High Performance Factory Built Housing

2015 Building Technologies Office Peer Review

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

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ARIES / The Levy Partnership, Inc.

Project Summary

Timeline:

Start date: **November 2010**

Planned end date: **October 2015**

Key Milestones:

1. TO2 Detailed Test & Work Plan, Phase 1: Planning; May 2011
2. TO2 Technical Report, Phase 2: Prelim Design–Development; Feb 2012
3. TO3 Technical Report, Phases 2 & 3: Advanced Design–Development; May 2013
4. TO4 Technical Report, Phase 3: Prototyping; Mar 2014
5. TO5 Technical Report, Phase 4: Prototyping and Testing; Oct 2015

Budget:

Total DOE $ to date: **$810,426**

Total future DOE $: **$1,090,113 proposed**

Key Partners:

Accuvent	AFM
Bayer Material Science	BASF
CertainTeed	Dow
Factory Home Builders	Hunter Panels
Johns Manville	Louisiana Pacific
Mitsubishi	MHI
Owens Corning	SBRA
Senco	Tjernlund

Target Market/Audience:

Manufactured housing industry

Project Goal:

Provide factory homebuilders with high performance, cost effective alternative envelope designs as a comprehensive solution for reaching net zero energy use

Relevance to BTO Needs and Objectives

BTO Objective: Develop and deploy technologies and systems that reduce building energy consumption by 50%

BTO' Strategies	How this Project Fulfills BTO's Needs and Objectives
Research and develop advanced technologies	Develop and test technologies to reduce new MH energy use by half
Stimulate the market for innovations	Partner with those responsible for 80%+ of all new MH through a process referred to as "Collective Impact"
Develop and implement codes and standards	Participate in the ongoing MH standards development process – informed by the R&D work

Purpose and Objectives: Problem Statement

How to move a highly price-sensitive industry to exemplary levels of energy efficiency.

Barriers

- 1st cost is king
- Communicating energy benefits faces major hurdles

Challenges

- Technologies must be production friendly
- New building methods must be HUD approved
- Sold by dealers like autos

Knowledge Gaps

- Industry mindset focused on 1st cost; must shift to total ownership costs
- Few examples of high performance homes
- HUD energy standards last updated in 1994, many iterations behind the IECC

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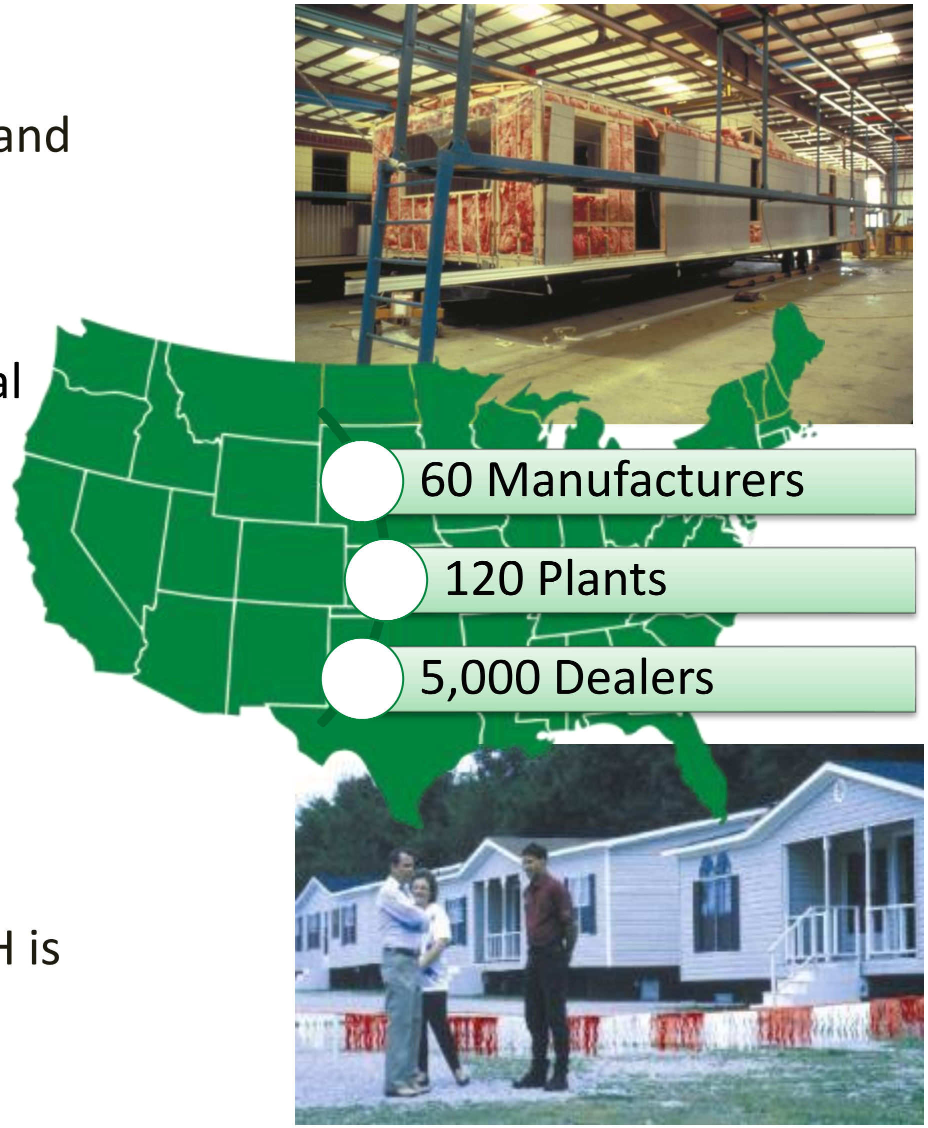
Purpose and Objectives: Target Market and Audience

- Manufactured Homes (MH) are built in plants across the nation and shipped to sites nearly ~95% complete.
- ~70% of unsubsidized affordable housing nationally (Congressional study)
- Preemption of HUD standards enables home standardization, key to achieving efficient production
- 10-12% of all new homes on average
- Financial crisis hurt affordable housing hardest and earliest. MH is likely to bounce back fast due to pent up demand and attractive pricing.



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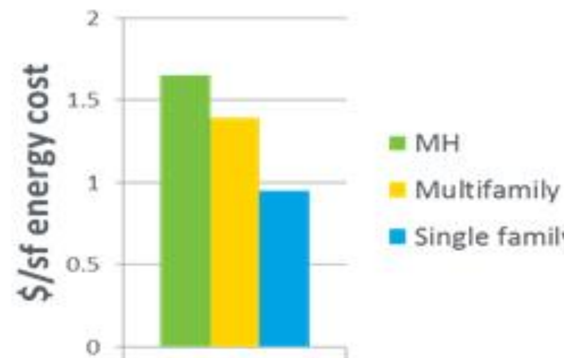
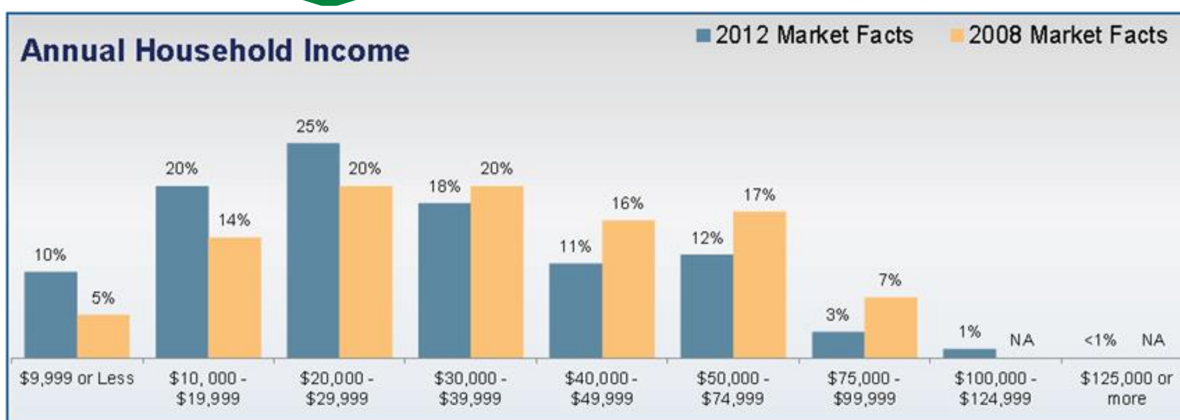
Purpose and Objectives: Target Market and Audience

75% of MH are owner-occupied (Foremost)

Nearly 7 million MH use 0.47 quad Btu/yr (site) (RECS)



Homeowners quality of life greatly impacted by efficiency. Energy costs can be as high as home payments.



Purpose and Objectives: Impact

Project Output

- Demonstrated solutions for building affordable, high performance MH; clear guidelines for plants and installers.

Measuring Achievement

- Interim—testing and prototype evaluation.
- Ultimate—number of homes built using high performance measures.

Impact Path

- Working with manufacturers to develop and demonstrate solutions
- Mfgs will drive the adoption: “affecting the operation of a few companies will change the industry.”
- If successful, can be wildly successful
- Industry needs cost-effective strategies for complying with the new energy code

Goals

- Near-term (through 2016): Pilot projects; limited adoption by progressive plants.
- Intermediate-term (2017-2019): New HUD standards drives adoption.
- Long-term (2020+): Reach critical mass; adoption starts in north then spreads south. SBRA helps facilitate adoption.

Approach: Collective Impact

Collective Impact is the commitment of a group of actors from different sectors to a common agenda for solving a specific problem, using a structured form of collaboration.

The Five Conditions of Collective Impact

- Common agenda
- Shared measurement
- Mutually reinforcing activities
- Continuous communication
- Backbone support

The concept of collective impact is clearly articulated in the 2011 Social Innovation Review article *Collective Impact*, by John Kania and Mark Kramer.

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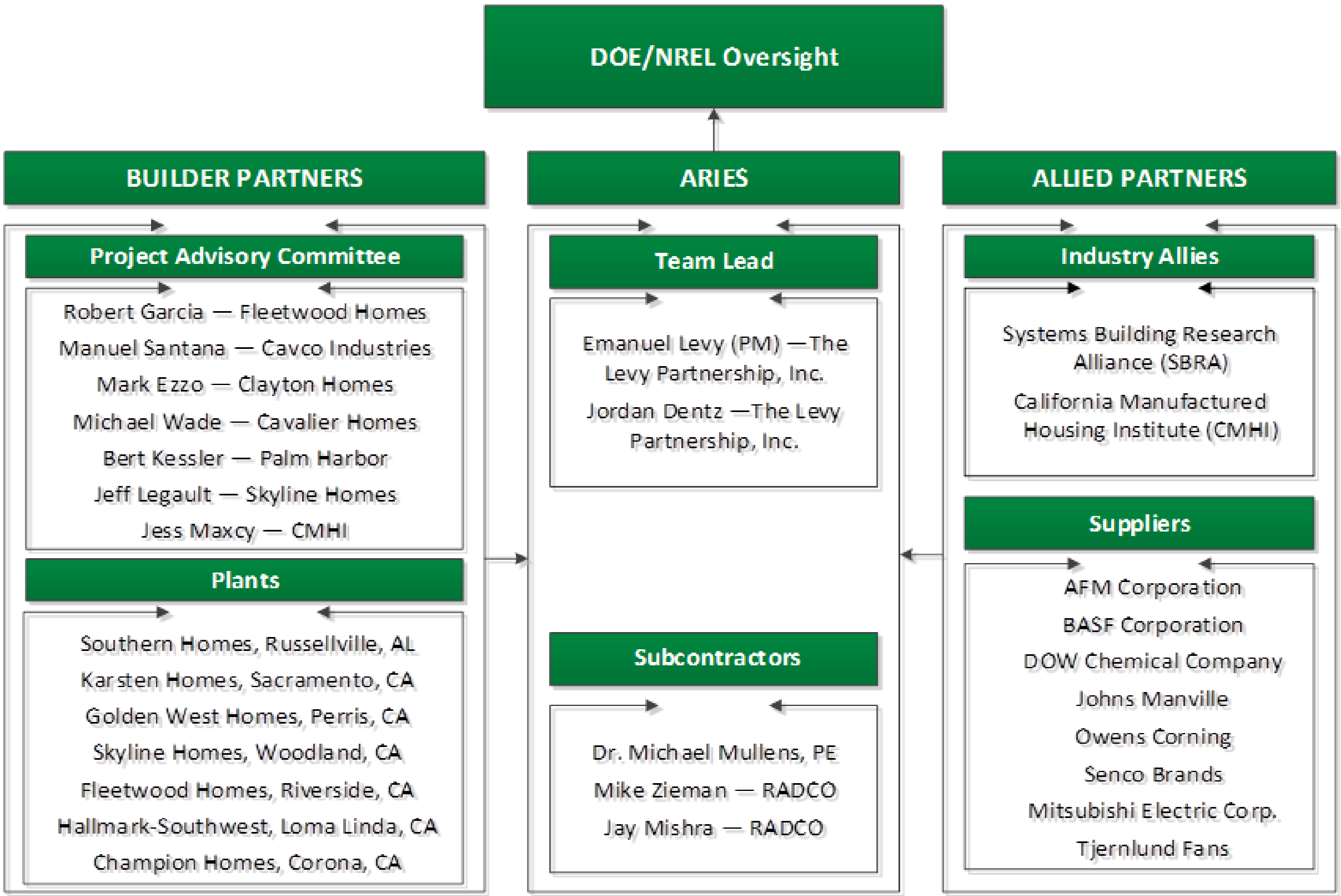
Approach: Partners



Approach: Key Issues

For a defined market segment, a holistic solution, including:

Thermal envelope: wall, roof, airtightness, windows

Space conditioning and ventilation

Integrating into the building process (production environment requires speed)

Cost and installation: quality key considerations

Ultimate goal is market transformation

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Approach: Planning

TO1	TO2	TO3	TO4	TO5
Planning	**Design Development**	**Advanced Design Development**	**Component Prototyping**	**Whole House Prototyping**
Screen design options	Code compliance	Detailing	Constructability assessment	Monitoring of moisture and thermal performance
Select three options to move forward	Thermal performance	Wall component prototyping and testing	Transportation test	
	Moisture analysis		Cost-benefit analysis	

Approach: Heat Maps

Process for structuring committee input and focusing down on those solutions most likely to succeed in the long run

Option	DK	ME	BK	MW	BS	MS	KF	LS	Man.	Code	Thermal
1. Structural insulated panels or SIPs for ceilings	33 (7)	26 (3)	31 (5)	24 (4)	(6)	23 (5)	(4)	32 (6)	5	5	5
2. Structural insulated panels or SIPs for walls	23 (2)	25 (2)	34 (6)	20 (1)	(5)	23 (5)	(3)	23 (4)	2	4	4
3. Stud wall with insulating sheathing board	23 (2)	24 (1)	20 (1)	20 (1)	(2)	10 (1)	(2)	17 (1)	1	2	1
4. Un-vented attic with insulating sheathing board	24 (4)	31 (7)	26 (4)	25 (5)	(3)	11 (2)		27 (5)	2	6	3
5. Flash and batt wall construction	11 (1)	29 (5)	25 (3)	23 (3)	(1)	20 (4)	(1)	20 (3)	1	1	6
6. Poured closed cell foam	25 (5)	29 (5)	22 (2)	27 (6)	(4)	19 (3)		19 (2)	4	3	2
7. Innovative new floor	28 (6)	28 (4)	31 (5)	---	---	---			---	---	---

Scores indicate the simple sum of the qualitative ratings. Figure in parenthesis is the rank for that rater.

Key: red box = top pick; yellow box = second pick; green box = third pick.

Approach: Distinctive Characteristics

- Collective Impact
- Heat Maps
- Three lab homes side by side – located at the production facility
- Dovetail with code update process – hand in glove

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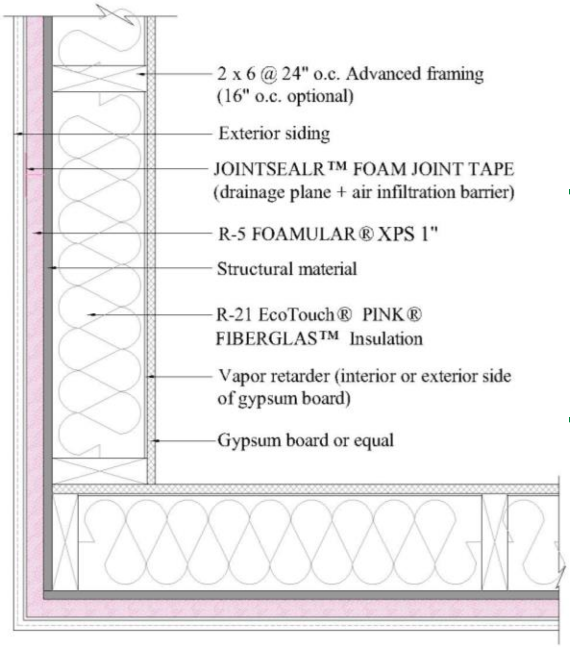
Progress and Accomplishments

Progress and Accomplishments: TOs1-2

Developed advanced wall design that improves the thermal performance of the envelope and reduces annual energy use

Analysis of proprietary products

Supplier68	Product	Structural sheathing	WRB/ Sealant	VR	Fastener	FG Batts	Freight factor	TOTAL	
								$/home	$/sq. ft.
AFM	Nailbrace	✓	✓	✓	✓	---	✓	6,151	2.13
DOW	Styrofoam	---	✓	---	---	---	---	2,860	0.99
Johns Manville	ValuTherm	---	---	---	✓	---	---	1,415	0.49
	AP Foil	---	✓	---	✓	---	---	2,682	0.93
	Structural Insul. Sheathing	✓	✓	---	✓	---	---	2,942	1.02
Owens Corning	Foamular	---	✓	---	---	✓	---	3,252	1.13
Saint Gobain	Faced CertaPro	---	---	---	---	---	---	2,336	0.81
BASF	Neopor UnFaced	---	---	---	✓	---	---	1,966	0.68
	Neopor Poly/Foil	---	---	---	✓	---	---	2,053	0.71
	Neopor 3/8" OSB	✓	---	---	---	---	---	3,667	1.27



TO2 – Design development and material selection

Progress and Accomplishments: TOs 3-4

Tested, prototyped and perfected the advanced wall design over five prototype builds at different manufacturing plants.

TO4 – Whole-house prototyping and constructability assessment

TO3 – Component prototyping and testing

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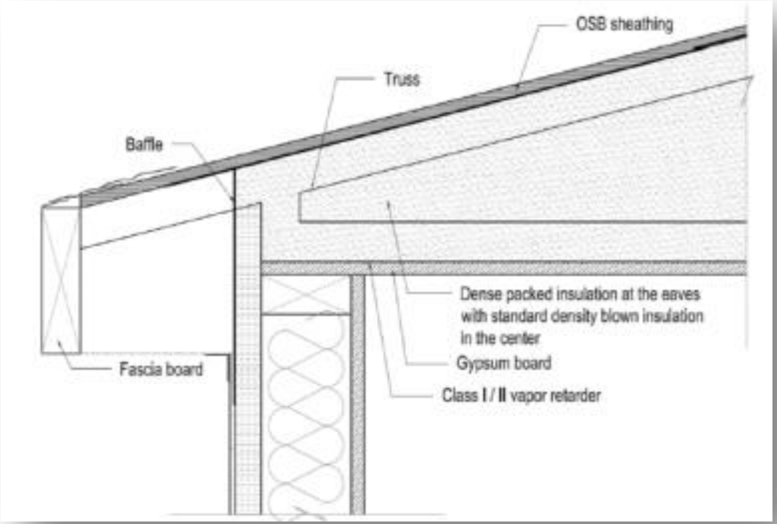
Progress and Accomplishments: TO5

Developed advanced roof design that reduces heat loss at the eaves – traditionally a weak link in the thermal performance of attics.



Advanced Roofs

Progress and Accomplishments: TO5

Full-scale wall and roof prototyping; instrumentation and testing of advanced roofs, monitoring of moisture and thermal performance.

- Constructed and instrumented three side-by-side lab homes
- Monitored for one year (on going)

Traditional MH Home	Advanced (ZERH) MH
Standard fiberglass batt in wall cavities	Reduced thermal bridging with exterior rigid insulation
Cooling equipment site installed	High efficiency equipment plant-installed, commissioned
Ducts under floor and in crawl	No ducts
Code minimum 13 SEER / 8 HSPF or electric resistance	22 SEER / 12 HSPF
Envelope U_o = 0.116	Envelope U_o = 0.063

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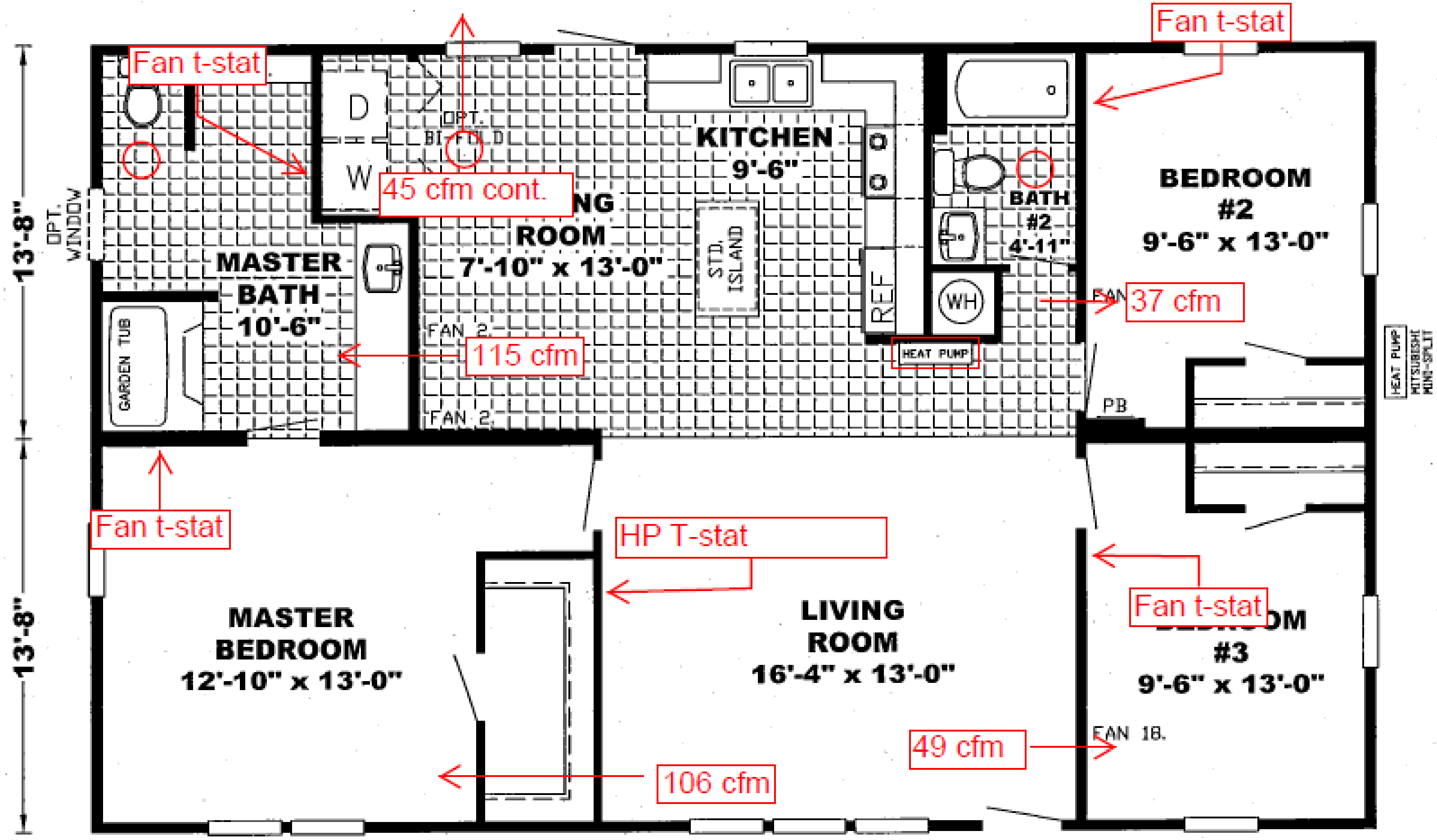
Progress and Accomplishments: TO5

Better understanding of the interplay between heat pump, fan locations and home configuration



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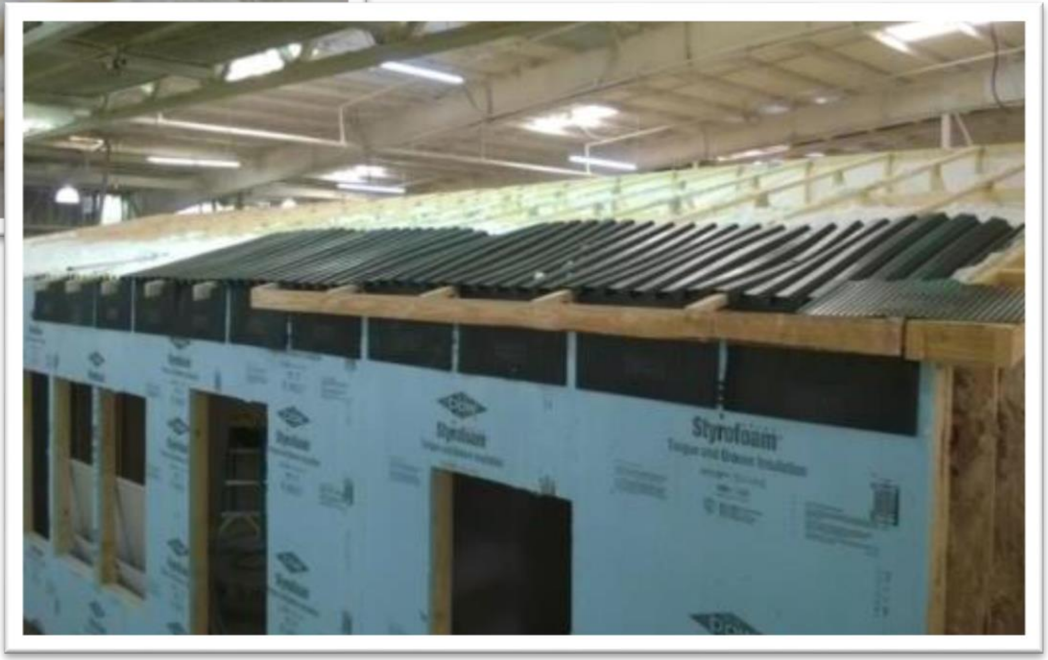
Progress and Accomplishments: Advanced Wall Construction

Progress and Accomplishments: Advanced Roof Construction

Dense-pack insulation

Baffles and insulation dams



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Progress and Accomplishments: Ductless Mini-split Heat Pump

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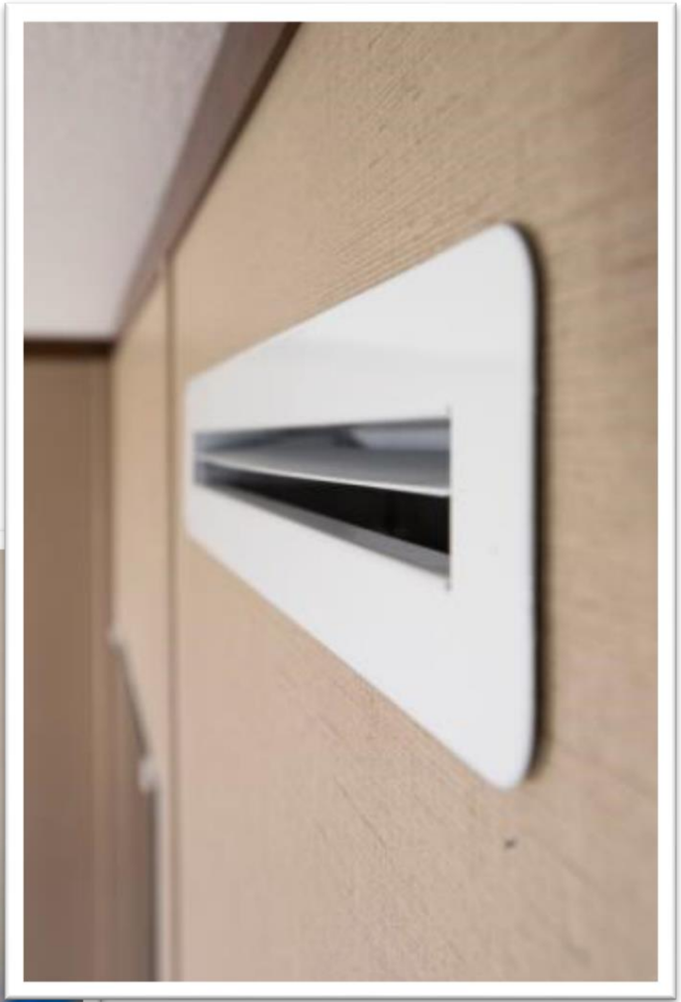
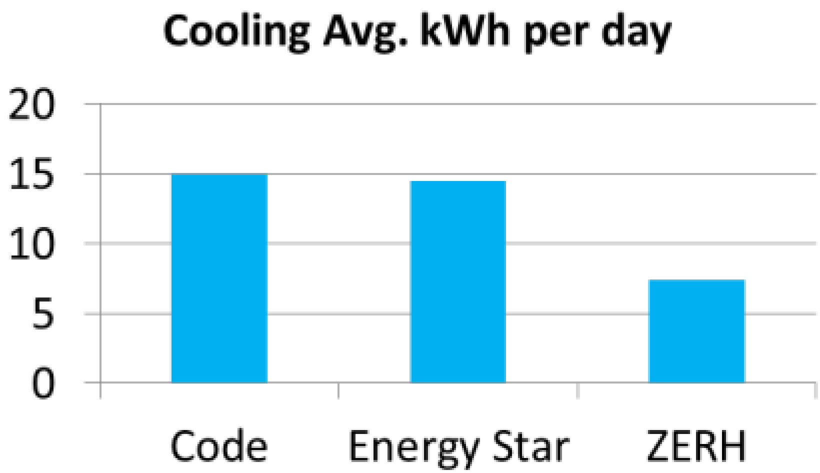
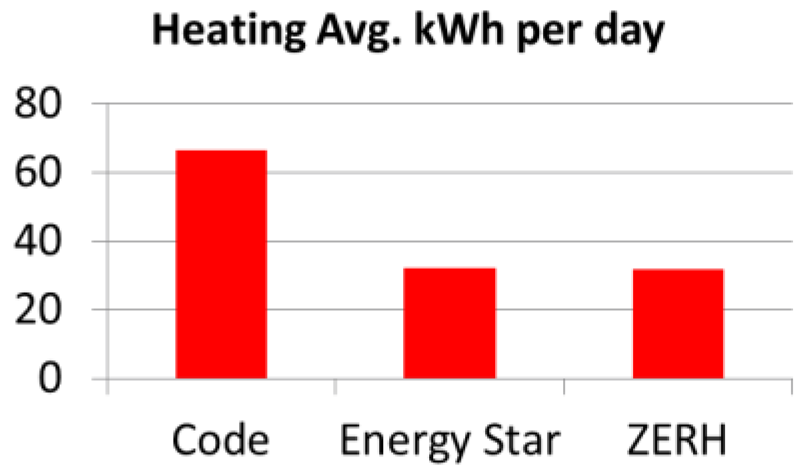
Progress and Accomplishments: Transfer Fan Distribution



Progress and Accomplishments: Lab Home Results





Code and ES used similar cooling energy because less cool-off for ES home in evening.

ES and ZERH used similar heating energy because the mini-split heat pump unexpectedly operated at about the same COP as a traditional, split system heat pump.

Other Results:

- Site-installed equipment problems – how typical is this?
- Transfer fan configuration in heating.
- Effective ventilation rates with traditional POS systems.

Progress and Accomplishments: Awards/Recognition

Building America Top Innovation Award 2014

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

BUILDING AMERICA TOP INNOVATIONS

ZERH Housing Innovation Award 2014

DOE ZERO ENERGY READY HOME™

Southern Energy Homes

First DOE Zero Energy Ready Manufactured Home

Russellville, AL

BUILDER PROFILE

FEATURED HOME/DEVELOPMENT

ZERO

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Progress and Accomplishments: Summary

Lessons Learned	In-situ performance of mini-split heat pump in heating unexpected (further analysis needed)
Accomplishments	Developed, tested advanced wall and roof designs that improve envelope thermal performance, reduce energy use, cut CO_2 emissions, reduce equipment size, improve comfort and durability
Market Impact	Impacted ASRAC process –new standard based on IECC 2015. Engaged many factories in demonstrating new building methods
Awards/ Recognition	BA Top Innovation Award 2014 and ZERH Housing Innovation Award 2014

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Project Integration

Left to Right: Emanuel Levy, TLP; Brian Lieburn, DOW; Kevin Clayton, Clayton Homes; Bryan Mallon, DOW; Jim Morey, DOW; Sam Rashkin, DOE; David Brewer, Southern Homes

- Stakeholders participate and guide the research
- Bi-monthly stakeholder conference calls
- All major decisions owned by steering committee
- Participation of many companies, not just those involved in the prototyping
- More than 70% of industry
- In-kind contributions $274k
- Demos/prototyping/testing at industry facilities

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Project Collaboration

- **Funding Partners:** DOE, TVA, CEC
- **Research Collaboration:** NREL on lab home instrumentation, experiments and analysis
- **Industry Partners:**

SEhomes

Dow

Building America U.S. Department of Energy

Clayton homes

Johns Manville

NREL National Renewable Energy Laboratory

Systems Building Research Alliance (SBRA)

SENCO

ZERO Energy Ready Home U.S. Department of Energy

ARIES Collaborative

TVA

MHI Manufactured Housing Institute

Mitsubishi

California Energy Commission

Project Integration and Collaboration: Roles

Industry Partner	Role
Clayton Homes	Engineering, plant selection and logistics
Southern Homes	Manufacturer of lab homes
Mitsubishi	Provider of space conditioning equipment and technical support
DOW	Provider of wall insulation, flashing system and technical support
Johns Manville	Provider of roof insulation and technical support
Accuvent	Provider of roof ventilation system and technical support
Tjernlund	Provider of transfer fans and technical support
Senco	Provider of fasteners, fastening tools and technical support

Collaboration on Lab Home Construction

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Project Integration and Collaboration: Communications

- MHI Meetings
- MH Congress & Expo
- MH NewsWire
- The Journal
- BA Reports
- CFED and others


BUILDING TECHNOLOGIES OFFICE

Advanced Envelope Research for Factory Built Housing, Phase 3—Whole-House Prototyping

E. Levy, M. Mullens, and P. Rath
Advanced Residential Integrated Energy Solutions (ARIES) Collaborative

April 2014

cfed
expanding economic opportunity

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Next Steps and Future Plans: Ongoing CEC Work

Roof test structure: Five roof configurations being tested in Jamestown, CA

2015 Plans:

- Radiant barrier/cool roof testing
- Full scale production testing
- Multiple full-scale homes at multiple plants
- Multiple occupied homes monitoring

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Next Steps and Future Plans: Integrated Solution

Ongoing experiments will answer important outstanding questions pertinent to high performance MH and site built homes, including:

- In-situ performance of mini-split heat pumps
- Performance of transfer fan distribution strategy (heating & cooling)
- Impact of open doorways on airflow and comfort

Future Work – Important for commercialization

- Understand airflow dynamics via calibrated CONTAM/TRNSYS model
- Level of envelope efficiency by climate necessary for success of point-source space conditioning strategy
- Interaction of real life homeowners with advanced home

REFERENCE SLIDES

Project Budget

Total Project Budget: $1,084,364 ($810,425 DOE; $273,939 cost-share)

Variances: $95,000 increase in TO5 for additional tasks/modified scope of work

Cost to Date: 81% of project budget expended to date (FY2011-FY2015 to date)

Additional Funding: California Energy Commission, Tennessee Valley Authority, Industry partners

Budget History					
FY2011–FY2014 (past)		FY2015 (current)		FY2016–FY2018 (proposed)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$580,570	$95,647	$229,855	$178,262	$1,090,113	$353,500

Project Plan and Schedule

Project Schedule				
Project Start: November 2010	▒	Completed Work	▓	Active Task (in progress work)
Project End: October 2015	◇	Milestone/Deliverable (Originally Planned)	◆	Milestone/Deliverable (Actual)

Task		FY2011				FY2012				FY2013				FY2014				FY2015			
	Q4 Nov-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec
Past Work																					
TO1: 1.2 Draft Project Plan	▒ ◆																				
TO1: 1.3 Final Project Plan	▒ ◆																				
TO2: 2.1 Detailed Test and Work Plan		▒ ◇	▒ ◆																		
TO2: 2.2.1 Draft Technical Report			▒	▒	▒ ◆																
TO2: 2.2.2 Final Technical Report					▒	▒ ◆															
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TO4: 2.1.1 Draft Technical Report											▒	▒	▒ ◇	▒ ◆							
TO4: 2.1.2 Final Technical Report													▒ ◇	▒ ◆							
TO5: 3.1.1 Test Plan														▒ ◆							
Current Work																					
TO5: 3.1.2 Draft Technical Report															▓	▓	▓	▓	▓	▓ ◆	
TO5: 3.1.3 Final Technical Report																				▓	▓ ◆