Integrated Design for Affordable, Factory Built Homes

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ABSTRACT

In many respects that impact energy efficiency, manufactured housing is an anomaly in the shelter business. The industry builds to a national standard, most of the construction is done in a controlled manufacturing environment typically far removed from the building site, and portions of the home are completed by installers outside the control of the factory. While using construction practices nearly identical to site building, factory building is shaped by the need to optimize production flow in the plant. Further, the industry serves a highly income-constrained customer, limiting their ability to offer energy features that, while cost-effective, significantly increase home cost. First cost considerations, in particular, are a drag on efficiency advances. However, this is about to change as the industry energy standards, last updated in 1994, will be raised to levels roughly equivalent to IECC 2015, an unprecedented leap in efficiency regulation.

The work profiled identified and demonstrated a set of energy technologies specifically selected for factory building that together profoundly moved the efficiency needle without significantly increasing first cost. The effort involved a field-test comparison of three homes: one built to the current standards; the second qualifying for the ENERGY STAR label; and, the third containing a new set of efficient technologies integrated in a highly thermally efficient home to qualify for DOE's Zero Energy Ready Home designation. The results offer insights into the future of using a whole-building, integrated-design approach for the design of the next generation of factory-built homes.

Introduction

Energy is one of the major contributors to homeownership costs, and high energy costs create a pronounced financial burden on households with modest incomes. Manufactured homes in particular are susceptible to excessive energy costs because industry energy standards, nationally-promulgated by the U.S. Department of Housing and Urban Development (HUD), were last updated in 1994. Programs such as ENERGY STAR and the U.S. Department of Energy (DOE's) Zero Energy Ready Home (ZERH) showcase ways to improve efficiency and reduce energy costs. These efforts often incur higher construction costs (associated with enhanced efficiency) to achieve lower energy bills—a combination designed to yield lower net monthly homeownership costs.

Field tests exploring better ways to build affordable, durable, comfortable, energy-efficient homes have been performed in Tennessee (Gehl et al. 2012), Texas (Chasar et al. 2010), North Dakota (Chasar et al. 2004), North Carolina (FSEC 2004), Washington (PNNL 2010), and other locations. Many of the side-by-side tests have focused on site-built techniques that may not translate well to manufactured housing.

Manufactured homes face additional challenges in applying alternative construction techniques given the need to work within the limitations of factory-available materials, short construction timeframe, durability during transportation and minimal on-site work. The best approaches for reducing energy use, improving indoor air quality, and increasing durability in homes constructed on-site are sometimes different from those built on an assembly line.

Experimental Protocol

Approach

Creating new approaches to energy efficiency in manufactured housing. Through field-testing and analysis, this project evaluated whole-building approaches and estimated the relative contributions of select technologies toward reducing energy use in new manufactured homes. These approaches are tested in three unoccupied lab houses of varying designs that were built and tested side-by-side under identical climate and operating conditions.

The tests compared the performance of the three houses (referred to as House A, B, and C) built to different levels of thermal integrity. These tests allowed for a side-by-side comparison of whole-house performance focusing on the impacts that heating, ventilating, and air-conditioning (HVAC) selection, distribution systems, and envelope construction have on space conditioning energy use. House A met the HUD thermal standards and was equipped with an electric furnace and a split- system air conditioner. House B complied with the manufactured home ENERGY STAR requirements, including an improved thermal envelope and a conventional, split-system heat pump. House C qualified for Zero Energy Ready Home (ZERH) designation and included a high-efficiency, single-point, ductless, mini-split heat pump, with a transfer fan distribution system in place of the traditional duct system for distribution. House A and House B used a standard duct system for air distribution.

Research questions. The research sought to answer the following questions:

- What combination of energy measures can achieve exemplary performance while minimizing the impact on total cost to the customer? Are there ways to achieve low cost by balancing the design of the envelope, equipment and distribution system?
- Specifically, can factory- built, manufactured homes meet the ZERH program requirements? If not, what changes are suggested in the ZERH specifications to better reflect and take advantage of the unique aspects of factory building?
- From energy efficiency and comfort standpoints, how does point-source space conditioning, the cornerstone of an affordable solution, perform in a ZERH?

Design specifications. The three manufactured homes were built and co-located on a single site adjacent to the SE Homes manufacturing facility in Russellville, AL (International Energy Conservation Code [IECC] Climate Zone 3) (Figure 2).

The houses varied only in the technologies being evaluated and were identical (floor plan, orientation, construction) except for the differences associated with the measures listed in Table 1 and Table 2. They were inspected during manufacture to ensure that the construction methods were consistent and uniform, and then operated for 15 months. Data was collected in order to assess the following strategies for reducing energy use:

Figure 2. Lab house floor plan (left) and site with test homes installed (right).

1. **Thermal envelope technologies.** The walls are built with a combination of batt and exterior rigid foam insulation, enhanced air sealing, and highly insulated low-slope roofs utilizing a new, dense-pack roof insulation technique.
2. **Site-installed heat pumps.** Site-installed, split-system heat pumps are used as required to qualify for ENERGY STAR designation. However, their contribution to energy-use reduction and the specific performance characteristics of heat pumps when used in HUD Code minimum homes had not been previously quantified through field study.
3. **Ductless mini-split heat pumps.** Ductless heat pumps can be fully installed and commissioned during home manufacture in the plant and transported to the site, ready for operation. They are used in place of a typical furnace and site-installed split-system air conditioner. Ductless heat pumps offer several advantages including: eliminating the need for ductwork and associated thermal losses; eliminating the need for a furnace closet; come as one packaged system that provides both heating and cooling and reduces mismatching of indoor-outdoor equipment; provide zoning flexibility in their ability to connect multiple indoor AHUs to one outdoor compressor; and, are quieter than conventional split system equipment. They also incorporate inverter-driven compressors and variable-speed fan technology, resulting in very high efficiencies of up to 27 SEER and 12.5 HSPF—much higher than standard heat pumps. Mini-splits also come in small capacities (as low as 9,000 Btu/h) appropriate for low-load buildings, such as small, highly efficient manufactured homes.

Table 1. Lab house thermal-enclosure specifications (see Levy et al. 2016 for more details)

Items	House A	House B	House C
Floor	R-14 fiberglass blanket	R-28 fiberglass blanket	R-28 fiberglass blanket
Wall	R-11 fiberglass batts, ¼-in sheathing (R-1) (perm rating >5)	R-13 fiberglass batts, ¼-in sheathing (R-1) (perm rating >5)	R-13 + 1-in. extruded polystyrene (XPS) (R-5) (perm rating 1.5)
Windows	U: 0.47, SHGC: 0.73; single-pane, metal frame	U:0.31, SHGC: 0.33, double-pane, vinyl frame, low-emissivity	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	Standard plant practice; 4.7 ACH50	Standard plant practice; 4.6 ACH50	Foam and tape penetrations, caulk top and bottom plates, gasket marriage line; 3.8 ACH50

Table 2. Mechanical equipment specifications

	House A	House B	House C
Cooling Equipment	Intertherm central AC Cooling capacity: 23.4 kBtuh SEER: 13.0	Intertherm heat pump: 35 kBtuh resistance backup Cooling capacity: 18 kBtuh/ SEER: 13.0 Heating capacity at 47°F: 20.2 kBtuh/HSPF: 8.0 Heating capacity at 17°F: 11.5 kBtuh	Mitsubishi mini-split heat pump assisted by temp.-controlled heaters when temp. falls below 69°F Cooling capacity: 15 kBtuh/ SEER: 22.0 Heating capacity at 47°F: 18 kBtuh/HSPF: 12.0 Heating capacity at 17°F: 11 kBtuh
Heating Equipment	Resistance heating capacity: 35 kBtuh		
Air Handling Unit (AHU)	NORDYNE electric furnace, down flow	NORDYNE electric furnace set to low speed	
Mechanical Ventilation	Fresh air duct to air handling unit, no mechanical damper; 44 cfm intermittent (14 cfm continuous equivalent)	Fresh air duct to air handling unit, no mechanical damper; 32 cfm intermittent (12 cfm continuous equivalent)	45 cubic feet per minute (cfm) exhaust fan
Space-Conditioning Distribution	Metal ducts sealed with mastic, R-8 crossover between home sections; duct leakage 54 cfm25 to outside	Metal in-floor ducts sealed with mastic, R-8 crossover duct between home sections; duct leakage 10 cfm25 to outside	Bedrooms 2 and 3: Tjernlund AS1 transfer fan, 21 W Master bed/bath: Tjernlund AS2 transfer fan, 33 W

Note that the home manufacturer, SE Homes, routinely builds ENERGY STAR homes so efficiency practices, such as routine envelop tightening, are applied to all homes, resulting in a baseline condition that is above industry average. As a result, shell leakage in Houses A and B were nearly identical. Therefore, on a comparative basis, House A is considered a best-practice manufactured home.

Operation

The homes were operated in an identical manner, including interior temperatures (71°F heating set-point and 76°F cooling set-point) and simulation of occupant loads.

Auxiliary electric resistance heaters were used to supply backup heat to the House C bedrooms and master bathroom. These heaters were tested with set-points of 69°F and 71°F with and without through-wall transfer fans in operation. The transfer fans in House C were set on independent thermostats in each room to which the fans delivered air. These thermostats were set to activate the fan at an upper set point of 76°F during the cooling season and at 69°F during the heating season. House C was also tested with the transfer fans operating continuously.

Sensible internal heat gain was simulated through the use of electric resistance heaters controlled by the data loggers. Latent internal heat gains can also impact energy consumption and comfort; however, internal latent loads were not simulated. A short-term humidification test was conducted in each home to assess the dehumidification capability of the equipment.

While a closed-door scenario was studied separately, the interior doors were kept open and blinds were kept at 50% closed for the majority of the testing period.

Measurements

The homes were monitored for 15 months with 1-min data uploaded on a daily basis. Air temperature was recorded at six locations in each home: in the crawlspace, attic, and in each room. Air temperature and relative humidity (RH) were measured both inside and outdoors at one location in each home. Power consumption of HVAC equipment and total house power were measured using power current transducers. Solar radiation was measured on-site.

Results

Cooling Season HVAC Energy

A representative cooling season period that exhibited a wide range of outdoor temperatures was selected for analysis (August 29-September 15, 2014). A plot of cooling power relative to ambient temperature for this period shows that House C used less cooling energy than the other houses did at outdoor temperatures in excess of approximately 75°F (Figure 3).

House A and House B have very similar cooling requirements. House B used slightly less cooling energy than did House A when temperatures rose above approximately 77°C. At lower temperatures, House A used less cooling energy than did House B. This inversion may have occurred because House A’s lower insulation values and higher ventilation rate allowed more natural cooling, whereas the better insulated House B held the heat longer. (Both homes had similar airtightness.) This was especially prevalent after sunset when the lower solar heat gain through the windows of House B no longer provided an advantage over House A.

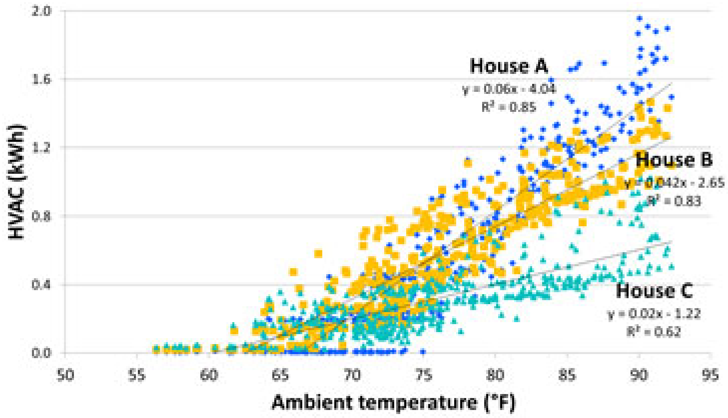

Figure 3. Cooling power relative to outdoor temperature for all three houses (Aug. 29-Sept. 15, 2014).

Table 3 summarizes the cooling performance of all three houses. During this summer period, House C used half the HVAC energy as did the other houses. House B used slightly less than House A did for cooling. Average indoor temperatures were similar and close to thermostat set-points. Average RH was slightly higher in House C, but within the acceptable limit below 60% (NREL 2006). During this period, House C's fresh-air ventilation rate was 3.5 times higher than that of the other houses (meeting the American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE] Standard 62.2-2010), which contributed to the higher RH. If ventilation rates in House A and House B were to have met the standard, the difference between the cooling energy consumption of House C and the others would have been greater.

Table 3. Cooling statistics (Aug. 29-Sept. 7, 2014)

	House A	**House B**	**House C**
Total cooling (avg. kWh/d)	15.0	14.5	7.4
Average indoor temp. (°F)	76.4	75.9	75.4
Cooling set point (°F)	76.0	76.0	73.0–75.0*
Avg. relative humidity (%)	39.0%	44.8%	52.5%
Maximum relative humidity (%)	43.8%	49.6%	59.7%
Air handling unit fan run time	31%	37%	100%
Ventilation—effective continuous rate (cfm)	14	12	45

* The mini-split thermostat was on a programmable schedule during the cooling period that allowed it to maintain an average temperature of 76°F throughout the house.

Heating Season HVAC Energy

Table 4 summarizes the initial heating performance of all three houses in November 2014. During this period, when average ambient temperature was 41.3°F, House C used 66% less heating energy than House A and 8% less than House B. House B used 63% less than did House A. Average indoor temperatures were slightly lower than the thermostat set-point in House B and House C. Average RH was similar in all three homes. During this period, House C's fresh-air ventilation rate was approximately four times higher than that of the other houses (meeting the ASHRAE Standard 62.2-2010).

Table 4. Heating statistics (average ambient temperature of 41.3°F) (Nov. 12–17, 2014)

	House A	House B	House C
Total heating (avg. kWh/d)	48.7	18.1	16.6
Avg. indoor temp. (°F)	71.3	69.9	69.5
Heating desired temp. (°F)	71	71	71
Avg. relative humidity (%)	28%	30%	33%
Air handling unit fan run time	22%	33%	100%
Ventilation—effective continuous rate (cfm)	10	11	45

As discussed below, bedrooms were not maintaining acceptable temperatures in House C. To compensate, resistance heaters with dedicated thermostats set to 69°F were added to those rooms. Table 5 summarizes the heating performance of all three houses from January 6–13, 2015, with the inclusion of resistance heat in House C.

Average indoor temperatures were close to the thermostat set-point in all houses. Average RH was similar in all three homes. During this period, House C's fresh-air ventilation rate was approximately two to three times higher than that of the other houses.

Table 5. Heating statistics with resistance heat in House C remote rooms (average ambient temperature of 32.6°F) (Jan. 6-13, 2015)

	House A	House B	House C
Total heating (avg. kWh/d)	66.6	32.3	31.8
Avg. indoor temp. (°F)	71.2	69.9	70.4
Heating desired temp. (°F)	71	71	71
Avg. relative humidity (%)	20%	21%	22%
Air handling unit fan run time	48%	47%	100%
Ventilation—effective continuous rate (cfm)	21	15	45

Figure 4 shows heating energy compared to ambient temperature. House B and House C used less heating energy than did House A at all outdoor temperatures. House B and House C used a similar amount of heating energy, but the trend lines indicate that as temperatures fell, House C used less energy relative to House B. At colder temperatures, the heating system in House B relied more on electric resistance and less on the heat pump, whereas House C's heat pump ran continuously due to its variable-speed technology (Figure 4). Monitoring of power revealed that House B's backup resistance heat turned on when the outdoor air temperature fell below approximately 40°F, and it increased with decreasing temperatures. During this period, the heat pump showed stable and limited energy consumption. The resistance heaters in House C were responsible for 46% of the total space-conditioning energy use during this time period.

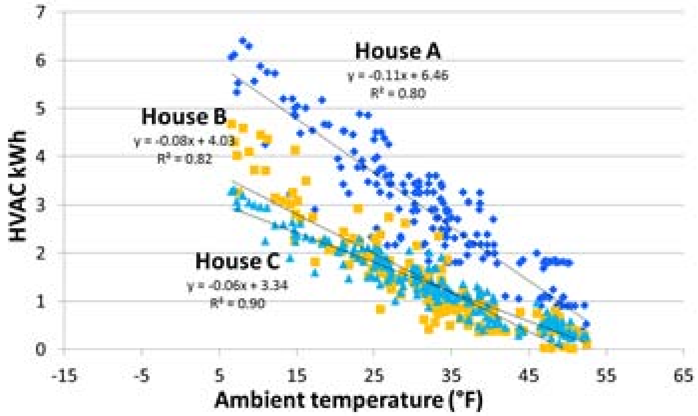

Figure 4. Heating energy compared to outdoor temperature for all three houses (Jan. 6-13, 2015).

Mini-Split Heat Pump Coefficient of Performance

Co-heating and air-side temperature measurement methods were used to calculate the COP of the House C heat pump. The COP was lower than expected based on manufacturer data (Table 6). One theorized cause was low fan speed and therefore low supply airflow. The fan speed had been set to auto-speed mode, in which the AHU automatically selects the fan speed based on internal logic. However, the fan operated at low power (5–7 W) and commensurately low speeds (164–190 cfm) all the time in this mode, even when the heating loads were high.

Table 6. Mini-split heat pump COPs at high and low fan speeds

		High fan	**Auto fan (low)**
Co-heat method	COP	4.11	2.49
	Avg. ambient temp.	36.8°F	30.7°F
Air-side method	COP	2.25	1.39
	Avg. ambient temp.	43.2°F	42.1°F
Manufacturer rating	COP	Approx. 3.5 (12.0 HSPF; fan speed unknown under rating conditions)	
	Ambient temp. for rating	47.0°F	

Forcing the fan to high speed (January 27-30) increased the COP to an average of 4.11 as measured by the co-heat method (Table 6), which accounts for building heat loss measured by the energy required by portable space heaters to maintain a constant elevated temperature. The high fan speed COP as measured by the air-side method (using supply- and return-air temperatures) also increased but not as dramatically (Table 6). It is possible that as airflows increased, the supply air temperature became less uniform across the outlet and the single-point air-side measurement did not capture a truly average reading. The average ambient temperature was 6.1°F higher during the high-speed period. Air stratification due to thermal buoyancy with higher return-air temperatures could have also contributed to low COPs.

Temperature Variation during Heating and Cooling Seasons

Cooling season temperature swing. For the most part, all three houses were successful in maintaining indoor temperatures within the range of ±3°F of the cooling set-point, as recommended by the Air Conditioning Contractors of America (ACCA 1997). House C showed the widest temperature fluctuation from one room to another, but only the master bathroom exceeded the upper bounds of the temperature range specified by ACCA. This room had the longest air pathway from the main living space and southern exposure.

Heating season temperature swing. Bedroom 2, Bedroom 3, and to a limited extent, the master bathroom struggled (sometimes unsuccessfully) to maintain 69°F in both House A and House B. The master bathroom and master bedroom in House C often fell well below the ACCA acceptable heating variation from the set point limit (+/- 2°F from the set point in heating) when the outdoor temperatures fell below approximately 50°F. It was therefore decided to add electric resistance heat to the bedrooms and master bathroom controlled on independent thermostats to maintain at least 69°F in those rooms.

After adding the resistance heat with the transfer fans running continuously, the bedrooms were still cooler than the main space (at or above the 69°F electric heat set point); however, the comfort metrics met the ACCA guidelines.

Building Envelope Thermal Performance

Short-term co-heat testing in cold weather using portable electric-resistance space heaters was conducted in all three houses to measure whole-house heat loss (Table 7). The test data were used to obtain envelope UA-value information that was used to tune simulation parameters. These data confirm that airtightness measures and more thermal insulation led to lower heat loss.

Table 7. Co-heat test results summary, including infiltration

	House A	**House B**	**House C**
Modeled heat loss (Btu/h/°F)	300	235	183
Heat loss per co-heat test (Btu/h/°F)	333	256	208

Moisture Levels within Assembly

One risk of adding exterior foam insulation (XPS) to House C was that the reduced vapor permeability could lead to higher moisture content in the wall cavity. To explore the potential for condensation within the wall cavities with exterior foam sheathing, air temperature and RH were measured in a cavity between the sheathing and interior fiberglass insulation on a north wall. The moisture content of a wood stud in the cavity was also measured at this same location.

Wood moisture content was slightly higher in House C, but it was still well within the safe limits of 19% (Forest Products Laboratory 2015). Additionally, the House C wall-cavity temperature was moderated by the exterior insulation, which resulted in a minimum temperature that was 5.5°F higher than it was in House B, mitigating condensation risk. Seasonal data followed expected trends—higher moisture in the summer and lower moisture in the winter. House C's moisture content tended to increase in the summer, consistent with higher overall humidity. House B had slightly higher readings in the winter. No moisture was added to simulate latent loads in the unoccupied houses. Because the homes were newly constructed in the plant, wood was not subject to wetting, but it could have had residual natural moisture.

Modeling-Based Performance Results in Three Climate Regions

Calibrated energy models were generated using the measured data and as-built features and were used to assess the impact of the primary measures on the test houses for three selected cities within the Tennessee Valley Authority's service territory. Simulations were performed using BEopt V 2.3.0.2 with the Energy Plus (version 8-3-0) engine.[1] The calibrated models account for internal gains due to people, lights, and appliances, as well as the transfer-fan energy use in House C. To assess the impact of the HVAC systems as compared to the envelope, Houses A and B were each modeled with (1) a split-system heat pump and (2) with an electric-resistance furnace and split-system AC.

From warmest to coolest, the climate locations tested were: Columbus, MS; Knoxville, TN; and Bowling Green, KY. All three climates showed similar trends (Knoxville results shown in Figure 5): House A with the electric resistance furnace (A1) used the most space-conditioning and ventilation energy, followed by House B modeled with an electric furnace (B1). The conventional heat pump models of Houses A and B (A2 and B2) were next in consumption. Model C had the least space-conditioning/ventilation consumption—generally less than half that of A1 and 20% to 35% less than the next most efficient model, B2. Compared with House A1, House C saved 15 MMBtu/yr of space-conditioning energy, and 20 MMBtu/yr in site energy.

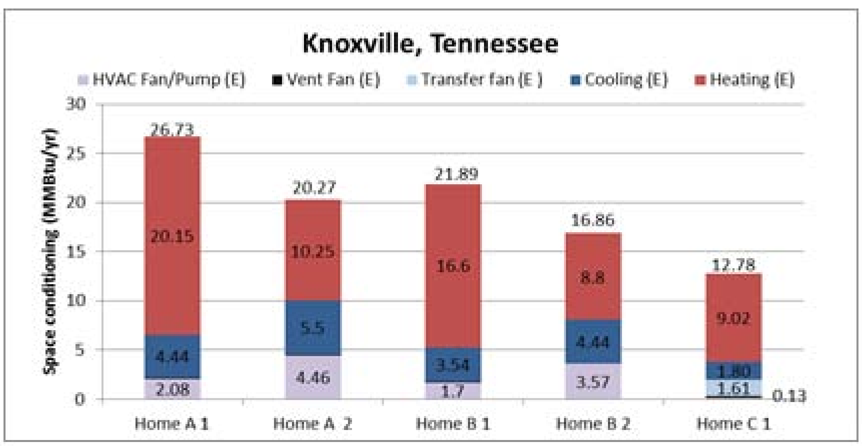

Figure 5. Modeled annual space-conditioning energy use comparison, Knoxville, TN.

Cost Analysis

The total incremental cost to the builder to build House C compared to House A was approximately $2,500. This figure includes non-energy-related measures required to comply with ZERH criteria (gutters, ventilation fans, and carbon-monoxide alarms). This translates to $6,600 in incremental costs to the retail home buyer. Excluding the non-energy-related ZERH items, the customer premiums to build House C compared to Houses A and B were $5,843 and $3,575, respectively. Modeled energy savings and payback for Knoxville, TN are shown in Table 8.

[1] Calibration error was generally within 1%, although House A had a 9% error during the heating season.

Table 8. Energy savings and payback—Knoxville, Tennessee

		Compared to House A			**Compared to House B**		
House	Annual Cost	Savings	Incr. Cost	Payback (yr)	Savings	Incr. Cost	Payback (yr)
A	$1,656	N/A	N/A	N/A	N/A	N/A	N/A
B	$1,263	$393	$2,268	5.8	N/A	N/A	N/A
C	$1,055	$601	$5,843	9.7	$208	$3,575	17.2

The energy savings from House C compared to House B was highest in the warmest climate (Columbus). House B and House C showed payback periods that ranged from 4.9 to 9.7 yr across the climates compared to House A. In Bowling Green, House C achieved the largest savings ($664/yr) compared to House A. The ENERGY STAR home (House B), had the shortest payback period in all climates compared to House A. Figures are based on current pricing and do not capture volume cost reductions that would be realized if Home C were in routine production.

Additional Findings

Sensitivity studies performed on the Russellville homes highlighted other factors that potentially impact results. Closing window blinds, for example, reduced cooling needs by a measured 36.9%, 20.4%, and 25.7% in House A, B, and C, respectively. The higher savings in House A is theorized to be due to the higher SHGC in House A's windows.

Door position was crucial to performance in House C. Keeping interior doors open decreased the temperature difference between rooms by 4°F during the heating season. This speaks to the importance of the transfer fans. Additionally, although latent loads were not simulated during the testing, the placement of humidifiers in each house injecting water vapor into the air at 200 gram/hr for a full summer day demonstrated the ability of each house's cooling equipment to maintain stable humidity levels at standard latent loads (NREL 2010).

Conclusions

Using the methods described in this research, Zero Energy Ready design becomes a realistic path for manufactured housing in terms of both energy savings and price. House C was successfully built in compliance with the HUD Code and with 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. Similar to site-built homes, ZERH criteria for these test homes can save both heating and cooling energy, but the price premium to meet all program requirements increases the payback period. The simple payback for Zero-Energy design versus the HUD code standard is less than 10 years in the locations tested. The preliminary results indicate that it may be possible to maintain acceptable moisture levels within the ZERH envelope using exterior foam sheathing, although future tests with simulated latent loads are necessary.

Mini-split heat-pump technology, combined with a high-performance building envelope, is shown here to reduce space-conditioning energy use by half as compared to a HUD-code home. Its cost premium as compared to the furnace/AC system, including air distribution, was measured to be $1,735. When combined with a high-performance envelope (a total $2,500 cost premium), at least $600 in energy costs are recovered annually in the climate zones tested. Notably, equipment improvements had a larger impact than did envelope improvements.

Point-source space conditioning with mini-split heat pumps shows the potential to meet high thermal- and comfort-performance standards in manufactured homes, but operational settings and air distribution must be designed and tuned properly to avoid temperature stratification and excess use of resistance heat.

Future Work

In addition to continuing to investigate space conditioning and air distribution techniques, the team has built a home in Eatontown, NJ. That home will be used to explore solutions to the issues encountered in the Russellville study and start to address the effect of occupant behavior. Tests will be conducted for a 6-month unoccupied period followed by a 12-month monitored occupied period. This new location also means additional data for a cold climate.

References

ACCA (Air Conditioning Contractors of America). 1997. Manual RS: Comfort, Air Quality, and Efficiency by Design. Arlington, VA: Air Conditioning Contractors of America.

Chasar, D., N. Moyer, S. Chandra, L. Rotvold, and R. Applegren. 2004. "Cold Climate Case Study: High-Efficiency North Dakota Twin Homes." Performances of Exterior Envelopes of Whole Buildings IX International Conference. Atlanta, GA.

Chasar, D., V. vonSchramm, J. Sherwin, and S. Chandra. 2010. "Measured Performance of Side-by-Side South Texas Homes." ASHRAE Transactions. http://www.ba-pirc.org/pubs/pdf/3cps-homes_B11.pdf

Forest Products Laboratory. "Frequently Asked Questions (FAQs)." U.S. Department of Agriculture. Accessed August 27, 2015. http://www.fpl.fs.fed.us/faqs/index.shtml

FSEC (Florida Solar Energy Center). 2004. "Optimizing Manufactured Housing Energy Use." Symposium on Improving Building Systems in Hot and Humid Climates. Richardson, TX.

Gehl, A., J. Munk, P. Boudreaux, R. Jackson, and G. Khowailed. 2012. "Tennessee Valley Authority's Campbell Creek Research Homes Project: FY 2012 Annual Performance Report." Prepared by Oak Ridge National Laboratory for: U.S. Department of Energy.

Levy, E., J. Dentz, E. Ansanelli, G. Barker, P. Rath, and D. Dadia. "Field Evaluation of Advances in Energy-Efficiency Practices for Manufactured Homes." Unpublished manuscript, last modified March 4, 2016. Prepared for: U.S. Department of Energy's Building America Program.

NREL (National Renewable Energy Laboratory). 2006. "Building America Residential System Research Results: Achieving 30% Whole House Energy Savings in Mixed-Humid Climates." Golden, CO: U.S. Department of Energy.

NREL (National Renewable Energy Laboratory). 2010. Building America House Simulation Protocols. Oak Ridge, TN: U.S. Department of Energy.

Pacific Northwest National Laboratory. "Welcome to the PNNL Lab Homes!" U.S. Department of Energy. Revised February 2016. http://labhomes.pnnl.gov/

U.S. Department of Housing and Urban Development. 2010. Manufactured Home Construction and Safety Standards. Washington, DC.