# High Performance Hybrid Assemblies

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## 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

Building America U.S. Department of Energy
*Research Toward Zero Energy Homes*

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



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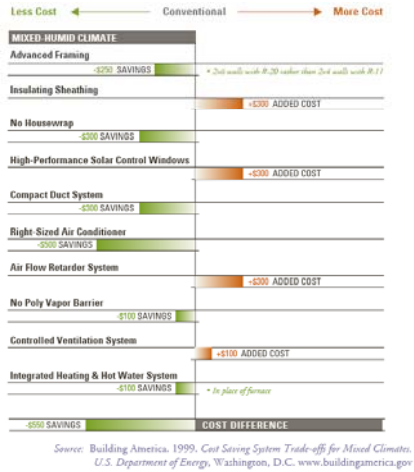
## Systems Engineered for Zero Cost




Source: Building America. 1999. *Cost Saving System Trade-offs for Mixed Climates.* U.S. Department of Energy, Washington, D.C. www.buildingamerica.gov



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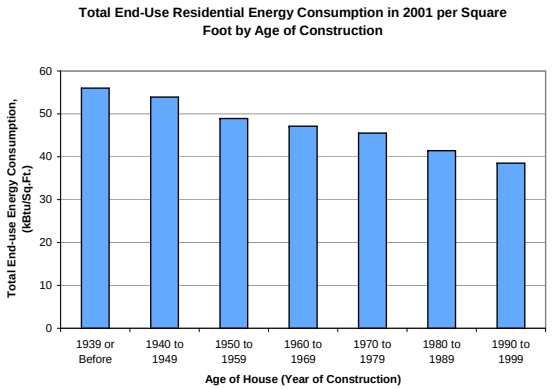
## Energy Efficient Construction is Catching on



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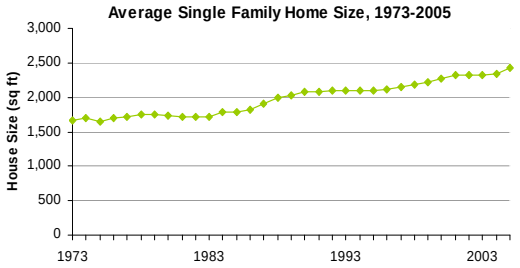
## But size matters . . .

- Average House Size in **1940: ~1100 sq ft**[1]
- Average House Size in **1973: 1660 sq ft**[2]
- Average House Size in **2005: 2434 sq ft**




1. Wilson, Alex and Jessica Boehland "Small is Beautiful" *Journal of Industrial Ecology*, Vol 9, No 1-2. 2005
2. EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer



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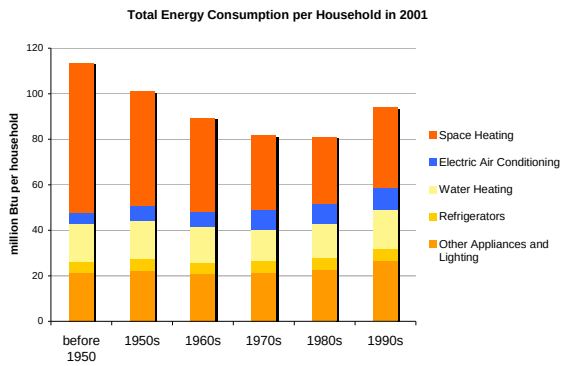
## Total Energy Use is on the Rise







## 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?**




## Introduction

- **Research Focus on Hybrid *Wall* Systems**
- **Combinations of materials and approaches provide optimum performance**
- **No single manufacturer provides all necessary components**
- **Integration of materials and manufacturers is key**




## 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

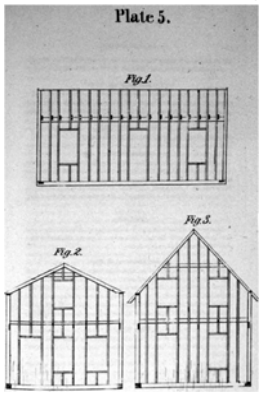
- And Structure!




## 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)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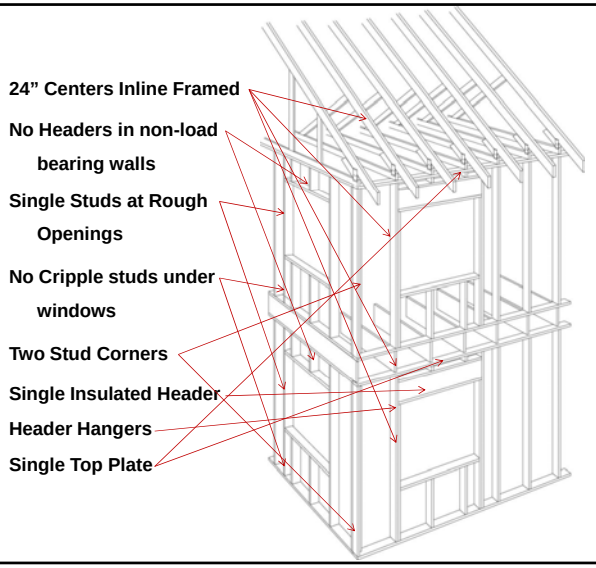



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## Overview

**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


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## Hybrid Wall Assemblies

| | | Standard Wall | Exterior Insulated Wall | Hybrid Wall 1 | Hybrid Wall 2 | Hybrid Wall 3 | Hybrid Wall 4 | Hybrid Wall 5 |
|---|---|---|---|---|---|---|---|---|
| Exterior Finish | Any | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Drainage | Housewrap | ✓ | ✓ | | | | | |
| | Exterior Face of Exterior Insulation, Joints Sealed with Liquid Applied Membrane | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Exterior Insulation | 1.5" XPS | | ✓ | ✓ | ✓ | | | |
| | 1.5" FF PIC | | | | | ✓ | ✓ | |
| | 3" FF PIC | | | | | | | ✓ |
| Structural | 7/16" OSB Sheathing | ✓ | ✓ | | | | | |
| | Diagonal Metal Strapping + ccSPF | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Framing | Advanced Framed | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Cavity Insulation 1 | 1.5" ccSPF | | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Cavity Insulation 2 | Cellulose (damp spray) | | | ✓ | | ✓ | | ✓ |
| | Spray fiberglass | | | | ✓ | | ✓ | |
| | R21 Fiberglass Batt | ✓ | ✓ | | | | | |
| Interior Finish | Painted Gypsum | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |


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## 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**


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## 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**


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## 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**


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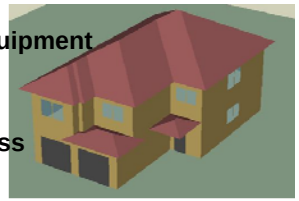
## BEopt Analysis

- 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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## BEopt Specifications

| Building Enclosure | |
|---|---|
| Roof Cladding | Medium colored asphalt shingles |
| Roof Insulation | R-38 Blown in Fiberglass, vented attic |
| Walls | Varying |
| Insulating Sheathing | Varying |
| Windows | vinyl double glazed with spectrally selective glass (U=0.35, SHGC=0.32) |
| Infiltration | 3.3 ACH 50, 0.23 nACH |
| | |
| **Mechanical Systems** | |
| Heat | 92.5% AFUE gas furnace, in conditioned space |
| Cooling | 13 SEER air conditioner in conditioned space |
| DHW | gas tank water heater (EF=0.62) |
| Ducts | R-6 flex runouts in conditioned space |
| Ventilation | Central Fan Integrated Supply Ventilation |
| | |
| **Appliances, Lighting, MELs** | |
| Lighting | 100% Energy Star CFL Package |
| Appliances | Energy Star Refrigerator, Dishwasher and Clothes Washer |


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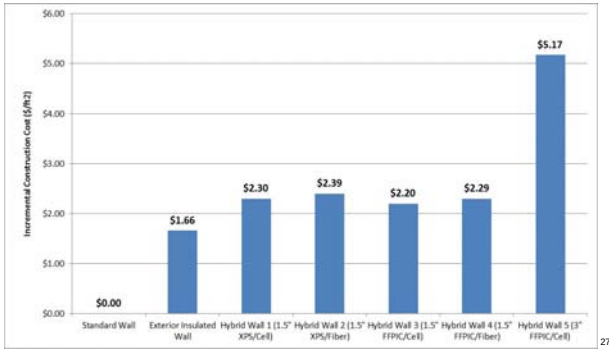
## BEopt Analysis - Costs

**RSMeans CostWorks 2011**

- Industry average costs
- Production builders may have better prices





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## 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


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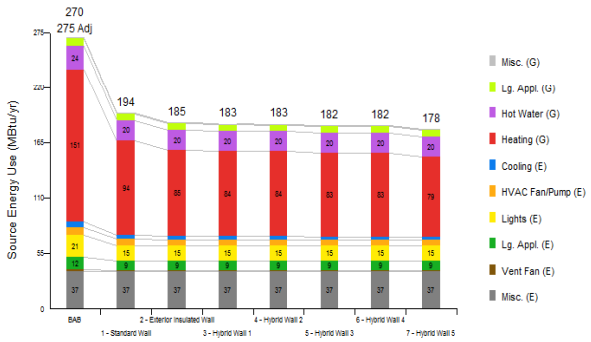
## BEopt Analysis




**Source Energy Use for Minneapolis Model**



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## BEopt Analysis

**Annual Utility Costs for Minneapolis Model**



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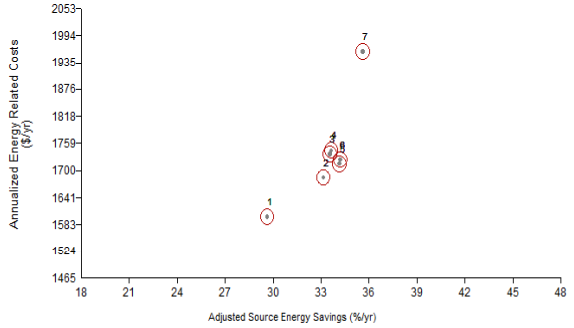
## BEopt Analysis




**Annualized Energy Costs for Minneapolis Model**



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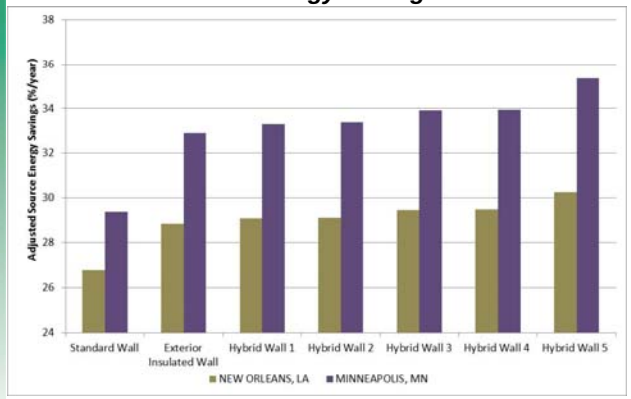
## BEopt Analysis - Energy

***3% - 5% Source Energy Savings***




***More analysis required to find optimal wall***



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## Thermal Analysis

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

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

| Enclosure Component | Thermal Conductivity k [W/mK] | R-Value Per Inch [hr·°F·ft²/Btu] |
|---|---|---|
| Drywall | 0.160 | 0.9 |
| SPF Framing | 0.100 | 1.4 |
| Oriented Strand Board | 0.110 | 1.3 |
| Extruded Polystyrene (XPS) | 0.029 | 5.0 |
| Foil Faced Polyisocyanurate (PIC) | 0.022 | 6.5 |
| 2.0 PCF CC Spray Polyurethane Foam | 0.024 | 6.0 |
| Fiberglass - Batt - R21 | 0.038 | 3.8 |
| Damp Spray Cellulose | 0.037 | 3.9 |
| Spray Fiberglass | 0.034 | 4.2 |


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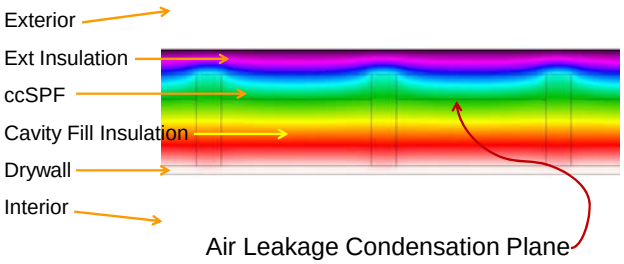
## Thermal Analysis

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





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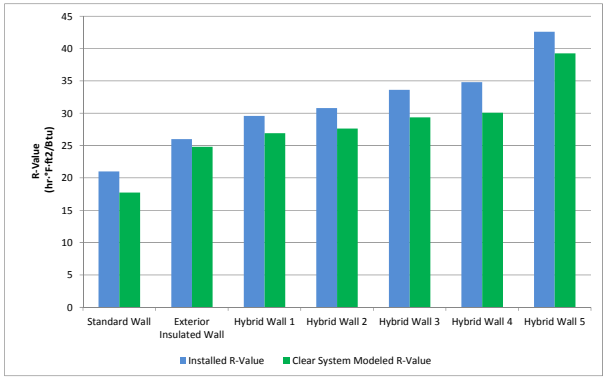
## Thermal Analysis

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





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## Thermal Analysis

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

- ***Hybrid Walls improve R-Value***
- ***Hybrid Wall 5 improves the most***
- ***Hybrid Wall 4 improves second most***
- ***More Analysis Required***


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## 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**


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## 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**


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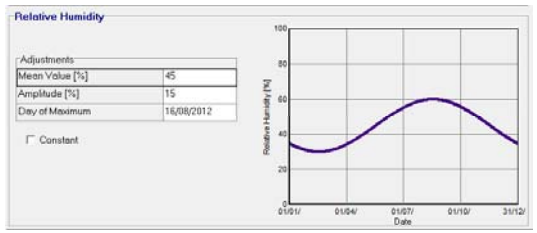
## Hygrothermal Analysis

### Two Humidity Cases

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





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## Hygrothermal Analysis

### 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**


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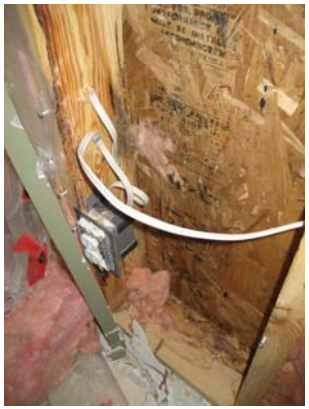
## Hygrothermal Analysis

**Air leakage condensation - air leakage must be present**





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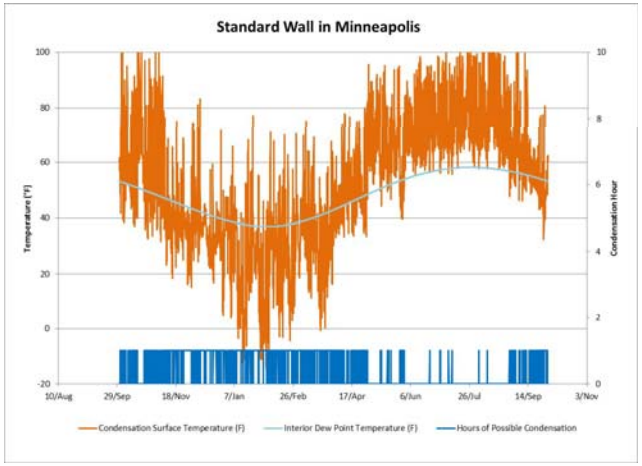
## Standard Wall - 2x6 Advanced Frame, OSB Sheathing



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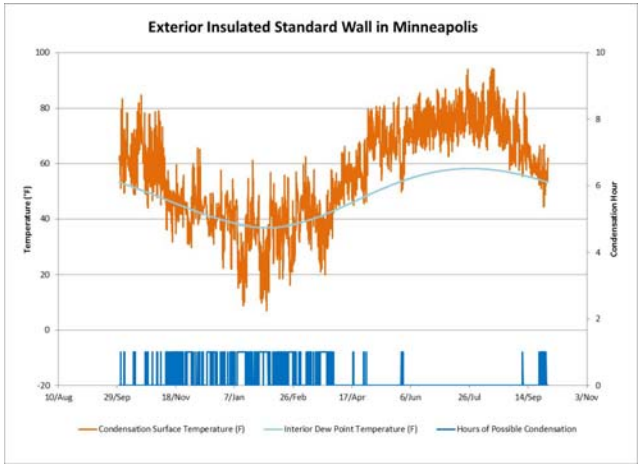
## Exterior Insulated Wall - 2x6 Advanced Frame, 1.5” XPS



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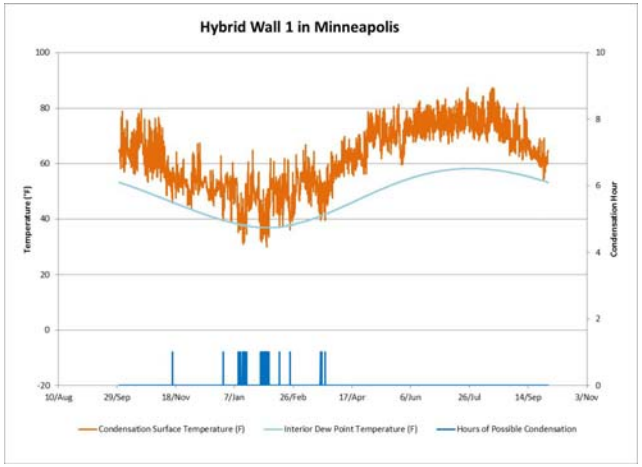
## Hybrid Wall 1 - 1.5” XPS, 1.5” ccSPF, Cellulose



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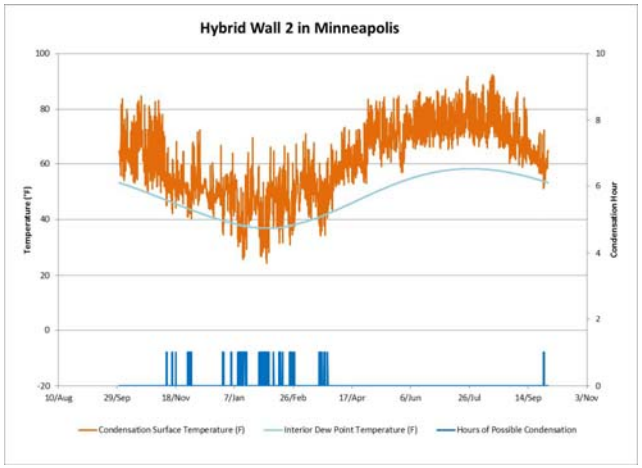
## Hybrid Wall 2 - 1.5” XPS, 1.5” ccSPF, Fiberglass



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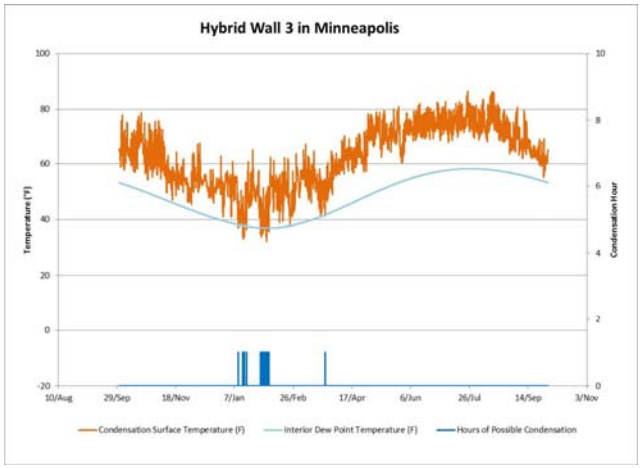
## Hybrid Wall 3 - 1.5” ffPIC, 1.5” ccSPF, Cellulose



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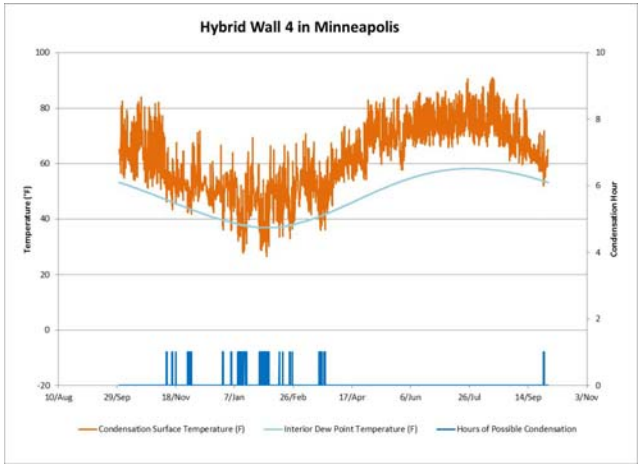
## Hybrid Wall 4 - 1.5” ffPIC, 1.5” ccSPF, Fiberglass



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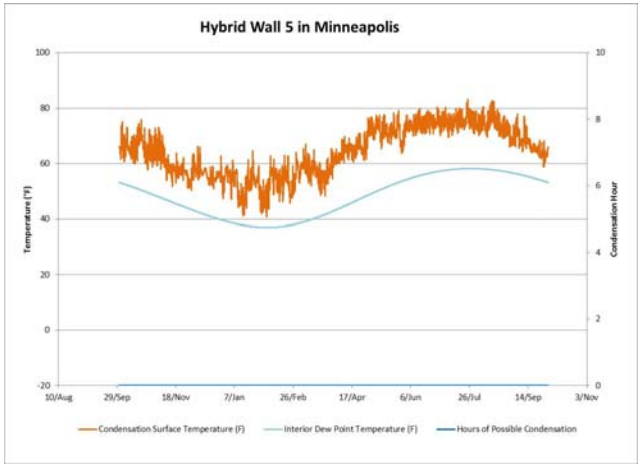
## Hybrid Wall 5 - 3” ffPIC, 1.5” ccSPF, Cellulose



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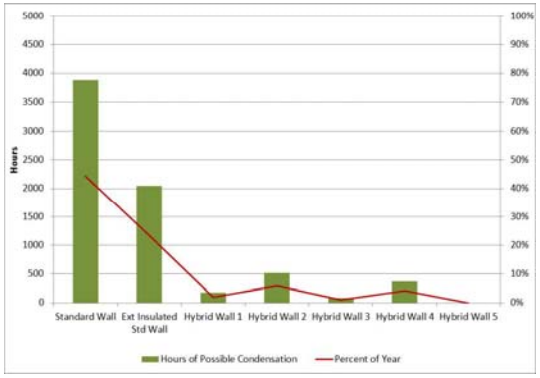
## Hygrothermal Analysis

### Risk Comparison - Minneapolis

**Hours of Possible Air Leakage Condensation**



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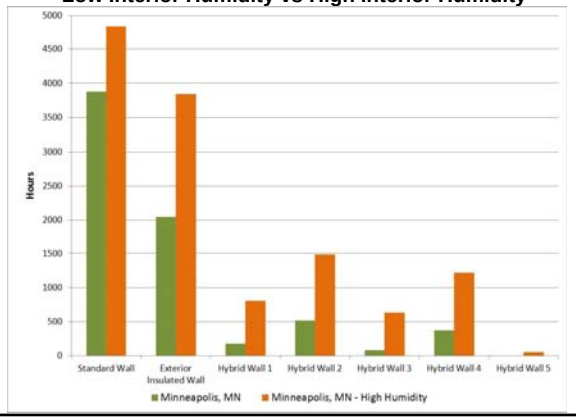
## Hygrothermal Analysis

### Risk Comparison - Minneapolis

**Low Interior Humidity vs High Interior Humidity**



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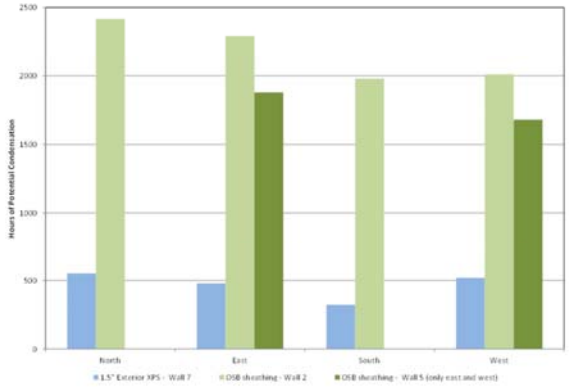
## Hygrothermal Analysis

### Risk Comparison – Coquitlam – Measured Data



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## Hygrothermal Analysis

**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!**



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## Structural Analysis

### ASTM E72 Testing

Standard Test Methods of Conducting Strength Tests of Panels for Building Construction

aka – Racking Tests

DOW - Midland, Michigan

### Build and Test

- Base Case Code Accepted Wall
- Base Case Strapping Only Wall
- Hybrid Walls


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## Structural Analysis

### 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


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## Structural Analysis

### 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


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## Structural Analysis

### Comparison and Analysis

All Walls Tested are 8’ High and 8’ Wide

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


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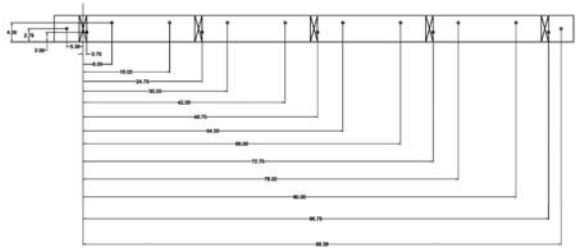
## Structural Analysis

**Drawings Provided to DOW Technicians**

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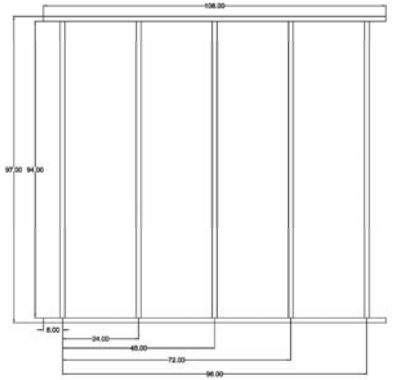
## Structural Analysis

**Drawings Provided to DOW Technicians**

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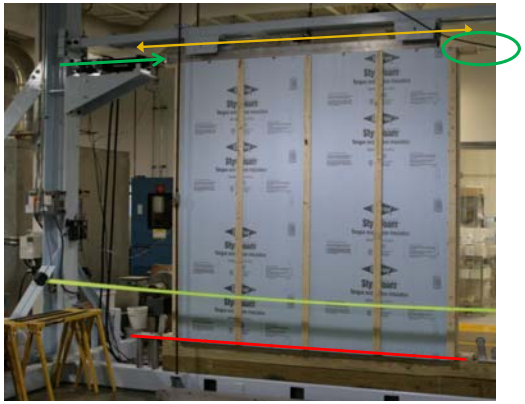
## Structural Analysis

**ASTM E72 Racking Testing**

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## Structural Analysis

**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 790lbs
  - Release loading
- Loading to 1570 lbs
  - Release loading
- Loading to 2360 lbs
  - Release loading
- Load to failure (4” deflection or 30,000 lbs)


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## Structural Analysis

**Base Case OSB Wall**



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## Structural Analysis

**Base Case OSB Wall**



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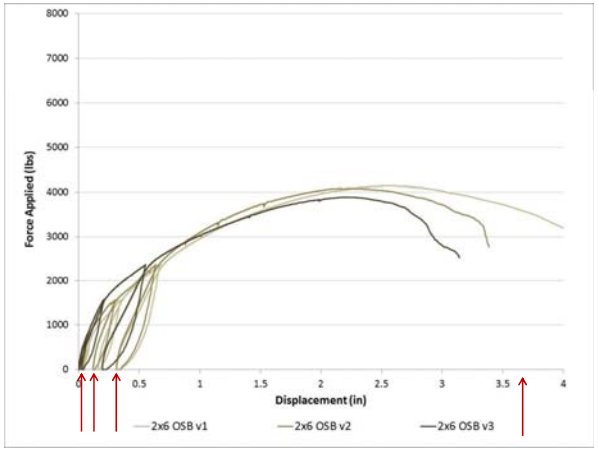
## Structural Analysis

**Base Case OSB Wall**



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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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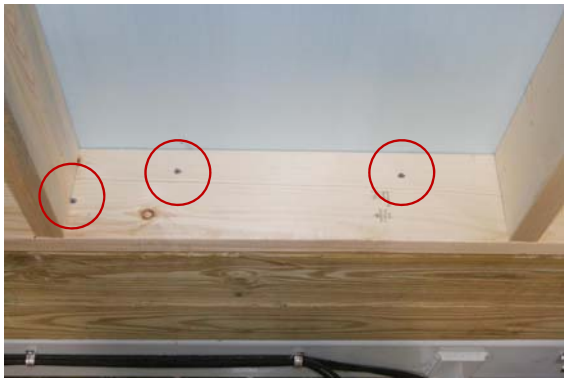
## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**





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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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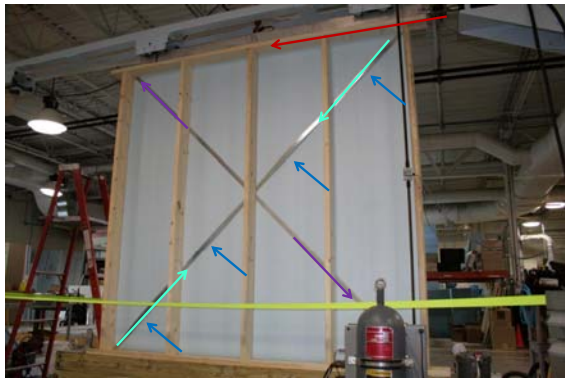
## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**





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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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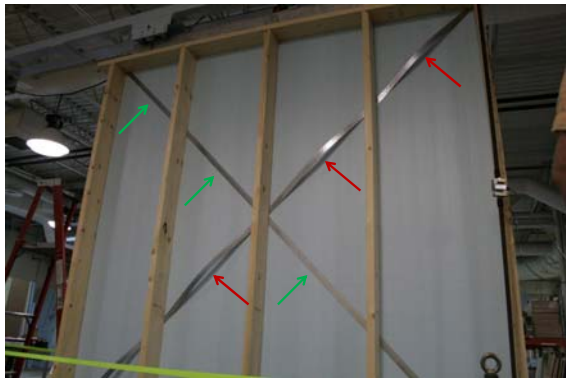
## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**





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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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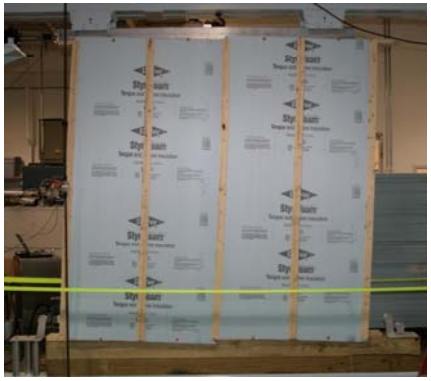
## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**





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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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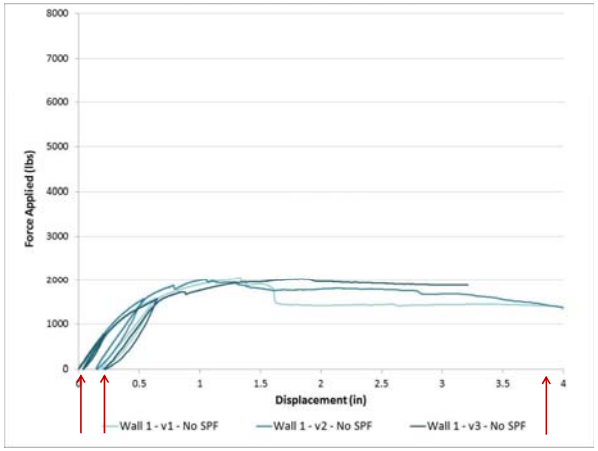
## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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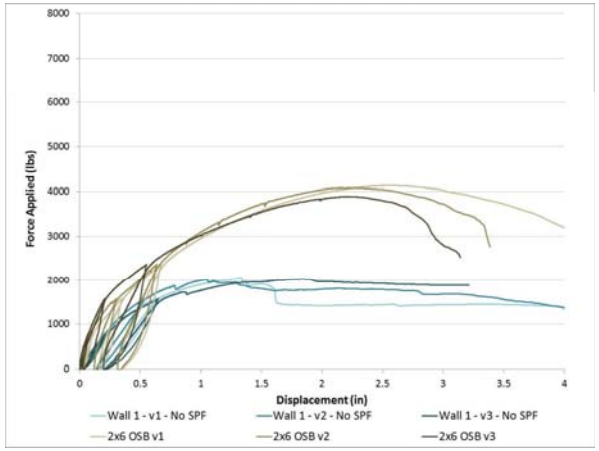
## Structural Analysis

**Base Case 1 – XPS Exterior Insulation**



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## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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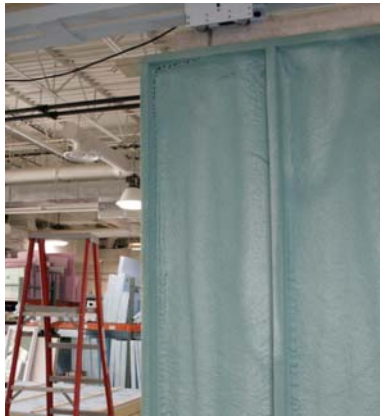
## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**





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## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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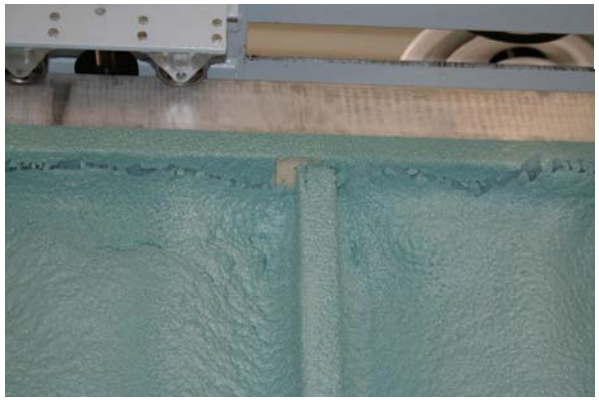
## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**





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## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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## Structural Analysis

**No ccSPF Comparison**



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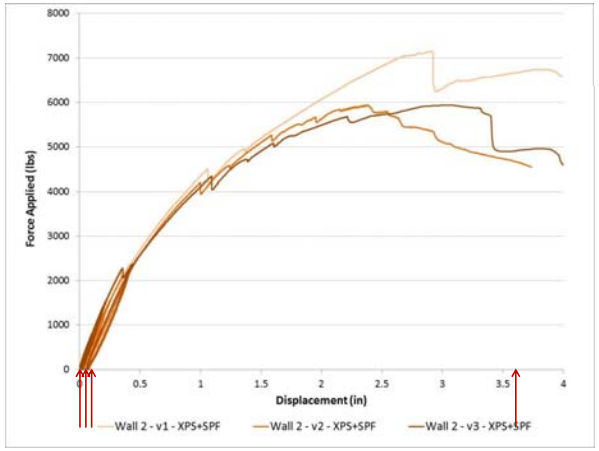
## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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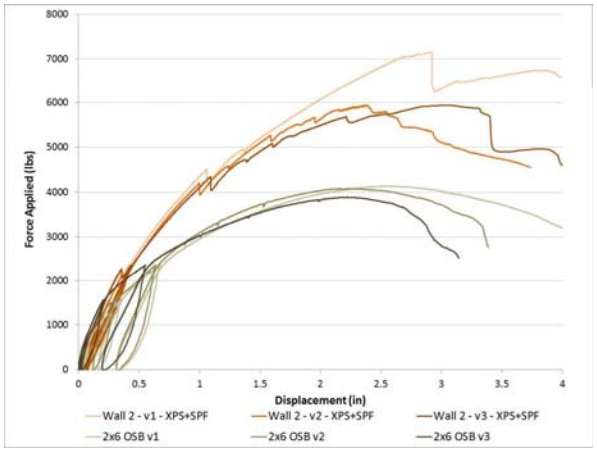
## Structural Analysis

**Hybrid Test 2 – XPS Exterior Insulation**



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## Structural Analysis

**Hybrid Test 3 – ffPIC Exterior Insulation**



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## Structural Analysis

**Hybrid Test 3 – ffPIC Exterior Insulation**



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## Structural Analysis

**Hybrid Test 3 – ffPIC Exterior Insulation**



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## Structural Analysis

**Hybrid Test 3 – ffPIC Exterior Insulation**



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## Structural Analysis

**Hybrid Test 3 – ffPIC Exterior Insulation**



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## Structural Analysis

**Hybrid Test 3 – ffPIC Exterior Insulation**




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## Structural Analysis

**Hybrid Test 3 – ffPIC Exterior Insulation**



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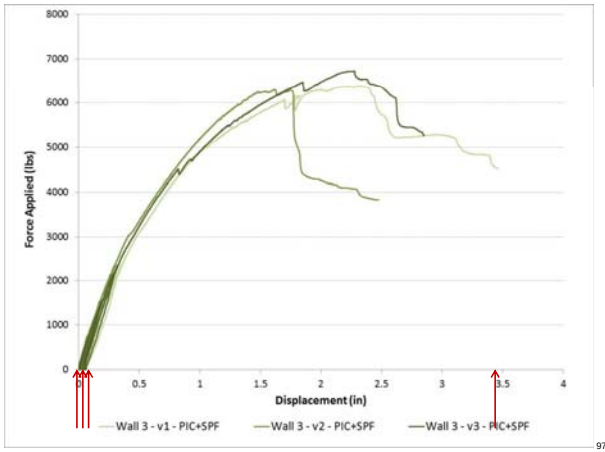
## Structural Analysis

### Hybrid Test 3 – ffPIC Exterior Insulation



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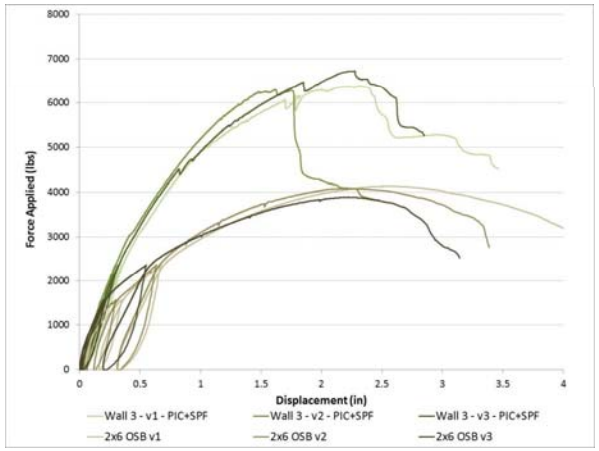
## Structural Analysis

### Hybrid Test 3 – ffPIC Exterior Insulation



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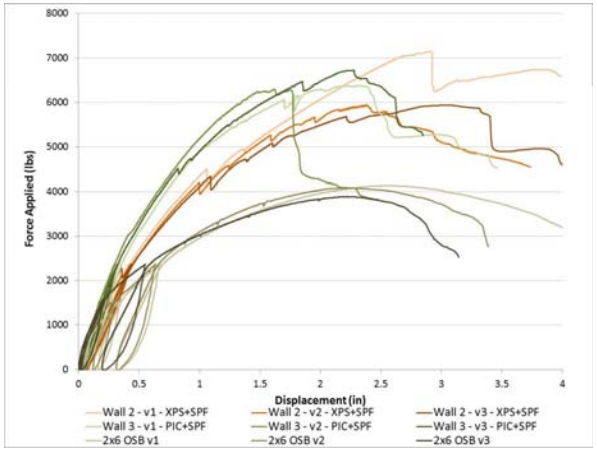
## Structural Analysis

### Hybrid Test 3 – ffPIC Exterior Insulation



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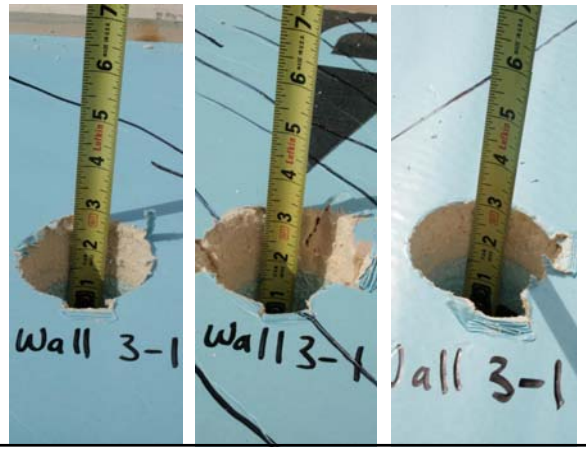
## Structural Analysis

### Hybrid Test 3 – ffPIC Exterior Insulation



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## Analysis Summary

**BEopt Hybrid Walls**

- **$2.20/ft$^2$ to $5.17/ft$^2$**
- **Wall 5 – 3" ffPIC highest cost**
- **$2.20/ft2 to $2.30/ft2 (w/o Wall 5)**
- **3% to 5% Annual Energy Savings**
- **Tight group of Annualized Energy Costs**
- **Wall 5 Ruled Out**
- **No Clear Wining Wall**


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## Analysis Summary

**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**


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## Analysis Summary

**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**


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## Analysis Summary

**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**


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## 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


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## Thank You

## Questions?

For more information and the full report visit

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