations that save builders and homeowners millions of dollars in construction and energy costs. This industry-led, cost-shared partnership program uses a systems engineering approach to reduce energy use, utility bills, construction time, and construction waste.

For more information, visit our website at: www.buildingamerica.gov

Why build energy efficient homes?

Consumers:
- Lower energy bills and maintenance costs
- More money for things other than energy
- Healthier, more comfortable, more durable homes

The nation:
- Wise use of resources through energy savings
- Greater energy security through the use of domestic resources
- A healthier environment through reduced emissions
- Increased use of onsite power and renewable energy systems
Overview of the Design approach

Our approach follows three general steps:

- Step 1: Reduce Enclosure Energy Use
- Step 2: Reduce Mechanical System Energy Use
- Step 3: Add Site Generated Energy

Energy Efficient Construction is Catching on

Total End-Use Residential Energy Consumption in 2001 per Square Foot by Age of Construction

But size matters . . .

- Average House Size in 1940: ~1100 sq ft
- Average House Size in 1973: 1660 sq ft
- Average House Size in 2005: 2434 sq ft

2. EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer
Introduction

• Closed Cell Spray Polyurethane Foam is Stiff
• Some prefabricated builders already use ccSPF for transportation
• Some builders use ccSPF for condensation control
• Can ccSPF add structural capacity?

Outline

1. Design and Hypothesis
2. Identification of hybrid wall assemblies
3. BEopt energy modeling
4. Thermal analysis
5. Hygrothermal analysis
6. Laboratory structural testing
7. Summary of testing results
8. Development of Recommendations
Design and Hypothesis

Hybrid walls will utilize a combination of:
- 1.5” to 3” exterior board foam insulation
- Diagonal metal strapping
- 2x6 Advanced Framing
- 1.5” closed cell spray polyurethane foam
- Cellulose or fibrous cavity fill insulation
  - *No wood based structural sheathing*

Design and Hypothesis

Hybrid walls can provide effective:
- Thermal control
- Air control
- Moisture control
- Drainage plane
- And Structure!

Advanced Framing History

The Year – 1854
The Book – The American Cottage Builder

Advanced Framing History

1970s
U.S. Department of Housing and Urban Development
NAHB Research Foundation
Operation Break-through delivered “optimum value engineering framing”
Today this is “Advanced Framing”
Overview

What is Advanced Framing today?

Framing system on 2’ centers
Reduce Framing Material Use
Increases Insulation Volume
Improves Energy Performance
Reduces Labor Costs (eventually)

Overview

Advanced Framing and The Building Code

Within the IRC the following are permitted:

- 24” On Centre Framing
- Single Top Plates
- 24” On Centre Interior Partitions
- No Headers in Non-Load-Bearing Walls
- Interior and Exterior Wall Covering on 24” On Centre
- Drywall Clips
- Single Headers
Hybrid Wall Assemblies

**Hybrid Wall 1 and 2**

**Exterior**
- 1.5" XPS Exterior Insulation
- Diagonal Metal Strapping
- 2x6 Advanced Framing
- 1.5" Closed Cell Spray Polyurethane Foam
- 4" Cellulose (1) or Fiberglass (2)
- Drywall

**Interior**

**Hybrid Wall 3 and 4**

**Exterior**
- 1.5" Foil Faced Polyiso Exterior Insulation
- Diagonal Metal Strapping
- 2x6 Advanced Framing
- 1.5" Closed Cell Spray Polyurethane Foam
- 4" Cellulose (3) or Fiberglass (4)
- Drywall

**Interior**

**Hybrid Wall 5**

**Exterior**
- 3" Foil Faced Polyiso Exterior Insulation
- Diagonal Metal Strapping
- 2x6 Advanced Framing
- 1.5" Closed Cell Spray Polyurethane Foam
- 4" Cellulose
- Drywall

**Interior**
BEopt Analysis

- Average Building America Home
- Modeled in New Orleans and Minneapolis
- Standard Layout and Form
- Average Mechanical Equipment
- Energy Star Appliances
- Average BA Air Tightness

- Only variable changed is the wall R-values

BEopt Specifications

<table>
<thead>
<tr>
<th>Building Enclosure</th>
<th>Medium-colored asphalt shingles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof Insulation</td>
<td>R-38 Blown-in Fiberglass, v-notched</td>
</tr>
<tr>
<td>Walls Insulation</td>
<td>Varying</td>
</tr>
<tr>
<td>Windows</td>
<td>vinyl double glazed with spectrally selective glass (0.95, 0.79, 0.75, 0.75)</td>
</tr>
<tr>
<td>Infiltration</td>
<td>3.0 ACH(0.65 Pa)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanical Systems</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Heat</td>
<td>92.5% AFUE gas furnace in conditioned space</td>
</tr>
<tr>
<td>Cooling</td>
<td>12 EER air conditioner in conditioned space</td>
</tr>
<tr>
<td>DHW</td>
<td>gas tank water heater (1.5 GPM)</td>
</tr>
<tr>
<td>Oven</td>
<td>6.6 kwh annual in conditioned space</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Central Fan Integrated Supply Ventilation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Appliances, Lighting, HVAC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>100% Energy Star CFL Package</td>
</tr>
<tr>
<td>Appliances</td>
<td>Energy Star Refrigerator, Dishwasher and Clothes Washer</td>
</tr>
</tbody>
</table>

BEopt Analysis - Costs

RSMeans CostWorks 2011

- Industry average costs
- Production builders may have better prices

BEopt Analysis - Energy

- Basic House is Building America grade
- Total Package Energy Savings
- Significant portion of savings due to BA Package
- Increments of savings are due to the Hybrid Walls
More analysis required to find optimal wall.
Thermal Analysis

**Therm5 - Clear Wall R-Values Calculated**

- **2x6 Advanced Framing**
- **Modeled 16% Framing Factor**

<table>
<thead>
<tr>
<th>Enclosure Component</th>
<th>Thermal Conductivity $k$ (W/m·K)</th>
<th>R-Value Per Inch (in²·°F/Btu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drywall</td>
<td>0.160</td>
<td>0.9</td>
</tr>
<tr>
<td>SPI Framing</td>
<td>0.100</td>
<td>1.4</td>
</tr>
<tr>
<td>Oriented Strand Board</td>
<td>0.110</td>
<td>1.3</td>
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<tr>
<td>Extruded Polystyrene (XPS)</td>
<td>0.029</td>
<td>5.0</td>
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<tr>
<td>Foil Faced Polystyrene (IP)</td>
<td>0.022</td>
<td>6.5</td>
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<tr>
<td>2.0 PCC CC Spray Polyurethane Foam</td>
<td>0.034</td>
<td>8.0</td>
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<tr>
<td>Fiberglass - Batt - R21</td>
<td>0.036</td>
<td>3.8</td>
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<tr>
<td>Damp Spray Cellulose</td>
<td>0.037</td>
<td>3.9</td>
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<tr>
<td>Spray Fiberglass</td>
<td>0.034</td>
<td>4.2</td>
</tr>
</tbody>
</table>

**Hybrid Walls improve R-Value**

- Hybrid Wall 5 improves the most
- Hybrid Wall 4 improves second most
- More Analysis Required
Hygrothermal Analysis

WUFI

Most advanced commercially available hygrothermal moisture modeling program

Modeling

• Two Base Walls
• Five Hybrid Walls
• Two Exterior Climates
• Two Interior Humidity Cases
• One Interior Temperature Profile

Looking to compare Temperature and Dew Point profiles

Hygrothermal Analysis

Two Exterior Climates

• New Orleans
  Temp - Mean 67°F, Max 95°F, Min 21°F
  RH - Mean 72%
  Rainfall - 57.5 inches
• Minneapolis
  Temp - Mean 43°F, Max 95°F, Min -26°F
  RH - Mean 72%
  Rainfall - 40 inches

Hygrothermal Analysis

Two Humidity Cases

• Low - 30% Winter, 60% Summer - Sinusoidal
• High - 40% Winter, 70% Summer - Sinusoidal

Criteria Monitored

• Condensation Plane Temperature
• Interior Temperature and Relative Humidity

Calculations

• Interior Air Dew point

Comparisons and Risk

• Air leakage condensation risk
• Air leakage must be present
• Duration, repetition, alternating drying
Hygrothermal Analysis

Air leakage condensation - air leakage must be present

Standard Wall - 2x6 Advanced Frame, OSB Sheathing

Exterior Insulated Wall - 2x6 Advanced Frame, 1.5” XPS

Hybrid Wall 1 - 1.5” XPS, 1.5” ccSPF, Cellulose
Hygrothermal Analysis

Risk Comparison - Minneapolis

Low Interior Humidity vs High Interior Humidity

Summary

- Hybrid Walls significantly reduced risk
- Hybrid Wall 5 reduced risk the most
- Hybrid Wall 3 reduced risk the second most
- New Orleans showed no condensation risks
- Only a little more analysis!
Structural Analysis

ASTM E72 Testing
Standard Test Methods of Conducting Strength Tests of Panels for Building Construction
aka – Racking Tests

Build and Test
- Base Case Code Accepted Wall
- Base Case Strapping Only Wall
- Hybrid Walls

Comparison and Analysis
All Walls Tested are 8' High and 8' Wide
Base Case – 3 Walls
- 2x6 Advanced Framing
- 7/16” OSB Sheathing
Base Case Strapping Only – 3 Walls
- 2x6 Advanced Framing
- Diagonal 16 Gauge Metal Strapping
- 1.5” XPS Insulating Sheathing

Comparison and Analysis
- Base Case Test 0 – 3 Walls
- Base Case Test 1 Strapping Only – 3 Walls
- Hybrid Test 2 with XPS Exterior Insulation – 3 Walls
- Hybrid Test 3 with ffPIC Exterior Insulation – 3 Walls

No Cellulose or Fiberglass
No Drywall
No Exterior Finish

Comparison and Analysis
- Hybrid Wall Structural Test 2 – 3 Walls
  - 2x6 Advanced Framing
  - Diagonal 16 Gauge Metal Strapping
  - 1.5” XPS Insulating Sheathing
  - 1.5” ccSPF Insulation

Hybrid Wall Structural Test 3 – 3 Walls
- 1.5” ffPIC Insulating Sheathing
Structural Analysis

Drawings Provided to DOW Technicians

ASTM E72 Racking Testing

Deflection as a result of loadings

- Ram locates wall and zeros its displacement measurement
- Loadings applied 395 lbs/minute
- Loading to 790 lbs
  - Release loading
- Loading to 1570 lbs
  - Release loading
- Loading to 2360 lbs
  - Release loading
- Load to failure (4" deflection or 30,000 lbs)
Structural Analysis

Base Case OSB Wall

Structural Analysis

Base Case OSB Wall

Structural Analysis

Base Case OSB Wall

Structural Analysis

Base Case 1 – XPS Exterior Insulation
Structural Analysis
Hybrid Test 2 – XPS Exterior Insulation
Structural Analysis

Hybrid Test 3 – ffPIC Exterior Insulation

![Graph 1](image1)

![Graph 2](image2)

![Graph 3](image3)

![Graph 4](image4)
Analysis Summary

BEopt Hybrid Walls
- $2.20/ft^2 to $5.17/ft^2
- Wall 5 – 3” ffPIC highest cost
- $2.20/ft^2 to $2.30/ft^2 (w/o Wall 5)
- 3% to 5% Annual Energy Savings
- Tight group of Annualized Energy Costs
- Wall 5 Ruled Out
- No Clear Wining Wall

Thermal
- All Hybrid walls outperform Base Cases
- Hybrid Wall 5 highest R-Value
- Hybrid Wall 3 and 4 Second Highest R-Value

Hygrothermal
- All Hybrid walls outperform Base Cases
- Hybrid Wall 5 Lowest Condensation Risk
- Hybrid Wall 3 and 4 Second Lowest
- Hybrid Wall 3 – 98% Reduction in Risk

Structural
- XPS and Strapping Capacity ~ 2000lbs @ 3.5"
- 7/16” OSB Capacity ~ 4000 lbs @ 2.5"
- XPS and ccPSF Capacity ~ 6000 lbs @ 2"
- ffPIC and ccSPF Capacity ~ 6000 lbs @ 1.5"
- Hybrid Walls 3 and 4 use ffPIC

Hybrid Wall 3 – Best Performer
- 1.5” ffPIC Exterior Insulation
- 26 Gauge Diagonal Metal Strapping
- 2x6 Advanced Framing
- 1.5” ccSPF Insulation
- 4” Cellulose Cavity Fill Insulation
- Drywall
Further Research

- Structural capacity of hybrid walls without diagonal strapping
- Structural capacity of hybrid walls with full cavity closed cell spray foam
- Structural capacity of hybrid walls with various stud fasteners
- Cyclic seismic structural capacities of hybrid assemblies
- Flood repair options for hybrid assemblies
- Full scale wind testing of homes with hybrid walls

Thank You

Questions?

For more information and the full report visit buildingscience.com