Advances in Manufactured Home Energy Efficient Design
“Integrated Design” Concept

• Goal: Reduce space conditioning energy use by at least 50% while holding the line on affordability
• Components of the strategy as an *optimized* system:
  ▪ Ultra-efficient thermal envelope
  ▪ Low capacity, highly efficient mechanical system
  ▪ Innovative distribution system
  ▪ Affordable and effective ventilation
ID Performance in Hot, Humid Climates

- Design, build, commission prototype
- Collect data, assess performance
- Dissect, diagnose, critique, strategize
- Refine design
Core Technologies

Advanced Walls

Advanced Roofs

Ductless, mini-split heat pump (single head)
Advanced Wall Construction
Advanced Roof Construction

Dense-pack Insulation
Advanced Roof Construction

Baffles and insulation dams
Window Installation
Ductless, Mini-split Heat Pump

- NO DUCTS, no site work
- Transfer fans for distribution
- Cost competitive
- High efficiency
- Factory installed
- Interior space saving (no furnace)
Other Home Features

- ENERGY STAR appliances
- Low-e, argon filled windows
- Quiet transfer fan distribution
- Dedicated fresh air ventilation
- 25% more airtight
- Reduced thermal bridging
Technology Refinement

Wall tests with foam (Fleetwood, Riverside, CA)

Prototype with advanced walls (Karsten Homes, Sacramento, CA)

Advanced roof tests (Golden West, Perris, CA)

Advanced roof tests (Fleetwood, Riverside, CA)

Advanced walls and roof prototype (Skyline, Woodland, CA)
Research Questions

- **Program design.** Is ZERH suitable for manufactured homes? What changes to ZERH would better recognize the unique features of factory building?
- **Use of MSHPs.** Can point-source space conditioning achieve comfort targets?
- **Costs.** What’s the incremental cost of achieving ZERH? Is it cost-effective?
- **MSHP performance.** How does MSHP perform in service?
Russellville Lab Houses
Site
## House Specifications

<table>
<thead>
<tr>
<th>Items</th>
<th>House A</th>
<th>House B</th>
<th>House C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Floor</strong></td>
<td>R-14 Fiberglass blanket</td>
<td>R-28 Fiberglass blanket</td>
<td>R-28 Fiberglass blanket</td>
</tr>
<tr>
<td><strong>Wall</strong></td>
<td>R-12</td>
<td>R-14</td>
<td>R-18</td>
</tr>
<tr>
<td></td>
<td>R-11 (Fiberglass batts )+ R-1</td>
<td>R-13 (Fiberglass batts)+ R-1</td>
<td>R-13 (Fiberglass batts )+ R-5</td>
</tr>
<tr>
<td></td>
<td>(¼-in ThermalStar board)</td>
<td>(¼-in ThermalStar board)</td>
<td>(1-in. Extruded polystyrene)</td>
</tr>
<tr>
<td><strong>Windows</strong></td>
<td>U: 0.47, SHGC: 0.73 Single pane, metal frame</td>
<td>U:0.31, SHGC: 0.33 Double pane, vinyl frame, low-emissivity, argon filled</td>
<td>U: 0.30, SHGC: 0.23 Double pane, vinyl frame low-emissivity, argon filled</td>
</tr>
<tr>
<td><strong>Ceiling</strong></td>
<td>R-22 Blown fiberglass</td>
<td>R-33 Blown fiberglass</td>
<td>R-45 Blown fiberglass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dense-packed at eaves</td>
</tr>
<tr>
<td><strong>Air Sealing</strong></td>
<td>Foaming ceiling penetrations, caulking under bottom plates and between top plates and ceiling, marriage line gasket</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mechanical Ventilation</strong></td>
<td>POS Fresh air duct to air handler No mechanical damper</td>
<td>POS Fresh air duct to air handler No mechanical damper</td>
<td>Exhaust Fan 45 cfm</td>
</tr>
<tr>
<td><strong>Space-Conditioning Distribution</strong></td>
<td>Ducts Metal in-floor ducts sealed with mastic; R-8 crossover duct between sections</td>
<td>Ducts Metal in-floor ducts sealed with mastic; R-8 crossover duct between sections</td>
<td>Transfer Fans</td>
</tr>
</tbody>
</table>
## House Specifications

<table>
<thead>
<tr>
<th>Cooling Equipment</th>
<th>House A</th>
<th>House B</th>
<th>House C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intertherm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air conditioner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity: 23.4 kBtuh</td>
<td></td>
<td></td>
<td>Mitsubishi</td>
</tr>
<tr>
<td>EER: 11.0, SEER: 13.0</td>
<td></td>
<td></td>
<td>Variable-speed mini-split heat pump with outdoor unit assisted by temperature-controlled heaters when temperature falls below 69°F in the bedrooms</td>
</tr>
<tr>
<td><strong>NORDYNE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric furnace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity: 35 kBtuh</td>
<td></td>
<td></td>
<td>September 2017</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heating Equipment</th>
<th>House A</th>
<th>House B</th>
<th>House C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NORDYNE</strong></td>
<td></td>
<td></td>
<td>Mitsubishi</td>
</tr>
<tr>
<td>Electric furnace</td>
<td></td>
<td></td>
<td>Variable-speed mini-split heat pump with outdoor unit assisted by temperature-controlled heaters when temperature falls below 69°F in the bedrooms</td>
</tr>
<tr>
<td>Capacity: 35 kBtuh</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Handling Unit</th>
<th>House A</th>
<th>House B</th>
<th>House C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NORDYNE</strong></td>
<td></td>
<td></td>
<td>Mitsubishi</td>
</tr>
<tr>
<td>Electric furnace, E3EB-010H, downflow set to low speed. Resistance heating capacity: 10 kW</td>
<td></td>
<td></td>
<td>Variable-speed mini-split heat pump with outdoor unit assisted by temperature-controlled heaters when temperature falls below 69°F in the bedrooms</td>
</tr>
<tr>
<td>Air handling unit wattage (heating elements + blower): 10.4 kW</td>
<td></td>
<td></td>
<td>September 2017</td>
</tr>
</tbody>
</table>

| **NORDYNE**       |         |         | Mitsubishi |
| Electric furnace, E3EB-010H, downflow set to low speed. Resistance heating capacity: 10 kW |         |         | Variable-speed mini-split heat pump with outdoor unit assisted by temperature-controlled heaters when temperature falls below 69°F in the bedrooms |
| Air handling unit wattage (heating elements + blower): 10.4 kW |         |         | September 2017 |

| **Mitsubishi**    |         |         |         |
| Variable-speed mini-split heat pump with outdoor unit assisted by temperature-controlled heaters when temperature falls below 69°F in the bedrooms | September 2017 |         |         |
| **MUZ-FH15NA**    |         |         | September 2017 |
| **MSZ-FH15NA**    |         |         | September 2017 |
| **EER:** 12.5     |         |         |         |
| **SEER:** 22.0    |         |         | September 2017 |

| Heating capacity at 47°F: 18 kBtuh; HSPF: 12.0 | September 2017 |         |         |
| Heating capacity at 17°F: 11 kBtuh | September 2017 |         |         |
## Commissioning Results

<table>
<thead>
<tr>
<th>Test</th>
<th>Method</th>
<th>House A</th>
<th>House B</th>
<th>House C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enclosure Leakage</td>
<td>Multipoint depressurization test</td>
<td>4.7 ACH50</td>
<td>4.6 ACH50</td>
<td>3.8 ACH50</td>
</tr>
<tr>
<td>Duct Leakage</td>
<td>Duct blower depressurization test</td>
<td>54 cfm25 to outside</td>
<td>~10 cfm25 to outside</td>
<td>N/A</td>
</tr>
<tr>
<td>Ventilation Rate</td>
<td>Powered flow hood</td>
<td>44 intermittent</td>
<td>32 intermittent</td>
<td>45 continuous</td>
</tr>
<tr>
<td>Air Handling Unit Air Flow</td>
<td>Pressure equalization</td>
<td>980 cfm</td>
<td>1,000 cfm</td>
<td>Variable</td>
</tr>
</tbody>
</table>
18 Months of Monitoring
Measurements

One-minute data uploaded daily:

- Air temperature
- Relative humidity
- Condensation
- Power consumption
- Status
- Current
- Solar radiation
# Results - Cooling

<table>
<thead>
<tr>
<th></th>
<th>House A (HUD-Code)</th>
<th>House B (Energy Star)</th>
<th>House C (ZERH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Cooling (avg. kWh per day)</strong></td>
<td>15.0</td>
<td>14.5</td>
<td>7.4</td>
</tr>
<tr>
<td><strong>Average Indoor Temp (F)</strong></td>
<td>76.4</td>
<td>75.9</td>
<td>75.4</td>
</tr>
<tr>
<td><strong>Cooling Set Point (F)</strong></td>
<td>76</td>
<td>76</td>
<td>73-75</td>
</tr>
<tr>
<td><strong>Average Relative Humidity (%)</strong></td>
<td>46%</td>
<td>48%</td>
<td>59%</td>
</tr>
<tr>
<td><strong>Air Handler Fan Runtime</strong></td>
<td>31%</td>
<td>37%</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Ventilation - Effective Continuous Rate (cfm)</strong></td>
<td>14</td>
<td>12</td>
<td>45</td>
</tr>
</tbody>
</table>

*Configuration: Interior doors open Window blinds at 50%*  
*Data Aug 29-Sept 7, 2014, Avg. OAT. 77.3°F*
Cooling Power Relative to Outdoor Temperature

(Aug. 29–Sept. 15, 2014)
House A - Cooling

°F indoor

°F Outdoor

Desired temperature
Recommended maximum variation (ACCA Manual RS)
House B - Cooling

°F indoor

°F Outdoor

Dining  BR2  BR3  Living  MBR  MBath  Outdoor

Desired temperature
Recommended maximum variation (ACCA Manual RS)
House C - Cooling

Desired temperature
Recommended maximum variation (ACCA Manual RS)
# Results - Heating

<table>
<thead>
<tr>
<th></th>
<th>House A (HUD-Code)</th>
<th>House B (Energy Star)</th>
<th>House C (ZERH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Heating (avg. kWh per day)</td>
<td>48.7</td>
<td>18.1</td>
<td>16.6</td>
</tr>
<tr>
<td>Average Indoor Temp (F)</td>
<td>71.3</td>
<td>69.9</td>
<td>69.5</td>
</tr>
<tr>
<td>Heating Desired Temperature (F)</td>
<td>71</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>Average Relative Humidity (%)</td>
<td>28%</td>
<td>30%</td>
<td>33%</td>
</tr>
<tr>
<td>Air Handler Fan Runtime</td>
<td>22%</td>
<td>33%</td>
<td>N/A</td>
</tr>
<tr>
<td>Ventilation - Effective Continuous Rate (cfm)</td>
<td>10</td>
<td>11</td>
<td>45</td>
</tr>
</tbody>
</table>

*Configuration: Interior doors open. Window blinds at 50%*

_Data Nov 12-17, 2014_  
_Avg. OAT 41.3°F_
House A - Heating
House B - Heating

°F indoor

°F Outdoor

Dining  BR2  BR3  Living  MBR  MBath  Outdoor

Desired temperature
Recommended maximum variation (ACCA Manual RS)
House C - Heating

°F indoor

°F Outdoor

Desired temperature

Recommended maximum variation (ACCA Manual RS)
House C with Resistance Heat in Bedrooms

(Jan. 6–13, 2015)
Heating Energy Compared to Outdoor Temperature

(Jan. 6–13, 2015)

House A
\[ y = -0.1119x + 6.4583 \]
\[ R^2 = 0.8017 \]

House B
\[ y = -0.0815x + 4.0352 \]
\[ R^2 = 0.8204 \]

House C
\[ y = -0.0612x + 3.3383 \]
\[ R^2 = 0.8978 \]
House B Backup Electric Resistance Heating Energy

- Backup electric resistance heating energy - House B (kWh)
- Heat pump energy - House B (kWh)
- Poly. (Backup electric resistance heating energy - House B (kWh))

Outdoor air temperature (°F) vs. Heating energy kWh
House C Heat Pump, Transfer Fan, and Resistance Heating Energy

(Jan. 6–13, 2015)
Energy Consumption

- House B used slightly less energy than House A for cooling.
- House C used half the cooling energy of Houses A and B.
- House B and House C consumed about the same amount of heating energy.
- Compared with B and C, House A used about three times the heating energy.
Effective Ventilation Rates

The required whole-house ventilation rate should be 0.035 ft\(^3\) per square foot of the conditioned space or a minimum of 50 cfm. Conditioned area = 1,210 ft\(^2\).

<table>
<thead>
<tr>
<th>House</th>
<th>Measured</th>
<th>Code Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>22</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

The required whole-house ventilation rate should be 0.035 ft\(^3\) per square foot of the conditioned space or a minimum of 50 cfm. Conditioned area = 1,210 ft\(^2\).
# Wall Cavity Conditions

<table>
<thead>
<tr>
<th>House</th>
<th>Condition</th>
<th>Temp. (°F)</th>
<th>Humidity (%)</th>
<th>Wood Moisture Content (%)</th>
<th>Dew Point (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Maximum</td>
<td>91.6</td>
<td>71.0</td>
<td>14.2</td>
<td>67.2</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>27.0</td>
<td>38.2</td>
<td>7.0</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>Avg.</td>
<td>64.8</td>
<td>54.7</td>
<td>9.5</td>
<td>48.0</td>
</tr>
<tr>
<td>C</td>
<td>Maximum</td>
<td>86.2</td>
<td>77.4</td>
<td>14.6</td>
<td>73.3</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>32.5</td>
<td>40.0</td>
<td>7.0</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>Avg.</td>
<td>65.2</td>
<td>62.2</td>
<td>11.6</td>
<td>52.1</td>
</tr>
</tbody>
</table>

(April 2014–April 2015)
Monthly Peak Electric Demand

<table>
<thead>
<tr>
<th>House</th>
<th>Avg. Monthly Peak Demand During Peak Hours</th>
<th>Avg. Demand Reduction Compared to House A</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.1</td>
<td>N/A</td>
</tr>
<tr>
<td>B</td>
<td>2.6</td>
<td>18%</td>
</tr>
<tr>
<td>C</td>
<td>1.0</td>
<td>69%</td>
</tr>
</tbody>
</table>
Attic Temperatures
Heating System COPs

- The COP of the heating system was calculated for all three houses using a co-heat method.
- For House B and House C, the COP of the heat pumps was also measured using airflow measurements.
# Measured Heating COPs

<table>
<thead>
<tr>
<th></th>
<th>A NORDYNE Electric Furnace</th>
<th>B Intertherm Heat Pump</th>
<th>C Mitsubishi</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA (Incl. Infiltration) Btu/h/°F</td>
<td>313</td>
<td>245</td>
<td>209</td>
</tr>
<tr>
<td>COP (Co-heat method)</td>
<td>1.10</td>
<td>2.50</td>
<td>2.49</td>
</tr>
<tr>
<td>COP (Co-heat method) (without ventilation adjustment)</td>
<td>1.00</td>
<td>2.26</td>
<td>1.63</td>
</tr>
<tr>
<td>COP (air-side method)</td>
<td>Not measured</td>
<td>1.37</td>
<td>1.39</td>
</tr>
<tr>
<td>Expected COP, Based on manufacturer data</td>
<td>1 (Lower due to duct leakage)</td>
<td>3.2 (Lower due to duct leakage)</td>
<td>4.8</td>
</tr>
</tbody>
</table>
COP Measurements

Air-side method may be less reliable than the co-heat method due to:

- Non-uniformity of supply air measurements.
- Room-to-room temperature differences
- Higher convective airflow due to air handling unit operation than existed during the co-heat tests
- Variations from estimated ventilation rates

COPs calculated by the co-heat method are taken to be closer to actual performance.
Auto Setting Resulted in Low Fan Speed

Air handling unit fan power for auto- and high-speed settings

Fan curve based on onetime flow and power measurements

\[ y = -2.0750E-02x^2 + 8.7308E-01x \]

\[ R^2 = 9.2197E-01 \]
## Mini-Split Heat Pump COPs at High and Low Fan Speeds

The average COPs calculated from the air-side and co-heat (with ventilation adjustment) methods while the fan was set on high speed compared to the auto-speed COPs.

<table>
<thead>
<tr>
<th>Test Type</th>
<th>COP / Temp.</th>
<th>High Fan</th>
<th>Auto Fan (Low speed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-Heat Method</td>
<td>COP</td>
<td>4.11</td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td>Avg. Ambient Temp. (°F)</td>
<td>36.8</td>
<td>30.7</td>
</tr>
<tr>
<td>Air-Side Method</td>
<td>COP</td>
<td>2.25</td>
<td>1.39</td>
</tr>
<tr>
<td></td>
<td>Avg. Ambient Temp. (°F)</td>
<td>43.2</td>
<td>42.1</td>
</tr>
</tbody>
</table>
COP as Function of Ambient Temperature

Comparison of mini-split COP with low (auto) and high fan speeds

Air-side measurement method

Co-heat measurement method

ARIES Collaborative
Stratification Impact on COP

• High return temperatures may reduce COP
• January 6–13 average living room temperature:

<table>
<thead>
<tr>
<th>Height</th>
<th>Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entering heat pump</td>
<td>74.8</td>
</tr>
<tr>
<td>84 in. above the floor</td>
<td>75.4</td>
</tr>
<tr>
<td>60 in. above floor</td>
<td>70.2</td>
</tr>
<tr>
<td>12 in. above the floor</td>
<td>68.9</td>
</tr>
</tbody>
</table>
Extrapolating Energy Use

- **Objective**: Based on measured data, estimate space conditioning energy use in a range of Southeast climates.
## 3 Locations, 5 Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Thermal Envelope</th>
<th>Space Conditioning</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>HUD code</td>
<td>Electric resistance furnace; Split system AC&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Measured</td>
</tr>
<tr>
<td>A2</td>
<td>HUD code</td>
<td>Heat pump furnace; Split system AC</td>
<td>Simulated</td>
</tr>
<tr>
<td>B1</td>
<td>ENERGY STAR</td>
<td>Electric resistance furnace; split system AC</td>
<td>Simulated</td>
</tr>
<tr>
<td>B2</td>
<td>ENERGY STAR</td>
<td>Heat pump furnace; split system AC</td>
<td>Measured</td>
</tr>
<tr>
<td>C</td>
<td>ZERH (IECC 2012)</td>
<td>Ductless mini-split heat pump</td>
<td>Measured</td>
</tr>
</tbody>
</table>
Modeling Results – Knoxville Whole House Site Energy

Site energy (MMBtu/yr)

Home A 1: 20.15
  - Vent Fan (E): 4.44
  - Lg. Appl. (E): 2.08
  - Transfer Fan (E): 4.72
  - Cooling (E): 7.43

Home A 2: 43.78
  - Vent Fan (E): 11.36
  - Lg. Appl. (E): 4.46
  - Transfer Fan (E): 4.72
  - Cooling (E): 7.43

Home B 1: 42.75
  - Vent Fan (E): 10.3
  - Lg. Appl. (E): 3.54
  - Transfer Fan (E): 4.72
  - Cooling (E): 5.84

Home B 2: 37.72
  - Vent Fan (E): 10.3
  - Lg. Appl. (E): 3.57
  - Transfer Fan (E): 4.72
  - Cooling (E): 5.84

Home C 1: 30.89
  - Vent Fan (E): 9.54
  - Lg. Appl. (E): 1.80
  - Transfer Fan (E): 2.93
  - Cooling (E): 5.64
Modeling Results – Knoxville Space Conditioning Site Energy

Space conditioning (MMBtu/yr)

Home A 1: 26.73
- HVAC Fan/Pump (E): 2.08
- Vent Fan (E): 4.46
- Transfer fan (E): 3.54
- Cooling (E): 4.44
- Heating (E): 12.78

Home A 2: 20.27
- HVAC Fan/Pump (E): 10.25
- Vent Fan (E): 5.5
- Transfer fan (E): 1.7
- Cooling (E): 4.44
- Heating (E): 1.80

Home B 1: 21.89
- HVAC Fan/Pump (E): 16.6
- Vent Fan (E): 3.57
- Transfer fan (E): 1.7
- Cooling (E): 4.44
- Heating (E): 0.13

Home B 2: 16.86
- HVAC Fan/Pump (E): 8.8
- Vent Fan (E): 4.44
- Transfer fan (E): 3.57
- Cooling (E): 4.44
- Heating (E): 0.13

Home C 1: 12.78
- HVAC Fan/Pump (E): 12.78
- Vent Fan (E): 1.80
- Transfer fan (E): 0.13
- Cooling (E): 0.13
- Heating (E): 0.13
Energy Savings and Payback: Knoxville, TN

Compared to House A

<table>
<thead>
<tr>
<th>House</th>
<th>Annual Utility Cost</th>
<th>Savings</th>
<th>Incr. Retail Cost</th>
<th>Payback (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$1,656</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B</td>
<td>$1,263</td>
<td>$393</td>
<td>$2,268</td>
<td>5.8</td>
</tr>
<tr>
<td>C</td>
<td>$1,055</td>
<td>$601</td>
<td>$5,843</td>
<td>9.7</td>
</tr>
</tbody>
</table>

House C compared to House B

<table>
<thead>
<tr>
<th>Savings</th>
<th>Incr. Retail Cost</th>
<th>Payback (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$208</td>
<td>$3,575</td>
<td>17.2</td>
</tr>
</tbody>
</table>
Research Questions

• **Program design.** Is ZERH suitable for manufactured homes? What changes to ZERH would better recognize the unique features of factory building?

• **Use of MSHPs.** Can point-source space conditioning achieve comfort targets?

• **Costs.** What’s the incremental cost of ZERH? Is it cost-effective?

• **MSHP performance.** How does the MSHP perform in service?
1. **Program design.** *Is ZERH suitable for manufactured homes? What changes to ZERH would better recognize the unique features of factory building?*

- House C was built in compliance with the HUD code and DOE ZERH criteria.
- The use of a ductless heat pump simplified the compliance with ENERGY STAR version 3 HVAC requirements.
- Thermal envelope, ventilation, and indoor air quality requirements were not a barrier, although they did add costs.
- Existing ZERH criteria did not present a barrier for manufactured homes using this space conditioning strategy.
2. Use of MSHPs. *Can point-source space conditioning achieve comfort targets?*

- The ZERH performed reasonably well in cooling. There was some temperature fluctuation from one room to another but only the master bathroom exceeded the upper bounds of the ACCA temperature range (with the interior doors closed).

- In heating, the bedrooms did not maintain acceptable temperature. Resistance heaters were needed mainly when the ambient temperature was below freezing.
More Comfort Related Findings

- Open doors may obviate the need for transfer fans
- Closed doors are more consequential during the heating season
- Window shading (closed blinds) is an important cooling energy savings and comfort strategy
- Convective heat transfer through open doors was approximately 140 to 281 cfm
- Transfer fans are of limited value when doors are open
- Transfer fan low-high configuration not beneficial
### Responses to Research Questions


- House C had 50% space conditioning savings compared to House A.
- Strategies are available for reducing backup heat and increasing mini-split COPs.
- Equipment improvements have a larger, relative impact on energy use than envelope improvements.

<table>
<thead>
<tr>
<th>House C Compared to A / B</th>
<th>Energy Measure Manufacturer Cost Premium</th>
<th>Homeowner Payback Based on Retail Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>House A</td>
<td>$2,060</td>
<td>8.8 years</td>
</tr>
<tr>
<td>House B</td>
<td>$1,166</td>
<td>17.5 years</td>
</tr>
</tbody>
</table>

*Based on estimated costs at high production volumes*
4. **MSHP performance.** *How did the MSHP perform in service?*

- The COP of both the conventional split-system heat pump and the ductless mini-split were approximately 2.5.
- For the mini-split, this is well below the expectation based on manufacturer data.
- When the mini-split was run on its high-speed, its COP increased to 4.11. That is, low airflow lowers operating efficiency.
Other Findings of Note: Moisture

- **Wood moisture content.** Slightly elevated in House C but within safe limits. Likely due to exterior foam insulation reducing vapor permeability. Condensation risk mitigated by 5.5°F higher dew point at condensation surface.

- **Relative humidity.** RH within acceptable limits (latent loads not simulated). Short-term humidification testing revealed little impact on RH, indicating that equipment had sufficient capacity to handle the latent loads during hot weather.
Other Findings of Note: Peak Loads

- House B averaged 18% lower peak than House A
- House C averaged 69% lower peak than House A
- Some House B winter peaks similar to House A indicating that House B’s peak occurred electric resistance is the primary heating source

Awards and National Recognition

Building America Top Innovation Award 2014

Cost-Optimized Attic Insulation Solution for Factory-Built Homes

The low-cost, low-tech retrofit solution technique is therefore applicable to the nearly 500,000 new manufactured homes built each year. With widespread adoption, this one measure could save homeowners over $1 billion per year. Building America research suggests that improvements such as these could also reduce embodied energy and greenhouse gas emissions.

The U.S. Department of Energy’s ARIES research team, led by The Energy Partnership Inc., partnered with New Era Energy Resource Advocates and John Manzella Construction to develop and fund a new retrofit insulation strategy that two homes in the challenged after applying factory-built homes with home-located insulation.

With the new method of applying foam-blow insulation, installers are able to achieve a more efficient attic insulation due to their typically installed in manufactured homes. Specifically, a Southern Energy Home achieved an overall savings of R-44 and an additional R-25 in the attic over the entire house, due to the use of this insulation. These savings were achieved through the implementation of the Southern Energy Homes program, which targets an overall R-40 of R-values in the factory-built homes to meet Building America Certification Code and R-60 in the factory-built homes to meet Building America Certification Code.

The median home tested elevated 37% in Clayton’s Bayside, AL area.

ZERH Housing Innovation Award 2014

Southern Energy Homes First DOE Zero Energy Ready Home

The DOE Zero Energy Ready Home program aims to make new homes in the U.S. to energy efficient by 2020. It is based on the idea that the built environment should be as energy efficient as possible. The goal is to achieve net-zero energy homes, where the energy required to power the home is equal to the energy produced by the home's renewable energy systems. This program is part of the federal government's efforts to reduce the nation's energy consumption and greenhouse gas emissions.
Design Changes

- Ventilation system
- Distribution system
- Thermal enclosure
Ventilation System Analysis

- BEopt analysis of 6 options in 4 northern climates
Ventilation System Conclusions

• Panasonic WhisperComfort ERV 40CFM has lowest source energy consumption, but flow rate too low
• Source energy for all options similar – savings potential small
• Manufactured homes typically have exhaust fans which can be repurposed for whole house ventilation and thus are suitable from an ease of construction standpoint
• Low first cost makes exhaust fans attractive to manufacturers
Distribution System Redesign

Goals:
- More airflow
- Quieter

Strategy
- Straight through wall
- Different fan
New Distribution System Testing
Monitoring Results with New Fans

About as effective as an open door
Thermal Enclosure Revisions

• R-4 windows
• 2x6 walls
• More floor insulation
• Tighter envelope
New Cold Climate ID House
Production at Champion Homes, Claysburg, PA
Installation in Eatontown, NJ

• Six months unoccupied monitoring and testing
• One year occupied monitoring
Ribbon Cutting
Initial Testing Data

Transfer fans turned on here

Heating set point 23°C (74°F)
Next Steps

• Building America
  ▪ Implement internal gains
  ▪ Continue monitoring
  ▪ Occupancy
  ▪ Design two homes with Habitat using same principles

• NYSERDA
  ▪ Design and build two manufactured ZERH for New York State