ENERGY EFFICIENT
INDUSTRIALIZED HOUSING
RESEARCH PROGRAM

SUMMARY
FY 1995 RESEARCH ACTIVITIES

UNIVERSITY OF OREGON
AND
UNIVERSITY OF CENTRAL FLORIDA

ENERGY EFFICIENT INDUSTRIALIZED HOUSING RESEARCH PROGRAM

SUMMARY OF FY 1995 RESEARCH ACTIVITIES

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U.S. Department of Energy Contract No. DE-FC51-94R020277

June 1996

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1.0 EXECUTIVE SUMMARY

This report summarizes research results from March 1995 to February 1996 for the Energy Efficient Industrialized Housing Research Program.

One of our research focuses was stressed skin insulating core (SSIC) panel construction. SSIC panels, which carry their loads entirely through their skins, are of interest because they eliminate thermal bridging caused by studs and they easily form airtight construction reducing air infiltration. Working with a group of nonprofit developers and panel manufacturers, we have designed a SSIC panel, solar heated 1040 s.f. entry level house that costs $55,000 and uses 10% less energy than allowed by the stringent Oregon code. We are preparing a set of documents for nonprofits which includes construction documents with several variations of the house, marketing and financing information, and drawings for panel manufacturers. Working with industry partners, we have also designed and constructed scale and full-size models of an on-grade SSIC panel floor and foundation system. The system has been estimated to cost less than a concrete slab (the cheapest floor/foundation system currently in use) with superior thermal performance. In collaboration with three industry partners, we have completed structural tests on SSIC panels with fiber reinforced gypsum board interior skins. By substituting fiber reinforced gypsum board for the oriented strand board and conventional drywall layers currently used, we are able to reduce panel costs by 15% while maintaining both structural and thermal performance.

Closed wood frame panels, those shipped to the site with windows, siding, insulation, vapor barriers and gypsum board installed, are more energy efficient than open panels, those shipped to the site with only windows and siding. We surveyed panel manufacturers (40% of all residential construction is panelized) and determined that only 6% of them build closed panels. Through interviews and additional surveys we identified barriers to increasing the market for closed panels and developed a program for overcoming those barriers.

In collaboration with Softdesk, a large vendor of computer software, and Pacific Northwest National Laboratories, we developed and marketed Softdesk Energy, a module within Softdesk's CAD program, Auto Architect. Softdesk Energy interprets the drawings that architects and builders prepare and automatically inputs areas for walls, roofs, windows, etc. eliminating the need to reenter this information and thereby making the energy design process easier, faster and more accurate.

A key to convincing manufacturers to try energy efficient ideas is to convince them that the proposed design changes will not reduce their production efficiency. We have developed simulation software that enables manufacturers to see the impact of design changes on the production process before making costly production changes. As a result of our dissemination efforts we have had inquiries from some 50 manufacturers and have demonstrated the software to many more manufacturers at conferences. The software was also demonstrated in considerable detail to several industrialized home builders and housing industry suppliers who see simulation as a tool to facilitate the introduction of advanced manufacturing technologies.

In our constructability lab we focused on the development of a bay window which addressed the problems of air infiltration, cold feet complaints and framing complexities. We developed a new design which used triangular roof trusses from which the bay window's floor was hung. The design has better thermal integrity, is easier to construct, and can be added to the building at any stage in the construction process.

We have completed a number of component and whole house tests including the energy monitoring of the Springfield SSIC Panel Demonstration house, which is performing as expected with low amounts of energy used for heating. A similar house design built in Michigan has been tested and also shows low energy use for heating.

Recently HUD changed its ventilation standards for manufactured housing. We interviewed manufacturers in the South to see how they were meeting the new ventilation requirements and have begun field monitoring of ventilation systems to see if they are performing as required. We have discovered several problems that should be addressed by HUD code manufacturers.

In collaboration with local affiliates of the American Lung Association we have constructed and tested two Health Houses®, one in Orlando, Florida, and one in Minneapolis, Minnesota. These houses have been featured in *Professional Builder Magazine* and *Better Homes and Gardens*. Health Houses® feature airtight energy efficient construction with excellent air distribution, whole house dehumidification, ventilation, high efficiency filtration and interior furnishings and finishes with low levels of VOC. It is expected that Health Houses® will significantly benefit the 20 percent of the population who suffer from allergies and asthma. Testing is in progress to evaluate the allergen levels in Health Houses® and comparable control houses. New Health Houses® are currently under construction in New Orleans, Louisiana; Birmingham and Huntsville, Alabama; and in Jacksonville, Florida. We are actively involved in the design and monitoring of these houses.

We have also been working with the Energy Smart Corporation to improve the design of their houses and to monitor the performance of their houses. Through our newly established Residential Energy Efficient Design and Development Advisory Center (REDAC) we have been advising Habitat for Humanity affiliates throughout the United States on how to improve the energy performance of their houses.

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2.0 INTRODUCTION

The United States' housing industry is undergoing a metamorphosis from hand-built to factory-built products. Virtually all new housing incorporates manufactured components; indeed, an increasing percentage is totally assembled in a factory. The factory-built process offers the promise of houses that are more energy efficient, of higher quality, and less costly. To ensure that this promise can be met, the U.S. industry must begin to develop and use new technologies, new design strategies, and new industrial processes. However, the current fragmentation of the industry makes research by individual companies prohibitively expensive and retards innovation.

This research program addresses the need to increase the energy efficiency of industrialized housing. Two universities have responsibility for the program: the University of Oregon (UO) and the University of Central Florida (UCF). Together, these organizations provide complementary architectural, energy, systems engineering, computer science and industrial engineering capabilities.

The research program focuses on three interdependent concerns: (1) energy use, (2) industrial process, and (3) housing design. Building homes in a factory offers the opportunity to increase energy efficiency through the use of new materials and processes, and to increase the value of these homes by improving the quality of their construction. Our work in housing design strives to ensure that these technically advanced homes are marketable and will meet the needs of the people who will live in them.

Energy efficiency is the focus of the research, but it is always viewed within the context of production and design. This approach enables researchers to solve energy problems in ways that can help industry improve its product. These improved products will help U.S. companies compete with foreign companies, which would alleviate the trade imbalance in construction products, will increase the productivity of the U.S. housing industry, and will decrease both the cost of housing and the use of fossil fuels, which are expensive and damaging to the environment.

3.0 DEFINITIONS

Of the many definitions currently used to describe industrialized housing, we have selected four:

(1) **HUD code** houses (mobile homes)
(2) **modular** houses
(3) **panelized** houses (including domes, precuts, and log houses)
(4) **production-built** houses (including those that use only a few industrialized parts).

These four definitions were selected because they are the categories used to collect statistical data, and so are likely to persist. However, the categories are confusing because they are based on a mix of characteristics: unit of construction (modular, panelized), method of construction (production-built), material (panelized), and governing code (HUD Code).

There are other ways to categorize industrialized housing, each of which provides a different perspective on the energy use. Japan and Sweden, for example, define industrialized housing in terms of corporate structure. Industrialized housing is equated with home building companies. These companies vertically integrate or have under one roof all or most of the housing process, including raw material processing, component assembly, house construction, installation, financing, marketing, and land development. This definition is useful because it addresses the extent of control a given company has over the design, production, and marketing of the house, and therefore over its energy use.

Other definitions can shed light on important aspects of industrialization and enable us to predict the impact of innovations, establish priorities for research activities, and identify targets for information. For example, industrialized housing can also be defined as to whether it uses open or closed systems. A closed system, which limits design alternatives, has the potential to benefit its supplier because it is exclusive. An open system, by contrast, is more tolerant of a wide range of designs and gives the home owner a range of component choices and the opportunity to purchase these components in a more competitive market place.

Other important ways of categorizing include 1) the level of technology employed --high, intermediate, or low; 2) the percentage of value that can be supplied by the home owner, using sweat equity; 3) the physical size of the elements--components, panels, cores, modules, or complete units.

HUD Code Houses

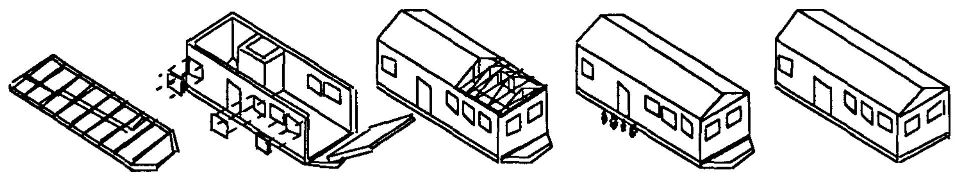


Figure 3 - 1
HUD Code House

A HUD code house is a movable or mobile dwelling constructed for year-round living, manufactured to the preemptive Manufactured Housing Construction and Safety Standard of 1974. Each unit is manufactured and towed on its own chassis, then connected to a foundation and utilities on site. A HUD code house can consist of one, two, or more units, each of which is shipped separately but designed to be joined as one unit at the site. Individual units and parts of units may be folded, collapsed or telescoped during shipment to the site.

Modular Houses

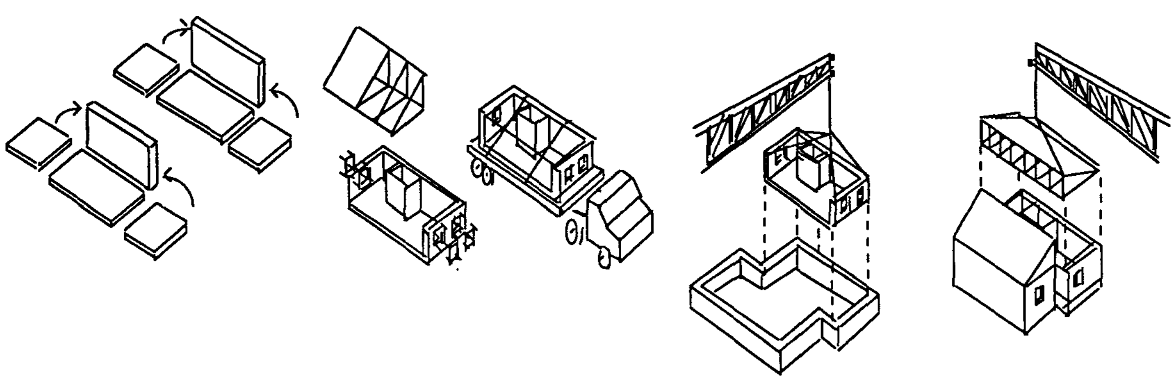


Figure 3 - 2
Modular House

Modular housing is built from self-supporting, three-dimensional house sections intended to be assembled as whole houses. Modules may be stacked to make multistory structures and/or attached in rows. Modular houses are permanently attached to foundations and comply with local building codes.

Panelized Houses

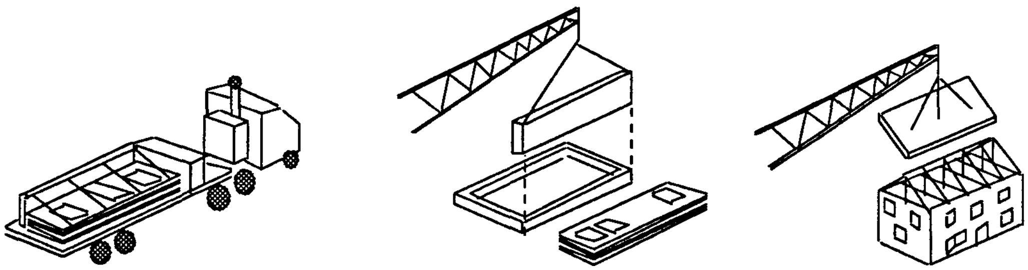


Figure 3 - 3
Panelized House

Panelized houses are whole houses built from manufactured roof, floor and wall panels designed for assembly after delivery to a site. Within this category are several sub-categories. *Framed panels* are typically stick-framed, carrying structural loads through a frame as well as the sheathing. *Open-framed panels* are sheathed on the exterior only and completed on site with interior finishes and electrical and mechanical systems. *Closed-framed panels* are sheathed on both the exterior and interior and are often pre-wired, insulated and plumbed. *Stressed-skin panels* are often foam filled, carrying structural loads in the sheathing layers of the panel only.

Production-Built Houses

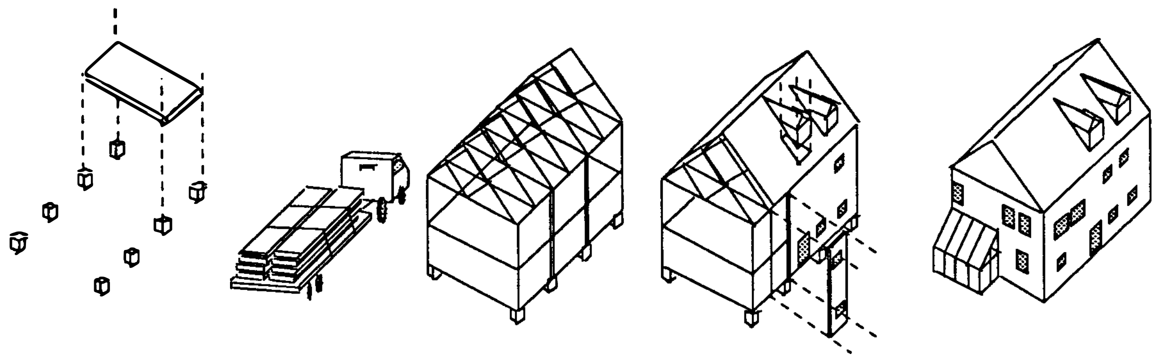


Figure 3 - 4
Production-Built House

Production building refers to the mass production of whole houses "in situ." This large and influential industry segment is industrialized in the sense that it employs rationalized and integrated management, scheduling, and production processes, as well as factory-made components. In this instance, however, rather than the house being built in the factory and moved to the site the factory is the building site, which becomes an open-air assembly line through which industrialized labor and materials move.

4.0 STRESSED SKIN INSULATING CORE PANEL COMPONENTS

This section describes three projects: the design of "Cascadia," a prototype, energy efficient entry level house, the continued development of the on-grade panel floor/foundation system, and the development of fiber reinforced gypsum board panel skins.

Design of Energy Efficient Entry Level Housing – Cascadia

The University of Oregon developed designs for a set of prototype energy efficient, low-income houses. These drew on our experience in building the Springfield Stressed Skin Insulating Core (SSIC) Panel Demonstration House in 1994. The objective was to develop an architecturally attractive entry level housing system suitable for construction by nonprofit housing developers such as St. Vincent dePaul Society or Habitat for Humanity.

SSIC panels are an important energy saving building technology. Compared to conventional stick framing, they offer greater thermal resistance by eliminating the thermal bridging caused by studs, and they more easily create airtight envelopes which reduce infiltration. They also result in a higher quality of construction for a similar cost, use less framing lumber, and create less site waste because of their factory construction.

Nonprofit housing developers are often the last organizations to avail themselves of innovation in the marketplace. Since funding for low-income housing is very limited, nonprofit developers are drawn to projects that eliminate risk and reduce cost. By offering design assistance and a variety of marketable schemes, we can allow nonprofit groups to build more energy efficient housing. Energy efficiency ultimately benefits the occupants of the houses by lowering their monthly energy expenses thus stretching their limited incomes. The large-scale projects we plan to pursue will also give us an opportunity to analyze and improve on the conservation potential of these designs.

We began the project in 1995 by performing a detailed whole-house cost study of the Springfield Demo House to determine how we could use the energy efficient innovations of that project in a house design that was affordable and acceptable to nonprofit builders. After a series of preliminary design studies, we held a focus group meeting with Oregon nonprofit developers to define their cost and design concerns. The results of this meeting were incorporated into design schematics that were then examined through detailed cost studies and energy analyses.

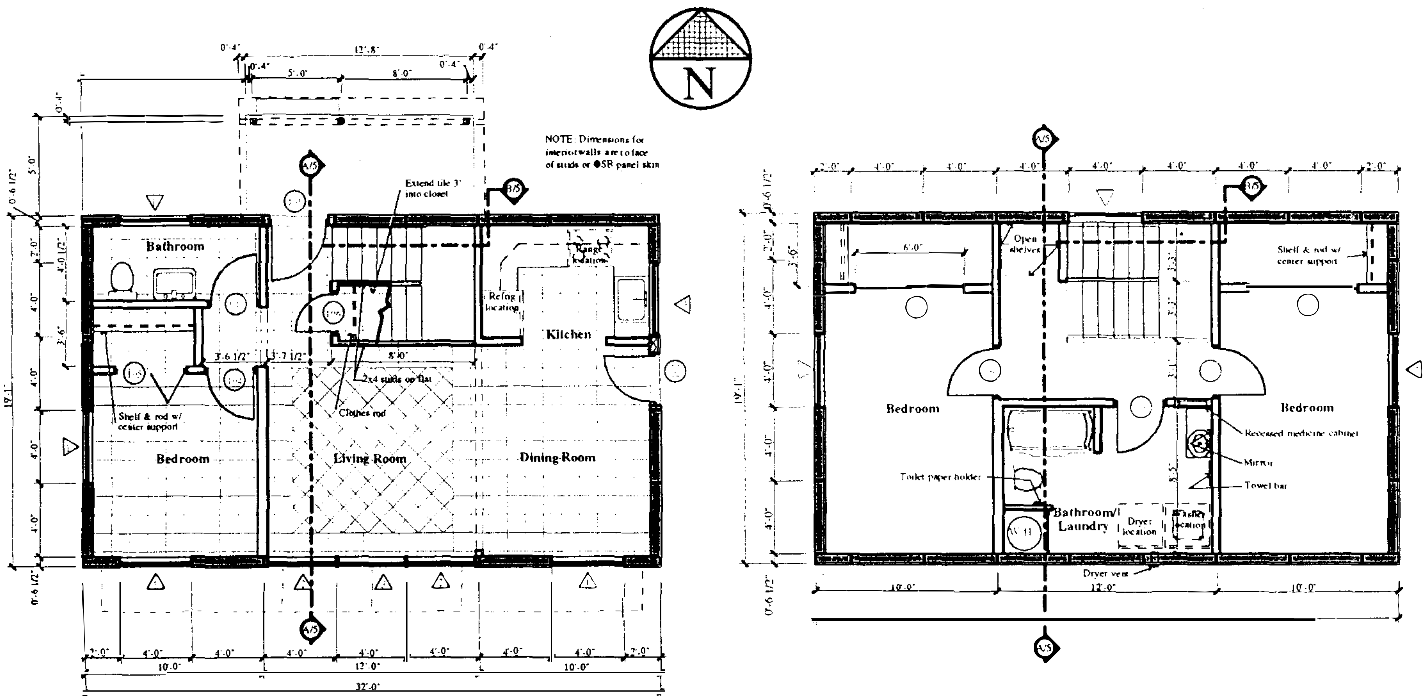


Figure 4-1, Cascadia Floor Plans—First and Second

The early schematics were presented in a second focus group in order to critique the design work and to bring out financing and development issues. This meeting also allowed us to promote energy efficient construction techniques and identify potential projects with the nonprofits. The results of this meeting led to further refinement of the basic design along with development of critical details. Our goal was to develop a construction system with a set of design variations that could be adapted to any site. We performed a code review and determined the barriers to getting manufacturers to supply the required panels at reasonable cost.

We concluded the year's efforts by making significant progress on construction documents for the housing system we are calling Cascadia. These will be part of a drawing package for developers that will also contain marketing materials and other supporting documents to assist nonprofits in realizing energy efficient housing for their clients. This includes a set of drawings for panel manufacturers to help keep panel costs as low as possible. We have reviewed and updated our cost estimate and found that we are meeting our cost goal of $55,000.

Panels	$7,179.78
Other Exterior Envelope	$14,155.31
Interior Carpentry	$11,438.89
Painting	$1,444.14
Porches	$355.18
Garage	$6,065.47
Plumbing	$5,962.15
Electrical	$4,019.66
Miscellaneous	$1,464.74
TOTALS	**$52,085.34**

Figure 4-2, Cascadia Cost Summary

Our system optimizes passive solar design and exceeds Oregon's energy code by 100%. We have also begun detailed energy studies to predict expected savings for our system over conventional construction.

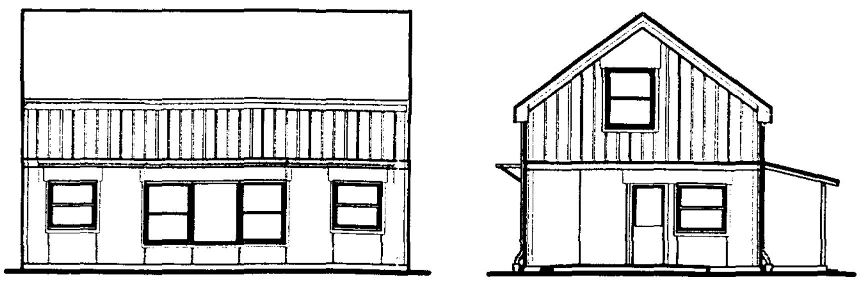


Figure 4-3 Cascadia Elevations—South and East

Continuing with the work completed thus far, we will enhance the marketing presentations for the designs to give nonprofit builders an edge in obtaining financing for their projects. Several specific projects will be identified for development. We will provide site planning and development assistance and aid in their bidding with contractors and panel manufacturers. When necessary, additional support such as educating contractors as to proper practice will be provided.

As the projects get built, video footage will be made of all critical procedures and reviewed as part of a detailed cost and construction analysis. A series of tests will be done on the houses as part of the energy analysis. Post-occupancy studies will provide additional input to ongoing design modifications. This research will be used to increase national exposure of the project.

On-Grade Insulated Panel Floor System

The objective of this task is to reduce floor and foundation costs, while maintaining energy and structural performance, through development of an on-grade insulated panel floor system.

An industry group of panel manufacturers, material and component suppliers, architectural and engineering designers, and housing developers was convened at the University of Oregon in January, 1995 to select a small number of component innovations worthy of further design development and testing. This group's conclusions, plus our experience designing the Stressed Skin Insulating Core (SSIC) Panel Demonstration House and other projects, indicate that considerable cost savings may be possible using foundation and floor systems based on SSIC panel technology. Recent developments in frost-protected shallow foundation systems, combined with all-weather wood foundation systems, suggest a direction for development of such a new system.

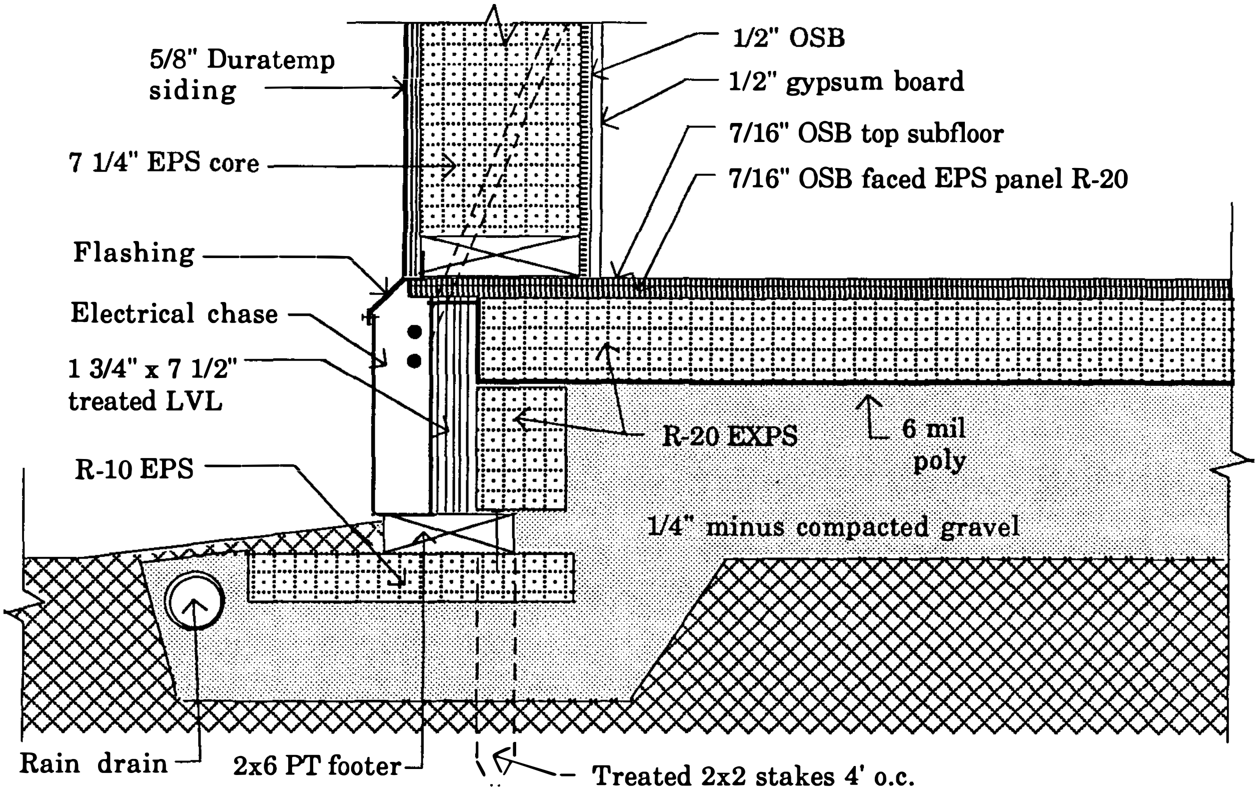


Figure 4-4, On-Grade Panel Floor System

This preliminary design has been explored through scale model studies and construction of full-scale part prototypes.

Comparative cost projections for 20' x 36' foundation and floor:

on-grade insulated panel foundation/floor	$4015
insulated concrete slab	$4902
Demonstration House (SSIC panel/pier)	$7206
reference house (wood frame/concrete)	$7465

The scale model and prototype studies have confirmed the feasibility of the on-grade panel floor concept. Comments of reviewers of the preliminary report were positive and helpful. Interest in the on-grade panel floor system has been expressed by AFM (SSIC panels), Trus Joist Macmillan and Willamette Industries (building materials), the Department of Housing and Urban Development, and private builder/developers.

Site prototype test floors will be built in several climates to examine constructability, the effects of temperatures and moisture (especially frost heave-related) and structural performance (settlement, creep, dimensional stability) of the system.

We will develop agreements with participating manufacturers to incorporate the floor system into their product lines and assist them in preparing documents for ICBO approvals and other product certifications.

We will continue development of the design, based on studies of models and prototypes plus feedback from industry reviewers. Prototypes will be constructed as needed to refine the design until it is ready to be released to trial builders.

Fiber Reinforced Gypsum Board Skins for SSIC Panels

The objective of this task is to reduce stressed skin insulating core (SSIC) panel construction costs while maintaining energy and structural performance through development of fiber reinforced gypsum board panel skins.

An industry group of panel manufacturers, material and component suppliers, architectural and engineering designers, and housing developers confirmed our observation that a useful strategy for reducing the cost of SSIC panels would be to develop skins capable of acting as inner and outer finish surfaces as well as structural elements.

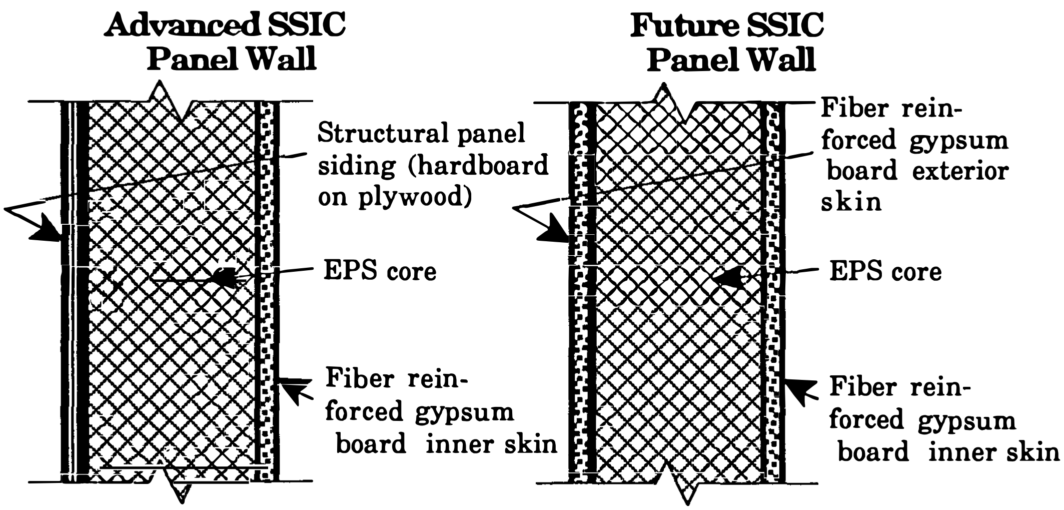


Figure 4-5, SSIC Panel with Fiber Reinforced Gypsum Board Skins

We subsequently surveyed the available materials as well as the building code, structural, manufacturing, fire and other criteria such materials would have to satisfy. Our attention focused on gypsum-bonded fiberboard as an inner skin, and a structural panel siding as outer skin. This work is being done in collaboration with W. H. Porter, Inc., Fischer Corporation, and PFS Corporation.

To date we have completed ASTM E-72 methods testing in racking, transverse loading, and axial loading; ASTM E 661-88 method tests for concentrated loads; and ASTM E 6 method tests for creep.

Working with the Fiber Reinforced Gypsum Board Panel Consortium (W.H. Porter, Inc., Fischer Corporation, and PFS Corporation), we will help consolidate and interpret fiber reinforced gypsum board test results and coordinate new tests as indicated. We will then use advanced fiber reinforced gypsum board SSIC panels in demonstration projects (the Cascadia entry level energy efficient housing systems demonstrations), monitoring and documenting post-construction panel performance. Continued explorations will pursue further cost efficiencies, including use of fiber reinforced gypsum board as both inner and outer finish surfaces.

The University of Oregon will use these studies to develop design guidelines, load charts, etc. to encourage builders to use the new panels. We will develop agreements with participating manufacturers to incorporate the advanced panels into their product lines and assist them in preparing documents for ICBO approvals and other product certifications.

The expected benefit of this project will be to substantially increase the use of energy efficient SSIC panels by the building industry through reducing the cost of the panels by an estimated 15%.

5.0 INCORPORATION OF ENERGY ANALYSES INTO CAD SOFTWARE

The objective of this task was to develop an energy analysis program that would encourage architects, builders, and housing manufacturers to improve the energy efficiency of their buildings. In order for these kinds of designers to readily attempt energy-efficient designs, several things must be possible:

- The analysis must be done early enough that design changes are feasible.
- The energy program should work within the user's normal design environment.
- Accurate data about the building should be available.
- The interface should be easy to use, highly visual, and nontechnical with respect to energy.

Embedding our energy analysis within Softdesk's Auto Architect, which uses an AutoCAD system (the largest selling PC CAD program), enabled us to meet the first three criteria. The fourth criteria required an interface that encourages visual input of data as well as the more common visual output of results in graphic form. We have succeeded in creating an interface that requires no numeric input, reports results graphically, and begins to develop the user's intuitions about energy efficiency.

The vehicle for this project was a collaboration between industry, government, and academia, represented respectively by Softdesk, in Henniker, New Hampshire; Pacific-Northwest National Laboratory (PNNL), in Richland, Washington; and the University of Oregon. The Collaborative Research and Development Agreement (CRADA) was signed by the three groups in late 1992. An extension was signed this year by all groups.

The product has three major parts: geometry interpretation, input of non-geometric data, and calculation and presentation of results. All three parts are oriented toward making energy analysis visual and nontechnical.

The geometry interpreter is a tremendous labor saver for the user. Most energy analysis programs require that the user type in the geometric features (length, area, pitch and thickness) of all energy elements – walls, windows, floors, roofs. However, this is information that the user has already indicated graphically in a CAD system. So in this tool the geometry interpreter scans the drawing and determines these parameters automatically, saving the user typing and preventing errors and inaccuracies. The user is then given visual feedback about what was interpreted.

Other, non-geometric data is input by the user through a series of dialog boxes. Although a mechanical engineer may be content to specify a building in terms of BTUs per square foot, most architects, builders, and manufacturers think of the spaces in terms of their functions or physical configurations. In our tool, the user picks wall types by looking at drawings of typical wall sections, then the tool reports an R-value. Likewise the user selects a human activity, and the tool reports the BTUs per hour per person that are expended.

The third major part of the tool is the graphic report of the energy analysis results. When the user requests results, a bar graph is drawn on the CAD work area depicting the heat load or loss due to each building component for each month of the year in the selected climate. Examination of this graph quickly shows the user what component is causing the greatest problem, and whether there is a general heating problem or a cooling problem. Several graphs can be displayed at once, allowing the user to compare the energy impact of different design choices.

Softdesk Energy was released by Softdesk in May, 1995 and demonstrated at the June AEC show. During the summer and fall we added a metric capability and developed Canadian climates and maps in addition to the US data included in the first version. These changes enable Softdesk to distribute Softdesk Energy throughout North America.

The Trane Company, a manufacturer of HVAC equipment, authors several sophisticated software tools to assist their users in the specification of HVAC equipment. Like all other energy analysis programs except Softdesk Energy, the analysis begins with the user typing in large quantities of detailed geometric and non-geometric data about the building. Trane Company has joined the CRADA team this year to consult on extensions to Softdesk Energy that would enable a user to export data from Softdesk Energy to the Trane product. This will save HVAC engineers many hours of data input for each customer. Instead of typing in pages of numbers such as 845 sq ft of floor area for Room 135, the user simply draws the building in Softdesk Auto-Architect, uses Softdesk Energy's graphical interface for the input of non-geometric data, and then exports a complete room-by-room building description for the HVAC engineer.

6.0 MANUFACTURING PROCESS AUTOMATION AND SIMULATION

This section describes two tasks aimed at improving the constructability of energy efficient housing. The first involves the development and use of software to simulate new production process technologies. The second task focuses on the development of a more energy efficient and constructible bay window design.

Manufacturing Process Simulator

The objective of this task is to develop and use simulation software tools to support housing manufacturers as they plan and implement advanced manufacturing systems. FY95 simulation activities had two major thrusts. The first was the broad dissemination of results from our successful efforts with Glaize Components. The Glaize effort was the subject of a two-page article which appeared in the August issue of *Automated Builder* magazine (Figure 6-1). Fifty housing manufacturers requested additional information via Automated Builder's reader service card. We responded to each request. The Glaize model was demonstrated to a large number of attendees at the 1995 Building Systems Council Showcase in Pittsburgh. The model was also demonstrated in considerably greater detail to several industrialized homebuilders and housing industry suppliers who see simulation as a tool to facilitate the introduction of their advanced manufacturing technologies. Industrialized homebuilders included Ryan and BuildTech, and suppliers included MiTek (the truss manufacturing equipment and systems supplier), Icynene (the insulation supplier), Burmek (the Swedish automated equipment supplier), and Makron (the Finnish automated equipment supplier), We continue to believe that suppliers of advanced process technologies are the most likely vehicle for transitioning simulation technologies into the industrialized housing marketplace. The Glaize modeling effort was also the topic of presentations given to the Build America contractors, the BETEC (Building Environment and Thermal Envelope Council) Symposium, and the Institute of Industrial Engineers.

The second thrust of the simulation effort was to identify industry partners who would work with the EEIH team,to use simulation to improve manufacturing operations. We now have three partners for modeling: MiTek, Icynene and

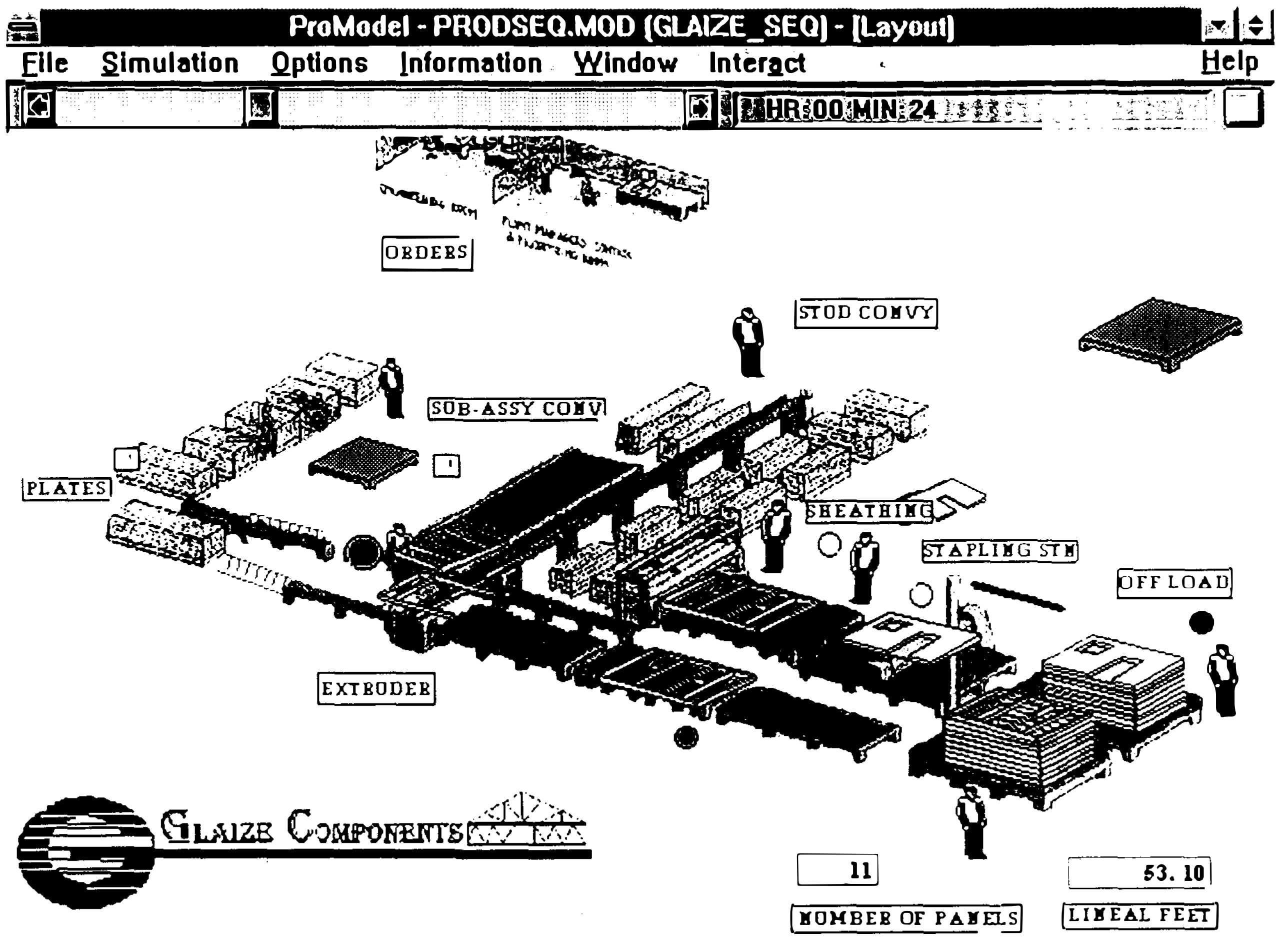


Figure 6-1, Computer Simulation of Makron Wall Panel Line

BuildTech. Modeling a second manufacturing operation has been delayed at the request of our partners; however, we expect each of the partners to support a modeling effort in FY96.

Optimum Manufacturing/Construction Mix

The objective of this task is to develop and prototype a bay window design that is both more energy efficient and constructible. Bay windows are one of the most popular options in homebuilding. However, when built on a cantilevered floor deck, bay windows are often a source of air infiltration, cold feet complaints, and framing complexities. These problems are magnified when the bay window is added to the gable end of the house, requiring the bay's floor system to be tied to the perpendicular main floor system.

The EEIH team used a three step design approach to accomplish the objective. First, researchers reviewed floor plans and construction drawings from three major builders, Pulte, Ryan and Ryland as well as designs from four major window manufacturers. To better understand the manufacturing and construction complexities, the team visited several Ryan and Pulte construction sites in the Washington, DC area and the Ryan factory in Thurmont, MD. The trip yielded fresh insight into the design, construction, costing and pricing of bay windows. A key finding was the need for a design which can be easily added at any point during the construction process.

The second step involved developing a range of alternative design concepts, evaluating the concepts for energy efficiency and constructability and selecting a concept for prototyping. In the final step the team constructed an alpha prototype of the concept and documented preliminary findings in a report "Constructability Design Report for the Cantilevered Bay Window Prototype."

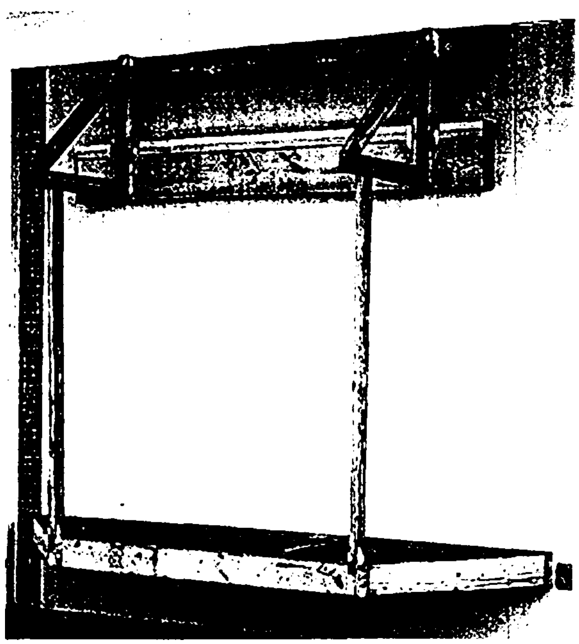


Figure 6-2, Structural Components of the Proposed Bay Window Design

The primary structural components of the alpha prototype are shown in Figure 6-2. The floor system for the bay is a 6" structural insulated panel (SIP). The moment load of the bay is supported by two 45 degree right angle trusses. Each truss includes a long vertical member which attaches to the outboard edge of the SIP. The SIP is attached to each truss by two metal twist straps (Figure 6-3). The straps are connected to the double 2x spline on the outboard perimeter of the SIP and to each side of the vertical truss member.

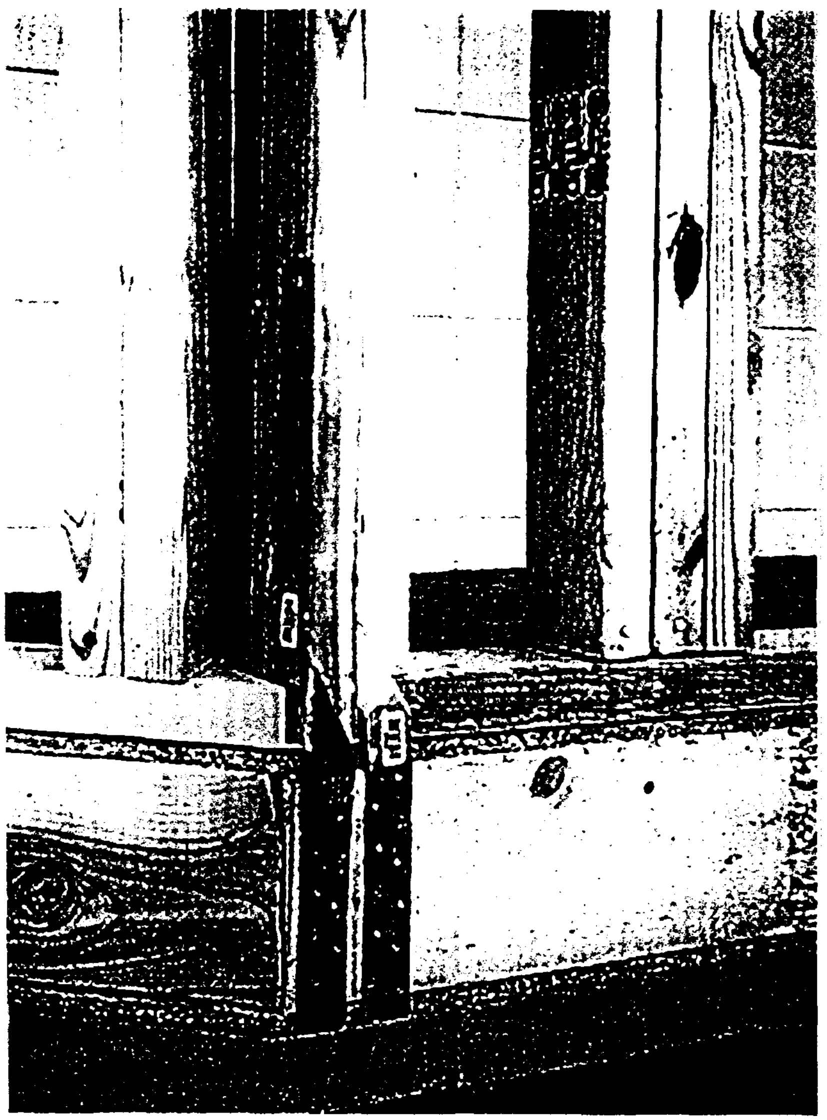


Figure 6-3, Truss to SIP Connection using Metal Straps

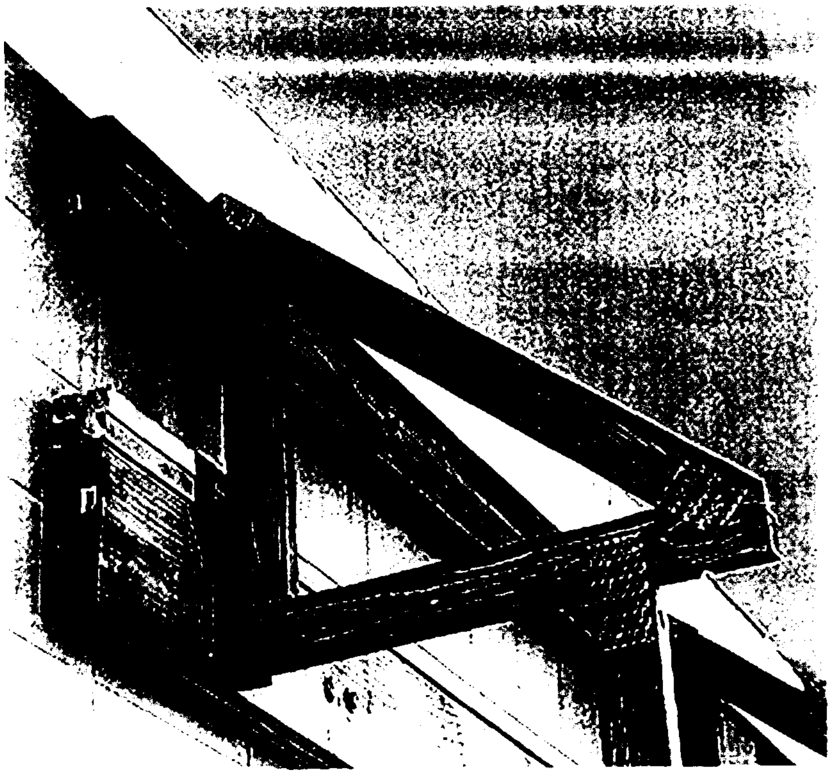


Figure 6-4, Truss and Connection to House

At the top of the bay, each truss is attached to the house by two metal hangers, one at the peak and one at the foot of the truss (Figure 6-4). The upper hanger is attached to the second floor exterior wall studs or to additional nailers. The lower hanger is attached to the header and double top plate of the bay. Figure 6-4 also demonstrates another important element of constructability research, the test jig, which is used to simulate the bay's interaction with the house. In this prototyping effort, the jig consists of a concrete block wall with a pseudo header/double top plate, a second floor nailer, and a first floor rim joist.

Framing for the completed bay window prototype is shown in Figure 6-5. The prototype design is expected to have several important advantages over current site built designs. First, the thermal integrity of the SIP should eliminate air infiltration and cold feet associated with current floor framing. Second, the simplicity of the design is likely to improve constructability. The design minimizes the framing difficulty and cost of tying to the floor deck. Major components are manufactured, reducing disruption on the construction site. It the site on a just-in-time basis. Finally, the ease of connection at the floor, even for difficult gable end applications, allows the bay option to be added later in the construction process, without extensive modification to the existing floor framing.

Figure 6-5, Completed Bay Window Prototype

The design has been reviewed by various industry representatives and their recommendations for further improvement are included in the report. The report has also been forwarded to parties in the SIP industry to explore interest in future efforts.

Monitoring and Analyzing the Energy Efficiency of the SSIC Panel Demonstration House

In 1994, the University of Oregon Energy Studies In Buildings Laboratory constructed a Stressed-Skin Insulating Core (SSIC) Panel Demonstration House. In November 1995, The Florida Solar Energy Center made repairs and additions to the installed energy-use monitoring instrumentation, and began data acquisition from both the Springfield demonstration house site and the Eugene weather station site.

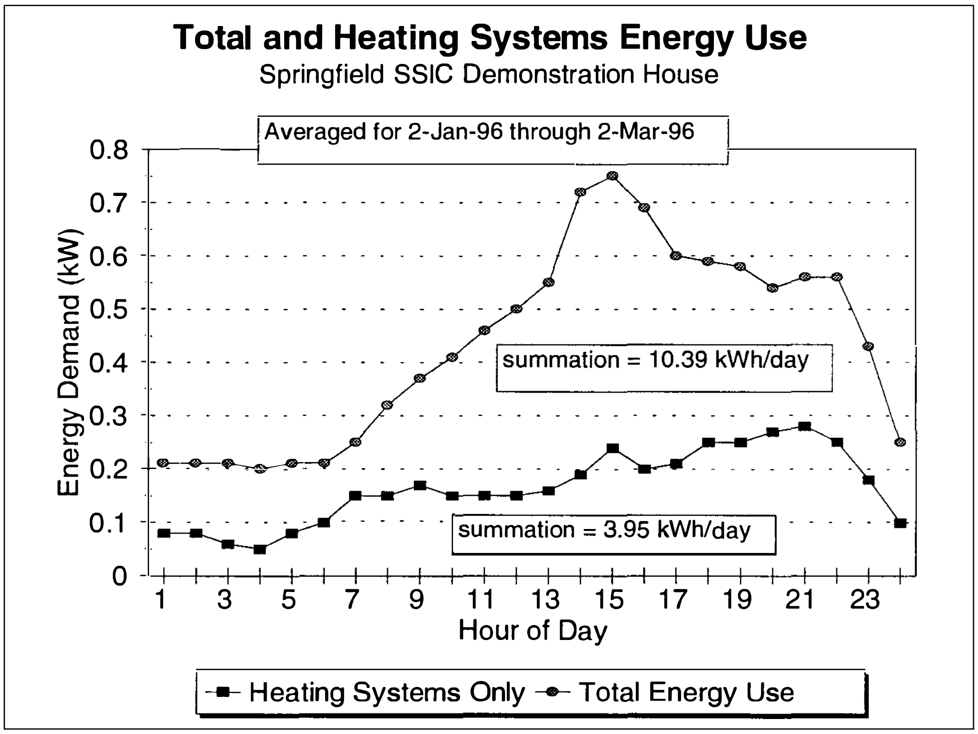


Figure 7-1 Measured total energy use and heating systems (heat pump + electric resistance) energy use for the SSIC demonstration house, Springfield, OR

Summary results for the '95-'96 winter heating season are best presented graphically in Figures 7-1 through 7-4. The period of analysis was chosen as 2-Jan-96 to 2-Mar-96. The summary analysis calculated an hourly profile of a "typical day" during the winter period by averaging the values at each hour of the day. Figure 7-1 shows that, for the all-electric house, the energy consumed for heating was less than half of the total energy consumed.

Figure 7-.2 shows the total energy consumption, normalized by floor area and inside to outside temperature difference, was low, at 5.39 Wh/m2/C/day. The hourly inside and outside temperatures, and the differential temperature are show in Figure 7-3. The winter-period average inside temperature was 23.2 C, average outside temperature was 5.6 C, giving an average differential temperature of 17.6 C. Although the house has a ventilation system which operates automatically by a timer, and can be operated manually, Figure 7-4 indicates that the carbon dioxide levels are consistently above the ASHRAE Standard 62-1989 recommendation of less than 1000 ppm (parts per million). Monitoring of the SSIC demonstration house will continue to complete one year.

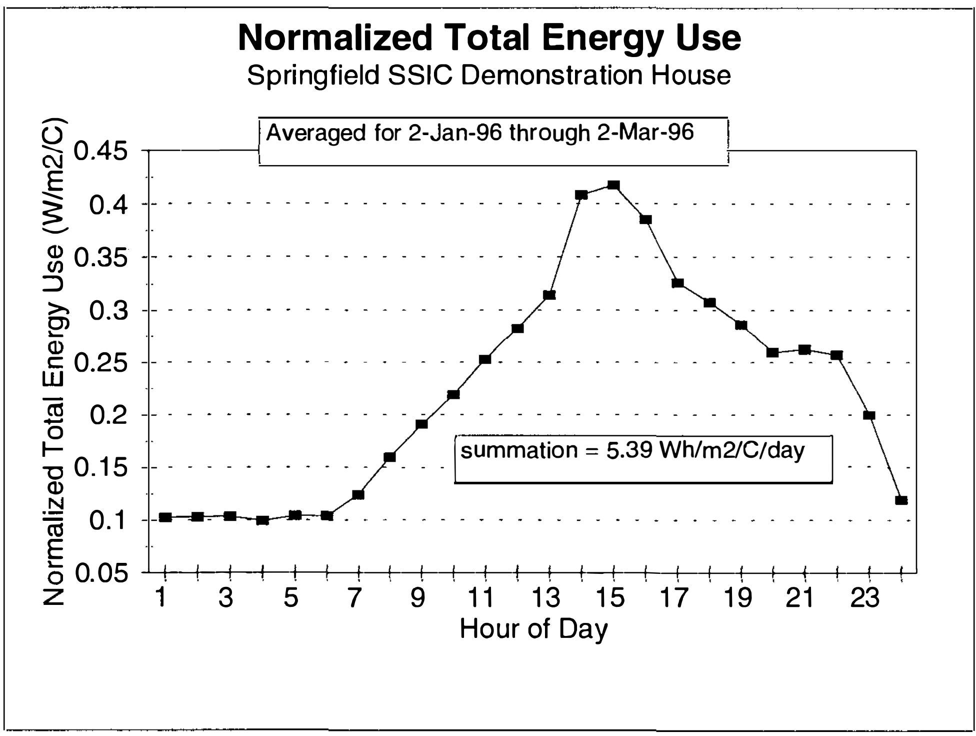


Figure 7-2 Normalized total energy use for the SSIC demonstration house Springfield, OR

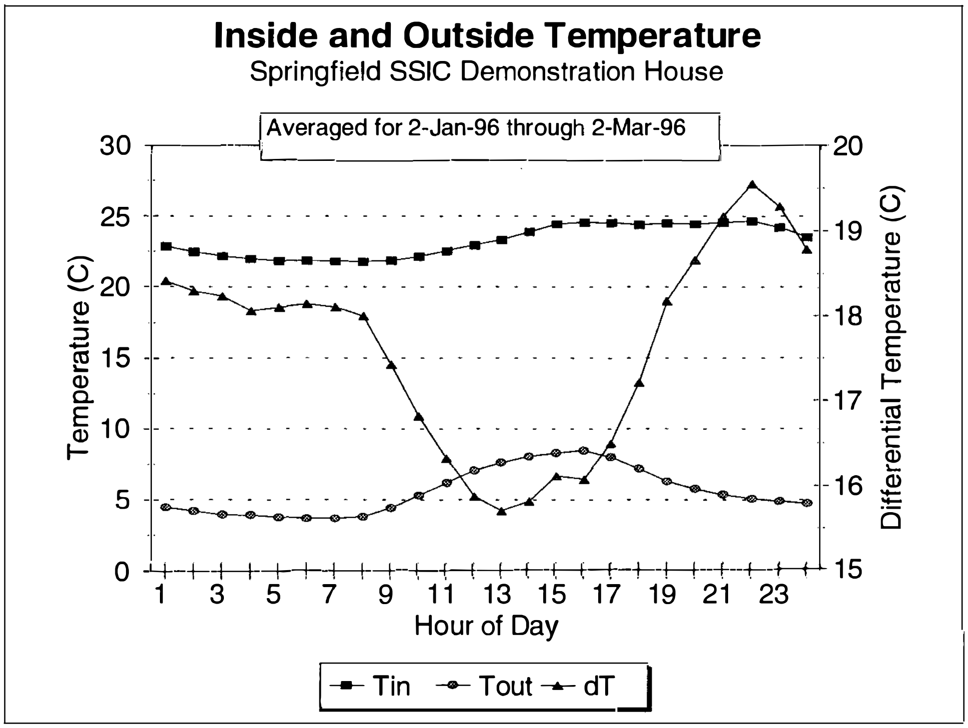


Figure 7-3 Measured inside and outside temperatures, and differential temperature for SSIC demonstration house, Springfield, OR

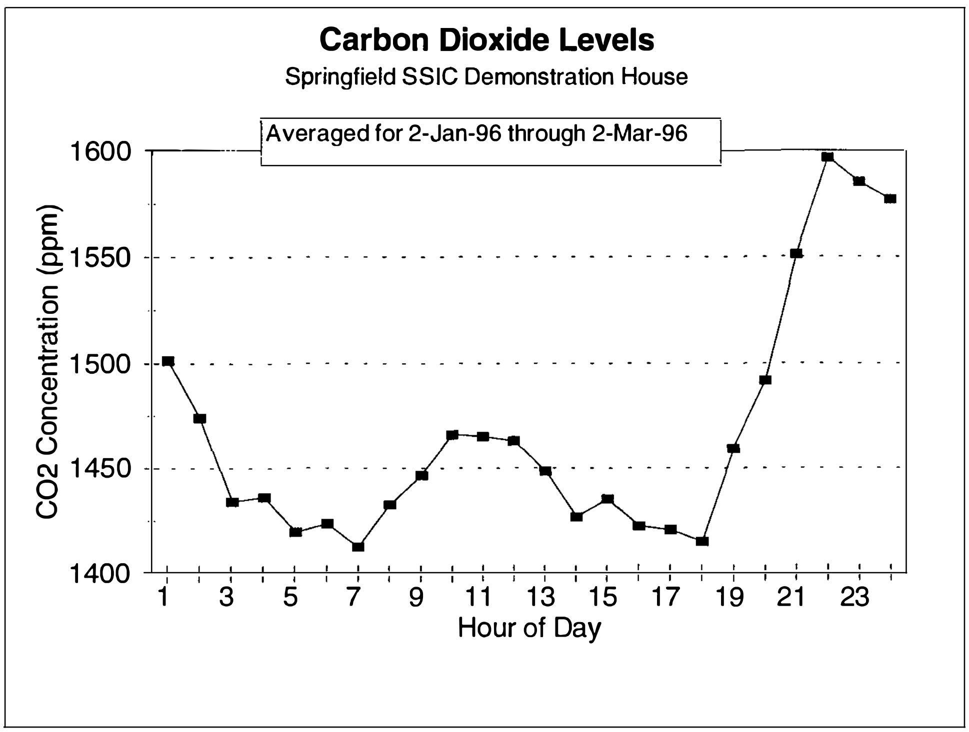


Figure 7-4 Carbon dioxide levels at the SSIC demonstration house, Springfield, OR

Cooling Short-Term Energy Monitoring

In 1994, an early version of a cooling season short-term energy monitoring protocol was developed and executed at the Florida Solar Energy Center on a single-wide mobile home. In 1995, in collaboration with Macrodyne Energy International and the National Renewable Energy Laboratory, refinements were made to the test protocol, and modeling routines were included in the analysis to separately account for latent loads and the effect of moisture adsorption and desorption processes. The refined four-day, three-night cooling season short-term energy monitoring test was repeated almost continuously between July and October 1995, on the same mobile home, to establish accuracy and repeatability limits. The experiments were conducted in collaboration with consultant C. Edward Hancock.

The basic test sequence consisted of:

a) maintaining a constant indoor temperature during daytime of day 1 through daytime of day 2

b) a night time pull down of indoor temperature, on night 2, by about 3 C over a few hours, and a warm up back to the original operating temperature over a few hours, while maintaining constant relative humidity

c) a night time pull down of indoor relative humidity, on night 3, by about 5% over a few hours and return to original operating relative humidity over a few hours, while maintaining constant indoor temperature

The part a) elicits solar gains and the building load coefficient; part b) elicits the heat capacitance; and part c) elicits moisture adsorption and desorption effects. Figure 7-5 shows data from the July testing period which illustrates the temperature and relative humidity "pulses."

A number of interesting technical issues arise in controlling temperature and humidity in different zones of a building to closely approximate a one-zone building. A system of seven ducts, each with its own fan, provided conditioned air to different parts of the building as needed to cool and/or dry the zone, by drawing air over a chilled water cooling coil and supplying it to the zone. Electric heaters in each zone were activated to provide reheat as needed. Indoor temperature and relative humidity were measured in each of the seven locations and were used for control purposes. Continuous measurement of air exchange rate was made by tracer gas injection, and outdoor environmental conditions were measured.

After filtering the data, three periods were selected for detailed analysis. The data analysis was conducted by Macrodyne Energy International. Results showed that the primary and secondary terms renormalization parameters were quite consistent, giving support for the test protocol and analysis. It became clear that moisture adsorption-desorption is an important secondary term. Previous, extensive experience with heating season short-term energy monitoring has clearly demonstrated that including the secondary terms is important in improving the repeatability and accuracy of determining building characteristics from short-term tests.

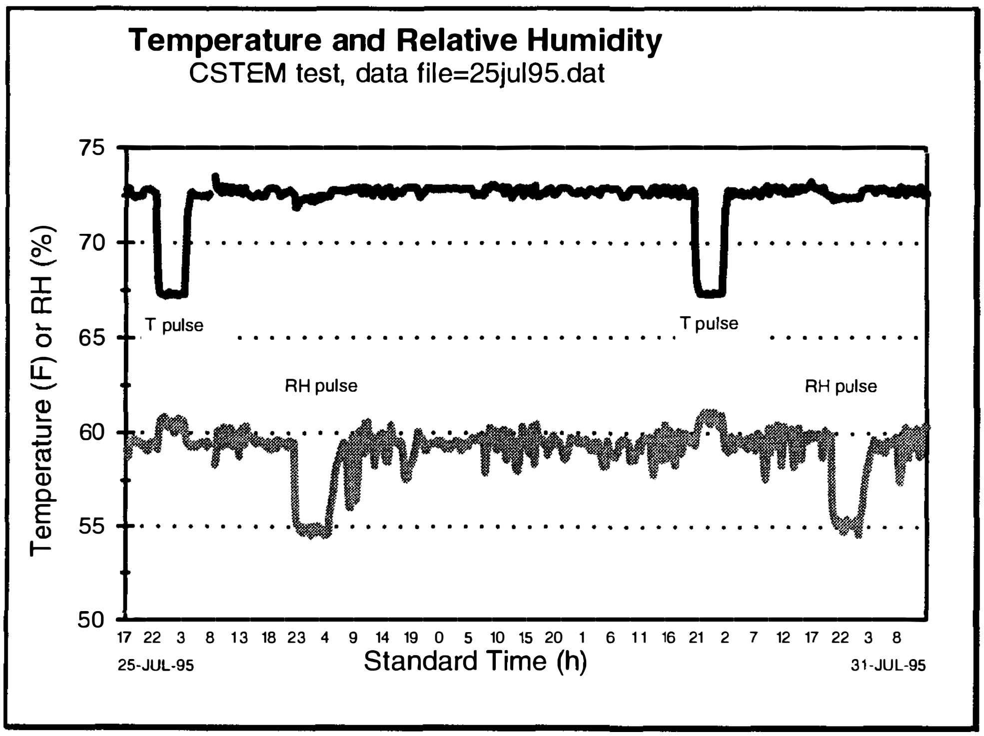


Figure 7-5 Controlled temperature and relative humidity pulses during cooling short-term energy monitoring test

HUD Code Ventilation System Assessment

Since October 1994, all new HUD Code manufactured housing is required to have a fresh air ventilation system installed. In the southern HUD Code Thermal Zone 1, the pressure relationship of the houses relative to outdoors should be either positive or neutral. This pressure relationship will reduce the potential for moisture problems, due to air transport, in the humid, cooling dominated south. In northern HUD Code Thermal Zones 2 and 3, the pressure relationship of the houses relative to outdoors should be either negative or neutral. This pressure relationship will reduce the potential for moisture problems, due to air transport, in the heating dominated climates. In FY95, the Florida Solar Energy Center surveyed the manufactures supplying houses to HUD Code Thermal Zone 1 to assess how they were complying with the new ventilation code requirements. It was determined that there were essentially four approaches being taken by the manufacturers:

1) An additional exhaust fan, such as is used to exhaust bathrooms, is installed in the main body of the house and exhausts to the outside through the roof;
2) An undampered and unfiltered five inch diameter duct from the return side of the central air distribution system fan to the outside through the roof;
3) A dampered and filtered five inch diameter duct from the return side of the central air distribution system fan to the outside through the roof;
4) A dampered and filtered five inch diameter duct from the return side of the central air distribution system fan to a roof mounted fan that supplies outside air to both ventilate the attic and provide fresh air whenever the central fan and the fresh air damper operated.

Figure 7-6 shows the percentages of the different system types being used by the 54 manufacturers surveyed.

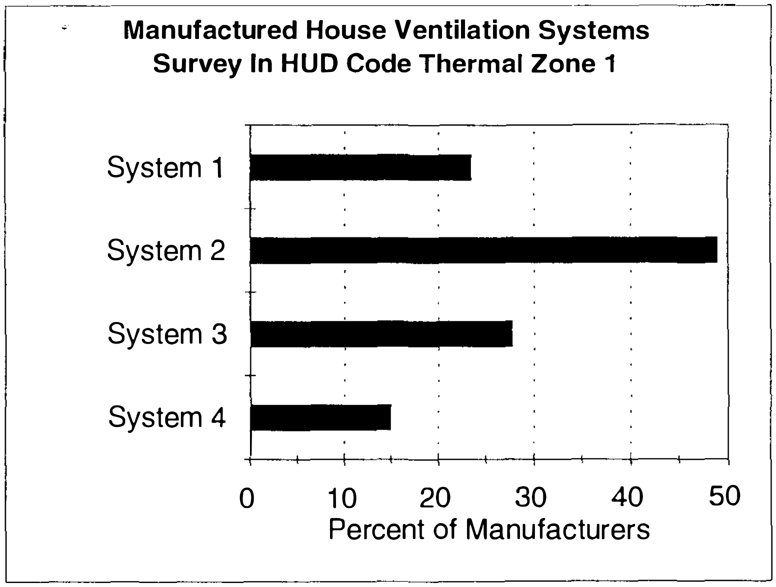


Figure 7-6, Manufacturer survey results for ventilation systems used in HUD Code Thermal Zone 1

In June 1995, a house with system 1), in Edgewater, Florida, was tested and instrumented for year-long monitoring of indoor air conditions to determine ventilation system effectiveness. The monitoring also included pressure differential with respect to outdoors and energy use. In order to obtain more useful information from the ventilation system monitoring, the occupants were given a schedule to follow which designated a sequence of four, three-month periods whereby the occupants would operate the ventilation system in any way they chose for the first month, then operated the ventilation system constantly for the second month, and turned it off for the entire third month. This sequence would repeat four times. Results for the house with system 1) show that when the ventilation fan is on continuously the level of carbon dioxide is below the ASHRAE Standard 62-1989 recommendation of <1000 parts per million (ppm). When the fan is not operated, the level of carbon dioxide often exceeds 1000 ppm. Figure 7-6 illustrates this graphically.

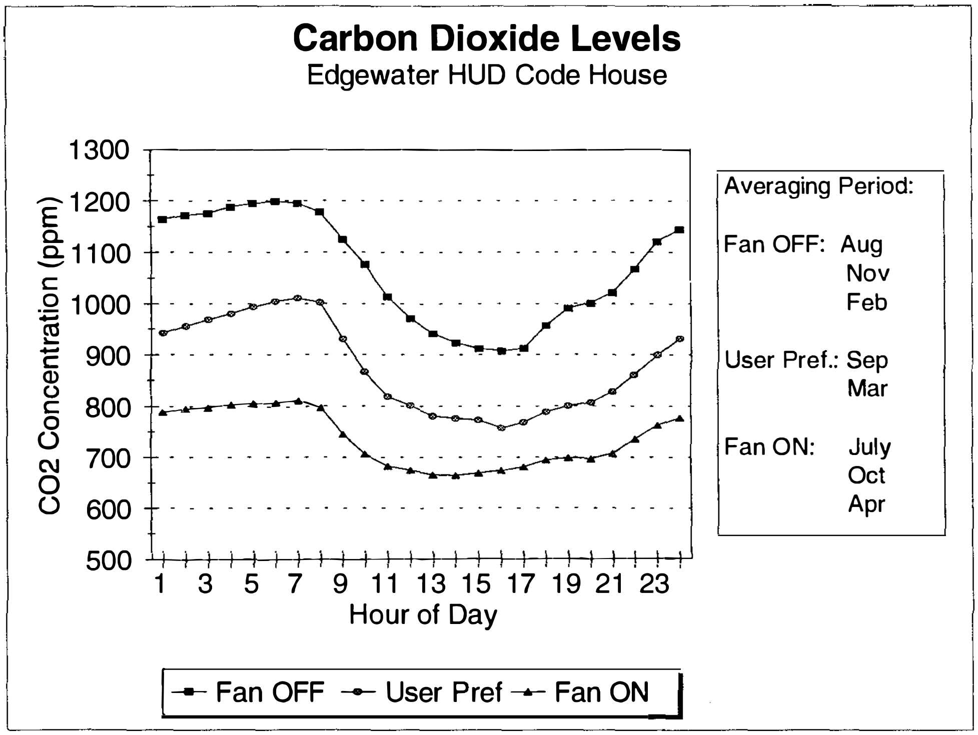


Figure 7-7 Carbon dioxide levels at the Edgewater, FL HUD Code house

In May 1996, a house with system 2), in Tallahassee, Florida, was also tested and instrumented for year-long monitoring. The assessment of this ventilation system has revealed many flaws which should be addressed by the HUD Code industry. They are listed as follows:

a) The fresh air duct from outdoors is ducted only to the furnace fan, the separate cooling system fan, in an outdoor packaged unit, has no provision for bringing in fresh air. Hence, when the house thermostat is switched to cooling mode, no ventilation air will be provided.

b) The fresh air duct has no damper to block unwanted air infiltration when the furnace fan is off, and, since the cooling and heating systems share the same supply ducts, when the cooling fan is on, cooled air flows backward through the furnace fan and up the undampered fresh air duct to outdoors.

c) The fresh air duct bypasses the furnace filter, this can allow outside dirt, dust and insects to pass directly into the air distribution system to be distributed throughout the house.

d) The house thermostat has a selection for the central fan to operate in either AUTO or ON mode. The ON mode should cause the central furnace fan to operate constantly. This should allow the occupant to constantly get fresh air, although the expense of operating the relatively large fan constantly (940 cfm measured) to get a small amount of fresh air (50 cfm measured) is questionable. For this system, with thermostat fan switch in the ON mode, no fan was activated. A switch to activate the furnace fan was found only by removing the fan access panel, an unlikely thing for most occupants to do, or think to do.

8.0 RESEARCH UTILIZATION

Cooperative Energy Efficient Industry Constructed Demonstration Housing

The objectives of this task are to:

1) Provide design assistance, construction quality control services and test the energy and indoor air quality performance of Health House®s being constructed throughout the U.S.as a project of the local affiliates of the American Lung Association (ALA). Health House®s were pioneered by the Minneapolis affiliate of the ALA in 1993. Health House®s are high visibility demonstration homes which feature energy efficient construction and excellent indoor air quality so that allergic individuals can breathe easier.
2) Test the energy efficiency and indoor air quality of other high visibility industry constructed energy efficient demonstration homes.

Health House®s

In 1995 two Health House®s were constructed. One in Orlando, FL and the other one in Minneapolis, MN. The Orlando Health House® is shown in Figure 8-1.

This house was featured as the cover story in the March 1996 issue of Professional Builder magazine, a widely read trade publication (circulation ~150,000). A key feature of the house is a whole house dehumidifier which independently controls the relative humidity(RH) in the house. Controlling RH to 50% is expected to create an environment where dust mites cannot survive. The house is being monitored to determine its energy efficiency and its indoor air quality. A key parameter of interest is the dust mite allergen level. Dust samples are being collected monthly in the Health House® and a neighboring control house. If, as expected, the dust mite allergens are lower in the Health House® then it will not have a principal cause of asthma and allergies in humid climates.

The Minneapolis Health House®, also completed in 1995, was a remodeling project and is featured in the May 1996 issue of Better Homes and Gardens. The EEIH team participated in conducting the diagnostics testing and recommending the remediation work to be done to alleviate the mold and mildew problems in the house.

Figure 8-1, The 1995 Orlando Health House®

In 1996, Health House®s are being planned in the cities of New Orleans, LA; Huntsville, AL; Birmingham, AL and Jacksonville, FL. The EEIH project is involved in all these houses and plans to continue the evaluation of energy efficiency and indoor air quality in these homes and comparable control homes.

READ Project, East Lansing, Michigan

The Resource Efficient and Affordable Demonstration Home (READ) project in East Lansing, Michigan is a house which was constructed for a family of five people. The goal, stated by the project organizers, was "...to strengthen the understanding of highly energy-efficient building technology and demonstrate its applicability and economic availability to the community-at-large." Figure 8-2 shows the front of the house, south facade, at the time of completion. The owners decided to build the same SSIC demonstration house designed by the EEIH project at the University of Oregon, except with a full basement. The basement walls are also of Structural Insulated Panel (SIP) construction, with a pressure treated plywood outside skin. The owner was able to solicit collaboration, and some cost share, from several private sector groups, including: Great Lakes Insulspan; John Barrie Associates Architects; Sunway Builders; and Consumers Power Company.

Figure 8-2, Front of READ Project House, East Lansing, MI

The USDOE EEIH project was requested to support the READ project with energy and indoor air quality testing and monitoring to verify project goals. In September, FSEC pre-wired the house for monitoring sensors, during construction. In December, an intensive three days of building diagnostic testing and monitoring system setup was completed. Two local television stations featured the testing project in their news programs. Initial results show the house to be well insulated, and exceptionally airtight. A small ventilation fan is capable of providing adequate ventilation air, and control of interior pressure relationship relative to outside. The house heating energy consumption, indoor air quality, and interior and exterior environmental conditions will be monitored for a one year period. Condensed results for winter '95-'96 monitoring are shown in Figure 8-3 Energy use is relatively low for the 1800 ft2 house, and indoor relative humidity is under good control, however, to dilute carbon dioxide generated from breathing, the ventilation fan ON-time should be increased. Figure 8-5 shows the total energy consumption, averaged by hour for the entire '95-'96 winter analysis period, and normalized by floor area and inside to outside temperature difference. The normalized total energy use was low, at 6.62 Wh/m2/C/day. This compares to 5.39 Wh/m2/C/day for essentially the same house (see section IV.A) in Springfield, OR. Major differences between the two houses are basement versus crawl space, and gas heat versus electric resistance and heat pump heat, for the East Lansing and Springfield houses, respectively. Hourly averaged inside and outside temperatures, and temperature differential, are show in Figure 8-4.

Winter '95-'96 *27-Dec-95 through 31-Mar-96*		
Average daily gas heating energy use	78.9 kW-h/day	269.4 ft3/day 269.4 kBtu/day 2.694 therm/day
Average daily total electric energy use	15.1 kW-h/day	
Average daily inside to outside temperature difference	22.3 C	40.1°F
Average daily outside temperature	-3.7 C	25.4°F
Average daily inside CO_2 concentration	>1000 ppm standard	
Average daily ventilation fan ON-time	15.8%	
Average daily inside relative humidity	45.1 %	

Figure 8-3, Summary Monitoring Results for READ Project House, East Lansing, MI

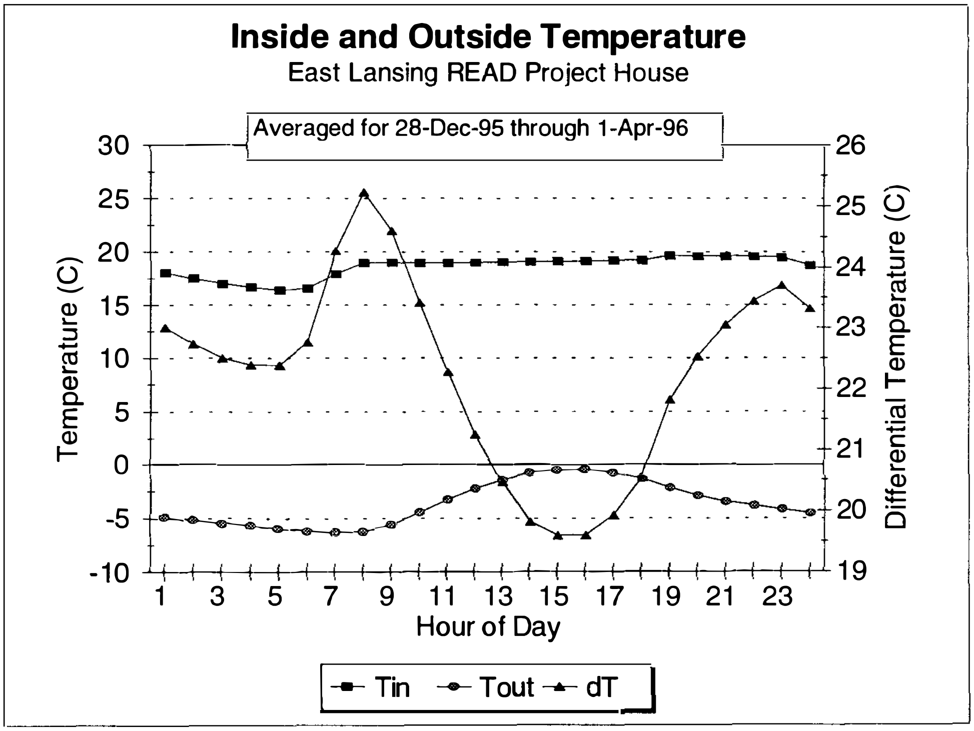


Figure 8-4, Measured indoor and outdoor temperature, and differential temperature for READ Project House, East Lansing, MI

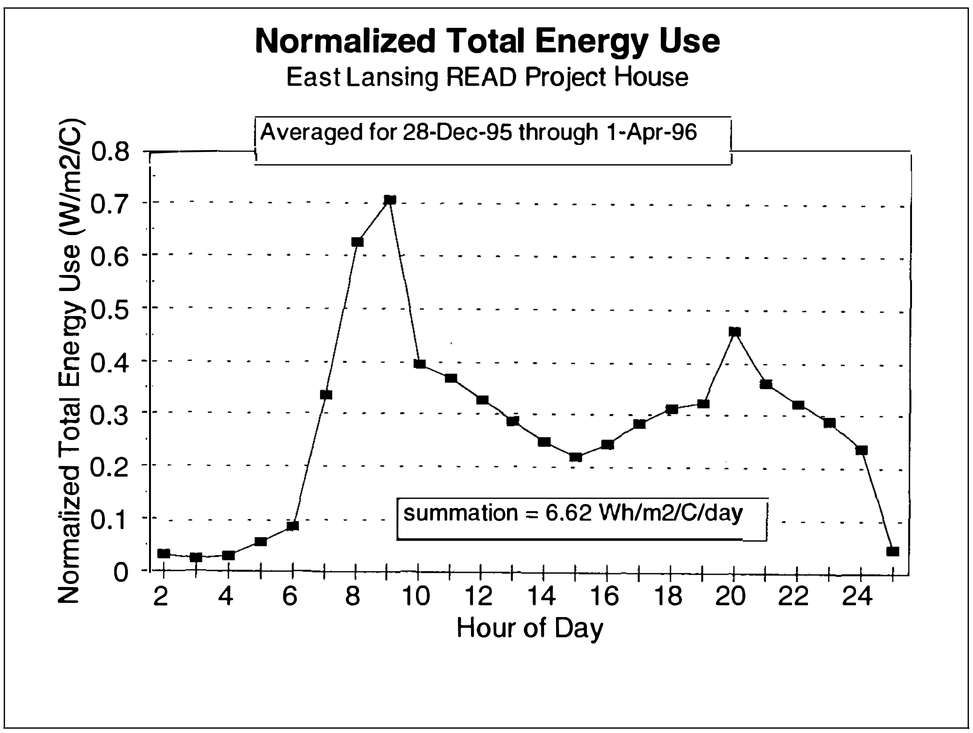


Figure 8-5, Normalized total energy use for READ Project House, East Lansing, MI

Energy Smart Demonstration House, Pensacola, FL

The Pensacola Energy Smart Demonstration House is the first of a series of demonstration houses being constructed by Energy Smart Corporation. Figure 8-6 shows the front of the house shortly after completion. The most important energy efficiency features of the home are: 1) high efficiency, heat rejecting windows; 2) high efficiency heating and cooling with two ground-source heat pumps, and one of those with two zones; 3) thicker insulation and outside air infiltration barrier; 4) sealed air distribution system; 5) sealed recessed canister lights. Nearly 60 product manufacturers contributed to the demonstration house in trade for extensive exposure to customers.

Figure 8-6, Photograph of front of Pensacola, FL Energy Smart Demonstration House

The Florida Solar Energy Center reviewed the house design and made specific recommendations regarding the Solarium and Sun Basement in July 1994. FSEC returned to pre-wire the house for monitoring instrumentation, conduct pre-drywall duct air tightness testing, and contribute in design discussions in November 1994. In January 1996, at the end of the three-month open-house period, FSEC completed building diagnostic testing, indoor air quality sampling, and the setup of instrumentation to monitor energy use and indoor air quality for one year. Three local television stations featured the testing project in their news programs, as well as in newspaper articles.

Testing results showed the house to be well insulated, with the exception of some knee-wall areas (vertical ceiling surfaces which transition between vaulted and flat ceilings) where the insulation was poorly supported from falling away. Air tightness testing of the large 7,000 ft2, 70,000 ft3 house showed the building envelope leakage to be lower than average new construction, with a dimensionless specific leakage area of 3.2, and a natural air change rate of 0.21 as tested by tracer gas. Duct air tightness was excellent upon the initial pre-drywall test, but was subsequently compromised by the poor installation of two short return air ducts and a zoning damper. This illustrated the need for vigilance throughout the entire building process. Sampling for volatile organic compounds and formaldehyde showed low concentrations, and odor levels below standardized thresholds except for the compound octanal which was slightly higher. The home was not occupied, except for tours, during the winter '95-'96 period. Hence, it was not usually heated to a normal setpoint, rendering little information on heating energy use performance. The summer '96 season should be more informative.

Residential Energy Efficient Design and Development Advisory Center (REDAC)

Objective:

Provide climate-specific design guidance to Habitat for Humanity affiliates through a variety of presentation, consultation, and publication activities. Provide similar information to designers, engineers, builders, and building owners as resources permit.

Rational:

This kick-off year of REDAC is preceded by a rich history of FSEC design advisory services to housing manufacturers nationwide as well as residential design assistance in a variety of climates. Historically, presentations to and publications for design decision makers deliver a message on the concrete methods of energy conservation. While review of specific projects helps professionals and building owners successfully apply these concepts and make the shift toward energy conscious design. Through these consultation activities, the research team fosters development of energy intuition, the thought process needed to repeat successful energy design.

Progress:

Announcement of this technical assistance service appeared in one Habitat for Humanity's newsletter for affiliates, Affiliate Update, and the Florida Solar Energy Center's newsletter, the Solar Collector. Exhibition at the National Home Builders Association in conjunction with Houston Habitat for Humanity's energy demonstration project and a presentation of planned activities at the American Society of Solar Engineers conference brought further focus to REDAC. Requested assistance has ranged from basic weather data to detailed building simulation and analysis. Each Habitat affiliate received climate specific information appropriate and was encouraged to continue pursuing energy conscious design and consulting with REDAC.

Design assistance was provided to the following Habitat affiliates:

- Hanover County, Virginia
- Indian River County, Florida
- Seattle, Washington
- Kansas City, Missouri
- Columbus, Ohio
- Rutherford County, Tennessee
- Washington DC
- Houston, Texas
- HFH International, Department of Environment
- HFH Florida, State Director
- HFH Southeast, Regional Director

Those affiliates requesting advisement fall into three general categories:

Curious: Thinking about pursuing energy conservation on a future project.
Active: Pursuing energy conservation on a current project.
Accomplished: Comprehensive energy design on three or more projects.

Because affiliates vary in understanding and commitment to energy design, a broad protocol is used to determine appropriate guidance for each type of requestor:

Curious requestors:

The research team offers guidance in energy goal setting, discussion of energy design concepts and the affiliate's current design as well as construction practices, publications, and brief design review including suggestion of inexpensive, volunteer friendly energy improvements.

Active requestors:

The research team reviews plans for current or future projects, evaluating current energy features as well as identifying the next level of efficiency to target. This involves simulation of annual energy use as well as interaction with the affiliate's design team and an obvious commitment to energy conservation by both the affiliate administration and the construction staff.

Accomplished requestors:

The research team requests a description of the energy design package and any formal material such as brochures or articles that detail the process and/or result of the project. These are made available to other requestors when appropriate. For an affiliate at this level of energy consciousness, REDAC serves as a clearing house for new technical information and a champion of successful projects .

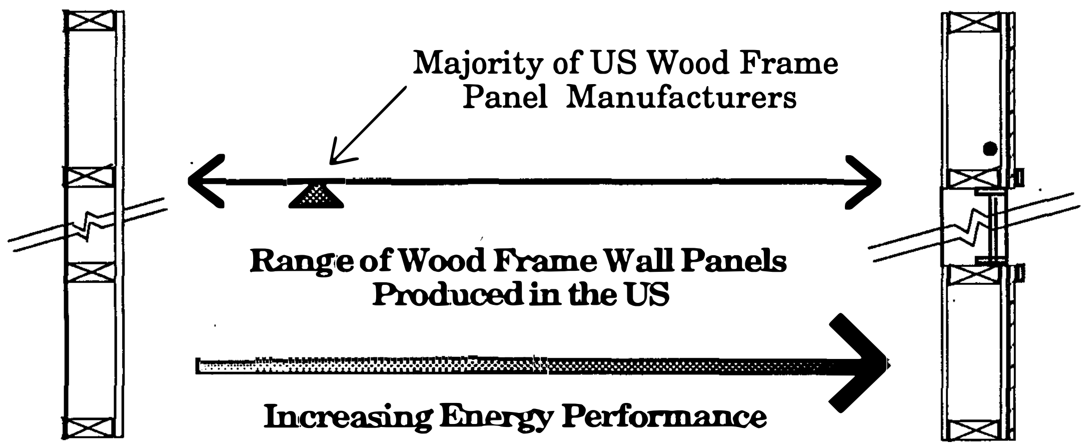
Future work:

The presentation, publication, and consultation strategy will continue to guide the activities of this task. REDAC will participate in several conferences and produce two publications for wide distribution. REDAC staff will work with several affiliates in different regions to exemplify energy conscience design. Seeking publicity for these projects to disseminate the concepts embodied in them will be a part of this activity.

Increasing the Market Share of Wood Framed Closed Panels

The objectives of this task were to identify market barriers to energy-efficient closed wood frame panels and to develop strategies to overcome these barriers.

The University of Oregon completed diagnostic testing of six units of housing which used *open* and *closed* panels. *Open* panels are built with wood studs and shipped to the site with sheathing and sometimes windows and siding installed but without insulation, vapor barriers, drywall, or wiring. *Closed* panels, in contrast, usually come to the site with insulation, vapor barriers, and electrical chases installed. The testing indicated that the units constructed of wood framed *closed* panels performed better thermally than *open* framed wood panels.



Open Panel	Closed Panel
INSTALLED IN FACTORY studs sheathing INSTALLED IN FIELD windows siding wind barrier electrical plumbing insulation gypsum board vapor retarder	INSTALLED IN FACTORY studs sheathing windows siding wind barrier electrical plumbing insulation gypsum board vapor retarder

Figure 8-7
Range of Value and Energy Efficiency Added to Manufactured Panels

Currently about 40% of U.S. homes are built from panels. Most of these panels are wood framed open panels which are finished in the field. Wood framed closed panels represent an opportunity for greater value and energy efficiency. In addition to increased energy efficiency, inherent to closed panels are increased quality control and cost savings available in the factory.

A survey of 363 manufacturers was performed to identify the number of manufacturers who produced wood frame closed panels and to determine the barriers to closed panels. Results of the survey indicated only 6% of panel manufacturers produced a wood framed closed panel. The majority of these manufacturers are producing panels for international markets.

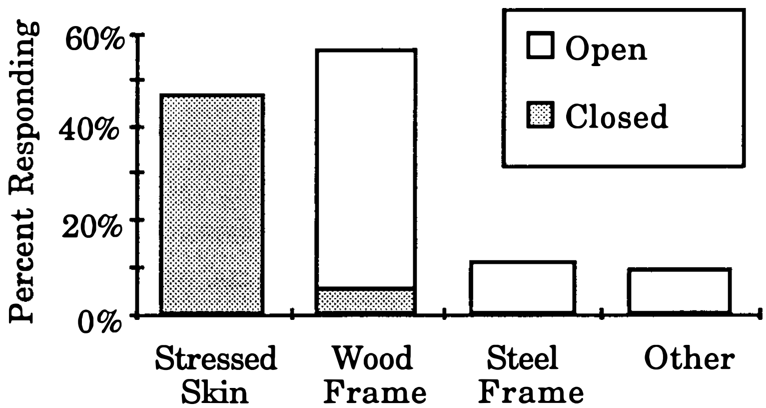


Figure 8-8, Survey Response

From the survey, open and closed panel manufacturers were identified and contacted to gather more in depth information on barriers to closed panels. Further insight into barriers to wood framed closed panels were gained through the observation of manufacturing and construction of a wood framed closed panel duplex by Soft Tech of Springfield, Oregon. Perspectives on barriers were also gained through interviews with Oregon State Building Code Officials.

The following list of barriers to wood framed closed panels were identified:

- Lack of flexibility in installation of panels, their wiring and plumbing.
- Misconceptions concerning codes and inspection requirements.
- Resistance of construction trades to increased industrialization due to

the fear of lost business.

- Damage to wood framed closed panels during shipping and installation.
- Lack of awareness of the benefits of wood framed closed panels by builders and prospective owners.
- Lack of knowledge concerning required manufacturing equipment to move from open to closed panels.
- Perceived loss of flexibility in design for manufacturers and a consequent loss of market.

The following strategies were identified to overcome these barriers:

- Develop educational material to increase awareness of the benefits of wood framed closed panels. Educational material required for development includes:
  - Data on the cost effectiveness of construction with closed panels
  - Cost studies on conversion from open panel manufacturing to closed panel manufacturing
  - Details of panelized construction techniques for contractors
- Increase computerization in office, field, and factory to facilitate production, communication, and design flexibility.
- Increase the adoption of on site construction cranes for residential scale projects. Contractors often must use large commercial cranes which require licensed operators. Contractors need greater access to smaller cranes for residential purposes to install closed panels.
- Increase the regional uniformity in building codes for manufactured panels. Uniformity in building codes would facilitate the growth of markets for wood framed closed panels.
- Increase the adoption of Manufacturing Compliance Programs for code approval. Manufacturing Compliance Programs ensure quality control and conformance with codes without factory inspection of every house.
- Improve the durability of finish skin through the use of more durable materials such as fiber reinforced gypsum board rather than conventional gypsum board to decrease damage during shipping and

construction.

- Make advances in storage containers made specifically for the shipment of panels to facilitate the loading and unloading of panels as well as their protection in transport

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10.0 ACKNOWLEDGEMENTS

This research is funded by the Office of Building Technology, Energy Efficiency and Renewable Energy Division of the U.S. Department of Energy, Mr. George James, Program Manager.