Not Your Parents' Mobile Home

Some scientists and builders of manufactured homes figured out how to make them more energy efficient, using new materials but the same old factory.

by Michael Baechler and Don Hadley

Manufactured housing constitutes 20%–30% of new housing across the United States. Because of its sheer volume and the opportunity for factory replication, efforts to improve energy efficiency in manufactured housing can pay big dividends. However, the same factories that represent automated efficiency also represent fixed costs that do not easily adjust to accommodate varying levels of demand. The incorporation of structural insulated panels (SIPs) into manufactured housing helps with both issues. It makes for a more efficient building envelope, and it may allow for more efficient management of production capacity. (For more on SIPs, see "The Lowdown on Structural Insulated Panels," *HE* Jan/Feb '02, p. 38. Some problems with manufactured housing were covered in "Moisture Problems in Manufactured Housing," *HE* Mar/Apr '02, p. 24.)

In June 2000, Champion Enterprises built the first HUD code-approved manufactured home using SIPs. The demonstration house—named Concept 2000—was built as part of a partnership among Champion, Premier Building Systems, Precision Panel Structures, and the U.S. DOE's Building America program. DOE's Pacific Northwest National Laboratory, (PNNL), where we work, coordinated the project and conducted long-term monitoring of the house.

In designing the project, we were as interested in the production line as we were in the house itself. Specifically, there were three key production questions that we wanted to see answered:

• Could the production line support SIPs without major modifications?

MICHAEL BAECHLER

• Could the line work in parallel with SIPs and traditional materials?

• Would using SIPs result in time saving that would translate into increased capacity?

For the manufacturer, a key motivation was to determine if SIPs could increase plant capacity at times of high product demand.

Project Planning and Preparation

We chose the house design for its simplicity, but not as an optimized SIP home (see Figure 1). Although cost was one element, this one-time demonstration house does not provide a basis for economic analysis. Design decisions and engineering issues were resolved over a three-year period. The Oregon Office of Energy certified the plans as being in compliance with Super Good Cents (SGC) and Energy Star programs. Preliminary DOE-2 model simulations indicated that the SIPs home would use about 50% less energy than a home built to minimum HUD standards.

The following key design elements are unique to this project:

• Floor panels are 6 inches thick and 4 ft wide by nearly 14 ft deep; 2 x 6 splines are used to connect the floor panels.

• Wall panels are 6 inches thick and 8 ft (vertical) by up to 22 ft (horizontal).

• Wall panels are connected with studs, because most breaks came at major openings for doors and windows. Panels are available in lengths up to 24 ft.

• Roof panels are 8 inches thick and 4 ft wide by about 14.5 ft deep. Roof panels are connected using two 7/16-inch OSB splines at each seam.

• The house is designed for a perimeter foundation system, so the floor must cantilever off the chassis.

Because the floor of the concept 2000 house cantilevers off the chassis, we were concerned whether the SIPs could provide enough structural support during transport. We also wanted to know how SIPs would respond to outriggers angled from the perimeter to the bottom of the chassis. Precision Panel conducted tests to measure deflection of the SIPs over the cantilever. The tests showed modest bowing, and engineering tables indicated that the panels could function using OSB splines. However, to be conservative, and to allow for attachment of the chassis, which was lag-screwed into the splines, we used 2 x 6 splines in the floor.

Some analysts suggested that using SIPs in manufactured homes would require (or perhaps would present an opportunity for) redesigning both typical

Concept 2000 Floor Plan

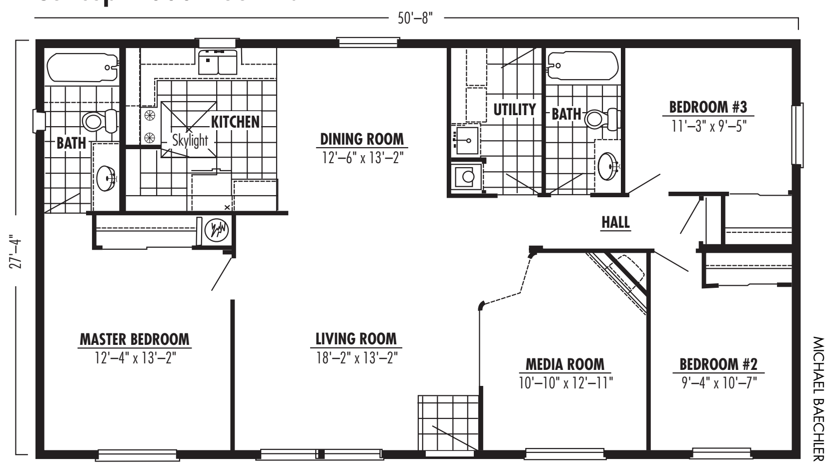


Figure 1. The design of the Concept 2000 house was chosen for its simplicity. The 1,456 ft^2 house that is laid out here went from the drawing board, to the factory, and then on a 300-mile road trip.

SIPs construction and the manufactured home chassis. We identified several potential problems in both areas and made recommendations to alleviate them. One concern was that SIPs might be too rigid to carry the weight of the structure during transport, and that the walls would carry much of the load and might fail without structural reinforcement. Other suggestions included the need to install reinforcing beams in sidewalls, the need to reinforce the openings in the marriage wall, the need for additional shear support to keep sidewalls from twisting, and the need to add structural brackets under the walls to carry loads to the chassis.

With proper reinforcement, the SIPs floor could be made to act as the chassis, eliminating the need for steel I beams under the house. The team did not attempt to design the house to eliminate the traditional chassis, but the idea could be further explored.

Although we discussed these structural concerns at length during planning, none of them turned out to be a problem. Transportation aside, SIPs provided about twice the structural strength required by the HUD code. (See "Transportation Test" to learn how the SIPs house fared on the road.)

Twelve Days to Finish

The Concept 2000 house was built at Champion's Redman Homes factory in Silverton, Oregon. Construction began on June 16, 2000. The envelope was completed (without windows and doors), along with the interior walls and furnishings in about 3 days. The remaining elements—windows, doors, skylight, exterior siding, interior finish mudding, interior trim, and interior and exterior paint—were completed in 9 days, which included a 300-mile transportation test. The house was set up on the factory lot for tours on June 28. Time from start of construction to setup (including the road test) was only 12 days, close to the 14 days it takes for a typical new order to be delivered to a customer.

Manufactured homes at the Redman factory begin their lives upside down and are built inside out as compared to site-built homes. Here are some of the experiences, and some conclusions that we drew from the production process.

Floor production. The floor was assembled upside down. Ductwork, plumbing, and electrical lines were installed. A belly wrap covered the bottom side of the floor, and the chassis was attached. The floor was then hoisted into the air and flipped right side up. This maneuver was conducted using

Transportation Test

Like most new models, the Concept 2000 house underwent a 300-mile road test over a variety of two-lane and interstate highways. Homes undergoing this test, or being transported for setup, are usually made more roadworthy with corner and vertical bracing. No such bracing was included in the Concept 2000 house.

An inspection after the road test found broken tree branches and crushed cherries inside the house. We can't be sure exactly what happened, but clearly the test route came close to cherry orchards. The road test also included one other variable. On one unit, one side of the chassis experienced blown-out tires. This is not uncommon. When one tire blows out, weight is shifted to the remaining tires, forcing them to blow out as well. Each unit had four axles. It is safe to say that many of the bumps and stresses that we envisioned in early structural design discussions occurred during the test.

The best performance indicator for road testing is the number of drywall cracks that develop during the test. This measure is difficult to quantify, because cracks may result from other than structural issues, such as blown-out tires. Problems with tape and texture finishes are the number one field repair identified by the Oregon Codes Division (OCD), which serves as the In-Plant Primary Inspection Agency (IPIA) in Oregon (Building Codes Division 2001). As the IPIA, OCD provides the factory inspections and certifications required by HUD. HUD also funds OCD to respond to consumer complaints.

The SIPs house performed well on the transportation test. First of all, it stayed together; it did not experience structural failure. Secondly, in spite of the lack of bracing, there were not many drywall cracks. An OCD inspector examined the Concept 2000 house during setup on the factory lot and agreed that it had far fewer cracks than would be expected in a typical manufactured home—especially on the outside walls and in stressed areas, such as above doors and windows.

MICHAEL BAECHLER

The Redman factory's first workstation is for floor layout. This photo shows the roughly 4 foot by 14 foot floor panels being assembled with 2 x 6 splines between the panels.

MICHAEL BAECHLER

Work continued on interior components such as flooring, interior walls, plumbing, and electrical while the exterior walls and roof were being prepared.

Table 1. Comparison of House Tightness

Description	Reported	Sample Size	EE/ SP*	Year Built	ACH
Northwest Survey	1992	21	SP	1965–80	14.30
Northwest Control Group	1992	29	SP	1989	8.75
Eugene, OR	1998	1253	SP	1959–89	12.10
Eugene, OR	1998	187	EE	1990–97	10.10
SGC, ID	2000	25	EE	1997–98	4.60
WSU Energy House	2000	1	EE	1996	2.40
Florida	1998	21	SP	1974–86	12.60
New York	1996	6	SP	1994–95	10.20
North Carolina	1996	8	SP	1994–95	12.00
Concept 2000	2002	1	EE	2000	3.50

*energy efficient (EE) and standard practice (SP)

overhead cranes and was seen as the first structural test of the SIPs. After the floor was flipped, a chalk line was taken. Less than $^1/_8$-inch variation was found in the floor from front to back, a distance of nearly 51 ft.

The top of the floor then became the focus of activity. The $^7/_{16}$-inch OSB skin on the SIP was sanded for the direct application of flooring—no additional subflooring was installed. Work continued on plumbing and electrical, and cabinets and fixtures were set near their destinations.

Interior walls. One small hitch in the production run came from the interior cathedral peak, which was more than 11.5 ft high. The walls were so tall that they needed extra bracing as the assembly line pulled the house along.

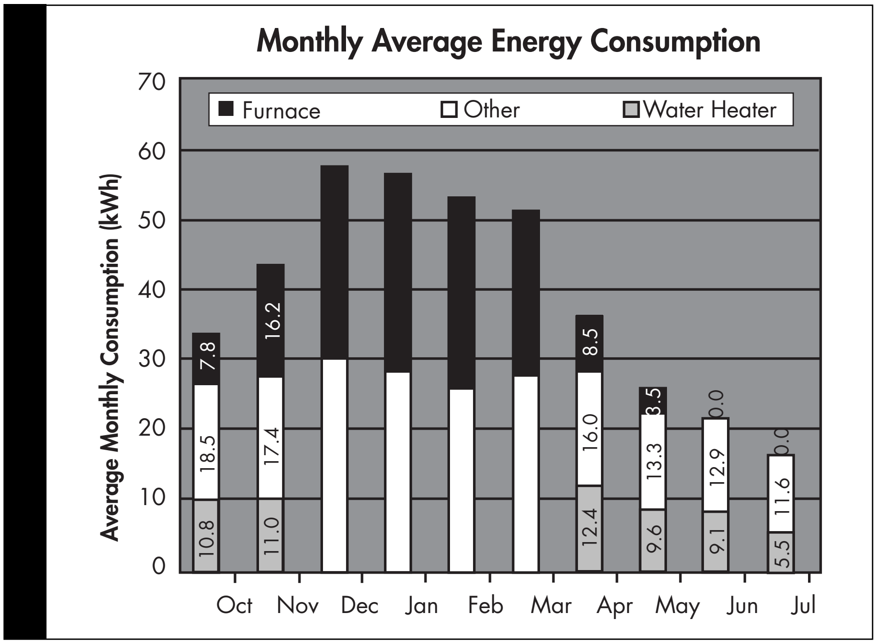
Exterior walls. Exterior walls were installed using overhead cranes. Both interior and exterior walls came to the main assembly line with Sheetrock and initial mud already installed.

Roof. The roof assembly was also installed using an overhead crane. The center beam on the ceiling was heavier than anticipated, and lifting the roof assembly required some experimentation to reach the proper balance point. Sheetrock and initial mud were installed on the ceiling before the roof was placed on the house.

Insulation is typically installed before wall assemblies come to the assembly line. Roof insulation is blown in afterward, as is floor insulation. None of the blanket or blown-in insulation was needed in the SIPs house except for the wrapping of ducts that were installed under the floor. These ducts were insulated to a minimum of R-5. The production crew took care to glue and seal the SIP assemblies and to seal all penetrations through the envelope. Jacks were used to keep the floor level as wall and roof assemblies were dropped into place. Overextending a jack can cause pressure in wall and roof assemblies that can later create cracks in the plaster. The production team believes that this happened in one instance in the SIPs house.

The two halves of the SIPs house building shell took about 6 hours longer to build than a typical manufactured home building shell. However, all the time was lost when the first half of the house went through the production line. The second half came through much faster. Of course there weren't as many experts, photographers, and observers to slow down the second half; and the factory crew had learned much from putting the first half together. Keeping the house moving down the assembly line was very important because slowing things down costs the factory money.

Champion production managers concluded that if storage were available in the factory, SIPs construction and standard construction could take place side-by-side. Dedicated facilities would not be needed. SIPs could be offered as a



MICHAEL BAECHLER

Figure 2. The Concept 2000 house, when installed and occupied in western Washington, uses about half of the energy of a HUD code manufactured home.

consumer option without disrupting traditional production lines. Some steps, such as blowing in roof insulation, would be skipped on the SIPs houses; however, these workstations would be needed for typical construction and so could not be eliminated in a side-by-side factory.

Champion engineers believe that, ultimately, SIP construction could lead to a 10% increase in capacity at production facilities. Taken together with the last point, SIPs could give manufacturers flexibility in meeting demand in a growing market without requiring investment in new facilities. Champion noted that the Concept 2000 house used 60 panels compared with more than 1,000 parts typical of traditional framing. In making this comparison it should be noted that the engineering and approval process in typical manufactured housing has taken value engineering concepts to their zenith. There isn't much room for improving on the typical design and manufacturing, so SIPs construction is a way for manufacturers to meet structural requirements with less lumber and therefore less expense.

Well-Sealed and Ventilated

The house is now occupied. It is situated in western Washington, in a climate similar to that of Portland, Oregon, and Olympia, Washington. The homeowners allowed us to conduct building diagnostic tests and to install long-term energy monitors. Two adults occupy the house. One works during the day and is off weekends, and one works swing shift and often works weekends with days off during the week.

Fan depressurization tests conducted on the SIPs home when it was temporarily set up on the factory lot found 4 ACH at 50 Pa of pressure. Tests conducted after permanent setup showed the house to be slightly tighter, at 3.55 ACH at 50 Pa. This difference may be explained by the fact that the setup on the plant lot was temporary, and sections were not taped and textured or as well sealed at the marriage line as they were during the final on-site installation. Depending on the climate, shielding, and terrain factors, 4 ACH at 50 Pa may result in average seasonal ventilation rates of 0.16 ACH. The tighter measurement found at the permanent site results in 0.14 ACH of infiltration. Smoke stick tests conducted on-site found typical leaks at window and skylight rough openings, supply duct registers, and plumbing fixtures.

This SIPs home is tighter than the average of 49 randomly selected SGC homes built in 1997 and tested in 2000. The SIPs home is over twice as tight as the average of 29 non-SGC current-practice manufactured homes, which averaged 8.75 ACH_{50} in tests done in the early '90s. (See Table 1 for the results of manufactured home blower door testing throughout the United States.)

The home has a 100 CFM kitchen exhaust fan, a 50 CFM bathroom exhaust fan, and an SGC-approved, whole-house exhaust fan in the central hallway. Whole-house exhaust fan flow tests indicated 104 CFM, which is twice the 0.035 CFM/ft^2 HUD code and SGC requirement for whole-house ventilation capacity for this 1,456 ft^2 home. The whole-house fan provides a maximum of 0.46 ACH mechanically. This mechanical ventilation

Further Innovations

Energy-efficient manufactured homes require downsized heating and cooling systems. These could cut costs in existing programs such as SGC, as well as in SIPs homes.

Combined exterior siding and SIP sheathing could also cut costs. SIP manufacturers are currently testing a Louisiana Pacific product that holds promise. Premier has developed a thinner-skinned SIP that was used for a post office roofing project. Thinner skins reduce weight and costs and could be applied to manufactured housing where HUD code-required structural loads are typically less than for site-built homes.

Panel manufacturing could be incorporated into manufactured home factories. Panel preparation could run the gamut from on-site modification of existing panels (cutting out windows) to actually producing panels.

Ducts in the Concept 2000 house were located beneath the floor. Although insulated, these ducts would be much more effective if they were located in conditioned space or eliminated. One easy way to accomplish this would be to build a chase in the ample peak of the cathedral roof.

MICHAEL BAECHLER

The Concept 2000 house was set up on the factory lot. Tests found the house among the tightest and stingiest ever built.

does not include natural leakage or infiltration induced by supply duct leakage when the heating system operates.

A Trio of Energy End Uses

Installation of the metering equipment in the SIPs home was completed in late September 2001. The data logger used was an electrical metering system capable of recording power and energy use. The particular logger installed in the SIPs home was configured with four power input channels, four digital input channels, and four analog signal input channels. Communication with the logger is via a dedicated phone line installed specifically for this purpose.

The energy end uses metered were (1) building total, (2) electric furnace, and (3) electric water heater. In addition, an "Other" end use category representing all other energy consumption in the home, such as lighting and plug-in appliances, was calculated as the difference between the building total and the sum of the furnace and the water heater. Room air temperature was recorded in the laundry room near the furnace system's return air register.

We collected data for analysis from September 27, 2001, through July 31, 2002. During this period, which spanned almost a year, the total energy consumption was 13,212 kWh, split among the major end uses as follows: 33% for the electric furnace, 28% for the electric water heater, and 39% for the Other end use category. This amounts to 4,360 kWh, or 3 kWh/ft^2 for heating. (Monthly energy consumption for each of the three end uses is shown in Figure 2.) The 33% heating fraction compares with a national average of 50% for all homes, 46% for manufactured homes, and 37% for SGC manufactured homes.

As can be seen, the water heater and the Other end uses do not vary significantly between months. However, as expected, the furnace use ramped up during the fall and was relatively constant during the three winter months (December through February). Furnace use ended in mid May. During the heating season, the furnace was on 24 hours per day.

It is difficult to compare energy use without a carefully designed control house. However, a 1995 study by David Baylon, Bob Davis, and Larry Palmiter estimated, based on electric bills, that the annual heating requirements for a 1,337-ft^2 SGC manufactured home in the same climate zone as the Concept 2000 house would be 5,700 kWh per year, or 4.2 kWh/ft^2. The total annual energy consumption would amount to 15,200 kWh. This same study showed in an engineering analysis that a hypothetical HUD code home in the same climate zone as the Concept 2000 house would consume 8,400 kWh per year for space heating. An SGC manufactured home in that climate zone would consume 4,700 kWh per year. Last heating season had 93% of the heating degree days of a typical year, which could explain some of the reduced energy consumption.

A Great Fit

The Concept 2000 house demonstrates that SIP materials and building techniques can be readily adapted for the manufactured housing industry. These materials performed well on the production line and resulted in a structure that stood up well to transportation. SIPs construction could take place in tandem with more traditional framing if adequate storage is available at the manufacturer's facility.

On-site depressurization tests found a very tight house, near the bottom of levels found in U.S. manufactured homes. Long term energy monitoring is ongoing, but to date demonstrates a house performing as predicted, at about 50% of energy consumption of manufactured homes meeting minimum HUD code. (See, "Further Innovations" to learn how the SIPs manufactured home could perform even better.)

Although the Concept 2000 house is compared with traditional manufactured homes for cost purposes, it outperforms typical homes both structurally and in reduced energy consumption.

Michael Baechler and Don Hadley are program managers at the Pacific Northwest National Laboratory (PNNL), in Richland, Washington. PNNL is a U.S. DOE science and technology center that conducts breakthrough research in the areas of fundamental science, national security, environment, and energy.

Our thanks to the Oregon Office of Energy, which conducted blower door and Duct Blaster tests on the house while it was temporarily set up on the factory lot. The Washington State University Energy Program conducted similar tests at the house's permanent site.

For more information:

To learn more about this project, go to www.buildingamerica.pnl.gov.

Monitoring data for the Concept 2000 house can be found on the Florida Solar Energy Center's Web site dedicated to energy monitoring, www.infomonitors.com/sip.