EERE Building America Webinar

April 27, 2016

Advances in Manufactured Home Energy Efficient Design

ARIES Collaborative

Building America
U.S. Department of Energy

Advanced Residential Integrated Energy Solutions

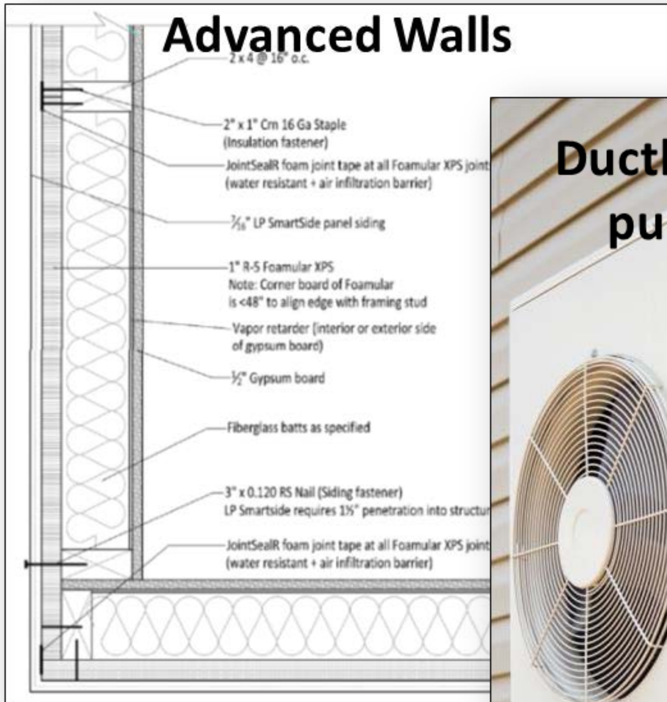
“Integrated Design” Concept

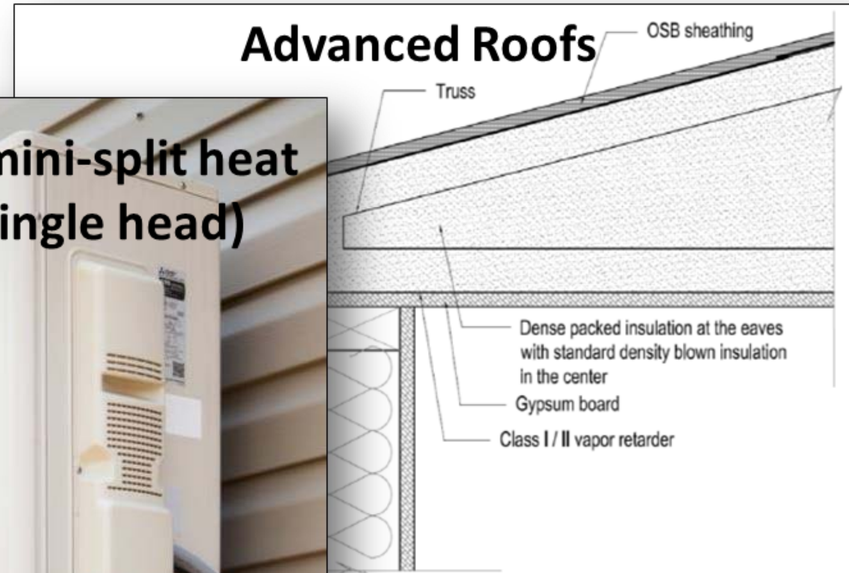
- Goal: Reduce space conditioning energy use by at least 50% while holding the line on affordability
- Components of the strategy as an *optimized* system:
  - Ultra-efficient thermal envelope
  - Low capacity, highly efficient mechanical system
  - Innovative distribution system
  - Affordable and effective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

ID Performance in Hot, Humid Climates

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

Core Technologies





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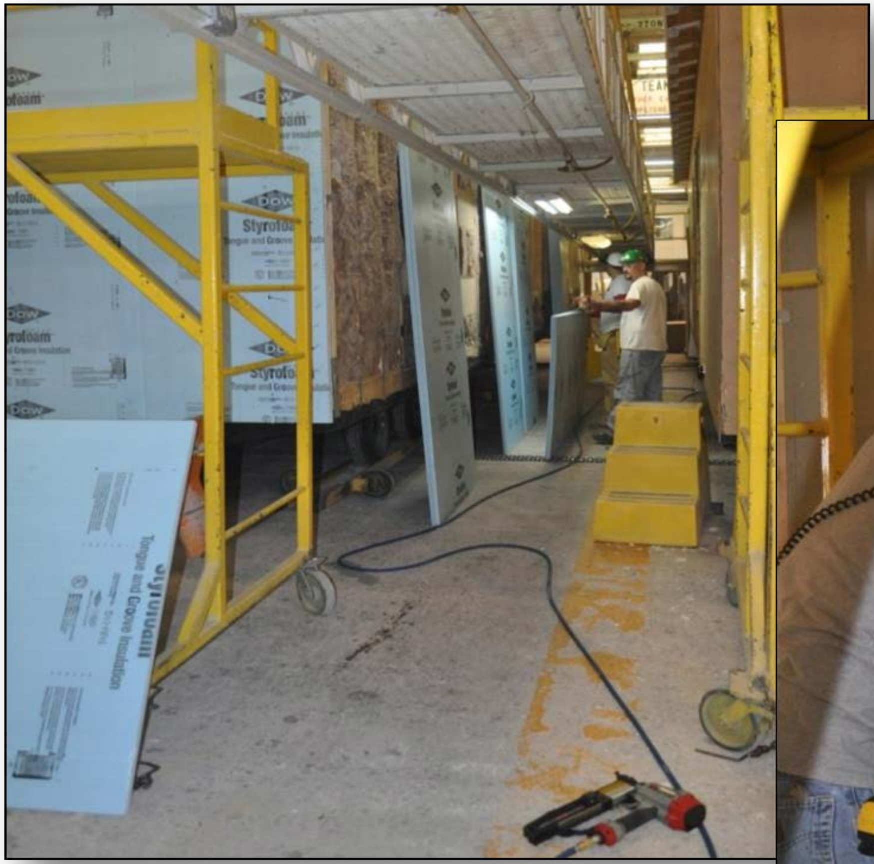
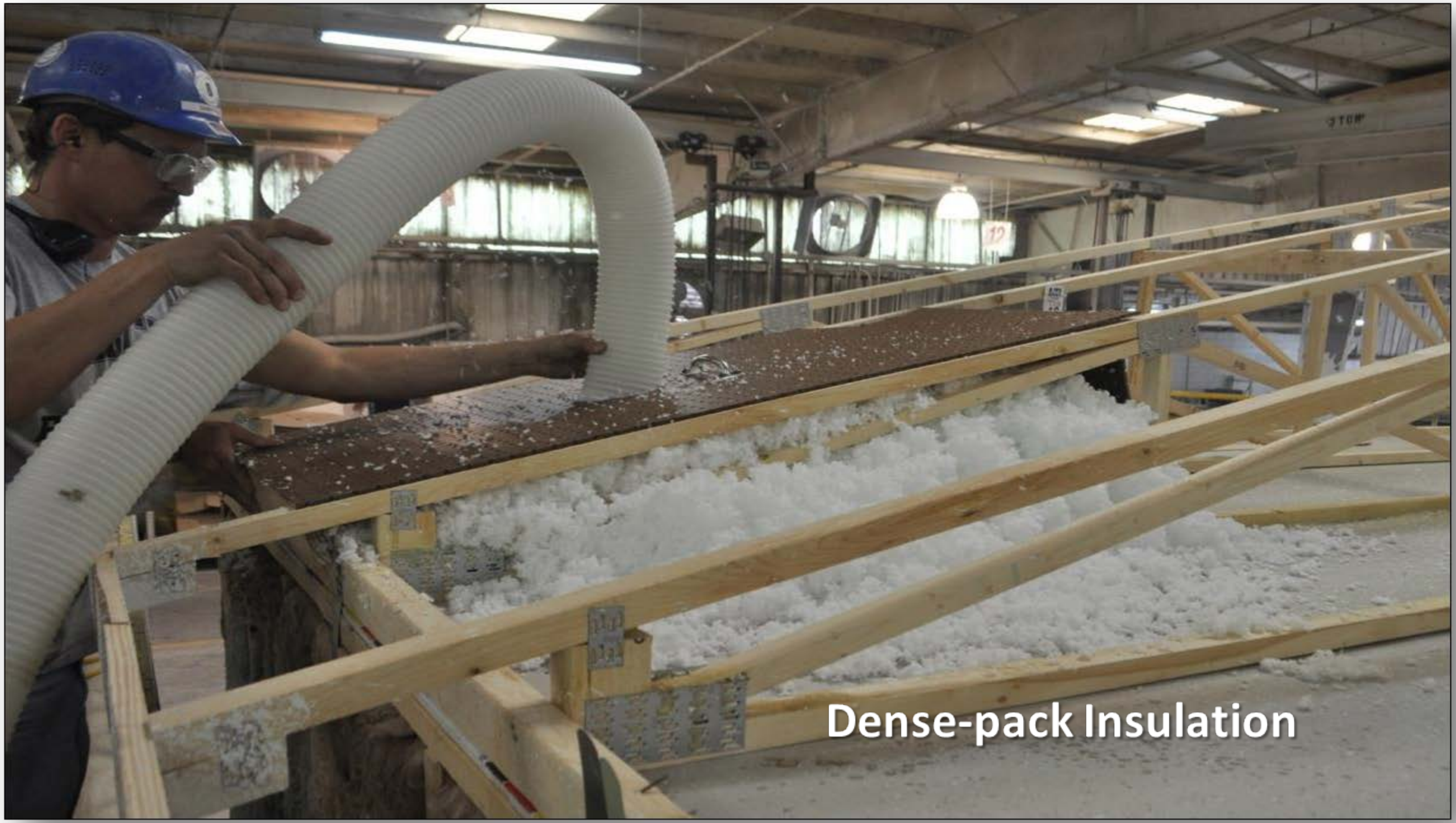
Advanced Wall Construction



Advanced Roof Construction



Advanced Roof Construction

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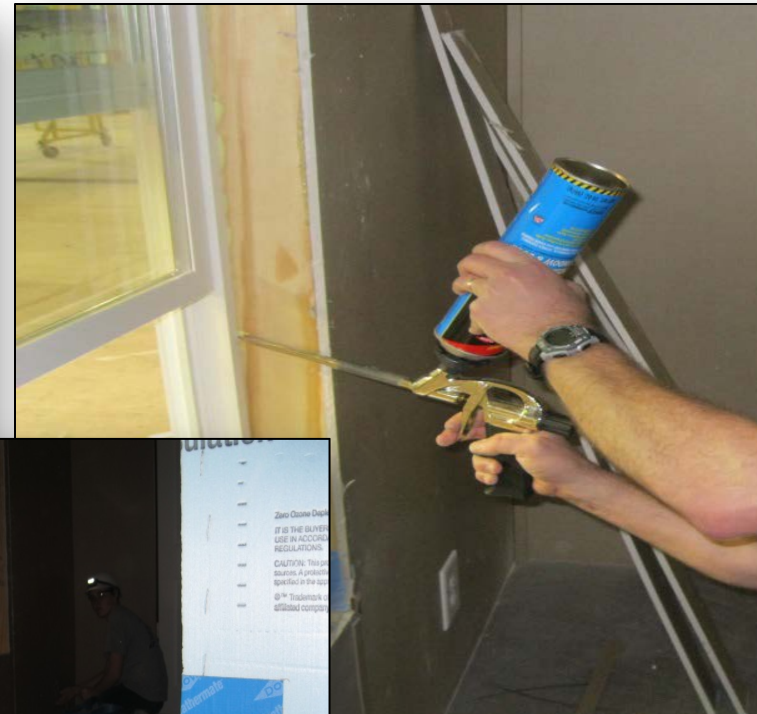
Window Installation



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

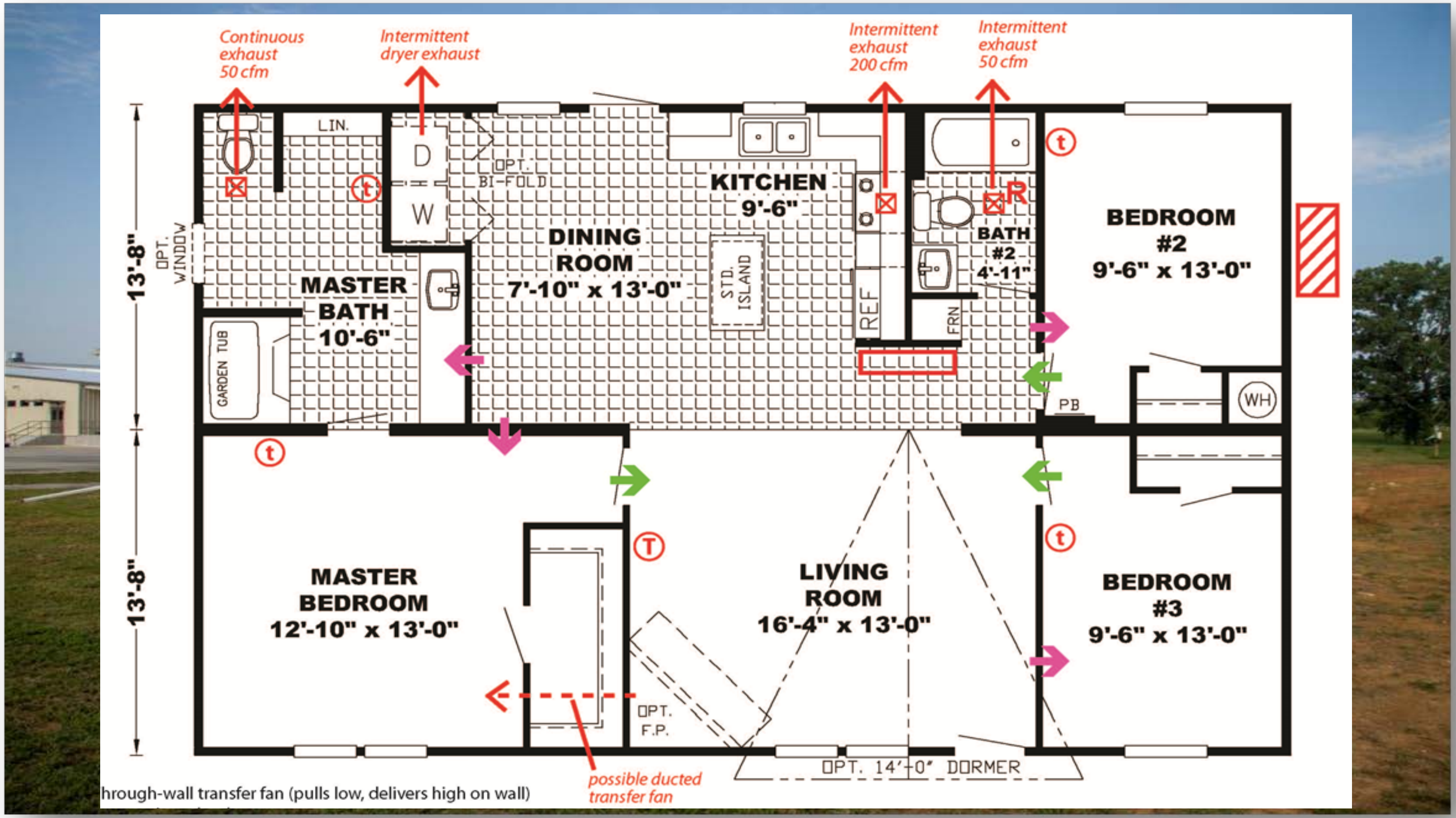
- ENERGY STAR appliances
- Low-e, argon filled windows
- Quiet transfer fan distribution
- Dedicated fresh air ventilation
- 25% more airtight
- Reduced thermal bridging

Technology Refinement

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



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Site

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House Specifications

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

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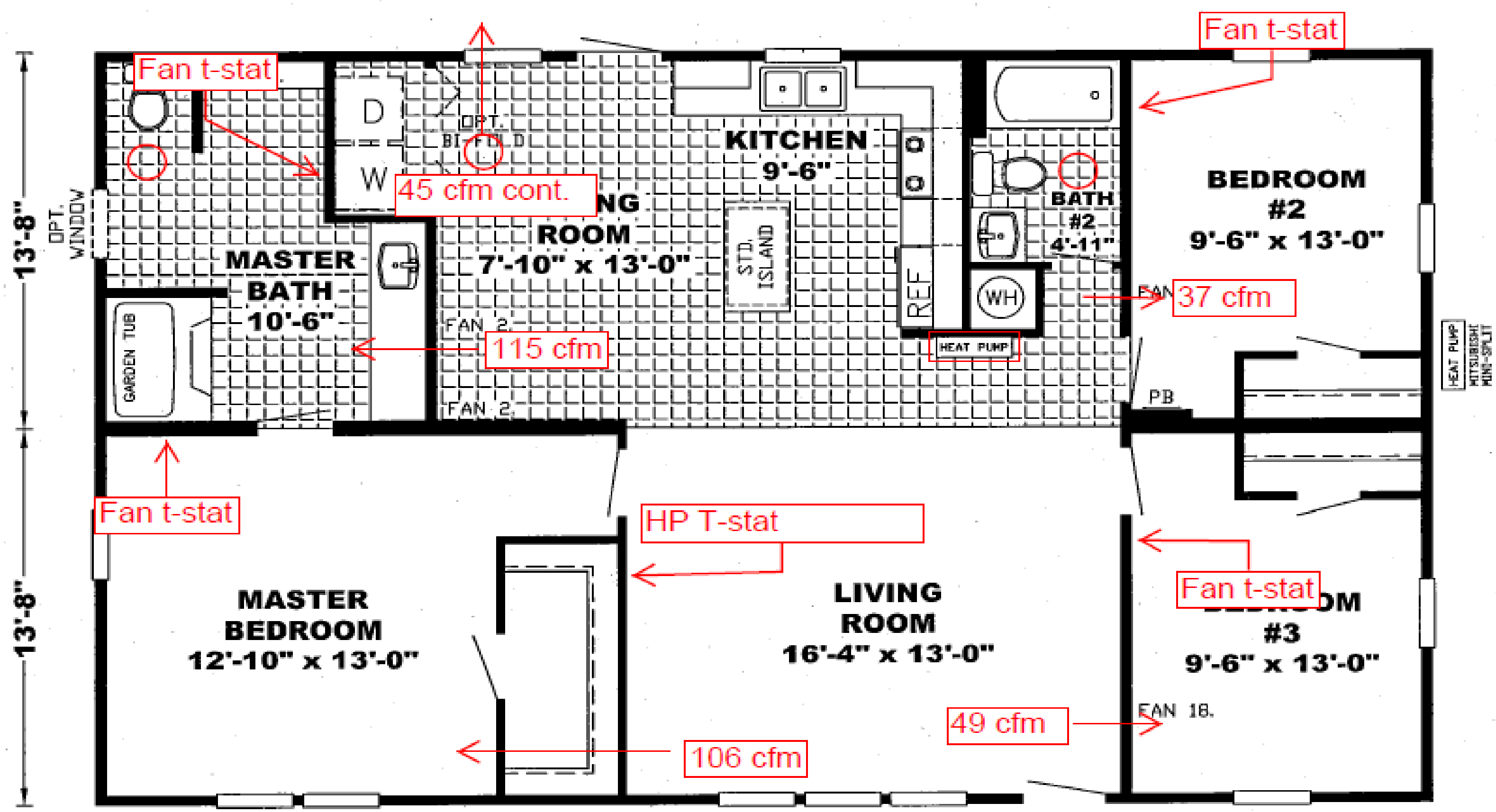
House Specifications

<table>
<tr><th></th><th>House A</th><th>House B</th><th>House C</th></tr>
<tr><td>Cooling Equipment</td><td>Intertherm
Air conditioner
Capacity: 23.4 kBtuh
EER: 11.0, SEER: 13.0</td><td rowspan="2">Intertherm
Air source heat pump
Cooling capacity: 18 kBtuh
EER:11.0, EER: 13.0
Heating capacity (47°F): 20.2 kBtuh
HSPF: 8.0</td><td rowspan="3">Mitsubishi
Variable-speed mini-split heat pump with outdoor unit assisted by temperature-controlled heaters when temperature falls below 69°F in the bedrooms
Outdoor unit: MUZ-FH15NA
Indoor unit: MSZ-FH15NA
Cooling capacity: 15 kBtuh
EER: 12.5
SEER: 22.0
Heating capacity at 47°F: 18 kBtuh; HSPF: 12.0
Heating capacity at 17°F: 11 kBtuh</td></tr>
<tr><td>Heating Equipment</td><td>NORDYNE
Electric furnace
Capacity: 35 kBtuh</td></tr>
<tr><td>Air Handling Unit</td><td>NORDYNE
Electric furnace, E3EB-010H, downflow set to low speed. Resistance heating capacity: 10 kW
Air handling unit wattage (heating elements + blower) :10.4 kW</td><td>NORDYNE
Electric furnace, E3EB-010H, downflow set to low speed. Resistance heat capacity: 10 kW
Air handling unit wattage (heating elements + blower) : 10.4 kW</td></tr>
</table>

House C Airflows



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Commissioning Results

Test	Method	House A	House B	House C
Enclosure Leakage	Multipoint depressurization test	4.7 ACH50	4.6 ACH50	3.8 ACH50
Duct Leakage	Duct blower depressurization test	54 cfm25 to outside	~10 cfm25 to outside	N/A
Ventilation Rate	Powered flow hood	44 intermittent	32 intermittent	45 continuous
Air Handling Unit Air Flow	Pressure equalization	980 cfm	1,000 cfm	Variable

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18 Months of Monitoring

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Measurements

One-minute data uploaded daily:

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

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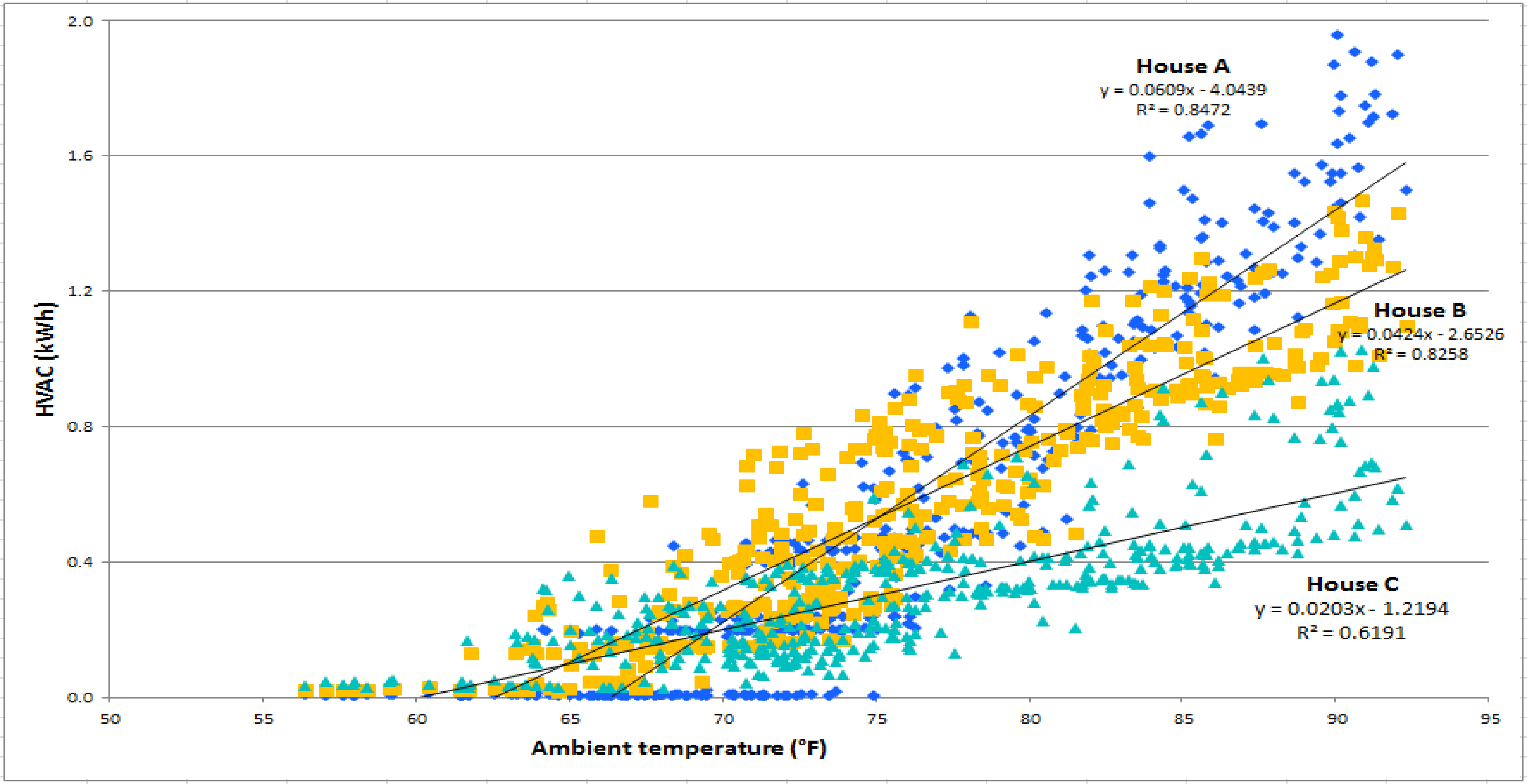
Results - Cooling

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

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)

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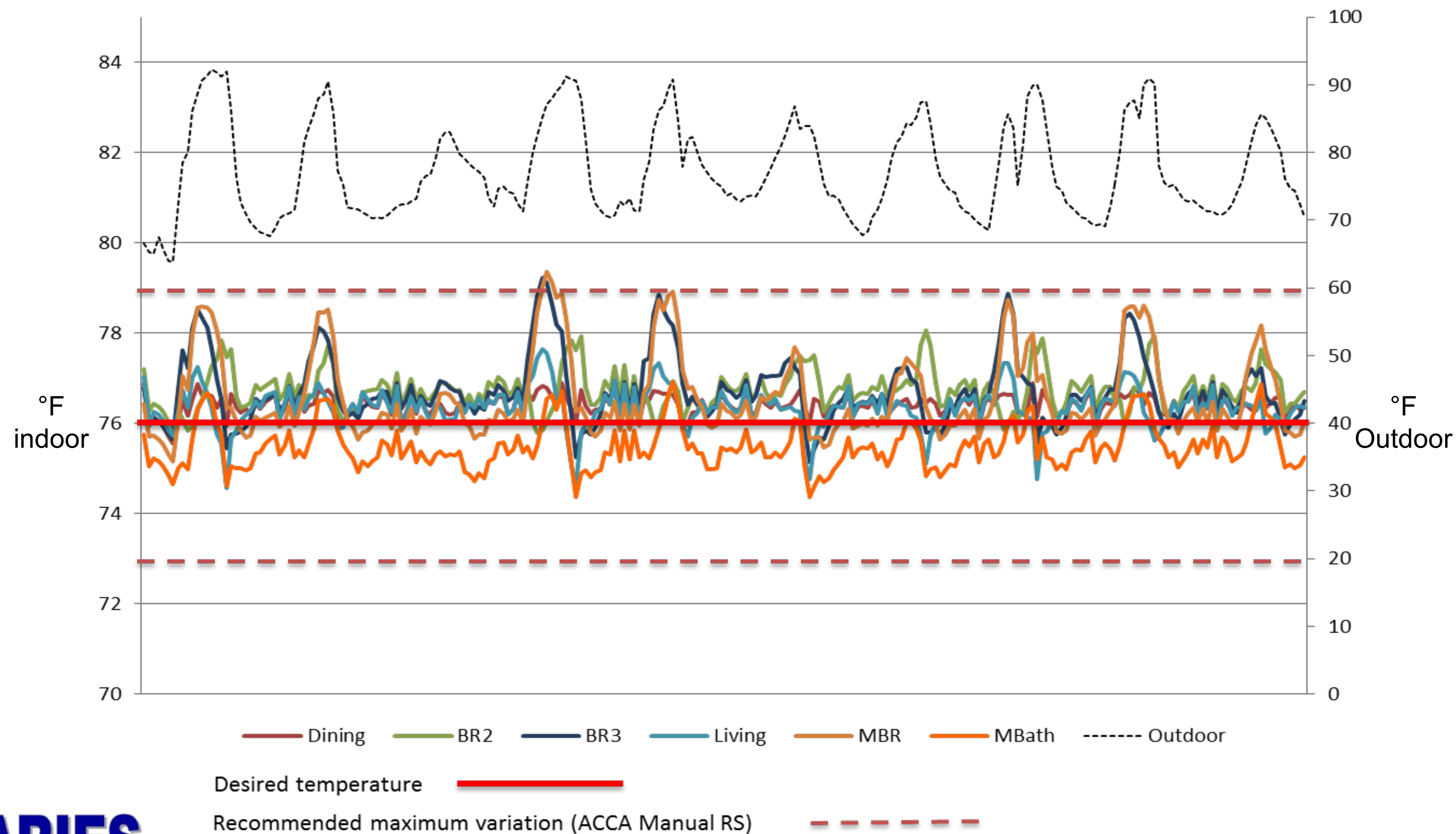
House A - Cooling



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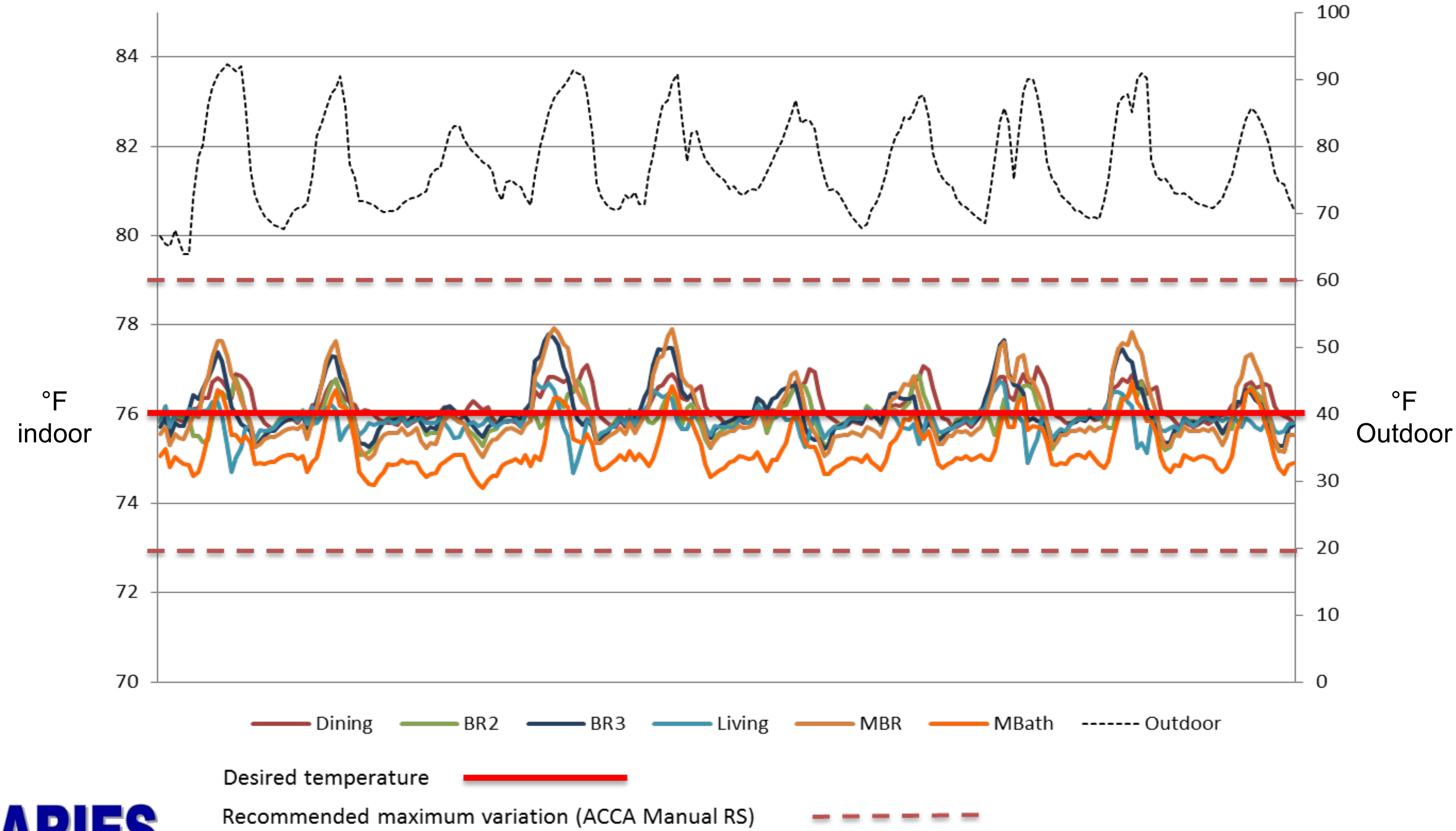
House B - Cooling



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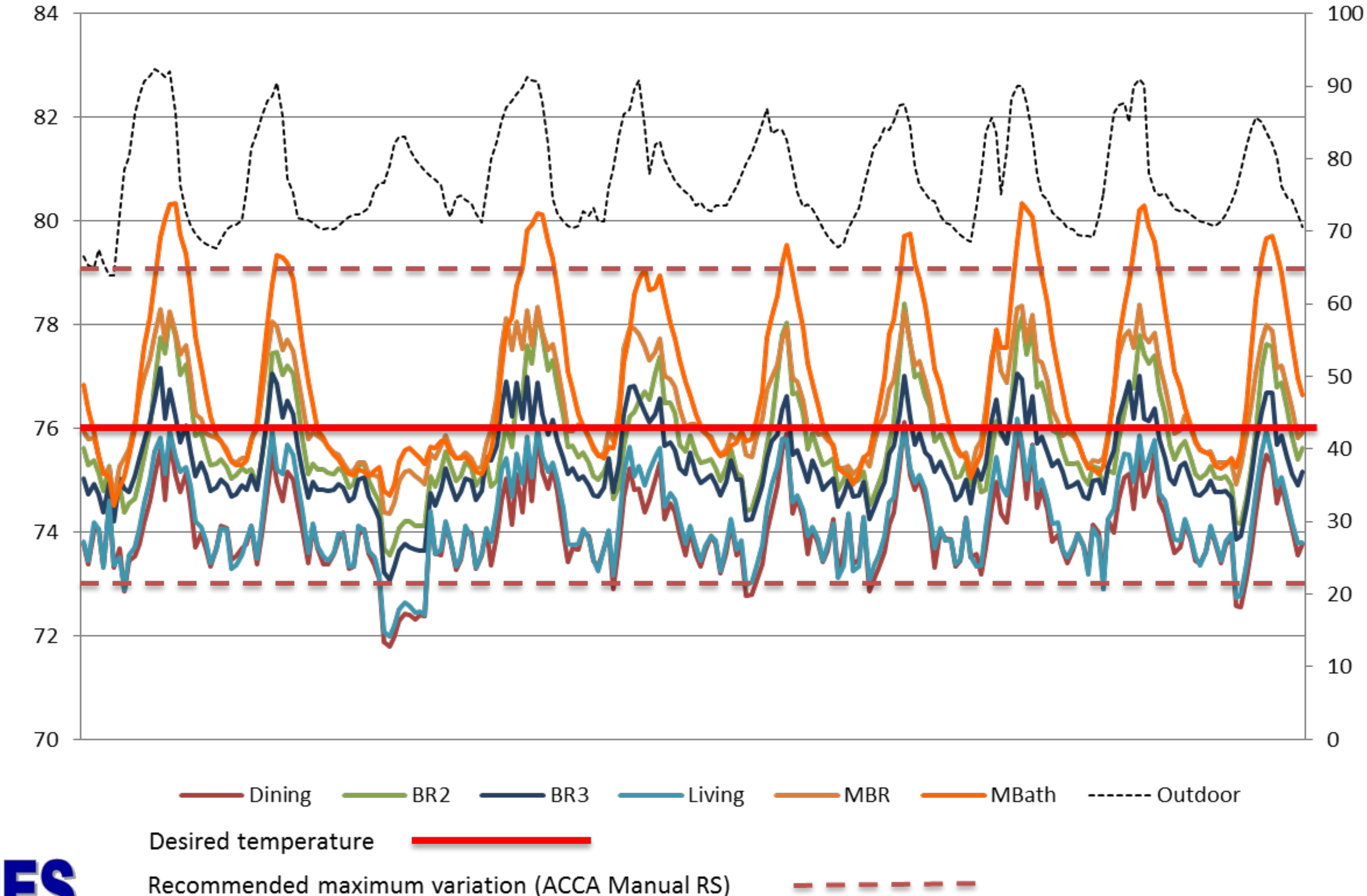
House C - Cooling



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Results - Heating

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

Configuration: Interior doors open. Window blinds at 50%
Data Nov 12-17, 2014
Avg. OAT 41.3°F

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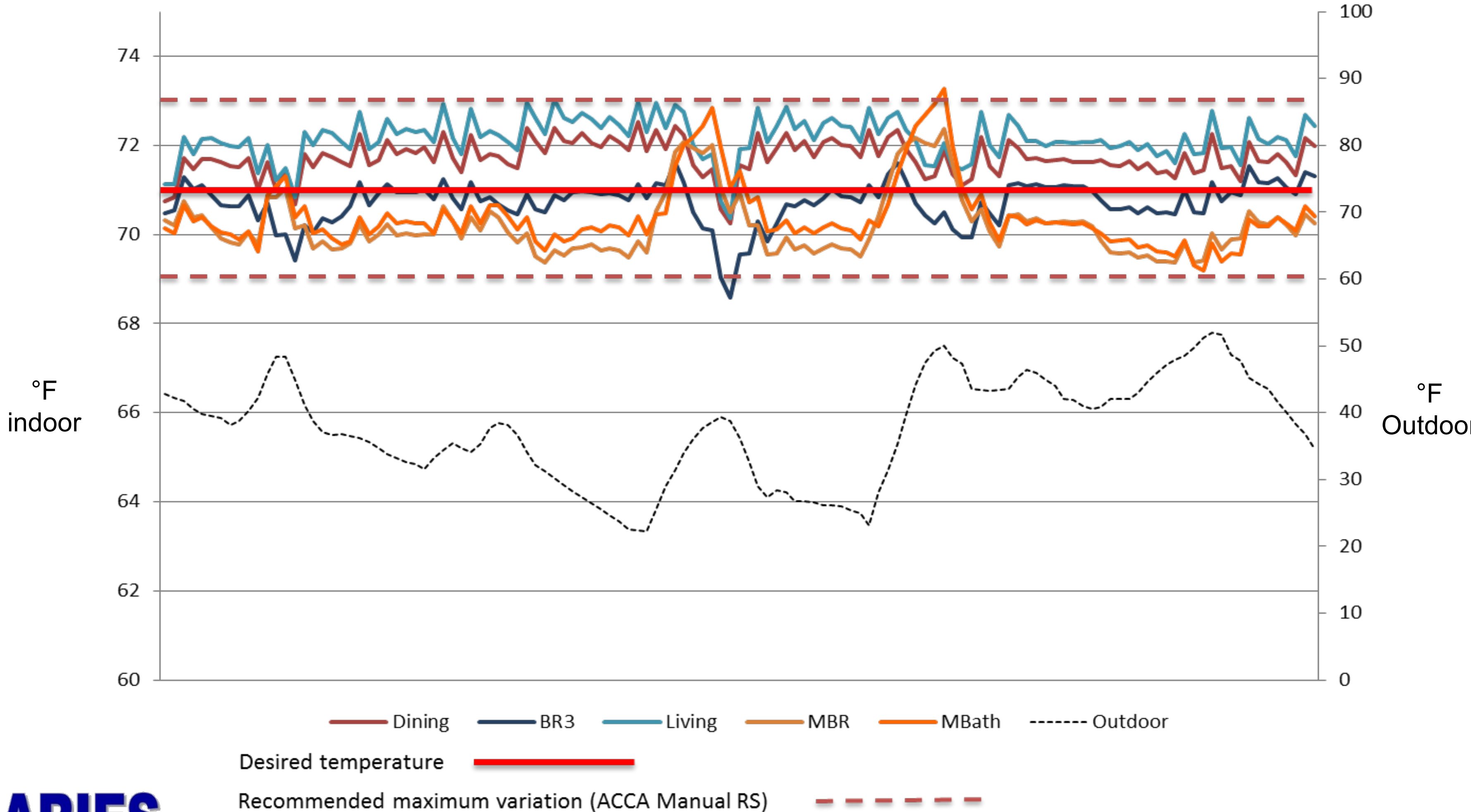
House A - Heating



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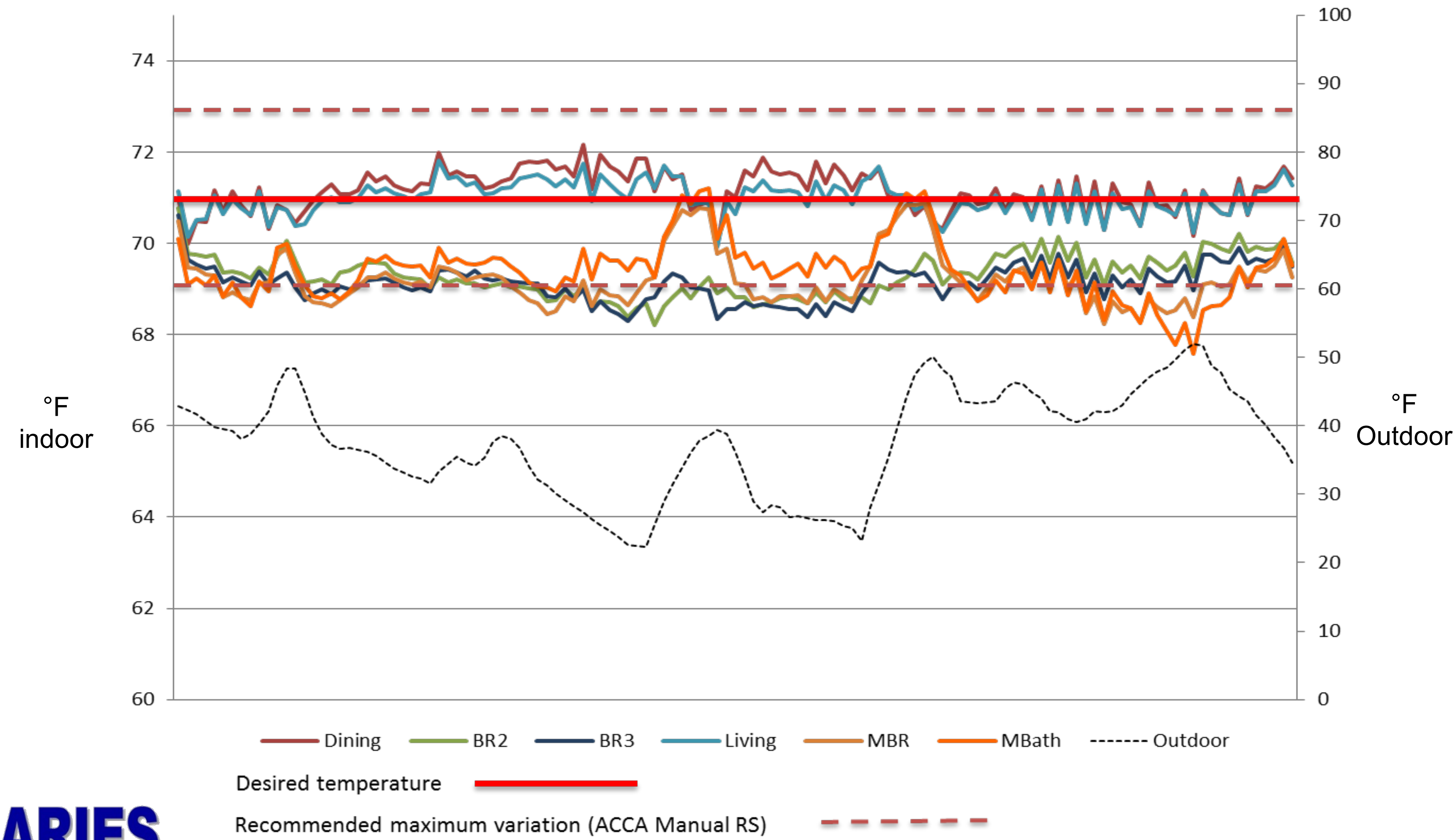
House B - Heating



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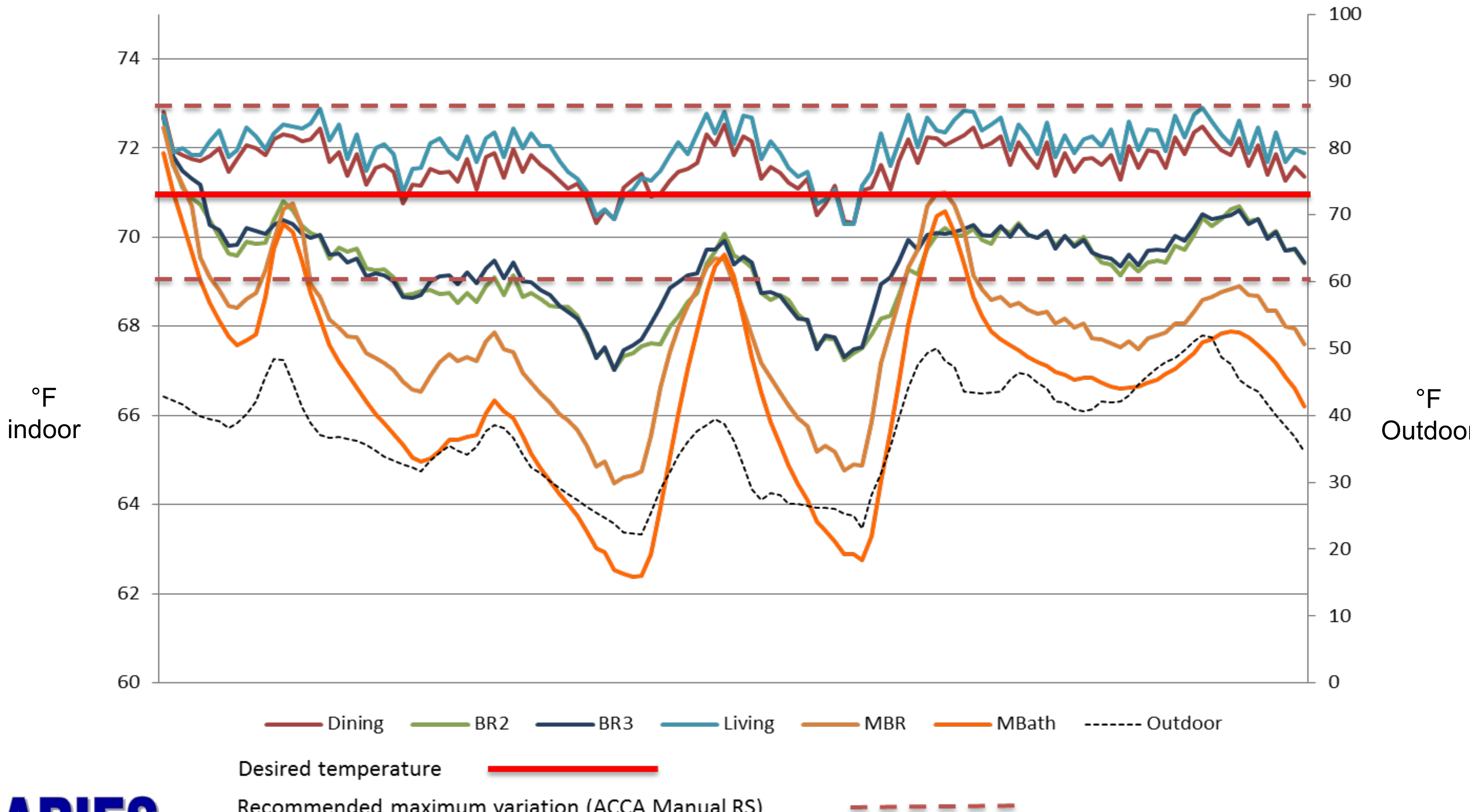
House C - Heating



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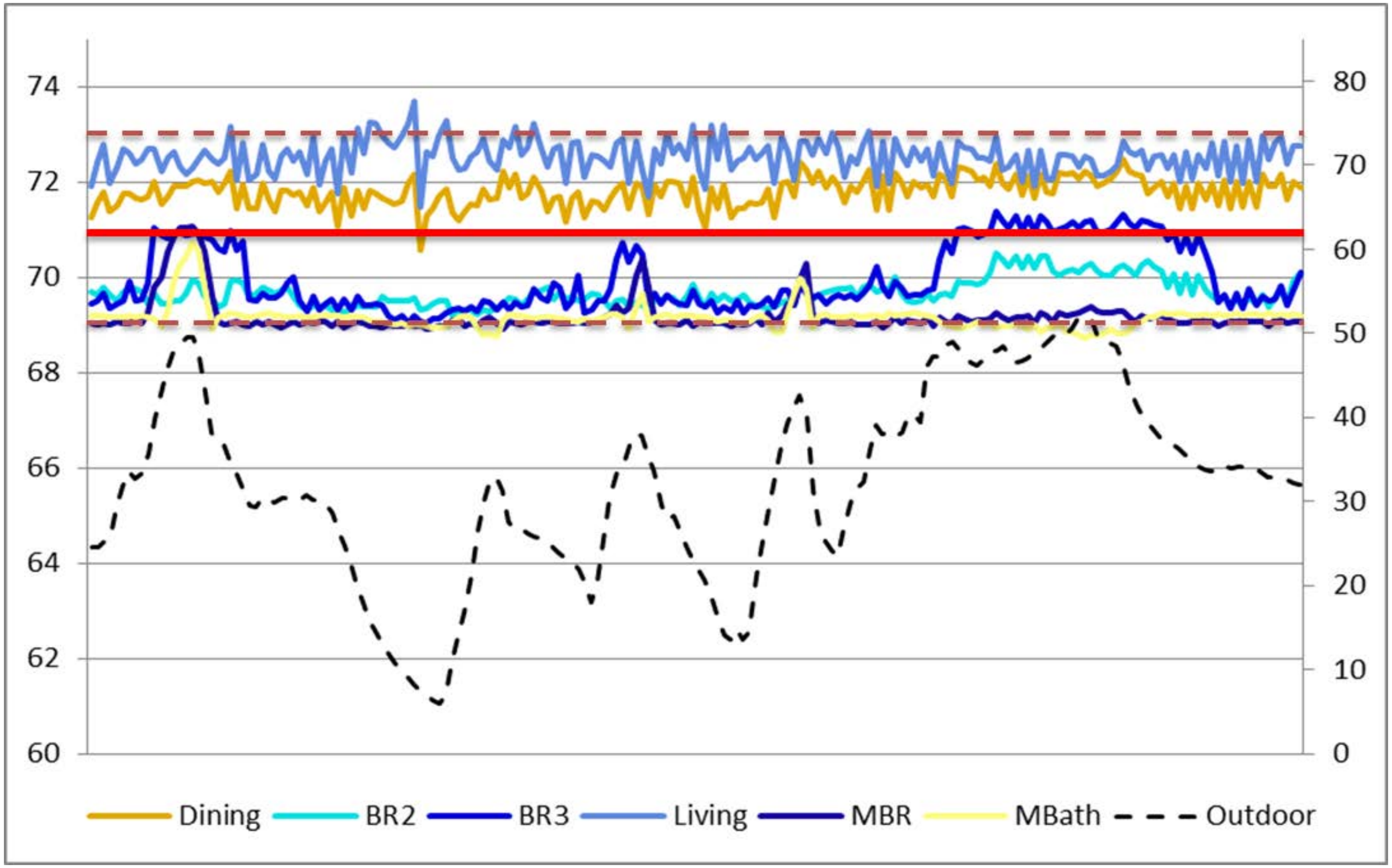
House C with Resistance Heat in Bedrooms



(Jan. 6–13, 2015)

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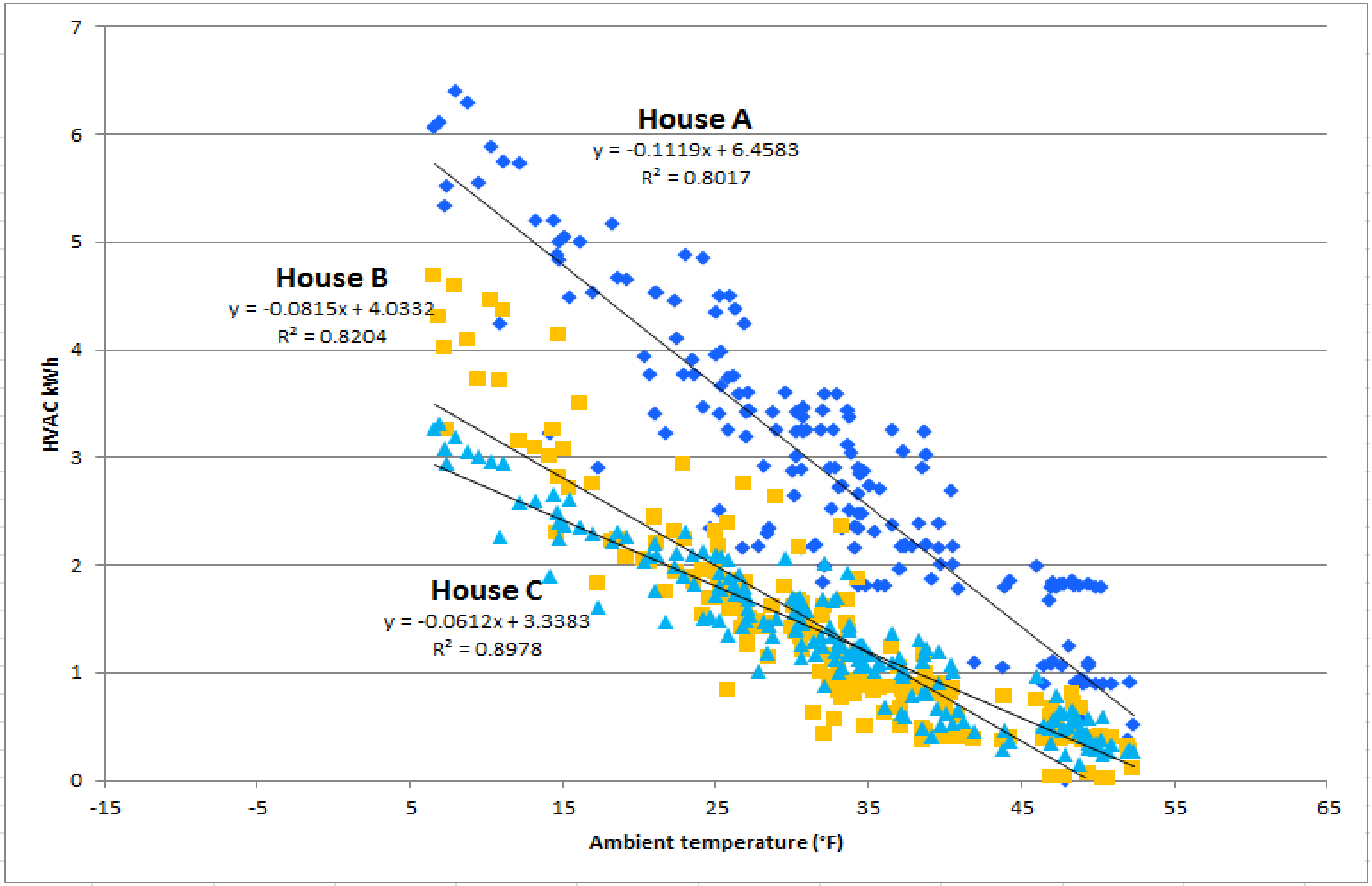
Heating Energy Compared to Outdoor Temperature



(Jan. 6–13, 2015)

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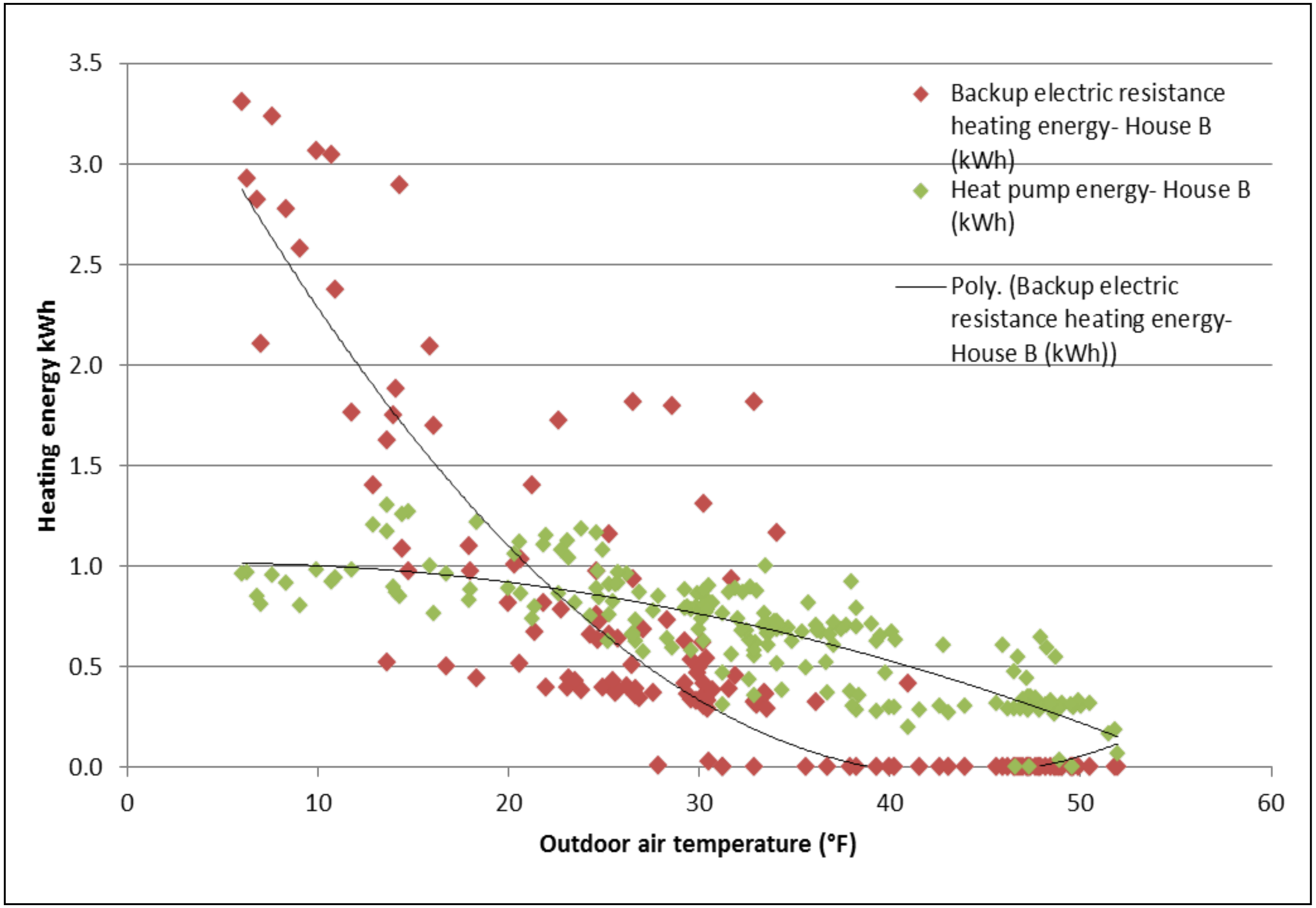
House B Backup Electric Resistance Heating Energy



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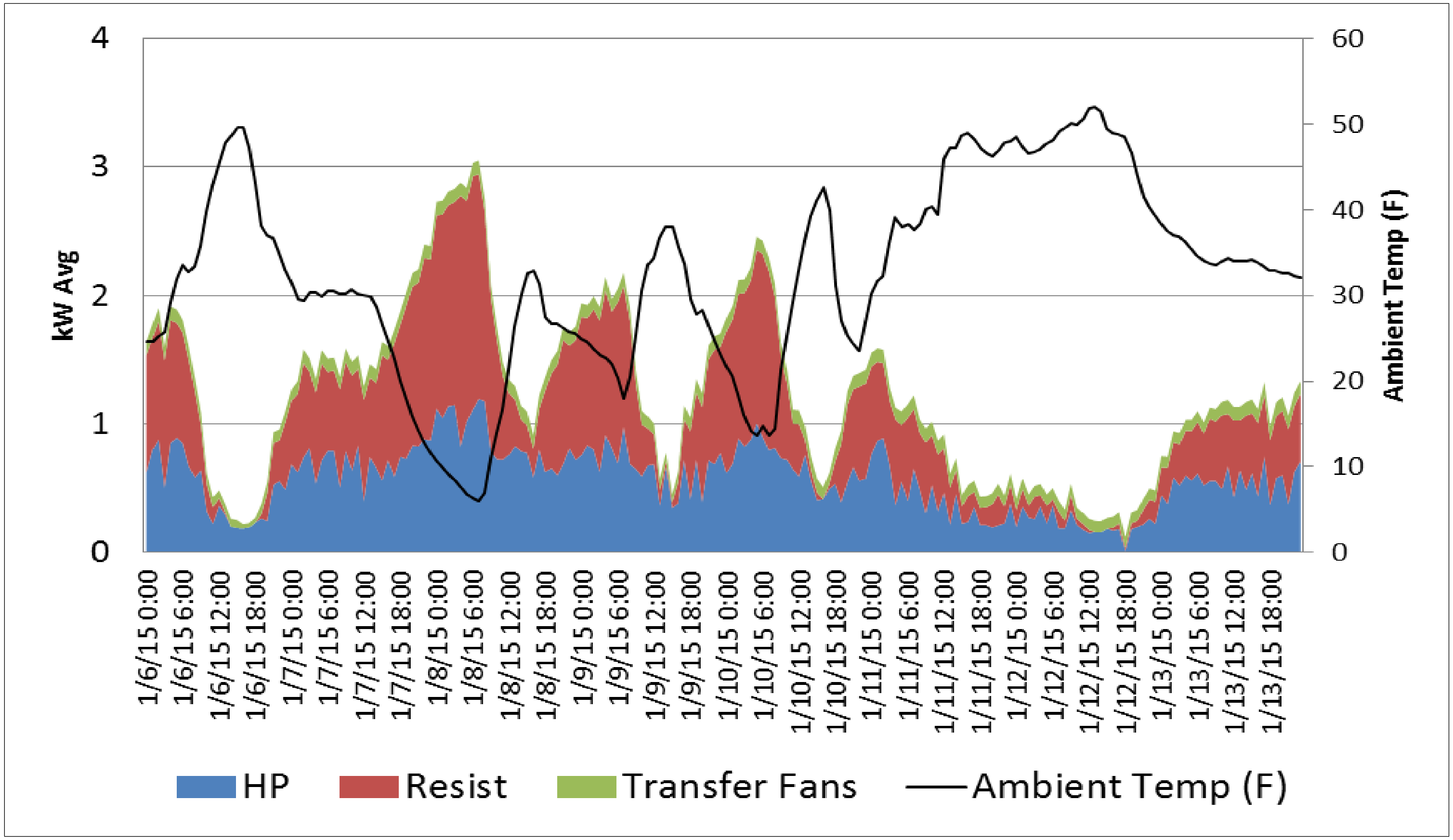
House C Heat Pump, Transfer Fan, and Resistance Heating Energy



(Jan. 6–13, 2015)

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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.

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Effective Ventilation Rates

	Whole-House Ventilation Flow (cfm)	
House	Measured	Code Required
A	22	50
B	13	
C	45	

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.

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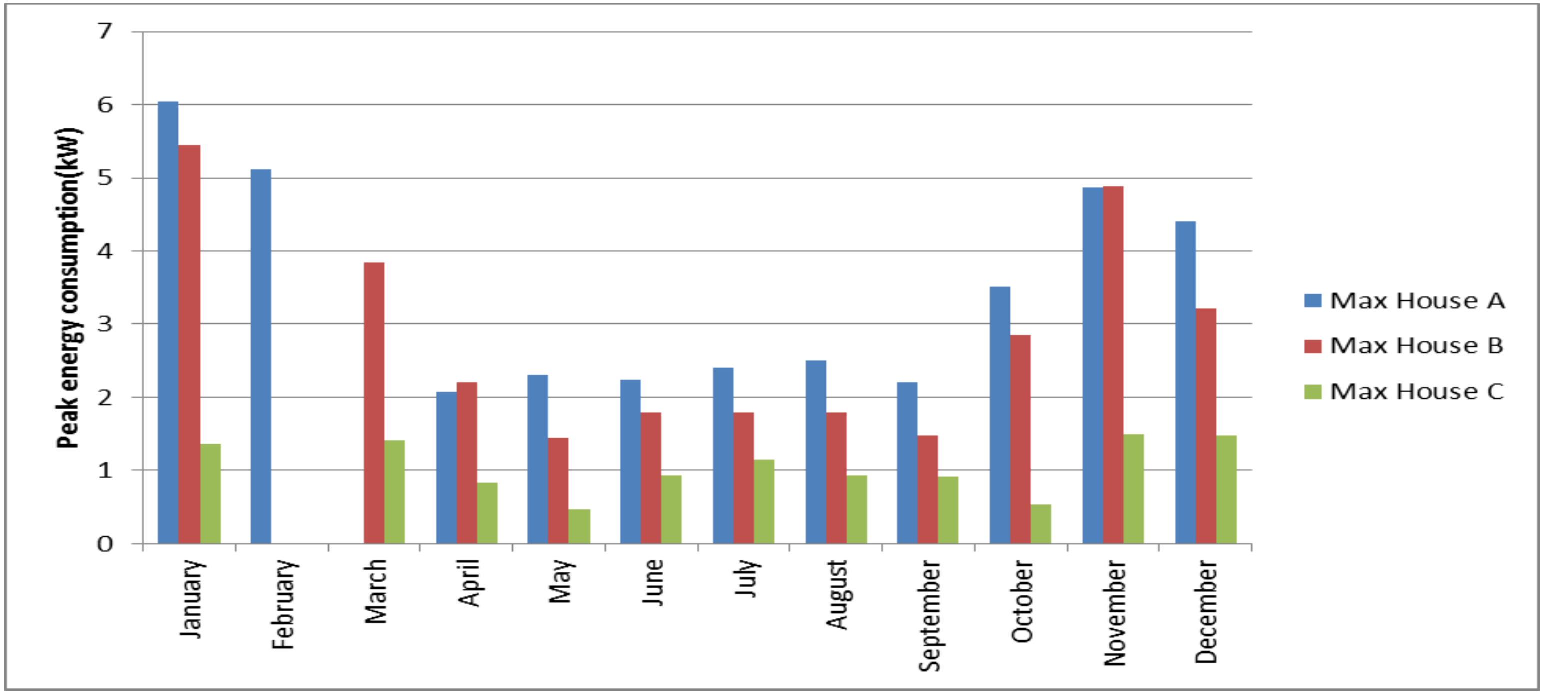
Wall Cavity Conditions

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

(April 2014–April 2015)

Monthly Peak Electric Demand



House	Avg. Monthly Peak Demand During Peak Hours	Avg. Demand Reduction Compared to House A
A	3.1	N/A
B	2.6	18%
C	1.0	69%

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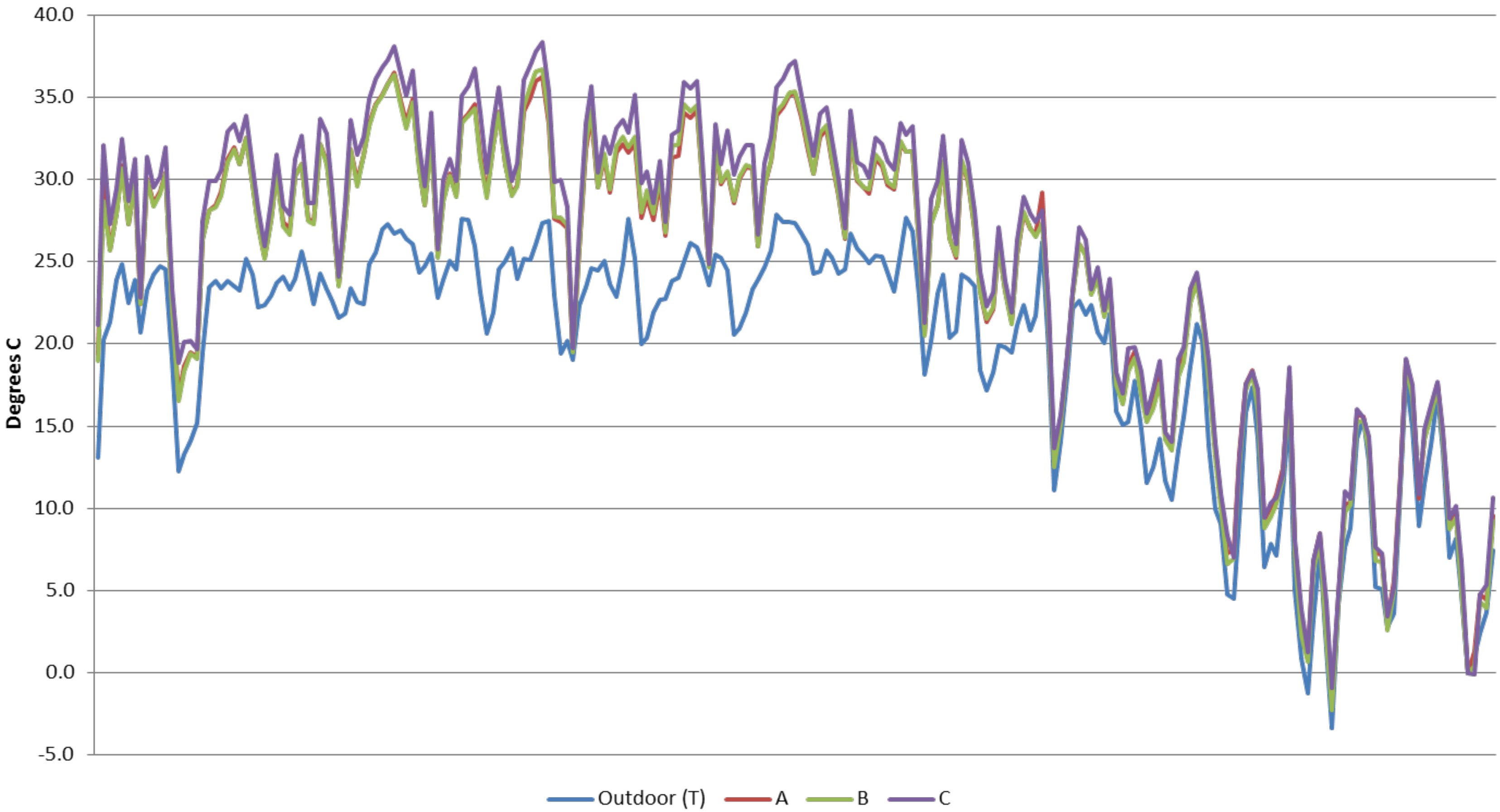
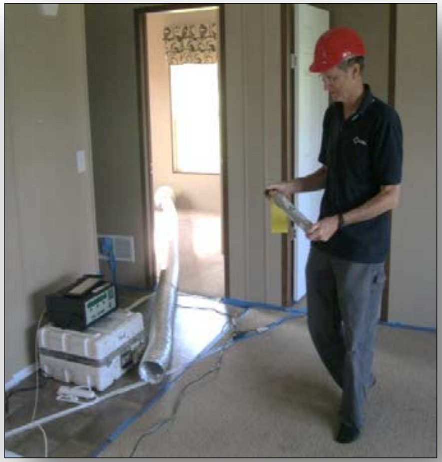
Attic Temperatures



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.



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Measured Heating COPs

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

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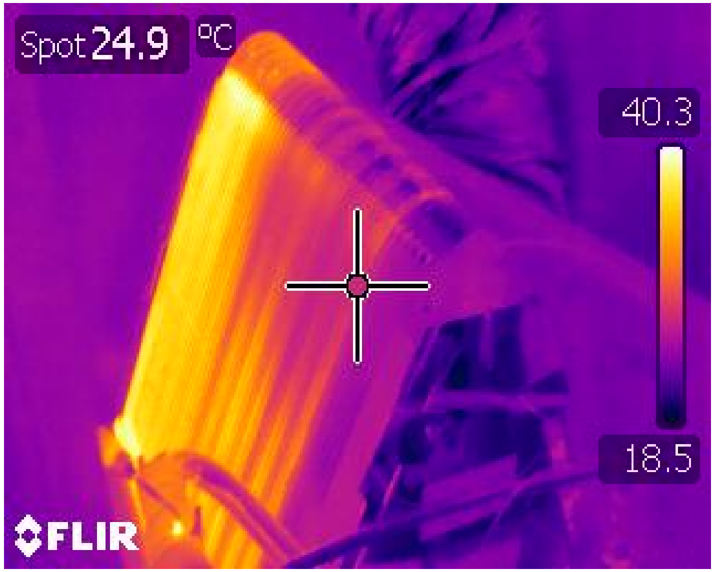
COP Measurements

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.



House B refrigerant coil in heating mode showing non-uniform temperatures

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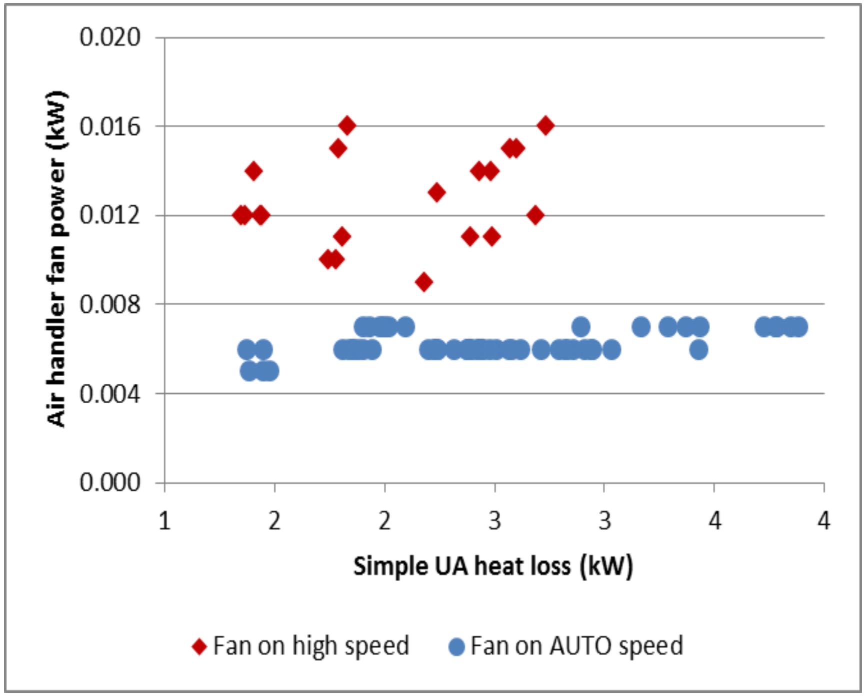
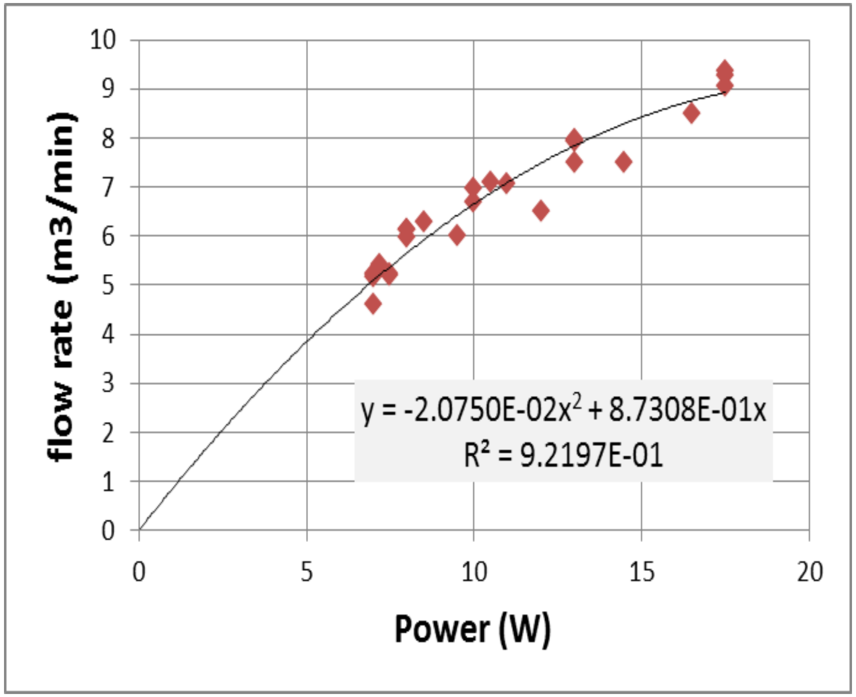
Auto Setting Resulted in Low Fan Speed



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



Fan curve based on onetime flow and power measurements

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Mini-Split Heat Pump COPs at High and Low Fan Speeds

Test Type	COP / Temp.	High Fan	Auto Fan (Low speed)
Co-Heat Method	COP	4.11	2.49
	Avg. Ambient Temp. (°F)	36.8	30.7
Air-Side Method	COP	2.25	1.39
	Avg. Ambient Temp. (°F)	43.2	42.1

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.

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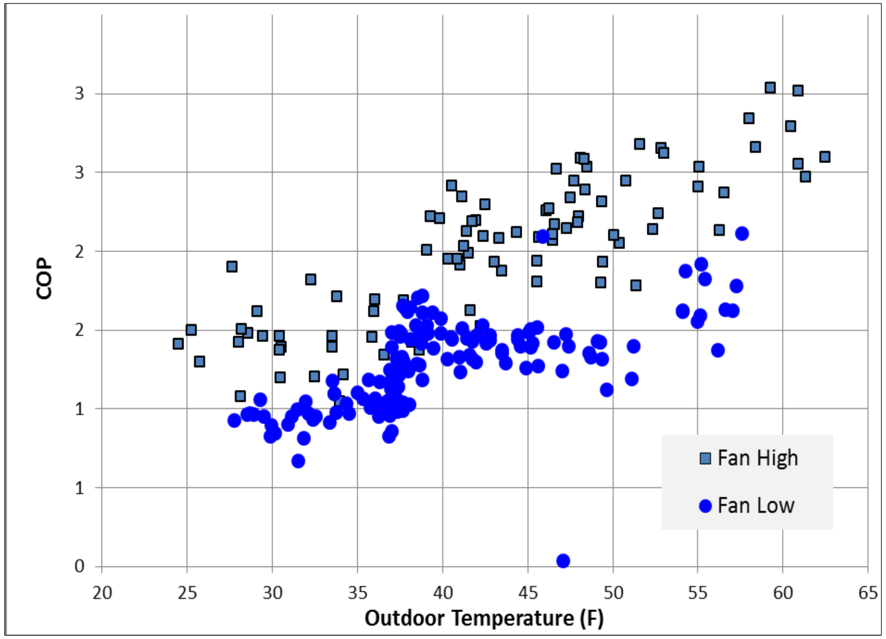
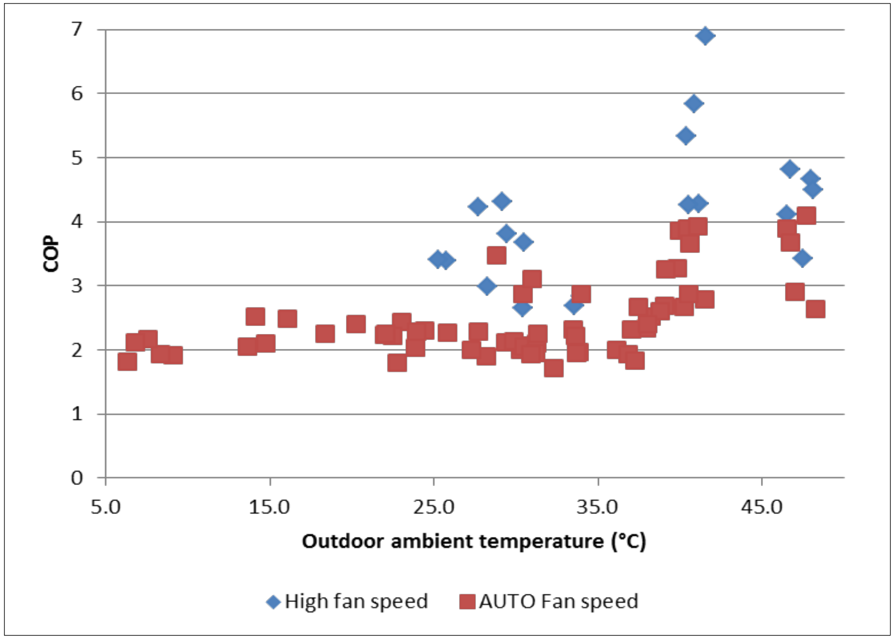
COP as Function of Ambient Temperature

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

Air-side measurement method



Co-heat measurement method



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Stratification Impact on COP

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

Height	Temperature (°F)
Entering heat pump	74.8
84 in. above the floor	75.4
60 in. above floor	70.2
12 in. above the floor	68.9

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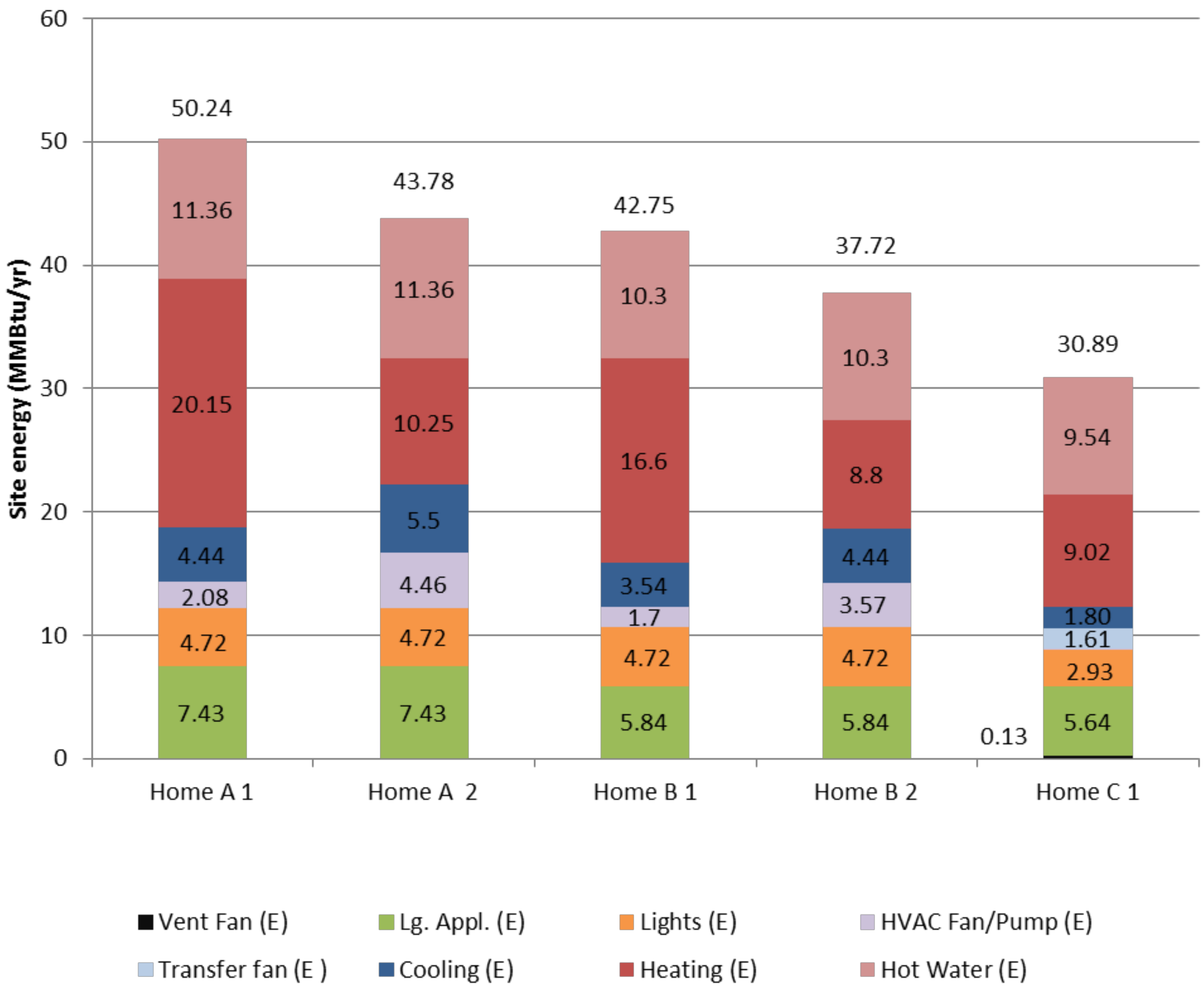
Extrapolating Energy Use

- **Objective**: Based on measured data, estimate space conditioning energy use in a range of Southeast climates.
- **Method**: Simulation with field-data-calibrated energy models using BEopt with Energy Plus engine.

3 Locations, 5 Models

Model	Thermal Envelope	Space Conditioning	Data Source
A1	HUD code	Electric resistance furnace; Split system AC[a]	Measured
A2	HUD code	Heat pump furnace; Split system AC	Simulated
B1	ENERGY STAR	Electric resistance furnace; split system AC	Simulated
B2	ENERGY STAR	Heat pump furnace; split system AC	Measured
C	ZERH (IECC 2012)	Ductless mini-split heat pump	Measured

Modeling Results – Knoxville Whole House Site Energy



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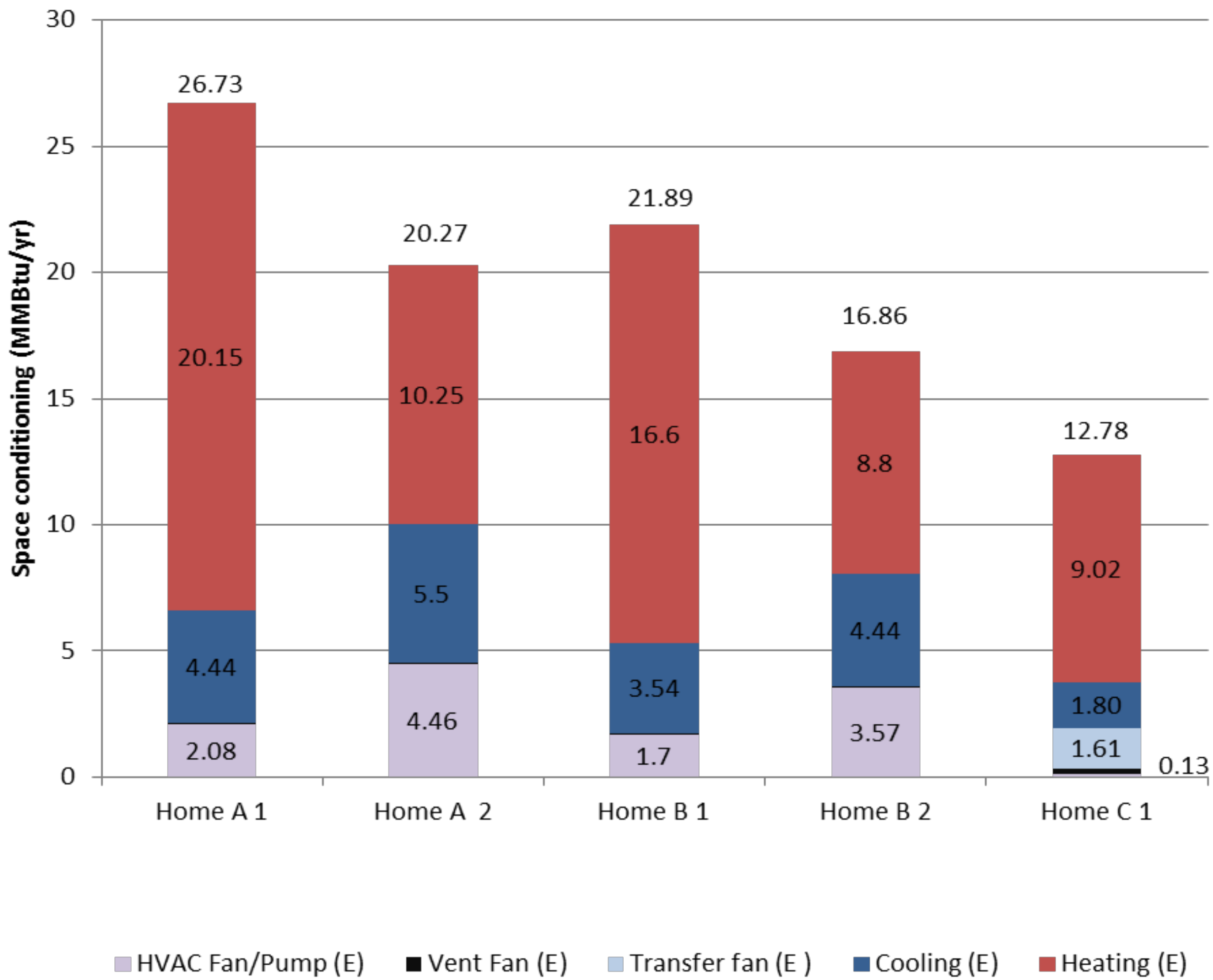
Modeling Results – Knoxville Space Conditioning Site Energy



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Energy Savings and Payback: Knoxville, TN

Compared to House A

House	Annual Utility Cost	Savings	Incr. Retail Cost	Payback (yr)
A	$1,656	N/A	N/A	N/A
B	$1,263	$393	$2,268	5.8
C	$1,055	$601	$5,843	9.7

House C compared to House B

Savings	Incr. Retail Cost	Payback (yr)
$208	$3,575	17.2

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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?

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Responses to Research Questions

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.

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Responses to Research Questions

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

3. **Costs.** *What's the incremental cost of achieving ZERH? Is it cost-effective?*

House C Compared to A / B	Energy Measure Manufacturer Cost Premium	Homeowner Payback Based on Retail Costs
House A	$2,060	8.8 years
House B	$1,166	17.5 years

Based on estimated costs at high production volumes

- 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

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Research Questions and Responses

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.

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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

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Full Report

Field Evaluation of Advances in Energy-Efficiency Practices for Manufactured Homes, E. Levy, J. Dentz, E. Ansanelli, G. Barker, P. Rath, and D. Dadia (*ARIES Collaborative)*

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/65436.pdf

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Awards and National Recognition

Building America Top Innovation Award 2014

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING AMERICA TOP INNOVATIONS 2014 PROFILE

INNOVATIONS CATEGORY:
Advanced Technologies and Practices
Building Science Solutions
Thermal Enclosure

INNOVATOR:
ARIES Collaborative

Cost-Optimized Attic Insulation Solution for Factory-Built Homes

This low-cost, low-tech attic insulation technique is immediately applicable to the nearly 1,25,000 new manufactured homes built each year. With widespread adoption, this one measure could save homeowners over 6 trillion Btus by 2030, equal to $190 million in savings that would go into the pockets of families with modest incomes.

BUILDING AMERICA TOP INNOVATIONS

Recognizing Top Innovations in Building Science - The U.S. Department of Energy's Building America program was started in 1995 to provide research and development to the residential new construction and remodeling industry. As a national center for world-class research, Building America funds integrated research in market-ready technology solutions through collaborative partnerships between building and remodeling industry leaders, nationally recognized building scientists, and the national laboratories. Building America Top Innovation Awards recognize those projects that have had a profound or transforming impact on the new and retrofit housing industries on the road to high-performance homes.

Increasing attic insulation in manufactured housing has been a significant challenge due to cost, production and transportation constraints. The simplicity of this dense-pack solution to increasing attic insulation R-value promises real hope for wide-spread industry adoption.

The U.S. Department of Energy's ARIES research team, led by The Levy Partnership Inc., partnered with Clayton Home's Southern Energy Homes division and Johns Manville Corporation to develop and test a new attic insulation method that involves dense packing the shallow attic space in manufactured homes with blown fiberglass insulation.

With this new method of applying dense-pack insulation, installers are able to achieve a much higher attic insulation R-value than is typically installed in manufactured homes.

Specifically, Southern Energy Homes has achieved an overall average attic R-value of R-44.6 and an R-value of R-54.6 at the center or peak of the attic using this innovative new dense-packing method. For comparison, a home certified to the ENERGY STAR Qualified Manufactured Homes program typically has an average R-value of between R-30 and R-38 in the ceiling. The typical ceiling insulation level in a manufactured home in HUD Code zone 1 is around R-22 at the peak.

The method was tested in a home built by Southern Energy to the performance criteria of the DOE's Zero Energy Ready Home program, which seeks to achieve whole house energy performance that exceeds the requirements of the 2012 International Energy Conservation Code.

The home is being monitored for 15 months at Clayton's Russellville, Alabama, plant in side-by-side testing with homes built to ENERGY STAR and to the U.S. Department of Housing and Urban Development's Manufactured Home Construction and Safety Standards (commonly known as the HUD code).

Building AMERICA U.S. Department of Energy

(top left) The dense-pack roof insulation technique is being tested in a side-by-side comparison with two other manufactured homes—one built to ENERGY STAR and one built to the HUD code. The homes are undergoing 15 months of performance testing by the DOE's ARIES research team and National Renewable Energy Laboratory.

ZERH Housing Innovation Award 2014

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE ZERO ENERGY READY HOME™

U.S. DOE ZERO ENERGY READY HOME 2014 WINNER Housing Innovation Awards

Southern Energy Homes

First DOE Zero Energy Ready Manufactured Home
Russellville, AL

BUILDER PROFILE

Southern Energy Homes, Inc.
(a division of Clayton Homes)
Russellville, AL
David Brewer
davidbrewer@claytonhomes.com
205-489-3433
www.claytonhomes.com
Rater: The Levy Partnership, Inc. Jordan Dentz, jdentz@levypartnership.com

FEATURED HOME/DEVELOPMENT:

Project Data:

- Name: First DOE Zero Energy Ready Manufactured Home
- Location: Russellville, AL
- Layout: 3 bedrooms, 2 baths, 1 floor
- Conditioned Space: 1,232 ft²
- Climate Zone: IECC 3A, mixed-humid
- Completion: May 2014
- Category: Affordable

Performance Data:

- HERS Index: without PV 57
- Projected Annual Utility Costs: without PV $799
- Projected Annual Energy Cost Savings (compared to a home built to the HUD Code): without PV $372
- Builder's Added Cost Over HUD Code (MHCSS): $1,817
- Annual Energy Savings: without PV 4,658 kWh

The country's first U.S Department of Energy-certified Zero Energy Ready manufactured home is up and running in Russellville, Alabama. The manufactured home is being put through its paces along side of a standard to-code manufactured home and an ENERGY STAR manufactured home. The manufactured home, built by Clayton Home's Southern Energy Homes subsidiary, has an impressive suite of energy-saving, water-saving, high-tech features that any home would be proud of. "The DOE Zero Energy Ready home is a potential game changer for the factory building industry," said Jordan Dentz, a building scientist for The Levy Partnership, a research partner in the DOE Building America program who is collaborating with Clayton Homes and the National Renewable Energy Laboratory to do 15 months of side-by-side performance testing on the three homes.

Testing began May 2014 and preliminary cooling-season results are already showing the DOE Zero Energy Ready Home as a strong leader in this energy savings race, using half the space conditioning energy of a manufactured home built to the U.S. Department of Housing and Urban Development's Manufactured Home Construction and Safety Standards (commonly known as the HUD code), which is the building standard for all U.S. manufactured housing. The other manufactured home, which was built to the ENERGY STAR criteria for manufactured homes has about a 15% savings over the HUD Code home.

The DOE Zero Energy Ready Home meets all of the requirements that site-built homes must meet to qualify for this high-performance home labeling program. The home is built to meet all of the air sealing and construction quality requirements of ENERGY STAR Certified Homes Version 3.0. It also meets the indoor air quality and water saving measures of the U.S. Environmental Protection Agency's Indoor airPLUS and WaterSense programs. The DOE

ZERO ENERGY READY HOME

The U.S. Department of Energy invites home builders across the country to meet the extraordinary levels of excellence and quality specified in DOE's Zero Energy Ready Home program (formerly known as Challenge Home). Every DOE Zero Energy Ready Home starts with ENERGY STAR Certified Homes Version 3.0 for an energy-efficient home built on a solid foundation of building science research. Advanced technologies are designed in to give you superior construction, durability, and comfort; healthy indoor air; high-performance HVAC, lighting, and appliances; and solar-ready components for low or no utility bills in a quality home that will last for generations to come.

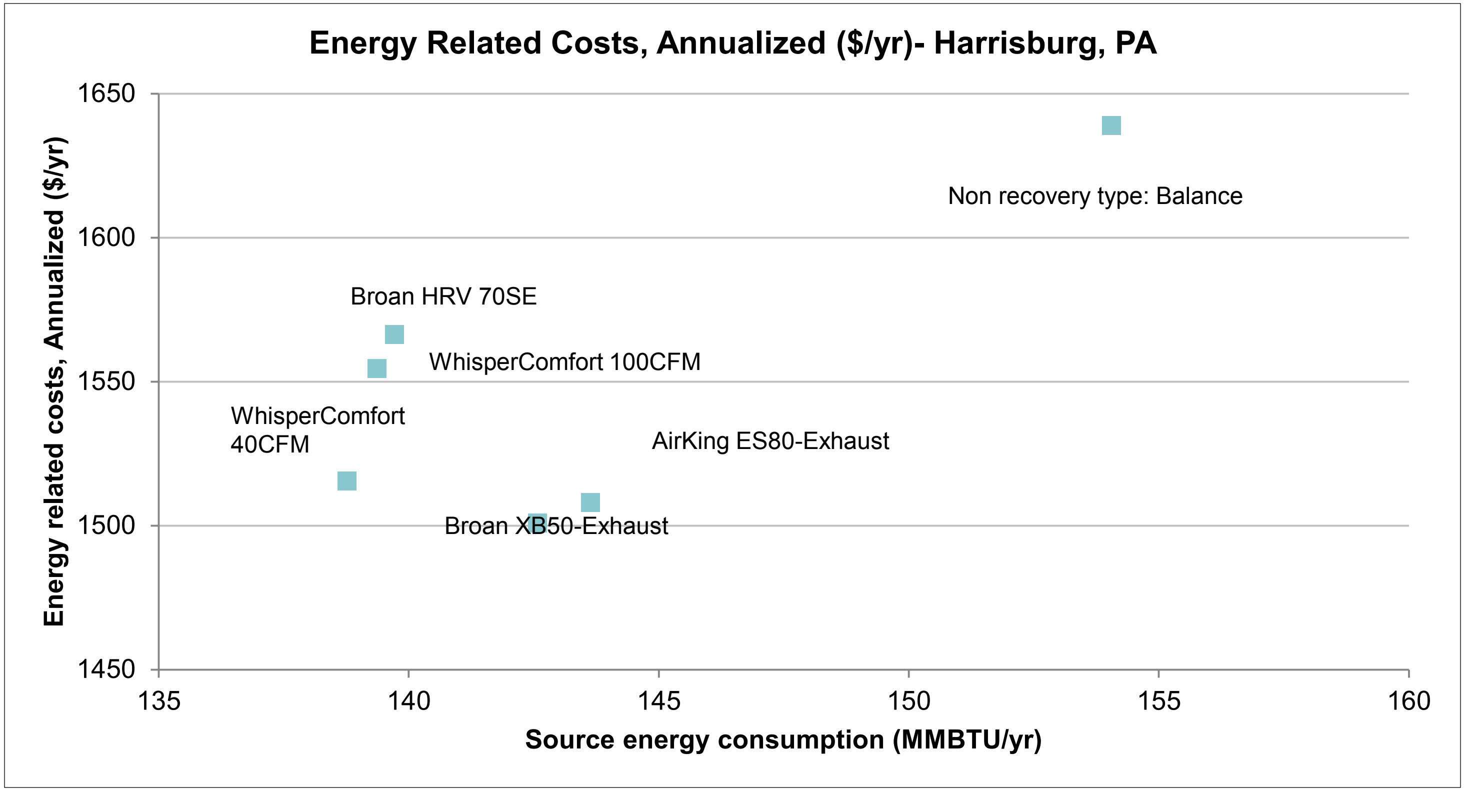
ARIES Collaborative

Design Changes

- Ventilation system
- Distribution system
- Thermal enclosure

Ventilation System Analysis

- BEopt analysis of 6 options in 4 northern climates



ARIES Collaborative

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

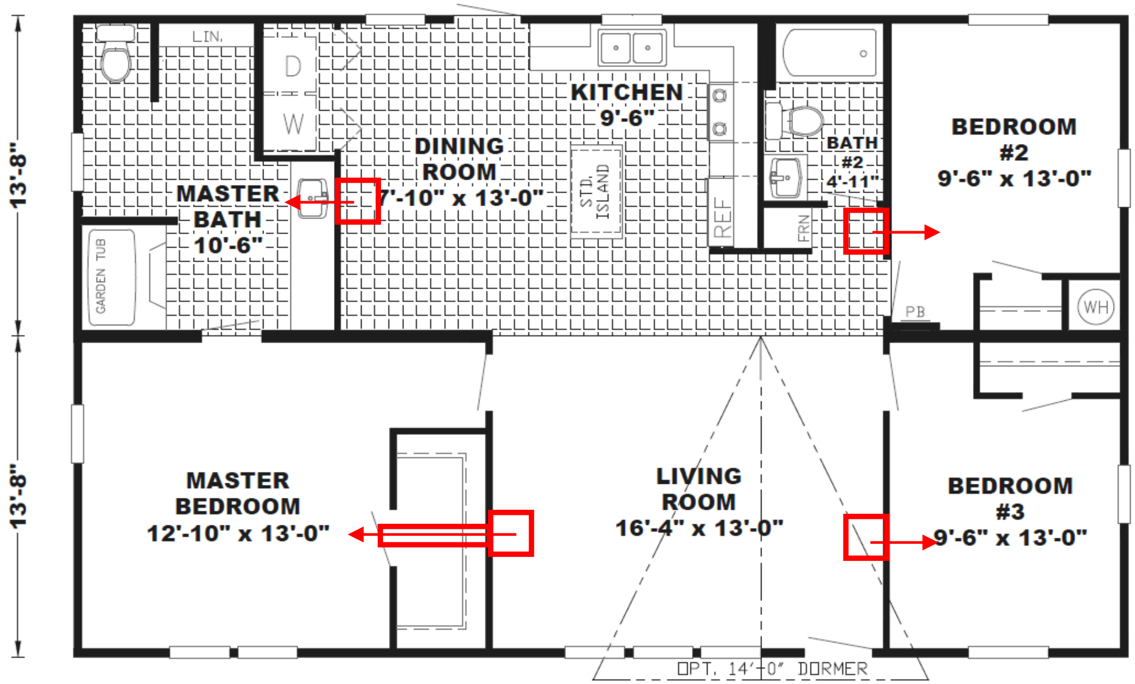
Goals:

- More airflow
- Quieter

Strategy

- Straight through wall
- Different fan

New Distribution System Testing



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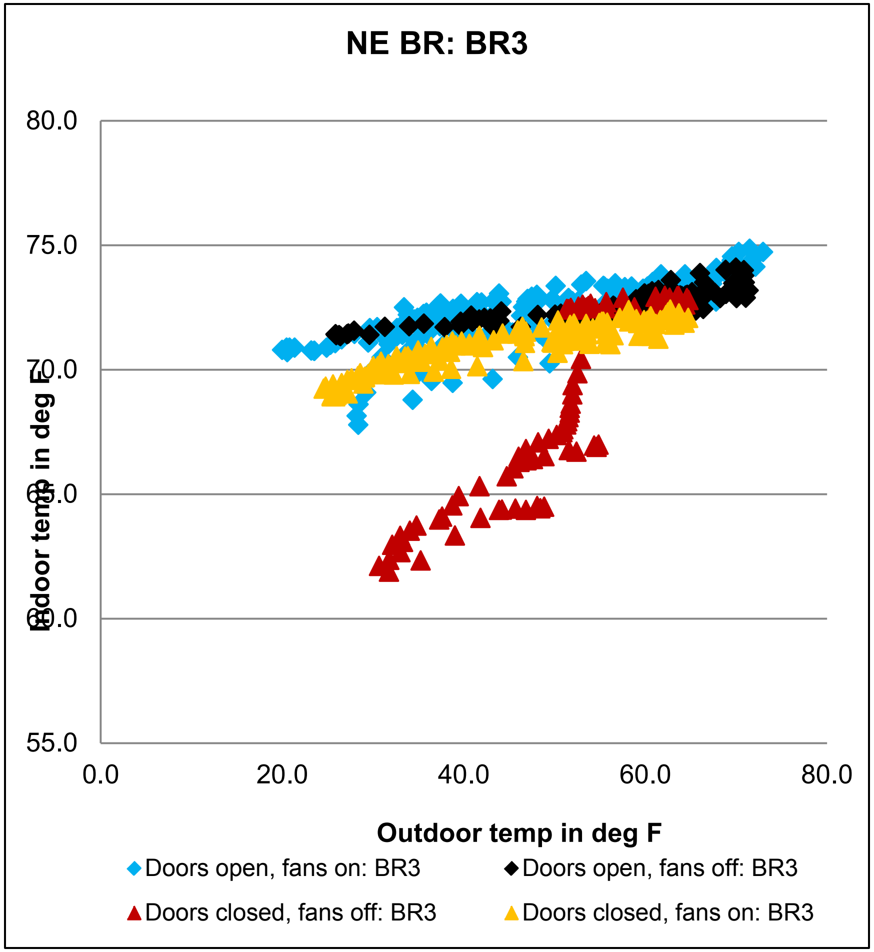
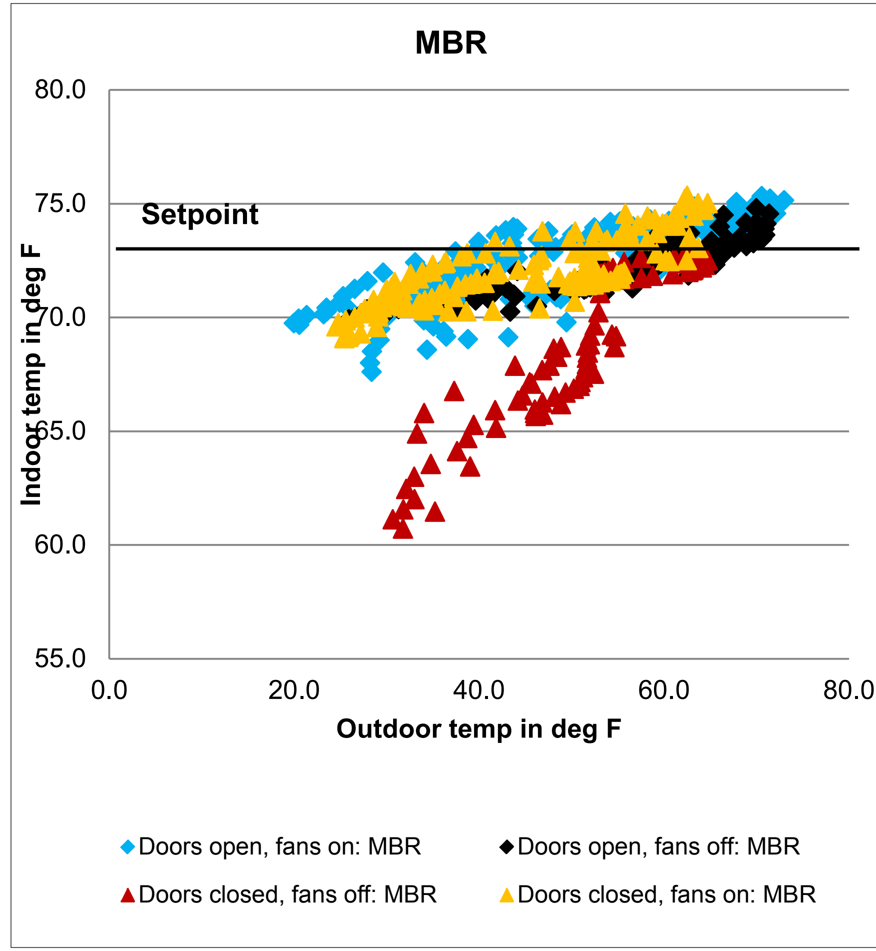
Monitoring Results with New Fans





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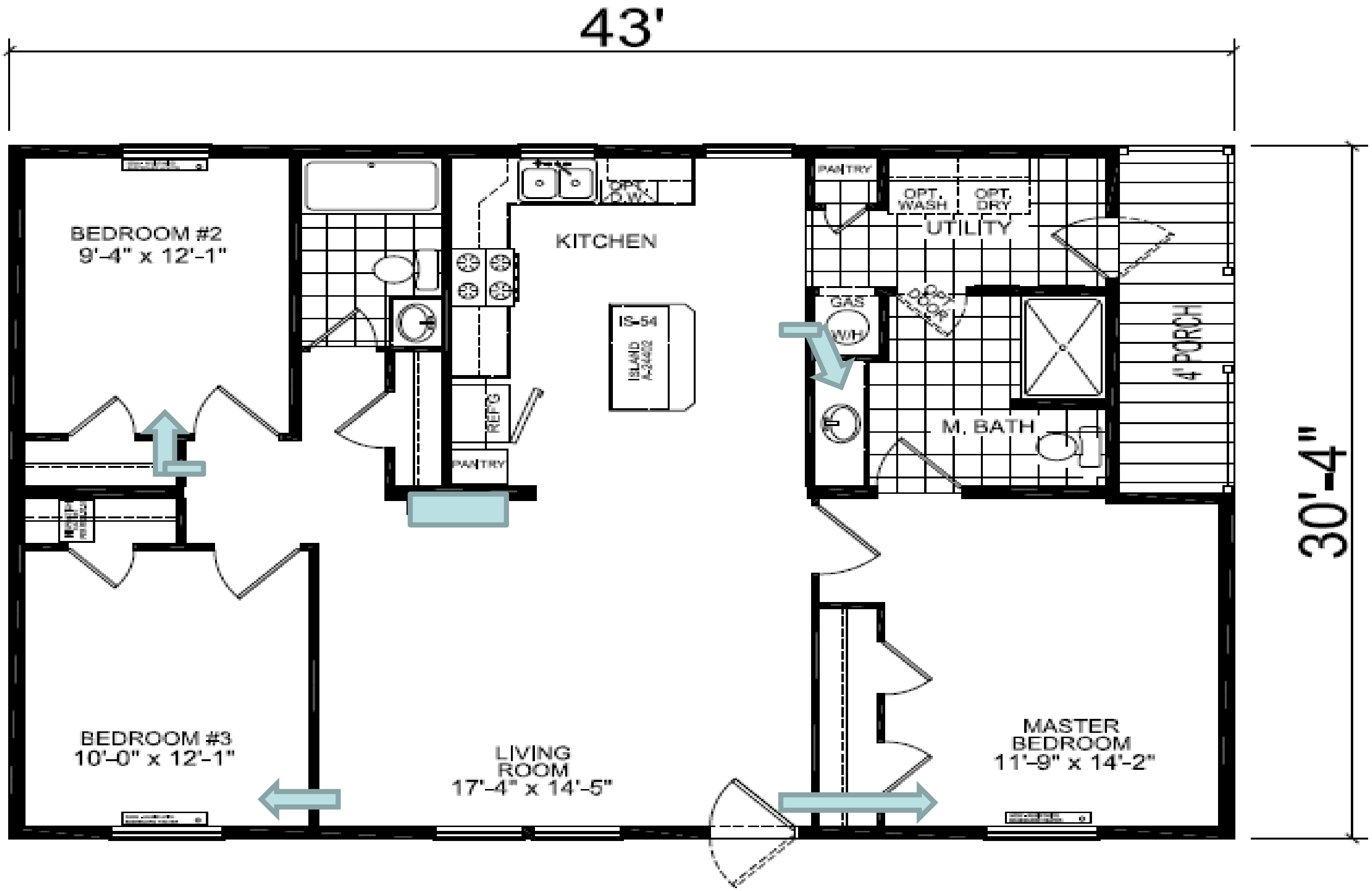
About as effective as an open door

Thermal Enclosure Revisions

- R-4 windows
- 2x6 walls
- More floor insulation
- Tighter envelope

New Cold Climate ID House



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Production at Champion Homes, Claysburg, PA

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Installation in Eatontown, NJ

- Six months unoccupied monitoring and testing
- One year occupied monitoring

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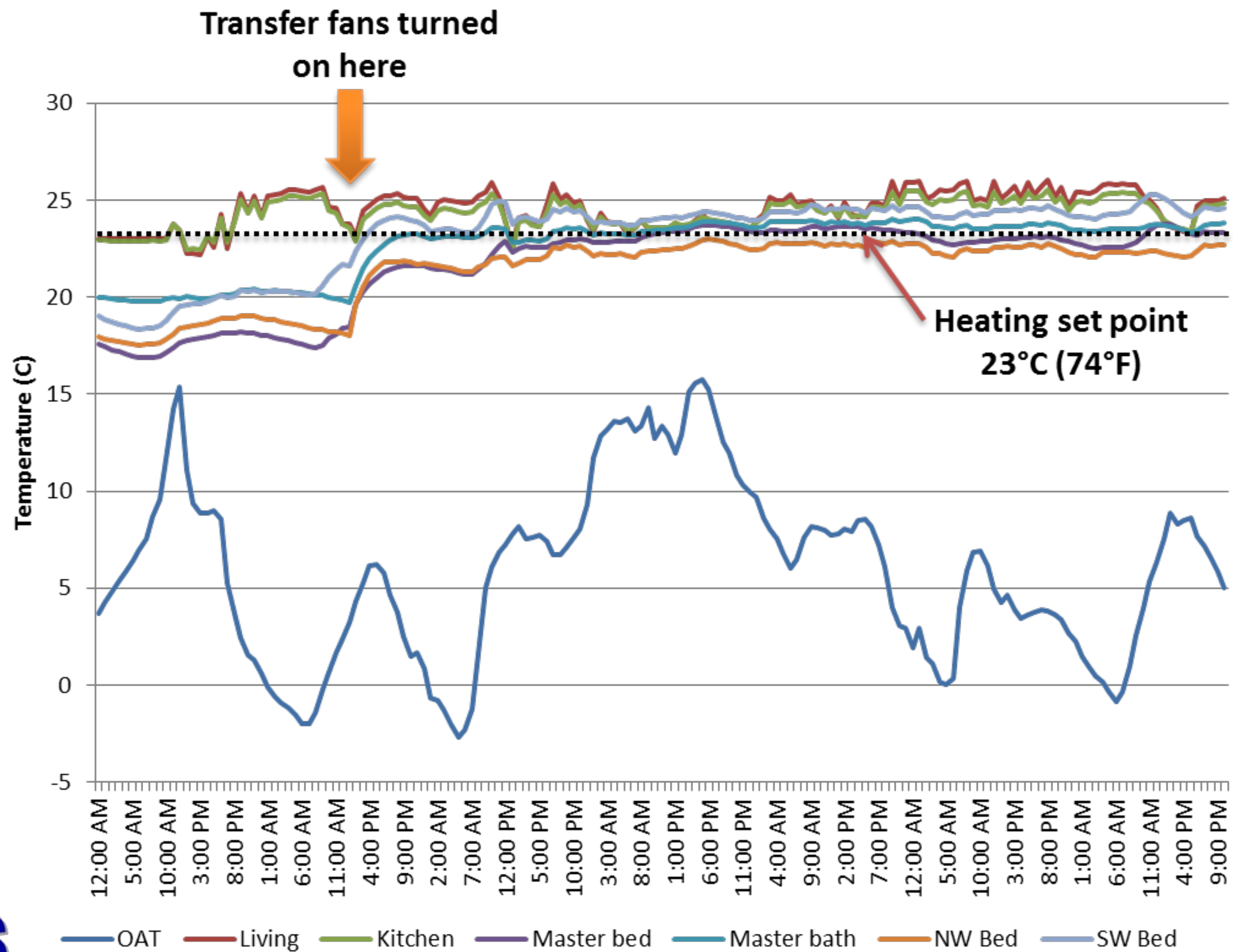
Ribbon Cutting

Initial Testing Data



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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

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