

**ENERGY EFFICIENT
INDUSTRIALIZED HOUSING
RESEARCH PROGRAM**

**SUMMARY
FY 1993 RESEARCH ACTIVITIES**

**UNIVERSITY OF OREGON
AND
UNIVERSITY OF CENTRAL FLORIDA**

**ENERGY EFFICIENT INDUSTRIALIZED HOUSING
RESEARCH PROGRAM**

SUMMARY OF FY 1993 RESEARCH ACTIVITIES

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SUMMARY OF FY 1993 RESEARCH ACTIVITIES

Abstract

This report summarizes research results from tasks conducted from March 1993 to February 1994 as part of the Energy Efficient Industrialized Housing Research Program. Detailed descriptions of tasks, methods, and results are available in the reports listed in section 13 of this document.

The "Future Housing Materials, Systems and Manufacturing and Design Process Development" section describes a vision of future industrialized housing and the systems and processes required to realize it. This vision is quantified in two sets of performance specifications. One is for a single-family wood composite frame and thin insulation panel house for a cool climate; the other is for a multifamily lightweight concrete panel house for a hot, arid climate. These specifications have been used to work with industry to establish a series of short- and medium-term research goals that are valuable to industry now, but also lead toward future high-performance economical industrialized housing. The project will be summarized and distributed to a broad audience.

The "Integration of Computerized Energy Analyses with Existing and Planned CAD Software Used by the Industry" section describes three projects. The first project is the development of an energy module for a CAD system. The project is a joint effort of the University of Oregon, Pacific Northwest Laboratories and a software vendor, Softdesk/ASG. Softdesk's software package *Auto-Architect* runs on top of *AutoCAD*. *Auto-Architect* and *AutoCAD* are popular and dominate their markets. The advantage of combining an energy module with a CAD system is that the energy module can get a geometric description of the building directly from the CAD software, and the user doesn't have to re-enter the data. We expect this product to be on the market in October 1994.

The second project, *SIP Scheming*, is energy analysis and cost estimating software for the Macintosh computer specifically designed for stressed skin insulating core panel producers. *SIP Scheming* can be used by someone with relatively little technical knowledge. Drawings are input either by scanning or importing from a CAD program. They can also be drawn directly using a basic

set of drawing tools. The construction of elements such as walls, roofs, and windows are specified in terms of materials, or panels, which the software translates into thermal properties. A digital tape measure is used to graphically “takeoff” areas by tracing over the drawings, so that within a matter of minutes an energy analysis and cost estimate is calculated. In addition to SSIC panels, *SIP Scheming* includes conventional framing and frame panels, and can be used for residential or commercial building types.

The third project in this section is the Sales to Manufacturing Tool. Because home buyers have the largest stake in the energy performance of a home, we believe that a computerized sales tool that allows buyers to design their own homes while considering energy has the potential to improve the energy performance of homes and increase sales. If this information is transferred electronically to engineering and manufacturing, the efficiency of the entire housing process will be improved, thereby reducing the cost of housing. The tool we are developing is a backbone that allows data flows from existing and proposed applications throughout the housing process. A prototype has been completed.

In the “Manufacturing Process Simulation” section we describe developing a computerized tool that allows manufacturers to understand the cost and labor consequences of changes to their manufacturing processes. This is extremely important because each change in a house design to increase its energy efficiency causes a corresponding change in the manufacturing process, which can affect the cost at which the home can be delivered. We have developed a prototype of the tool and are currently testing it by simulating various manufacturers.

In the “Benchmarking Innovative Homebuilding Technologies” section we describe our efforts to design an innovative wall panel by concurrently designing the product and the manufacturing process. Simultaneous consideration of product and process can result in increased energy efficiency, reduced manufacturing cost, increased quality, increased customer appeal and increased architectural design flexibility. We have completed a cost analysis of a “standard” 40’x8’ wall using three methods of construction – 2x4, 2x6, and stressed skin insulating core panel – and determined that frame walls are slightly (1-18%) less expensive than standard SSIC panel walls.

The “Field Testing of Whole Houses and Components” section describes side-by-side thermal testing of a stressed skin insulating core panel building system and a conventionally constructed base case built to identical calculated envelope conductances. Based on preliminary data the stressed skin insulating core panel house demonstrated 15% better performance because of its better thermal integrity.

In the “University Experimental Housing Demonstration” section we describe six housing units that have been built and tested on the University of Oregon campus. These units demonstrate good energy performance, available methods of industrialization, high levels of architectural quality and low cost.

We have completed the construction of the stressed skin insulating core (SSIC) panel demonstration house in Springfield, OR. The house meets BPA’s Long Term Super Good Cents standards: roofing R 49, wall R 26, floor R 30, and windows U 35. Our cost estimates show that we can build the SSIC panel house up to \$3,500 cheaper than the same design built conventionally, depending on location.

The “Spirit of Today House” is a new project intended to demonstrate to the American public houses that are energy efficient, have excellent indoor air quality, are comfortable and are handicapped accessible. The first house will be constructed in Orlando, FL, and will be featured in the October, 1994, issue of *Better Homes and Gardens*. This widely read magazine will also feature a smaller version of the Spirit of Today house. Plans and specifications for both houses will be available for sale to magazine readers. This is expected to lead to construction of several such homes in different areas of the country.

1.0 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, under the guidance of a steering committee composed of industry and government representatives, focuses on three interdependent concerns: (1) energy, (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. 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 viewed in the context of production and design. This approach enables researchers to solve energy problems in ways that can help industry improve its product and compete with foreign companies in order to alleviate the trade imbalance in construction products, to increase the productivity of the U.S. housing industry, and to decrease both the cost of housing and the use of fossil fuels, which are expensive and damaging to the environment.

2.0 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 define 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 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 using 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) level of technology employed --

high, intermediate, or low; 2) percentage of value that can be supplied by the home owner, using sweat equity; 3) physical size of the elements--components, panels, cores, modules, or complete units.

HUD Code Houses

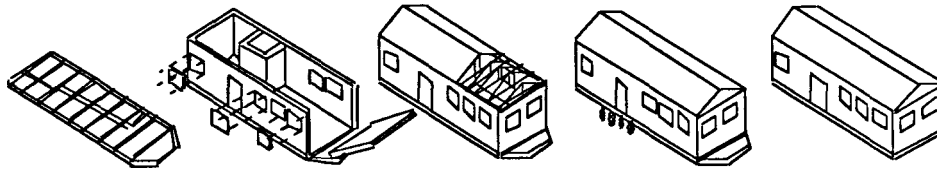


Figure 2 - 1
HUD Code House

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 on site. Individual units and parts of units may be folded, collapsed or telescoped during shipment to the site.

Modular Houses

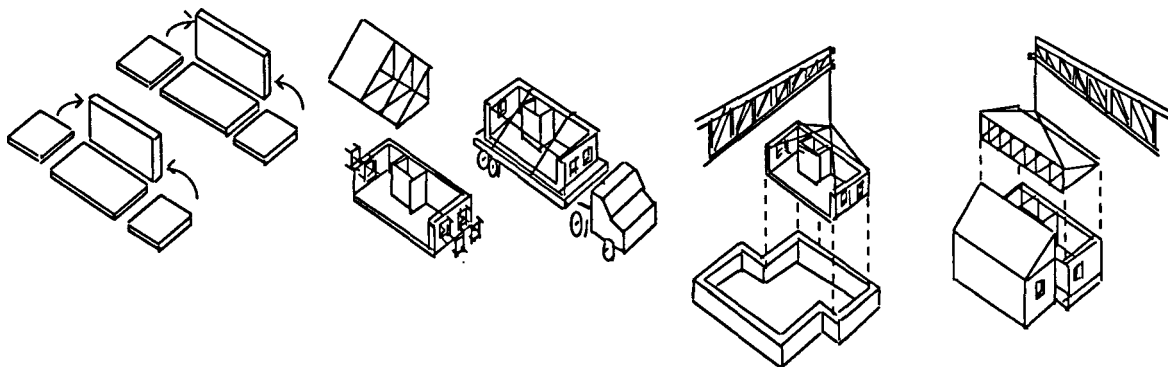
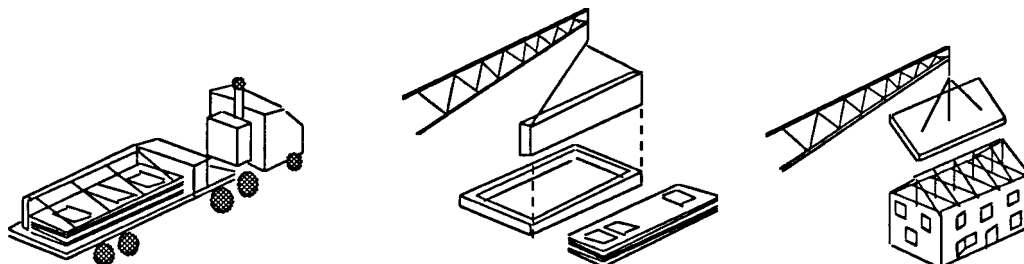


Figure 2 - 2
Modular House

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.

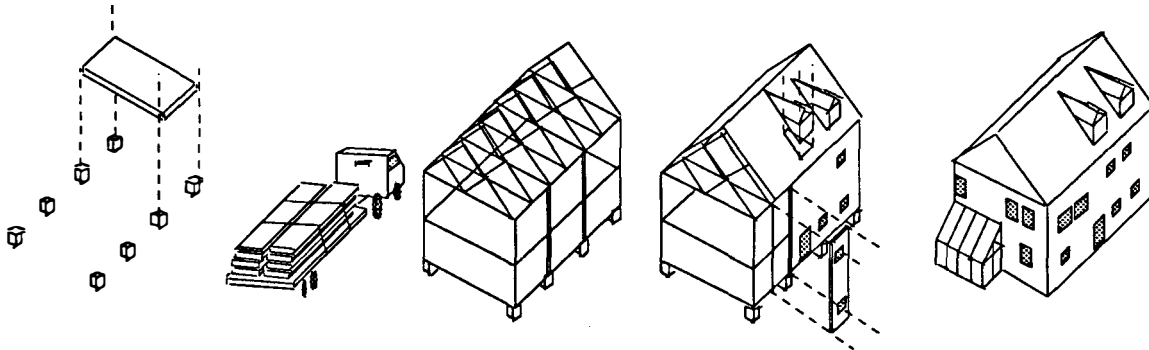
Panelized Houses



**Figure 2 - 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 2 - 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, the factory is a building site that becomes an open-air assembly line through which industrialized labor and materials move, rather than houses.

3.0 FUTURE HOUSING MATERIALS, SYSTEMS, AND MANUFACTURING AND DESIGN PROCESS DEVELOPMENT

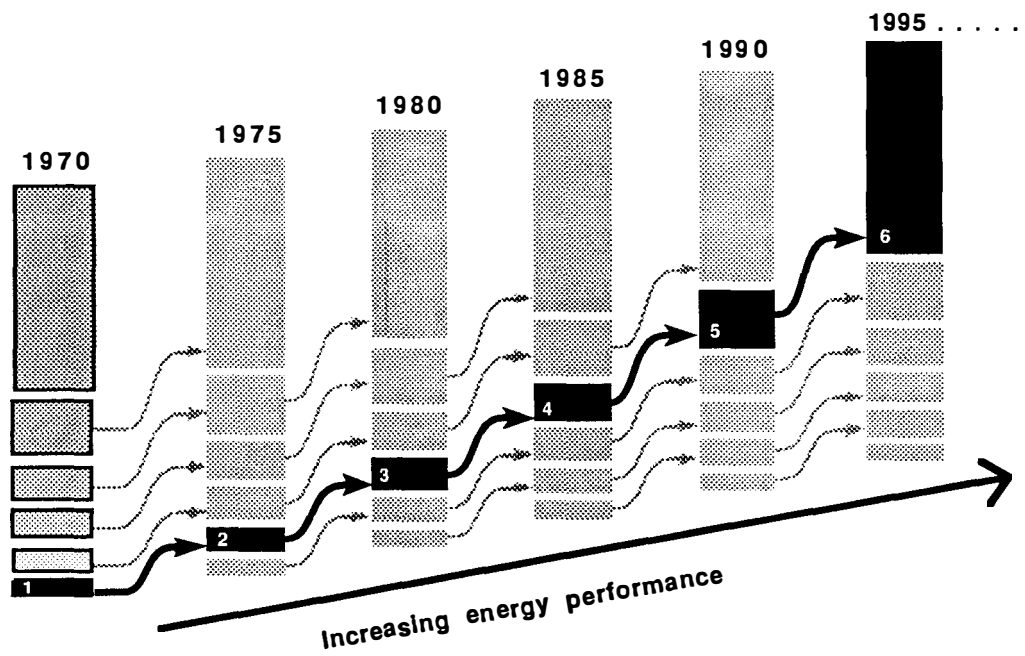
In the future housing materials and systems area of the Energy Efficient Industrialized Housing research program, design studies establish scenarios of energy efficient housing systems for the year 2030 based on the anticipated development of materials and technologies currently in basic research, development and early commercialization. Of the scenarios explored, two were developed in detail.

In the Cool Climate Scenario, materials and systems were developed for median cost single family density housing in a heating dominated climate (Minnesota). This scenario derives from current materials research underway in thin, high-performance insulations, phase changing finishes, wood composite materials, space conditioning appliances and process research underway in design process computing and manufacturing.

In the Hot-Arid Climate scenario, materials and systems were developed for low-cost multifamily density housing in a cooling dominated climate (Arizona). This scenario derives from current materials and process research underway in thermally massive concrete panel manufacturing, phase changing finishes, photovoltaics, and distributed utility systems. Like the Cool Climate Scenario, research underway in design process computing and manufacturing is integrated.

Objective

These studies enable researchers to envision future housing materials and systems and develop the research activities that bring them into application. Viewed from the perspective of a portfolio of technology development and research programs within the Department of Energy, futures research would be near the leading edge of a series of activities and programs that act together to achieve higher levels of energy performance over time.



**Figure 3-1
Future Housing Materials and Systems**

Futures research tasks are the bridge between basic and applied research activities. Basic research provides the science from which future opportunities and goals can be envisioned. Applied research programs develop and prototype the most promising opportunities. Demonstrations and programs apply the prototypes. Ratings and incentives stimulate the early adopters, and ultimately codes and standards mandate use. Over time, with effective research utilization programs, the entire portfolio moves forward toward higher levels of energy performance and acceptance.

Rationale

Housing systems integrate a matrix of processes and products that have been, and continue to be, in a slow but continuous process of refinement and evolution. For energy efficiency to be an active participant in this evolution, researchers must be prepared with visions of energy conservation opportunities that anticipate change in housing design and production, wherever they may come. In so doing, this research must recognize that:

There are multiple futures to anticipate. Change in the materials and

construction systems of housing will emerge from a wide variety of social, political, economic and technological forces acting on regional housing markets and those that serve them.

The question is “whole house” performance. While the materials and process technology of energy efficiency is the research focus of this work, technology is investigated “in context” to ensure that new technology results in housing that is well designed, energy efficient and costs less to purchase and operate.

Opportunities are distributed throughout a housing delivery process. While many opportunities are found in construction and materials technology, others are tied to qualitative human decisions establishing how those materials and systems are applied, such as decisions about site planning, design, and maintenance.

Change takes time. In an industry as mature, regional and fragmented as housing, up to two generations may pass between research definition of an innovation opportunity, commercial development, and regulatory approval and acceptance into conventional practice.

History of year's work

FY93 saw work completed on working reports summarizing performance specifications related to the Hot-Arid and Cool Climate design scenarios. Of these, the Cool Climate scenario illustrates materials and systems that could double the thermal resistance of residential envelope construction over the next 30 years to yield an envelope of approximately R-50 overall. Such an envelope would likely be manufactured in panels (Figure 3-2) made from thin, high-performance insulations currently in research and development.

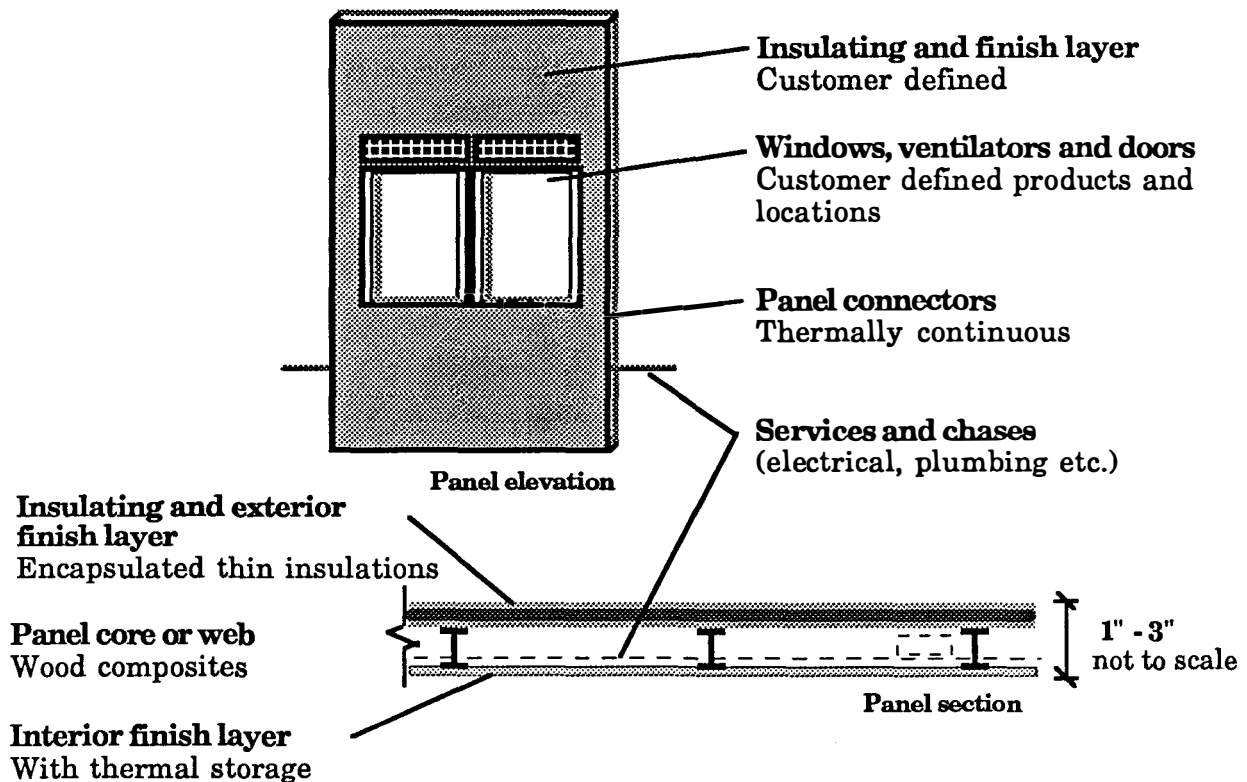


Figure 3-2
Schematic Section and Elevation of Cool Climate Scenario Panel

A panel of this type offers the opportunity of a thin, stressed skin envelope of light-weight, high thermal performance, air tightness, and structural efficiency. At the exterior is a rigid sheathing and finish layer encapsulating an insulation material. At the interior is a sheathing and finish layer incorporating a phase changing material. Between these layers is a series of laminated wood composite ribs. Windows and doors can be accommodated in a variety of locations and sizes. The thin insulations anticipated for use in this panel are in various phases of research and development primarily in national laboratories.

The envelope design anticipated in this scenario (Figure 3-3) integrates insulations with the high strength of fiber-based wood composite materials (parallel strand lumbers, laminated veneer lumbers and fiber composite sheets, for example) to create a light, material efficient assembly of very high thermal resistance — approximately R- 50 overall.

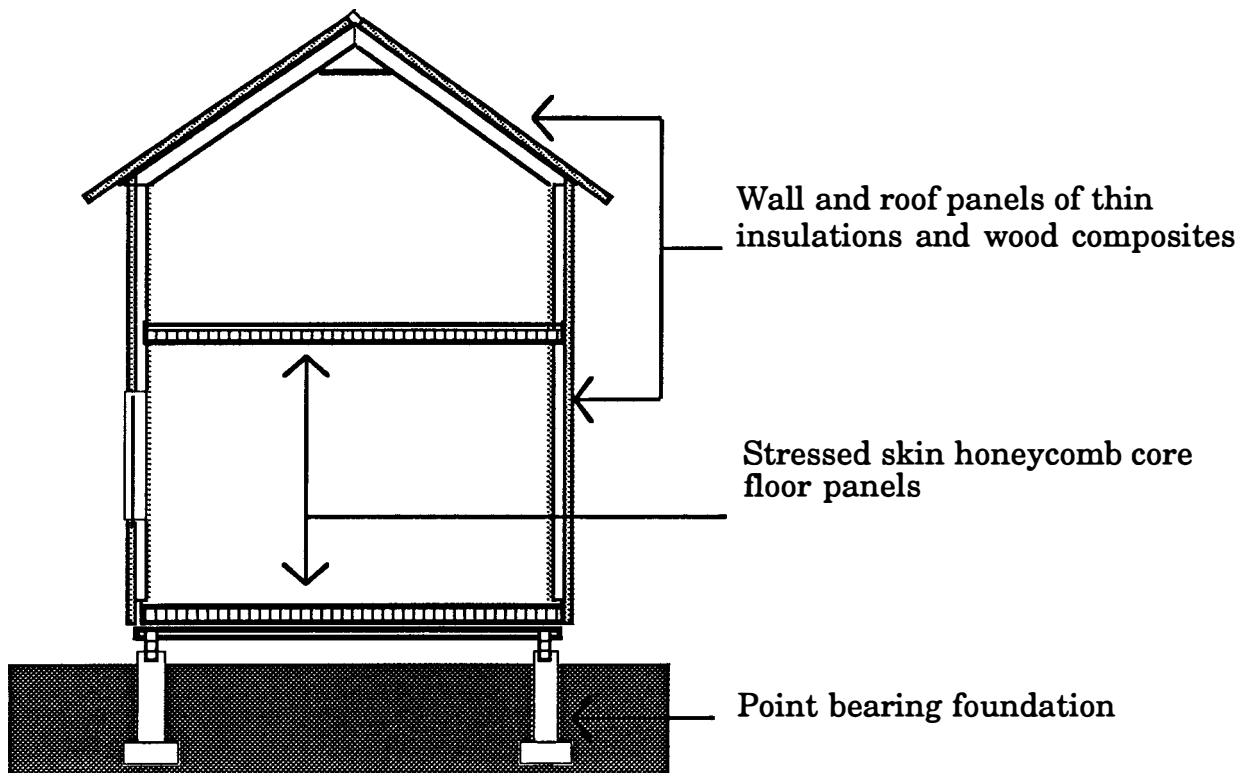


Figure 3-3
Schematic Section of Envelope System
Cool Climate Scenario

The technologies of this scenario should be compatible with the following whole house performance goals:

A “zero net” energy budget:

- space conditioning loads reduced by approximately 85% from Long Term Super Good Cents standards for thermal resistance and infiltration
- infiltration rates reduced to less than 0.15 ACH
- 85% of space conditioning loads met by heat recovery based systems
- electrical power supplied by a utility balance with household photovoltaic generation (photovoltaic power is returned to the utility)
- utility peak loads reduced and redistributed to off-peak hours

Conservation of raw materials:

- wood resource based materials decreased by about one-half over contemporary

practice

- material waste in production reduced by about one-half over contemporary practice

Affordability in a median income market:

- development portion (land, infrastructure, design and engineering processes etc.) of whole house cost reduced by 15%
- mechanical systems portion of construction costs reduced by approximately 50%
- use-based utility costs eliminated

Flexibility in site design:

- minimum densities of 8 detached houses per acre
- structure and envelope portion of gross floor area reduced by approximately 50%
- site configurations, plan types and architectural styles suitable for infill and scattered site development
- limitations of orientation associated with small or constrained sites mitigated by envelope design
- site impact of construction processes, utilities and paving reduced

Flexibility in house design:

- variation in house size, configuration, orientation, fenestration, finish and architectural style accommodated
- internal layout flexibility in room size, configuration and opening location
- size and capacity of space conditioning appliances, mechanical and distribution systems reduced
- remodeling and expansion by owners with low-technology tools and skills accommodated

Simplification of construction:

- site labor requirements reduced by half
- foundation system preparation and materials reduced
- assembly, disassembly and recycling of construction materials and components simplified

Figure 3-4 compares the whole house energy performance of a house of approximately 1000 square feet designed to Long Term Good Cents standards (a 1994 high-performance reference case – approximately R-49 roof, R-26 walls, R-30 floors, R-2.86 windows and R-5.26 doors) to the same house designed to performance goals in the Cool Climate Scenario (the 2030 high-performance illustration case). In this example, the illustration case also assumes higher efficiency appliances over and above envelope improvements.

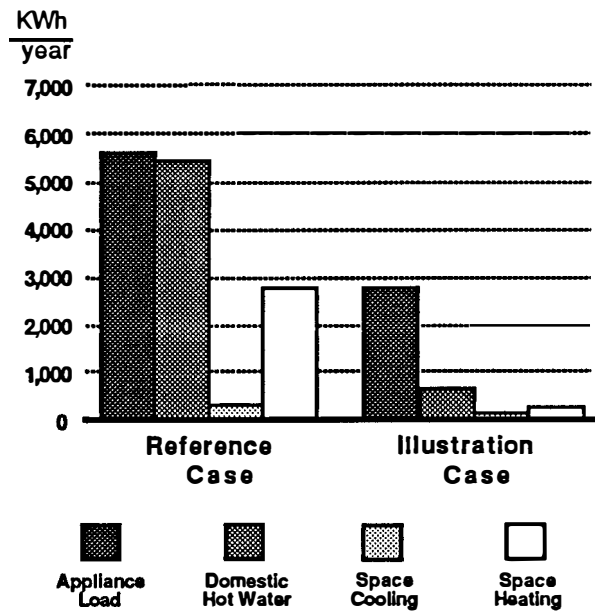


Figure 3-4
Cool Climate Scenario Average Annual Energy Load
for a 1000 Square Foot House in Minneapolis
 (Calpas3 analyses)

As research is initiated to realize these performance goals researchers must be aware that significant non-technical barriers must be overcome in parallel, including the following:

Housing innovation will always be first cost sensitive. Energy conservation measures have historically increased the first cost of design, materials and installation in housing. Although the economics of these energy conserving materials and technologies have been favorable on long-term and life-cycle bases,

housing consumers are very sensitive to first cost considerations. The affordability gap is increasing for many households in the United States. As a consequence, home ownership rates are in decline and fewer households are projected to be able to sustain the financial burden of homeownership in the future unless it declines in cost. Therefore, research anticipated to interest housing consumers in energy conserving technologies must accept first cost as a fundamental performance parameter.

The building industry and its market are traditionally risk averse. The materials and methods of housing construction have evolved over a sustained process of practice and field experience. In the absence of evidence of consumer interest and demand, builders and the manufacturers that supply them are less likely to assume extraordinary risk they associate with the adoption of new products and innovations. Both consumer and industry audiences are unlikely to be convinced in the absence of demonstrations and research results designed to stimulate their interest and awareness.

Many of the systems and technologies likely to be a part of housing in the future are already in phases of research and development. Some could be commercially available by the end of this decade. Others may not realize their commercial potential until 2030 or perhaps beyond. Progress toward those that require long development times must deliver interim products along the way to justify the investment of sponsors as well as to stimulate consumer interest and build industry confidence.

The research required demands sponsor cooperation. The nature of research needed to improve energy conservation in housing into the next century is changing. As the house becomes a more complex, better performing, lower cost product, its design will aggregate components into more sophisticated systems of fewer, higher-value, more integrated parts. The performance and boundaries between one part, component or system and another are becoming increasingly less distinct and their performance attributes more interdependent.

Research needed to realize the performance of the kinds of envelope systems anticipated in the Cool Climate Scenario, for example, is simultaneously

technical, design, manufacturing and economic in focus. Progress toward that vision will hinge on successful development of construction components that economically integrate the thinness and energy performance of thin insulations and phase changing finishes with the engineering efficiencies of wood composite materials and the manufacturing and assembly efficiencies of a highly skilled construction sector. For example, the vacuums and encapsulated gases common to the insulation materials must be manufactured with other construction materials and processes able to protect them during manufacture and installation.

And, new envelope systems must ultimately deliver a whole house that is first cost competitive with the systems they displace. In this example, cost premiums associated with these higher performing technologies may ultimately be offset with research that reduces building service requirements and expedites design, manufacturing and field assembly processes.

Future work

In FY 93, we substantially completed a 30-page publication "*Steps Toward Affordable and Energy Efficient Housing*" summarizing research progress and findings in this task for a broad audience including government, professional and public readers. It includes a section highlighting trends, a section reviewing conditions and specifications related to the Hot-Arid and Cool design scenarios, and a research agenda intended to assist government, universities, industry and national laboratories co-ordinate visualize and plan toward common research goals. Once the summary publication is completed early in FY94, no further work is planned in this area.

4.0 INTEGRATION OF COMPUTERIZED ENERGY ANALYSES WITH EXISTING AND PLANNED CAD SOFTWARE USED BY THE INDUSTRY

We believe that the U.S. is on the brink of extensive computerization of the housing industry, from sales and marketing, to design and production processes, through repair and maintenance tasks (Brown, et al 1990). This is a world-wide trend, and currently the U.S. is trailing other countries. Japan leads in computerizing the sales-through-design processes, whereas Sweden and Norway lead in computerization of the design-to-production processes. In order to remain competitive in the world housing market the U.S. will have to increase its use of computers in all facets of the housing industry. With this increasing computerization there is a significant opportunity to address environmental issues of energy efficiency and materials utilization.

We are working on three software products to more fully integrate energy efficiency and enhance processes within the housing industry. The first aims to improve design and plan production by incorporating energy analysis tools into the normal CAD (computer-aided design) process. The second product brings energy analysis to the sales process for stressed skin insulating core panel manufacturers. The third tool automates the entire building process from marketing and sales through design and manufacturing.

Energy Module for an Industrialized Housing CAD System

Objective

The objective of the first task is to develop an energy analysis program that will 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 true:

1. The analysis must be done early enough that design changes are feasible.
2. The energy program should work within the user's normal design environment.

3. Accurate data about the building should be available.
4. The interface should be easy to use, highly visual, and non-technical with respect to energy.

Embedding our energy analysis within a popular CAD system enabled us to meet the first three criteria. We chose AutoCAD, the largest selling of PC CAD systems. The fourth criteria required an interface that encourages visual input of data as well as the more common visual output of results in graph form. We have succeeded in creating an interface that requires no numeric input, reports results graphically, and begins to educate the user's intuitions about energy efficiency.

Background

Early stages of this project involved selecting an appropriate CAD tool and negotiating an agreement to develop software for the CAD company. During a trade-off analysis of different CAD-industry tools, we chose to use *AutoCAD* with Softdesk/ASG's *Auto-Architect* product. We worked directly with Softdesk/ASG with technical support through AutoCAD's Registered Developer program.

The vehicle for this project was a collaboration between industry, government, and academia, represented respectively by Softdesk/ASG in Sausalito, California, Pacific-Northwest Labs (PNL) in Richland, Washington, and the University of Oregon. The Collaborative Research and Development Agreement (CRADA) was signed by the three groups in late 1992.

Scenario

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

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: walls show up as red lines, doors and windows as blue lines.

Other, non-geometric data is input by the user through a series of dialog boxes such as the one shown in figure 4-1. 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 an activity ranging from “Light Work” through “Moderate Dancing” to “Heavy Work” and the tool reports a BTUs per hour per person of 365 or 800 or 1450. The precise numbers are always there for the energy specialist, but even a novice can use the tool with a high degree of confidence.

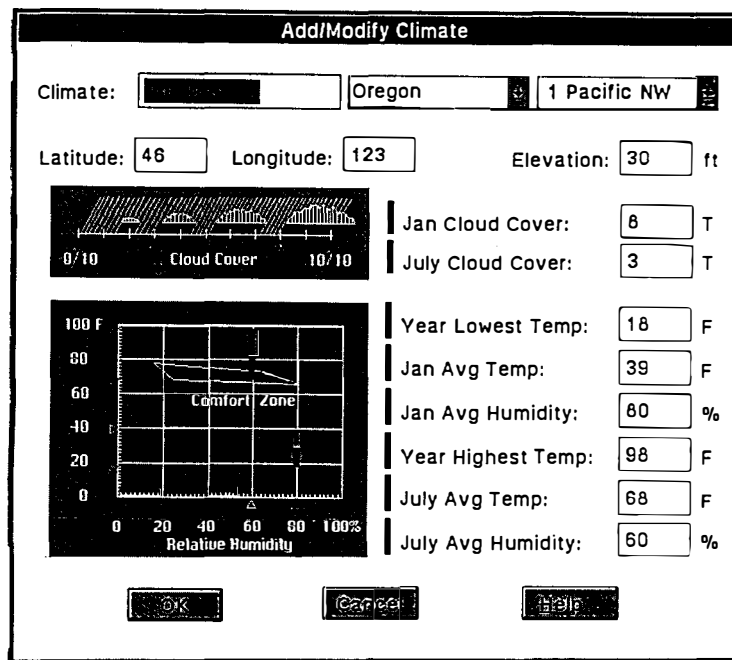


Figure 4-1
Add/Modify Climate Screen

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.

History of Year's Work

This year's work was the design, coding, and testing of the tool itself. PNL developed the energy analysis method for the product while the University of Oregon designed and coded the user interface and the geometry interpreter. The three CRADA members met four times in 1993 to review design decisions and present progress. The product was delivered in February of 1994. Integration and bug clean-up are nearly complete, with delivery to the public expected in October 1994. The Energy program will be delivered as an add-on to the next upgrade of Softdesk/ASG's *Auto-Architect*.

Future Work

Future work is still under discussion, but is expected to include functional enhancements for more sophisticated buildings. The University of Oregon will also explore the feasibility of converting the product to a stand-alone Microsoft Windows application that communicates with AutoCAD, rather than being an extension to AutoCAD itself. This would allow the product more elegant graphics, a more user-friendly platform, and possibly greater speed. The work will begin in the fall of 1994 with delivery in early 1995.

SIP Scheming

Objective

SIP Scheming is energy analysis and cost estimating software for the Macintosh computer specifically designed for stressed skin insulating core panel producers. It is intended to facilitate marketing, sales, and production processes by integrating cost estimating and exporting to CAD while also providing energy feedback.

Rationale

Cost quotes are typically done by hand and require as much as eight hours to complete, and only one in twenty quotes results in a sale. With a well-designed graphical interface, a computer has the potential to dramatically reduce cost estimating time.

Scenario

SIP Scheming's graphic input and output was designed for non-computer people which makes *SIP Scheming* ideal for marketing and sales of SSIC panels. Drawings are input by scanning, by importing from a CAD program, or by drawing directly in *SIP Scheming*. A digital tape measure is then used to graphically "takeoff" areas by tracing over the drawings, so that within a matter of minutes an energy analysis and cost estimate is calculated. The program will calculate thermal loads for both panel and non-panel buildings.

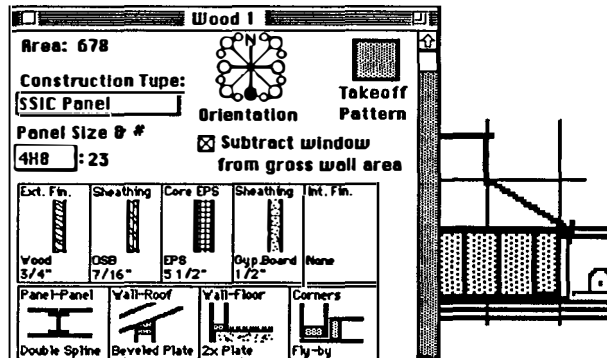
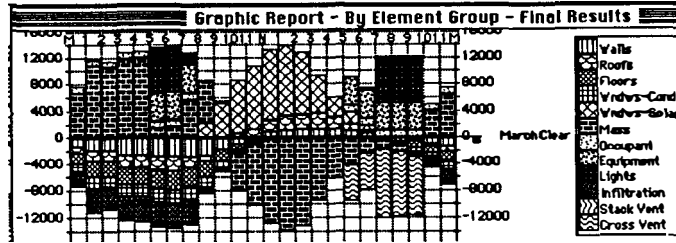


Figure 4-2
Takeoff Tape Measure and Specification Window

The results of the calculations are displayed in bar graphs. This makes it easy for non-technical personnel or clients to understand the building's performance. The results include the effects of conduction, solar radiation, internal gains, ventilation, daylighting and mass.



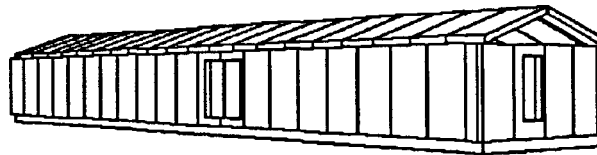
**Figure 4-3
Energy Performance Graph**

After completing an energy analysis SSIC panel manufacturers can request a cost estimate. A Microsoft Excel spreadsheet is created detailing panels and connections used. The use of *SIP Scheming* has the potential to reduce quote time to 30 minutes, thus substantially reducing a manufacturer's sales overhead.

SIP Scheming 1.0 Cost Estimate		6-Apr-94	11:47 a.m.	
4 Room House				
PANEL DESCRIPTION	PANEL SIZE	# PANELS	\$/SF	ITEM TOTAL
Walls				
OSB 7/16" EPS 5 1/2" OSB 7/16"	8'4"x8'	50	1.54	2464.00
Roofs				
OSB 7/16" EPS 7 1/4" OSB 7/16"	4'x12'	42	1.31	2640.96

**Figure 4-4
Cost Estimate Spreadsheet**

Once a sale is made, building geometry information can be exported to ArchiCAD, a powerful 3D CAD package created by Graphisoft. This gives the manufacturer a head start on design development and shop drawings. If a more detailed energy analysis is desired, *SIP Scheming* can also create an input file for DOE 2, a more sophisticated energy analysis program.



**Figure 4-5
Perspective Drawing Done in ArchiCAD**

History of Year's Work

During FY93 *SIP Scheming* was taken from a prototype tool and developed as a

commercial product. We signed an agreement with Graphisoft for support of this project. Graphisoft's technical assistance and product contributions have been invaluable. We have surveyed panel manufacturers and elicited the interest of several as potential beta testers. We have also started writing a user's guide.

Future Work

We are completing the final aspects of the export to CAD feature and are making revisions to the user's guide. We anticipate completing these tasks and releasing *SIP Scheming 1.0* for beta testing in early August of 1994.

Sales to Manufacturing Tool

Objective

The third product, the Sales to Manufacturing Tool, is intended to assist the home buyer in selecting and customizing a house design and also to support the sales and manufacturing of industrialized housing. Information generated by the Sales to Manufacturing Tool will enable other people involved in the house buying process to make decisions or carry out necessary functions such as loan approval, building permit approval and, of course, building production.

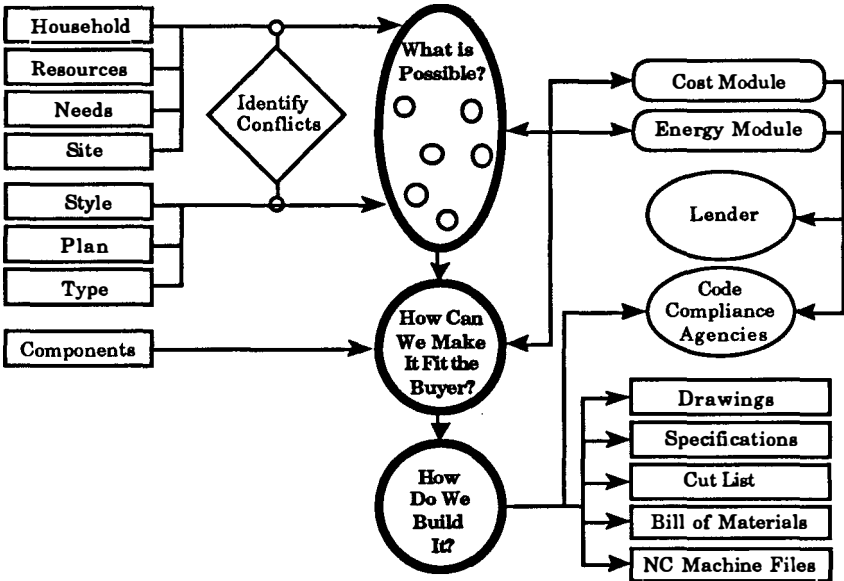
Rationale

Home buyers have the largest stake in the energy performance of housing products. We believe that sales processes that allow and encourage buyers to customize within manufacturer-specified guidelines have great potential to increase the market share of industrialized housing, improve energy performance, and enhance customer satisfaction. The greatest promise for improvement is in the ways increased systematic computerization can provide previously unavailable options for selling, designing, and manufacturing homes. An example would be a computer-based system that helps a buyer customize a manufacturer's standard house plan, visualize the changes, and then pass the information on to inventory and production managers in a more timely and efficient manner than is now possible.

Scenario

The computer-based Sales to Manufacturing Tool consists of hardware and software that is accessible to virtually anyone, regardless of computer experience.

A graphical user interface, hypermedia, and intelligent “agents” that assist the buyer in navigating the program insure ease of use. Figure 4-6 illustrates a scenario for the application. A buyer makes choices about a dwelling which the tool stores and uses to create a composite design program. Based on these choices and on answers to specific questions put to the buyer, an expert system makes inferences about the kind of dwelling desired and filters the immense quantity of data that could otherwise overwhelm the buyer. The expert system analyzes the choices and warns of conflicting decisions.



**Figure 4-6
Sales to Manufacturing Tool Scenario**

Among the interface agents are ones devoted to energy, building and operating costs, and finances. They present information in a graphic format allowing the buyer to immediately see the financial and environmental benefits of improved energy efficiency. They also provide lenders with an analysis in support of an energy efficiency mortgage credit.

The process of designing a house generates data in many forms: textual, numeric, graphic, and geometric. The Sales to Manufacturing Tool will automate the flow of data through the process, providing a direct electronic means for manufacturers to produce drawings, specifications, and the like.

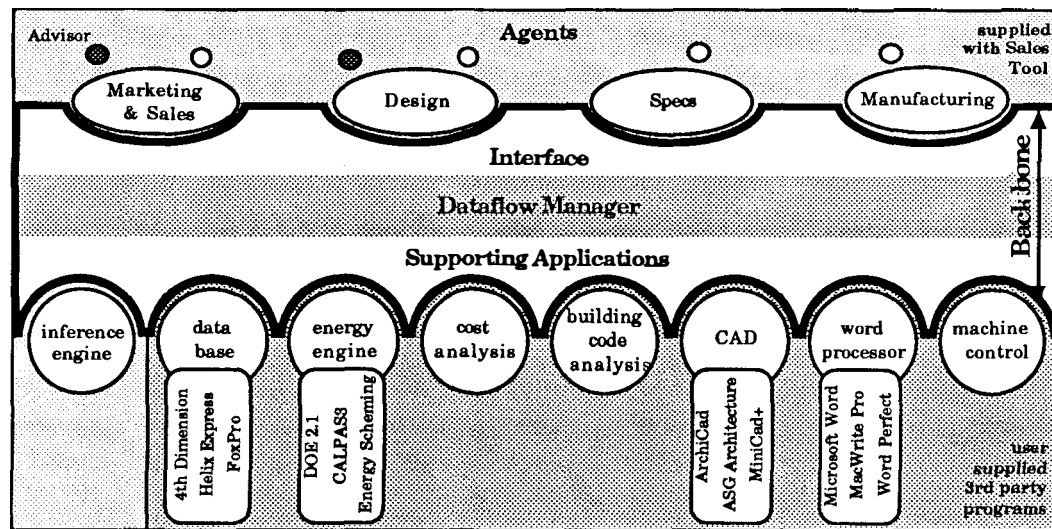


Figure 4-7
Sales Tool Development Strategy

The Sales to Manufacturing Tool is a backbone that will provide a consistent user interface and continuity of data flow between several user modules, as shown in Figure 4-7. In order to reduce development requirements the tool will rely heavily on existing software that runs on Macintosh, Windows, and UNIX systems. Hooks built into the Sales Tool will allow the user to choose among several acceptable products to supply necessary abilities such as word-processing, CAD, and database. Other modules or sub-programs will be built into the Sales to Manufacturing Tool. These are the pieces that are vital and specific for the Sales Tool and that users would not already possess, such as the inference engine and advising agents.

History of Year's Work

In FY93 we completed a working prototype that successfully demonstrated inter-application communication, the most crucial technical issue. We developed two metaphors for the tool. The first is that of "districts." These are the places where the work occurs, providing a means to integrate the various applications into a single tool. The second "navigating metaphor" links the individual applications and guides the users in finding and directing data between districts. We later focused on this metaphor to develop a functional input/output specification. We

also developed a data input/output list for each application and a metaphor for the user interface to help the user navigate between applications.

Future Work

In FY94 we will finish a report on our findings to date. We will then survey the current state of development of other Sales-to-Manufacturing Tools and components in the software industry, in the building industry, in U.S. national laboratories, and in universities. This work will assist the U.S. DOE in formulating directions for future support of sales-to-manufacturing computer software development.

5.0

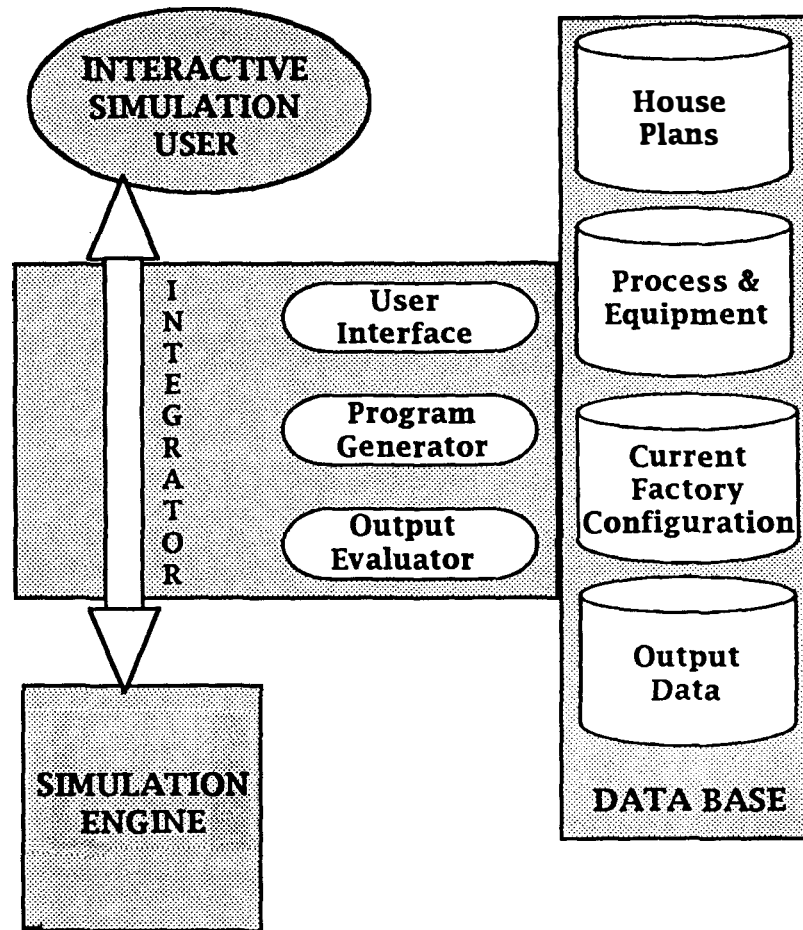
MANUFACTURING PROCESS SIMULATION

Industrialized housing manufacturers have few Computer Aided Engineering (CAE) tools to assist in planning and evaluating the next generation of manufacturing processes and systems. As a result, few housing manufacturers have been willing to take the financial and operational risks associated with “pioneering” innovative manufacturing technologies, and there has been little innovation on the manufacturing floor. Perhaps more importantly, the next generation of industrialized housing manufacturing processes and systems may continue to lack the technological innovation required for international competitiveness. This task provides a key CAE modeling tool which can assist housing manufacturers (both existing and new entrants) in planning for and assessing the impact of innovative manufacturing technologies. GIHMS (Generic Industrialized Housing Manufacturing Simulator) integrates computer simulation, animation and data base technologies to address these important issues. Several major milestones in the design and development of GIHMS were reached in FY93.

- The GIHMS system structure was finalized.
- Simulation engine development was initiated and completed.
- The user interface for stressed skin insulating core (SSIC) panel manufacturing was begun.

GIHMS System Structure

The design of the GIHMS system structure (Figure 5-1) is driven by the objective of bringing practical simulation modeling capability to users who are PC literate and have housing industry experience, but not necessarily computer simulation experience. The simulation engine contains the simulation computer program. When executed, it simulates factory operations and generates simulation output including reports and an animation of the operation. The distinguishing feature of GIHMS is the integrator which links the simulation user with the simulation engine, allowing the user to configure a factory and specify home designs for production without programming and with minimal data entry. To speed model development and enhance model validity, the user can use the integrator to draw from extensive data bases which contain detailed house plans, manufacturing process equipment and complete factory configurations.



**Figure 5-1
GIHMS Structure**

Simulation Engine

The simulation engine contains the simulation computer program. GIHMS is the first known generic simulator developed using a commercial manufacturing simulator (PROMODEL) as the simulation engine. This unique approach was chosen to capitalize on PROMODEL's advanced manufacturing constructs which are made accessible through a user friendly visual user interface. This approach not only shortened the simulation engine programming effort, it allowed the PROMODEL visual user interface to be incorporated directly into the GIHMS integrator. The structure of the simulation engine is discussed in greater detail in *The Role of Object Oriented CAD in a Generic Simulator for the Industrialized Housing Industry* (Armacost, et al, 1994).

User Interface

The GIHMS user interface or integrator links the simulation user with the simulation engine. The integrator is being developed under PC WINDOWS™, which provides the user with an icon-based, point-and-click modeling environment. The heart of the integrator is a specialized object oriented CAD system. Although appearing to the user as “seamless,” it is actually a highly-integrated virtual system consisting of a customized CAD front-end (C++), a relational data base management system (PARADOX) and the PROMODEL visual interface. Working together, they allow the user to configure a factory and specify home designs for production without programming and with minimal data entry. To demonstrate the capability of the GIHMS integrator, we summarize the modeling of an SSIC panel manufacturing operation.

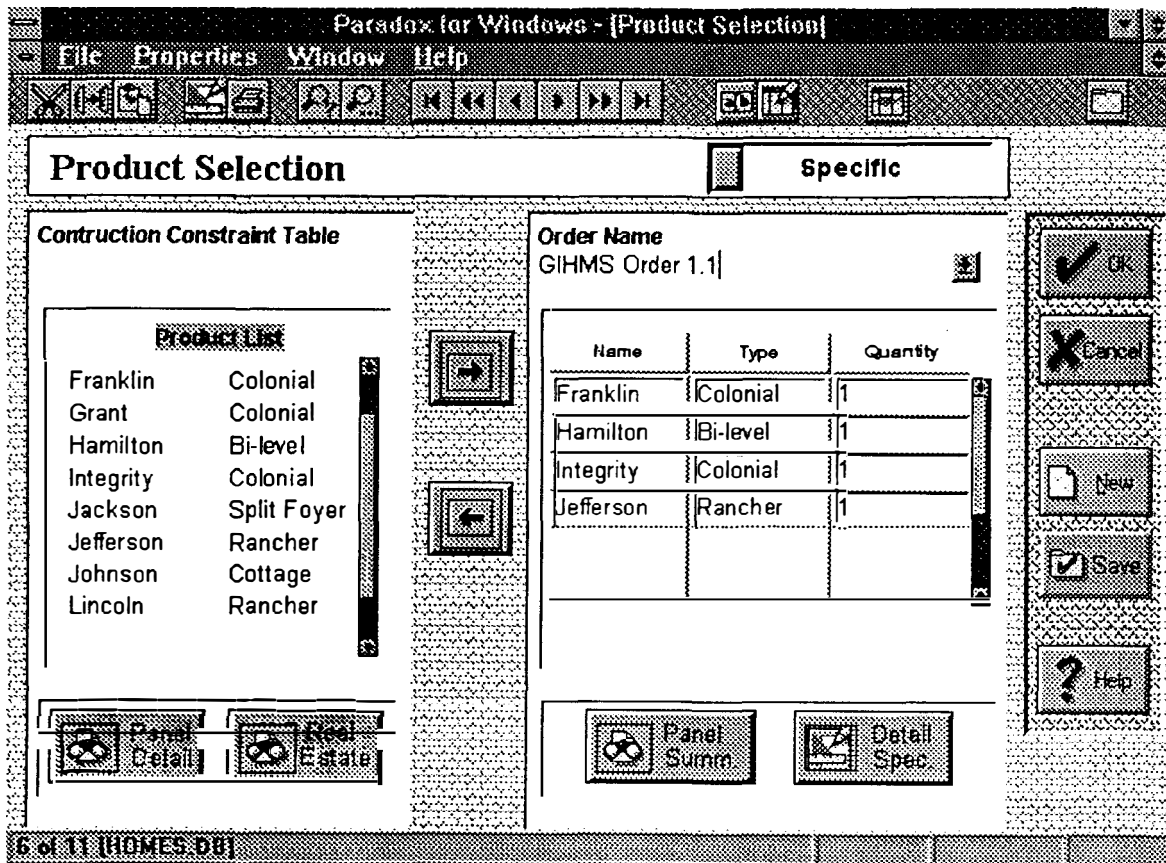


Figure 5-2
Product Selection Window

Customer orders (homes) which will be produced in the SSIC factory are selected

using the product selection window (Figure 5-2). Specific homes may be selected for manufacture or GIHMS can select orders randomly using user defined market shares. Using the product selection window, the user selects homes from a permanent library of house plans, tailors the order to builder/customer needs and, finally, schedules manufactured components for production.

Factory configuration is performed in two stages, a preliminary stage and a final stage. In the preliminary stage, the user first uses the process chart window (Figure 5-3) to define the sequence of manufacturing operations to be performed. The user is then prompted to select specific manufacturing equipment to perform each production operation. As equipment is selected, its icon appears in the preliminary layout window (Figure 5-3), which represents a rough layout of the manufacturing facility. The user may select equipment from an on-line equipment catalog which provides multi-media information such as vendor spec sheets, still-frame pictures and short video segments of the equipment in operation.

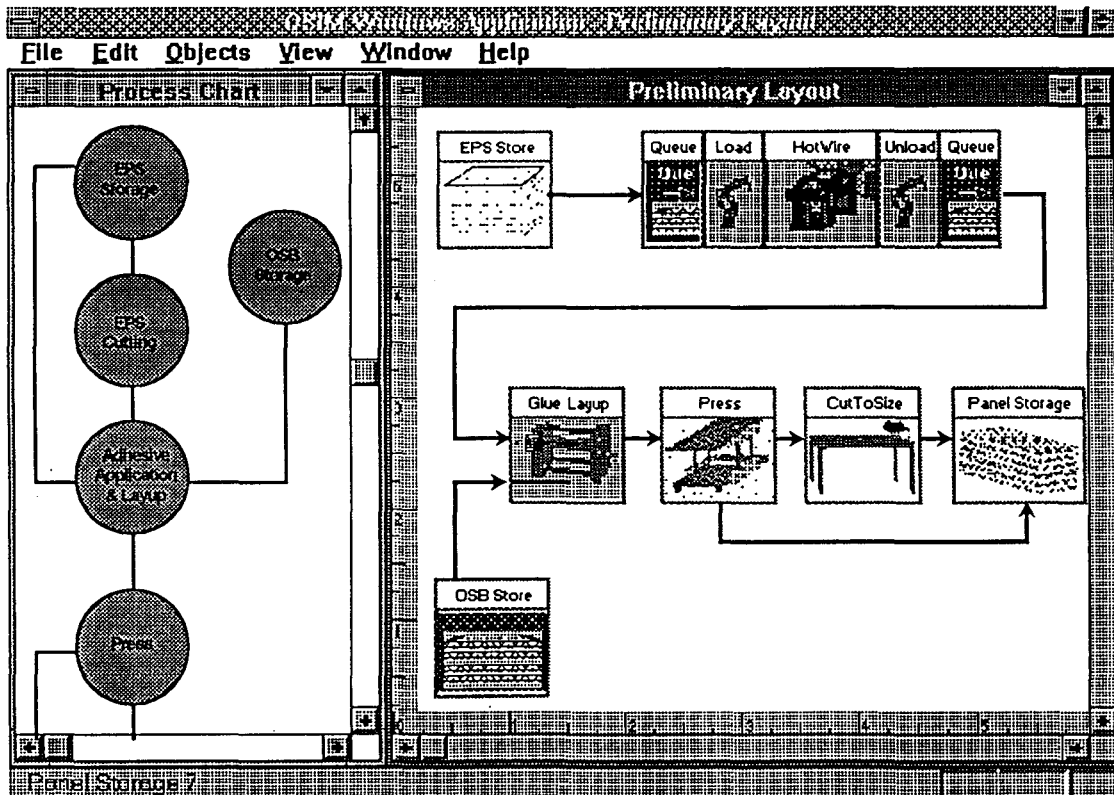


Figure 5-3
Process Chart Window and Preliminary Layout Window

In the final factory configuration stage, the user uses the final layout window (Figure 5-4) to arrange equipment on the factory floor and identify physical paths (aisles) for material handling equipment. The simulation is then run. GIHMS explodes each customer order (house) into its component panels, explodes each panel into its raw materials and the simulated factory fabricates these materials and reassembles them to form the required panels. An animation of simulated factory operation is shown in the animation window (Figure 5-4).

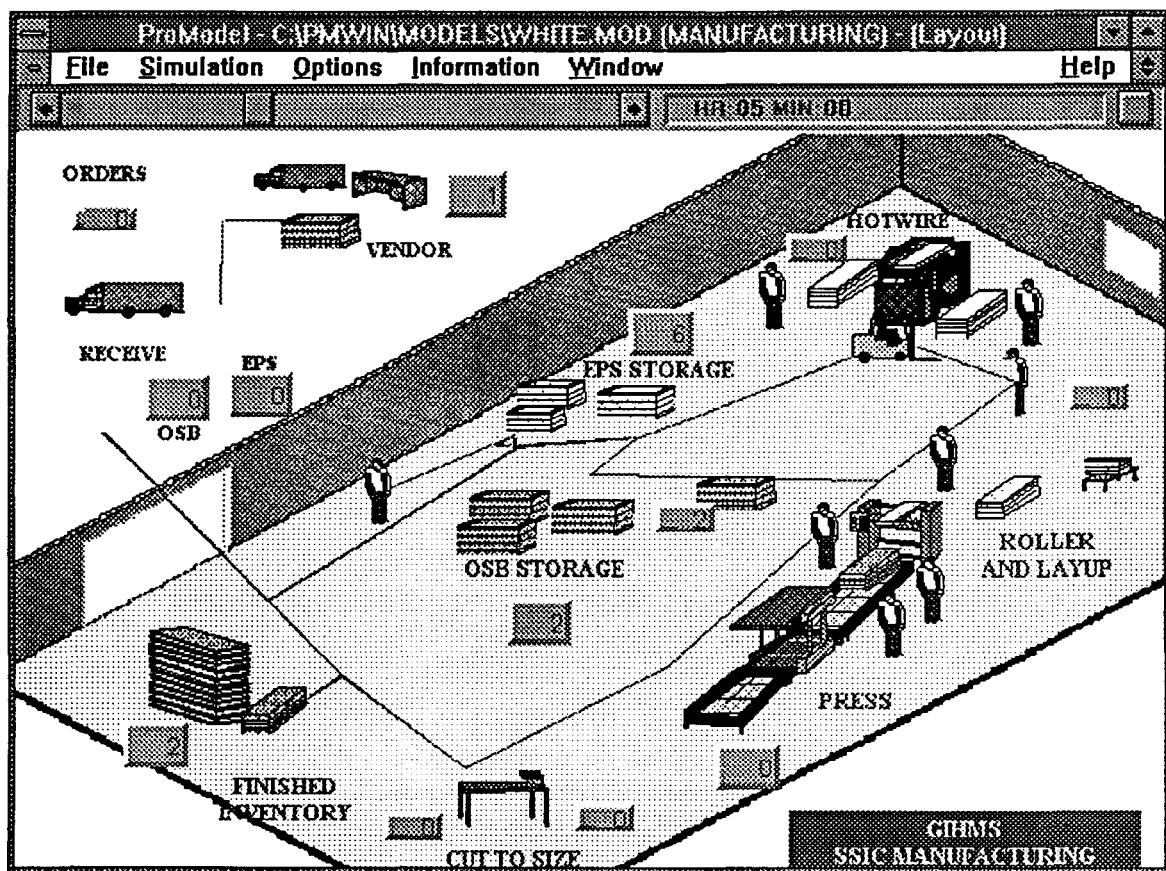


Figure 5-4
Final Layout Window and Animation Window

6.0 BENCHMARKING INNOVATIVE HOMEBUILDING TECHNOLOGIES

Today's homebuilder can select from a bewildering assortment of homebuilding technologies. The National Association of Homebuilders Research Center maintains an innovation database containing hundreds of innovative technologies from which the builder may choose. Many promise superior performance in first cost, construction cycle time, quality, energy efficiency, etc. However, for the vast majority of these technologies, market penetration has been minimal. Homebuilders continue to rely on conventional construction technologies such as wood frame and concrete block.

A key reason why these innovative technologies have not been more successful in the marketplace is that builders have too little objective information about their performance relative to more conventional homebuilding technologies. As an example, while published cost tables are available for conventional site built wood frame and concrete brick construction, no comparable quantitative costs have been reported for more innovative technologies. Most homebuilders are conservative. Few are large enough to afford the research and development required to investigate innovative building technologies. Therefore, they have continued to rely on conventional technologies. FY93 efforts have focused on developing and using methodologies for benchmarking innovative homebuilding technologies. Performance measures of interest have included total production cost and construction site productivity and cycle time. The benchmarking methodologies were used for refining the SSIC Panel Technology Characterization and for assessing the performance of various innovative technologies used in the IBACoS Lab Home Construction Program. The latter results are described in Section 10, Industry Assistance.

SSIC Technology Characterization

The purpose of the technology characterization (TC) is to provide a solid foundation of consistent and credible information on the current status of the technical performance, cost and environmental characteristics of new technologies being considered by DOE. A revised draft of the TC for stressed skin insulating core (SSIC) panels was prepared in FY93 (Mullens, et al 1993). The TC

compares the performance of walls constructed using 4" SSIC panels against the same walls constructed using conventional, stick-built 2x4 wood frame construction. The revision reflects refinements to earlier cost and energy savings estimates. Cost estimates were refined to reflect what costs should be using current (1990) manufacturing and construction processes and what they could be using advanced (year 2000) processes (Armacost, et al 1994). All costs are based on extensive field studies of manufacturing operations and construction sites. Energy savings estimates were refined to include not only conductive energy savings, but also savings due to reduced air infiltration and 3-dimensional thermal effects (Mullens, et al 1993). More realistic assumptions of duct leakage and heating/cooling unit efficiency were also provided. A summary of the resulting cost analysis is shown in Table 6-1.

Cost Item	1990	2000
Capital Cost (\$ per sq. ft.)		
4" SSIC	9.94	9.27
2x4 Wood Frame	8.52	8.52
Marginal Cost	1.42	0.75
Energy Savings (BTU/sq.ft./yr.)		
Electricity	8,355	8,355
Oil & Natural Gas	13,925	13,925
Payback (Years)		
Electricity	7.5	3.8
Oil	11.6	6.3
Natural Gas	15.1	7.1

**Table 6-1
TC Cost Analysis**

The cost analysis indicates that SSIC construction is currently more expensive than conventional frame construction, but this marginal cost will be reduced by half by the year 2000 with the introduction of improved product designs and manufacturing automation. Materials (sheathing, construction adhesive, and EPS foam) were found to contribute over 80% of this marginal cost. The thermal performance of SSIC construction was found to be significantly better than that of the benchmark frame construction. Specific energy savings were dependent on

the primary energy source; in general, electrical baseboard heat was more efficient than a fossil fuel furnace, since there is no duct loss and steady-state efficiency is 1.0. The analysis indicates that SSIC construction will pay for itself in 7-15 years assuming 1990 technology and in 4-7 years assuming year 2000 technology. It should be noted that all estimates are based on very small sample sizes and additional data collection is recommended.

Objective

To document by measurement and engineering analysis the benefits of advanced housing systems constructed with a significant level of industrialization.

Rationale

New and emerging technologies face many challenges. This is especially true in the slow-to-change domain of residential building construction. Marketing a viable product can be more challenging than conceiving and developing a product. This research task area seeks to identify and assist workable advanced housing technologies that could benefit from detailed performance evaluation for marketing and technology improvement. These performance evaluations of energy efficiency and indoor air quality are conducted as field tests of whole houses and of full-scale system components. Whenever possible, side-by-side tests are conducted of innovative and conventional housing.

Progress This Year**Louisville Project**

In cooperation with SIPA (Structural Insulated Panel Association), side-by-side energy testing and monitoring was conducted on two houses in Louisville, KY between 12 January 1993 and 5 March 1993. Both houses were identical except that one house was constructed with conventional U.S. 2x4 studs and a truss roof while the other house was constructed with stressed skin insulating core panels for the walls and second-floor ceiling.

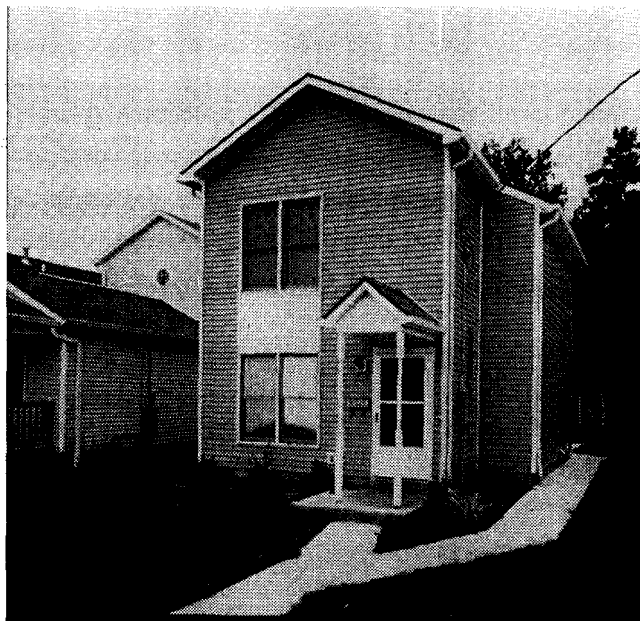


Figure 7-1
Photograph of SSIC panel house in Louisville, Kentucky

While both houses were considered to be more air-tight than average houses in the Louisville area, an average of all the air-tightness test results showed the SSIC panel house to have 22 percent less air infiltration than the frame house. Air-tightness testing resulted in a recommendation that both houses have a fresh air ventilation system installed to provide 0.35 air changes per hour continuously. Infrared imaging revealed good thermal insulation quality for both houses, but it was better for the SSIC house, primarily because of greater insulation uniformity and fewer thermal shorts due to wood framing.

Short-term energy monitoring was also conducted for the two houses. A 17-day period of electric heating and a 14-day period of gas furnace heating was evaluated. Monitoring results showed energy savings for the SSIC panel house over the conventional house to be 12 percent during electric heating and 15 percent during gas heating. A comparison of the two monitoring periods showed that the combined efficiency of the gas furnace and air distribution system, for both houses, was close to 80 percent, which was the same as the gas furnace manufacturer's listed Annual Fuel Utilization Efficiency. Simple regression models using Typical Meteorological Year weather data gave a preliminary prediction of seasonal energy savings of between 14 and 20 percent for the SSIC panel house.

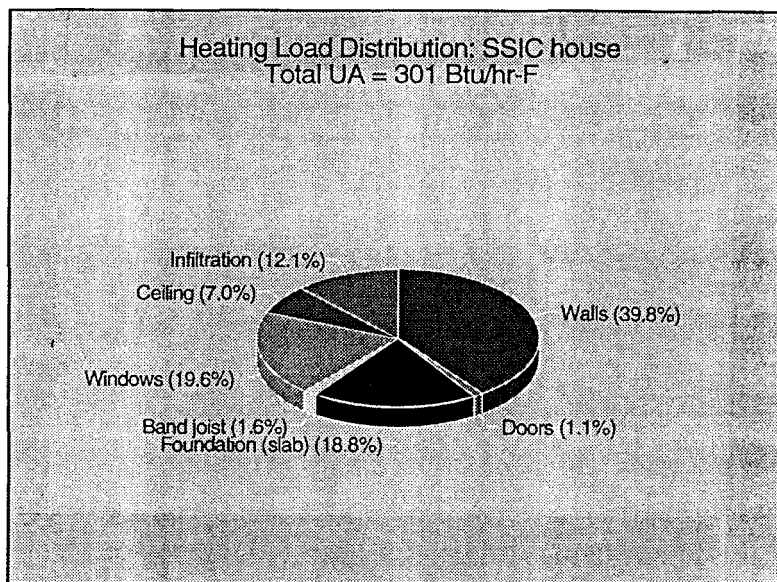


Figure 7-2
Heating Load Distribution and Calculated UA for the SSIC Panel House

Electric Heating Monitoring	
Night data	12%
Daily data	15%
Seasonal predicted	14-16%
Gas Heating Monitoring	
Night data	15%
Daily data	17%
Seasonal predicted	16-20%

Table 7-1
Percent Heating Energy Savings of SSIC Panel House Over Stud-frame House

Bonita Springs Project

A realty/investment company is considering the feasibility of building a factory in the Naples, Florida area to manufacture Therml-Impac panels for building construction. The 4' wide x 8' high panels are manufactured with a 2-1/4 inch core of expanded polystyrene foam insulation. Fourteen-gauge welded-wire trusses penetrate the foam and are welded to 14-gauge welded-wire mesh on both sides, which encloses the panel. The panels are connected together on site with a special wire-fastening tool, and with engineered connectors to reinforce the walls

at joints and openings and to anchor the panels to the foundation and roof. The completed wall assembly is sprayed and troweled with 7/8 inch thick cement plaster on both sides. The plastered wall has a 1-hour fire rating and is impervious to rot and structural damage due to insects, such as termites.

The calculated, steady-state, total-thermal-resistance of the panel, with plaster and air films, is 10.4 hr/SF-F/Btu; however, calibrated hot-box tests conducted by a private firm showed that the measured, steady-state, total-resistance was only 3.8 due to thermal shorting by the wire in the panel (McGrew 1981). McGrew also used empirical data to match a computer model, which he used to simulate the panel performance in various climates. His conclusions were that a house built with the panels would perform as well as a house built with R-11 frame walls, due to the increased air-tightness and thermal capacity of the panel walls. Considering the other non-energy benefits of the panel construction, including the presumed lower cost, the panel product could be well-liked in the residential construction marketplace. This is what Greg Haley and Associates wanted to test in full-scale as part of their consideration to invest in a plant to build the panels.

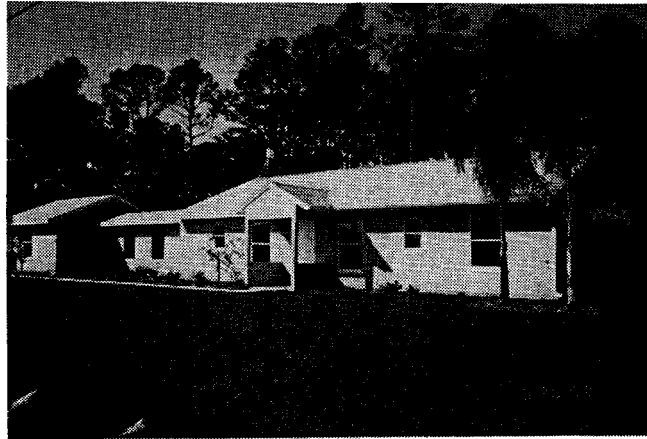


Figure 7-3
Photograph of Thermal Impac Panel House in Bonita Springs, Florida

The houses were identical in plan and elevations but reversed on a east-west axis. The house design was one-story with 1245 S.F. floor area and a glass-to-floor area ratio of 12%. The house was connected to a two-car garage by a covered breezeway which could be later enclosed as a porch. The control house was conventionally

constructed with 2x4 stud-frame walls and truss roof. The alternative house had both exterior and interior walls constructed with Thermal-Impac panels and a conventional truss roof. Ceilings in the living and master bedroom areas were sloped, and all other ceilings were flat. The panels were made in California by Impac International and shipped to Florida by truck, doubling the normal cost of the panels. A local contractor was hired to construct both houses although he had no experience with the panel construction. The major difficulties encountered were finding someone experienced enough to spray cement plaster, and in getting the building inspector to approve the connecting and anchoring details for a type of construction he was not familiar with. Both houses were nearly complete when FSEC became involved, so we had no influence on the construction of either house.

Energy testing and monitoring began when the houses were completed on 27 October 1993 and ended on 10 January 1994. Results presented here are preliminary; analysis is on-going. Air-tightness testing using fan pressurization equipment on both the house envelope and the duct system showed that the panel house was about 48% more airtight and that neither house had significant duct leakage. (The owners called the duct installer back to correct observed deficiencies before testing was done.) The natural air infiltration rate, approximated by a blower door test, was 0.31 and 0.16 ACH for the frame and panel houses, respectively. Tracer gas testing results gave 0.29 ACH natural air infiltration for the frame house and 0.20 ACH for the panel house. Air infiltration increased by only 13% due to operation of the air distribution system. Operation of the family bathroom fan in the frame house brought the air infiltration rate up to 0.33 ACH, almost to the ASHRAE standard of 0.35 ACH. A larger ventilation fan would be required for the panel house.

Infrared imaging, to evaluate the insulation quality, was done on a sunny day when the outside temperature was about 10°F warmer than inside. The IR scan revealed only a couple of minor insulation defects common to most construction. In both houses, the only defects found were at ceiling-to-wall junctions or at the ceiling peak.

Preliminary analysis of the cooling energy-use monitoring results showed that on

days when the house inside temperature was held constant, the frame and panel houses used about the same amount of cooling energy. The expected reason is that the increased air-tightness of the panel house compensated for the conduction deficiency of the panel walls. On days when outside nighttime temperatures fell, so that the house was losing heat instead of gaining heat, and houses were allowed to cool down as low as 65°F, the panel house used less cooling energy on the following day. These results demonstrate the inherent benefit of the high-mass masonry plaster walls in the panel house. However, it is expected that the largest benefit will be in utilizing the high-mass walls to aid in air-conditioner load shifting, to take advantage of time-of-use electric utility rates. Computer analysis, to quantify this thermal mass benefit with regard to time-of-use rates, is on-going, since the weather during the testing period was not consistently hot enough to get adequate measured data.

Future Work

Spirit of Today™ and Energy Smart™

The Spirit of Today™ house in Orlando, Florida (discussed in Section 11) and the Energy Smart™ house in Pensacola, Florida, will be tested and monitored to evaluate their performance in terms of 1) energy-use for space conditioning and hot water heating; 2) indoor air quality; 3) thermal comfort; and 4) water-use.

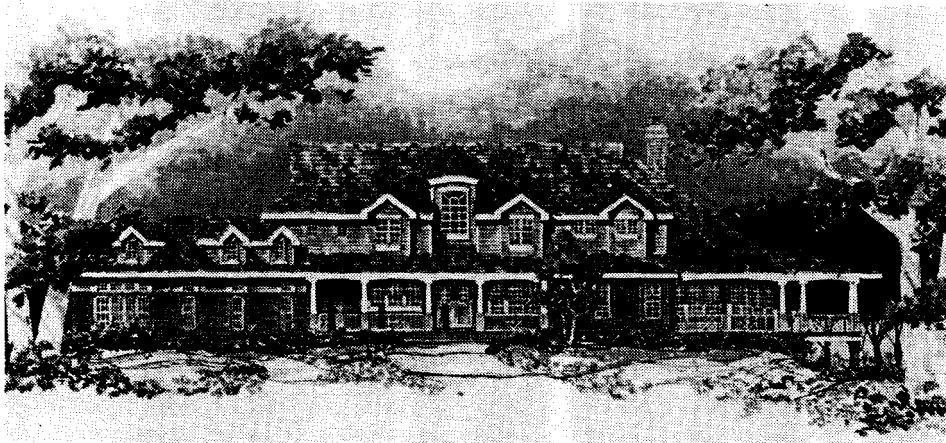


Figure 7-4
Rendering of the Energy Smart™ Demonstration Home, Pensacola, Florida

Ryland Air Distribution System Study

Thermal losses due to leaky or poorly insulated air distribution systems can result in substantial energy-use penalties for forced-air space conditioning

systems. Although two Ryland houses have previously been examined in this project, and were found to have fairly air-tight duct systems, the actual thermal losses due to the existing leaks and due to conduction heat transfer were not quantified. These air distribution system thermal losses will be examined in detail by whole-house testing.

Affordable Housing

Unless energy-efficient houses, with resulting lower operating costs, can achieve appraised values higher than their conventional comparables, it is not likely that the bottom-line affordable housing market will bear the additional first cost.

Informed builders and housing manufacturers can have an impact on the judgments made by appraisers and lenders concerning the value and operating costs of their quality homes. Actual measured data can have a decisive effect in this education process. Key opportunities to obtain measured data comparing an affordably priced reference house to the same house with an "energy upgrade option" will be pursued.

Cooling Loads Test Apparatus and Protocol

Development will proceed to achieve the capability to determine building cooling loads and building thermal and moisture capacitance through short-term whole house testing. A mobile test apparatus is being configured and is shown in Figure 7-5. This apparatus includes an air-source water chiller, quick-connect chilled water lines, indoor coiling coil, electronic modulating by-pass valve, condensate collection, insulated flexible duct, in-line fans, temperature and relative humidity sensors, and watt-hour transducers. A computer data acquisition system will control the test equipment to meet indoor temperature and humidity setpoints according to the test protocol.

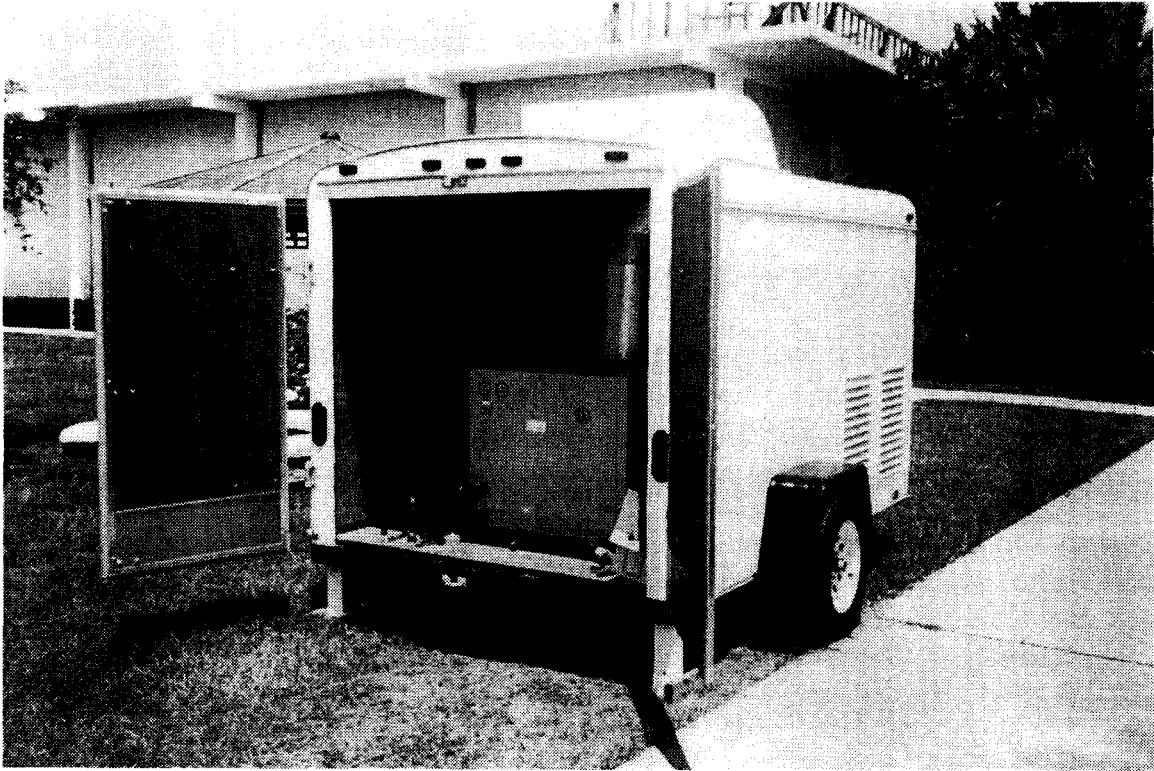


Figure 7-5
Mobile Test Apparatus Being Configured to Analyze Cooling Loads

Roofing Components

During FY92 encouraging results were obtained on the cooling performance of different roofing materials using side-by-side small scale models. In FY93, the FSEC flexible roof facility (FRF) was reconfigured (Figure 7-6) with different roofing materials to obtain full-scale data. As seen in the photo, the different roofing materials under test are red S-shaped concrete tiles, black shingles with a radiant barrier, black shingle base case and black shingles coated with a white elastomeric paint.

The FSEC Flexible Roof Facility

In FY94 the instrumentation on the facility will be revamped and seasonal data will be collected on the performance of different roofing materials. In addition, members of the roofing industry will be contacted to seek their comments and guidance.



Figure 7-6
The FSEC Flexible Roof Facility

Objective

The objective of this task is to provide energy testing of three duplexes of student housing built on the University of Oregon campus. These units meet BPA's Super Good Cents energy performance levels, incorporate industrialized housing technologies, exhibit high levels of architectural quality, and are low cost.

Description

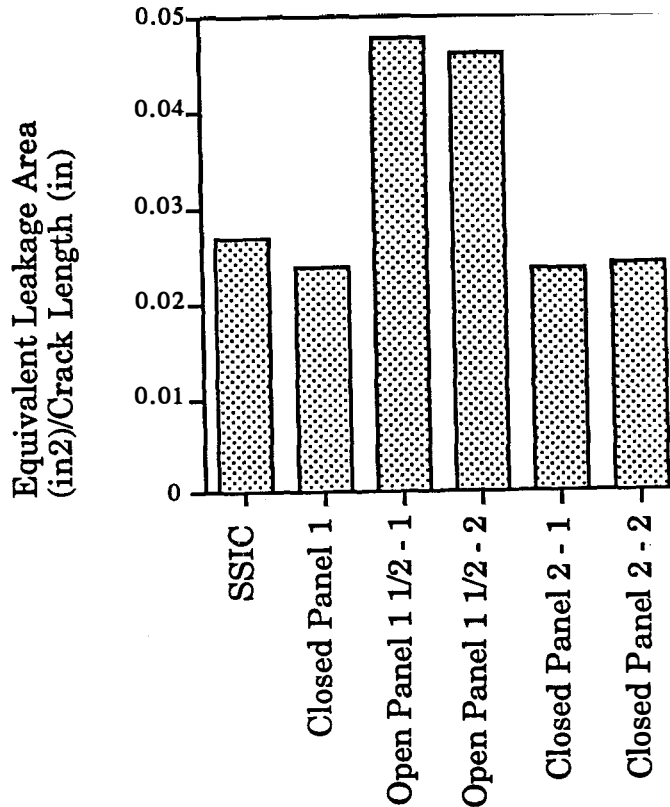
The first duplex is one story with a brick party wall. It utilizes closed (interior and exterior skins, electrical chases, insulation and windows installed) panels in one half and stressed skin insulating core panels in the other.

The second duplex is one and one-half stories and is constructed of open panels which are shipped to the site with exterior siding and windows but are insulated and drywalled in the field.

The third duplex is a full two stories with a concrete block party wall and is constructed of closed panels.

The building diagnostic tests and short-term monitoring for the university experimental housing energy monitoring project has been completed.

Preliminary results from the blower door tests showed that the closed panel units were more air-tight than the open panel units. In order to fairly compare air-tightness among units that have different geometries, a crack length normalization approach was employed. This approach first assumed that the primary leakages of the six units were through cracks of panel joints, doors and windows. Secondly, it was assumed that the cracks of doors and windows dominated the leakage areas for the closed panel units, since the panel joints of both types of closed panel buildings were typically tightly sealed. By normalizing the equivalent leakage area at the house pressure of 10 Pa for each closed panel unit with the total crack length of doors and windows, it was found that the equivalent leakage area per unit total crack length for each closed panel unit was very close to one another as shown in Figure 8-1.



**Figure 8-1
Crack Length Normalization**

This finding supported our second assumption that the leakages for the four closed panel units were primarily a function of the total crack length of doors and windows. This normalized leakage area was then used to predict the equivalent leakage area for doors and windows only for the open panel units. The equivalent leakage area for doors and windows was found to be only approximately less than 60% of the total equivalent area for each open panel unit. This suggested that significant leakages were through the cracks in the open panel joints.

Consequently, this suggested that the open panel joints were less air-tight than the closed panel joints. The data of infrared scanning tests showed only two notable defects in insulation for those six units. The data of co-heating tests, tracer gas tests and unoccupied monitoring are under analysis. A report of this testing project is being written and is scheduled to be completed by September 1994.

9.0 STRESSED SKIN INSULATING CORE PANEL DEMONSTRATION HOUSE

Objective

Working with a stressed skin insulating core (SSIC) panel manufacturer, we have designed, built and are now testing a prototype dwelling—one that showcases energy-efficient technology, and demonstrates that panelized construction delivers good quality homes with high energy performance at a lower first cost than conventional construction.

The SSIC demonstration project, a 1200 sq. ft., 3-bedroom, 2-bath, 1-1/2 story house, is designed to equal the annual energy performance of an architecturally equivalent home built with conventional framing to meet Bonneville Power Administration's Long Term Super Good Cents standards (Roof - R 49, Wall - R 26, Floor - R30, Window - U.35), but at a lower first cost. The demonstration house is projected to save 43% of the heating and cooling energy of its Oregon Code counterpart.

Rationale

Panelized construction uses industrialized techniques to produce panels—portions of walls, roofs and floors—which are assembled into houses on the building site. Stressed skin insulating core panels carry structural loads via sheathing “skins” bonded to a rigid insulating core. These panels tend to be highly energy efficient, and they reduce the amount of sawn lumber needed for construction.

Panelization is the strongest housing industrialization trend in the U.S., increasing its market share from 29% to 37% through the 1980's. We expect this trend to continue. Framing lumber prices climbed to record highs this year and are not expected to fall. Thus panelized construction is an important potential source of energy savings, with SSIC panels at the cutting edge of this opportunity.

Project Background

Key initial sources of support for the project were the St. Vincent dePaul Society, who agreed to supply the building site and construction funding, and AFM

Corporation, who offered to supply the SSIC panels for the house. The list of industry partners has since expanded to include the following firms and contributions:

AFM Corporation	stressed skin building panels
American Standard	plumbing fixtures
Ashland Chemical	high-grade structural adhesive
BASF Corporation	EPS raw material resin
Bonneville Power Administration	energy testing support
Brownlee Lighting	compact fluorescent lighting fixtures
Cadet Manufacturing Co.	electric heaters
Challenger Electrical Equipment	electric panels, boxes, breakers
DEC International	ventilating heat pump (discount cost)
Dura Undercushions, Ltd.	carpet pad
Elk Corporation	roof shingles
Eugene Sand and Gravel	concrete
Forbo Industries	linoleum floor coverings
The Glidden Co.	paints
Image Carpets Inc.	carpet (discount cost)
Jerry's Home Improvement Center	framing lumber
Levolor Corp.	window coverings
Lights of America	lighting fixtures
Louisiana-Pacific Corporation	Fiberbond wallboard, underlayment
Masonite Corporation	interior doors
Morse Bros. Prestressed Concrete	concrete
Oregon Strand Board Co.	Comply sheathing
OrePac Building Products	trim and decking timber
Owens Brockway	glass cullet structural fill
Sea Gull Lighting	lighting fixtures
Simpson Strong-Tie	building connectors
Sound Floor Coverings Inc.	carpet (discount cost)
Springfield Utility Board	testing support
Stimson Lumber	Duratemp siding
Gene Stringfield Bldg. Materials	framing lumber
Studor Inc.	internal plumbing vents

St. Vincent dePaul Society	development
Super Struct Systems	honeycomb interior partition panels
Temperate Forest Foundation	structural and finish lumber
Therma-Tru Corporation	Fiber-Classic exterior doors
Trus Joist MacMillan	engineered framing materials
Tumac Lumber	western red cedar lumber
Viking Industries Inc.	windows
Viscor Inc.	building gaskets
Wasco Products Inc.	skylights
Western Red Cedar Lumber Assoc.	western red cedar lumber
Weyerhaeuser Co.	oriented strand board
Willamette Industries	structural underlayment panels
Wirecon	integrated outlets and switches

Early research efforts focused on finding an optimum house design for SSIC panel construction, and on locating potential sources of energy and cost savings. Schematic designs and comparative cost analyses (panel vs. conventional construction) were developed for five versions of the house. The most promising design underwent further development, and the energy performance of its two variants (SSIC panel vs. conventional) was simulated using the WATTSUN program. The panel specifications were then “tuned” to provide annual whole-house energy performance matching that of the conventionally built house. Finally DOE 2 was used to model the energy performance of the conventionally built (annual heating budget: 6.6 kBtu/sf-yr) and panelized (annual heating budget: 6.3 kBtu/sf-yr) versions. Cooling loads were met by shading and cross ventilation.

Once this performance match was established, design work explored—through a series of component studies—ways to improve the cost effectiveness of panel composition and joinery, as well as other elements such as HVAC system and windows which was essential to support the goal of an affordable, high energy performance house.

Plans for the house were drawn and a building permit was secured. Detailed construction drawings for the SSIC panels were prepared and submitted to

Premier Building Systems of Kent, Washington, the nearest AFM affiliate.

A groundbreaking ceremony was held November 18, and construction commenced. By the year's end the SSIC panel shell of the house had been assembled.

The construction process forms a key element of the research; it has been monitored carefully, including time and motion studies and detailed time analysis in order to reveal potential areas of improvement. This record also helps provide an accurate account of actual construction costs.

Demonstration House Features

A number of innovations were developed to reduce the cost of the demonstration house while maintaining high levels of energy and structural performance.

Features that distinguish the demonstration house from conventional construction

- The structurally integrated roof and second floor system eliminate the ridge beam and the need for internal supports.
- The integrated floor / foundation system, exploiting the 2-way spanning capability of SSIC panels, distributes the floor loads evenly and reduces the size of the horizontal members, reducing costs.
- Offsetting the wall-to-wall and floor-to-wall connections provides an additional 28 square feet (2%) of floor area.
- The panel system replaces sawn lumber with a variety of plentiful wood resources.
- Site labor is reduced.
- Project length is shortened by one week.
- Because fewer days are required for shell construction, this system extends the building season.
- Shorter construction time reduces construction loan cost, improving affordability.
- The demonstration house is projected to save 43% of the heating and cooling energy of a conventional, Oregon Code-compliant house.

Features that distinguish the demonstration house from standard SSIC panel construction

- Internal plumbing vents minimize envelope penetrations, reducing energy transfer through the shell.
- The design optimizes building skin area for structural, thermal, and cost performance.
- Structural siding laminated directly to the insulation core eliminates one layer of OSB, saving cost.
- Panel cutoffs at gable ends are reused at the opposite end of the building to reduce waste.
- The house plan is based on the panel module to reduce waste.
- Shiplap joints reduce installation time by 20% and improve air tightness.
- Offsetting building corners reduces the impact of dimensional variations in wall and floor panels.
- Reducing the quantity of dimensional lumber in the floor and roof minimizes thermal bridges.
- Panel joints located at the exterior openings reduce panel waste.
- Overlapping the ridge joint reduces infiltration and improves thermal performance.
- Exterior electrical chases minimize wiring in the panels (reducing installation cost by 5%) and increase overall R-value.

Features of the 1-1/2 story design

- The master bedroom is usable as a separate rental or office space.
- The open stair and kitchen provide long sight lines for spaciousness.
- Free span structural design allows for maximum flexibility in arrangement of interior partitions.
- A minimum of two windows or skylights in all major rooms facilitates cross ventilation and quality daylighting.
- Heat pump water heater uses exhaust air as energy source.
- Eave overhangs shade south-facing glazing for solar control.

While in Eugene, Oregon, the demonstration house is cost competitive, our studies indicate that in other localities the cost advantage would be greater, as the graph of shell-only costs in Figure 9-1 indicates:

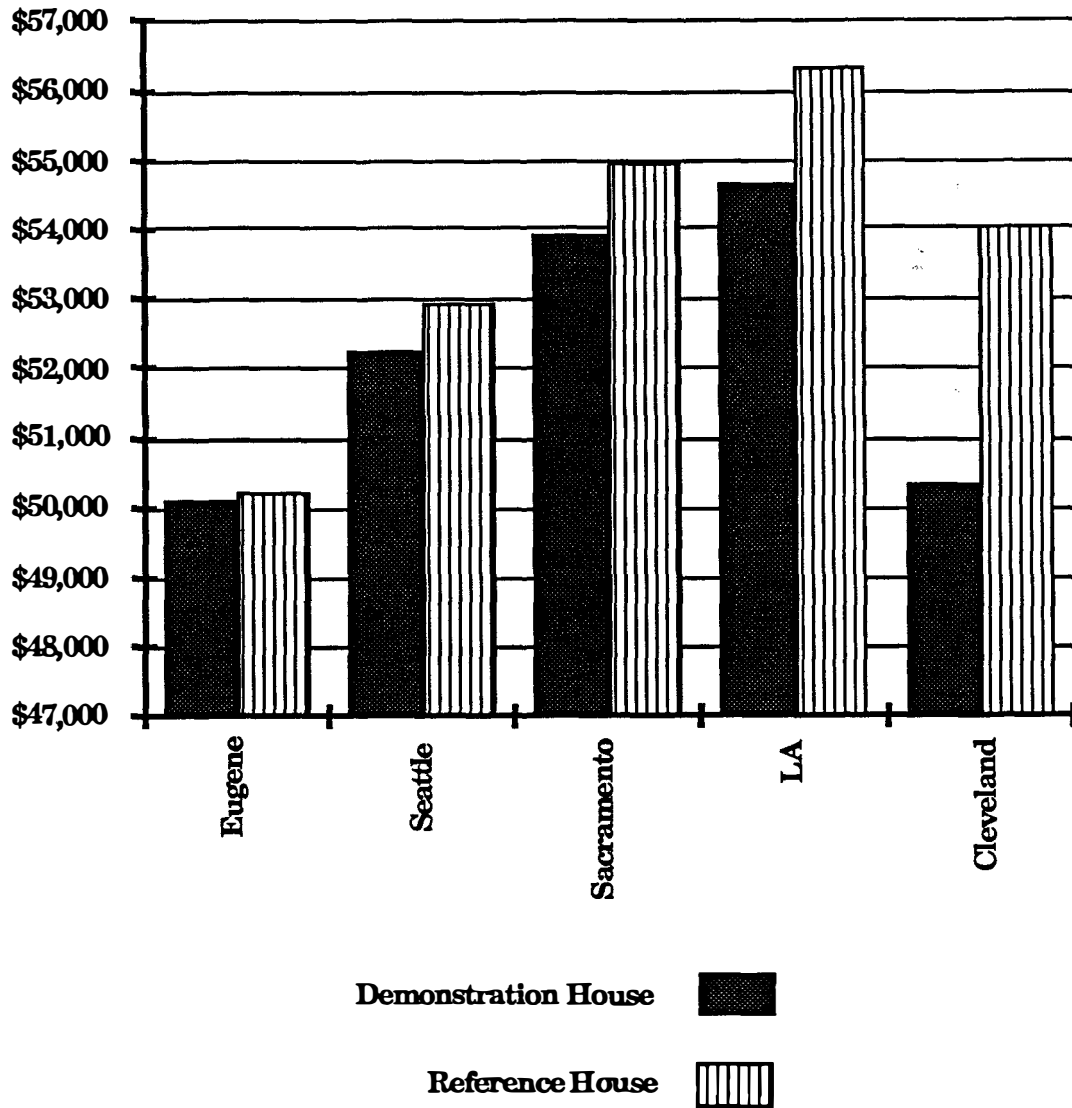
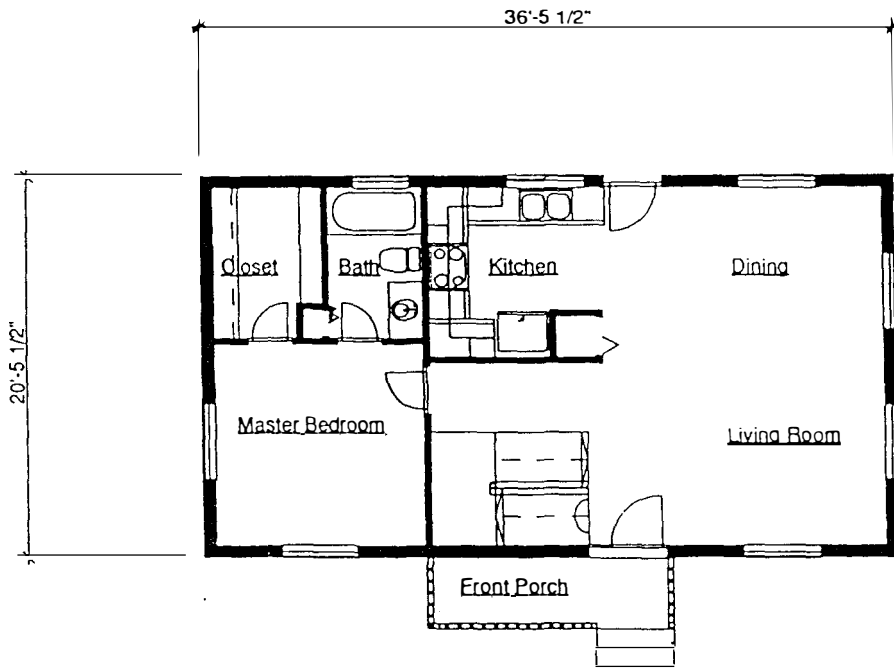


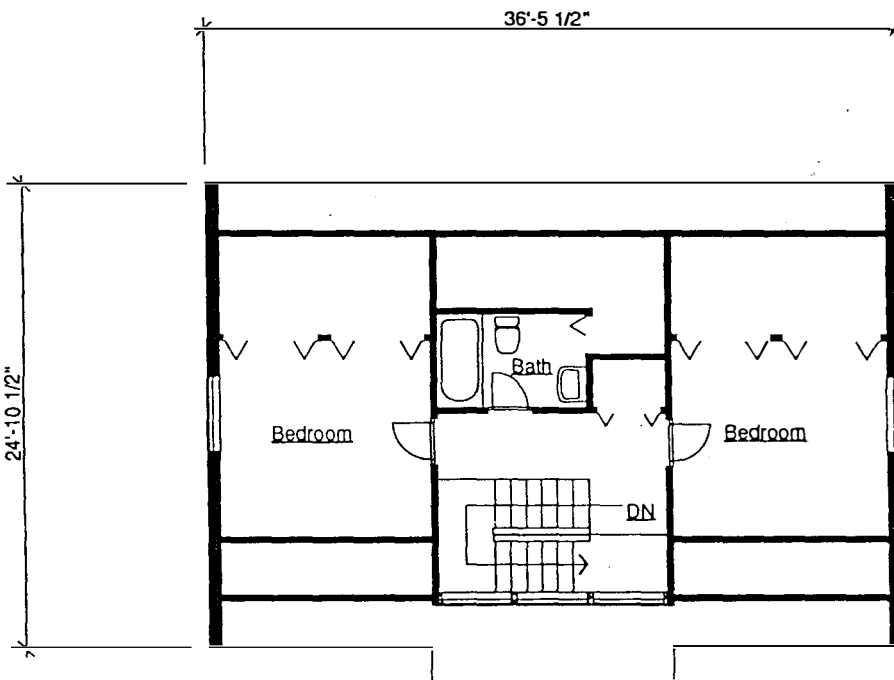
Figure 9-1
Shell Cost (including other systems affected by panel construction)



Figure 9-3
Stressed Skin Insulating Core Panel Demonstration House, Springfield, OR



**Figure 9-5
First Floor Plan**



**Figure 9-6
Second Floor Plan**

Energy Testing Plan

The energy testing involves two periods of unoccupied monitoring and one year-long term of occupied monitoring, using a remotely controlled data acquisition system. The purpose of this field monitoring is to verify the design performance goals of the demonstration house.

Infrared scanning, blower door and co-heating techniques will be used in conducting unoccupied tests. Infrared scanning will be used to locate areas where insulation details could be improved and to locate thermal shorts. A blower door will be used to determine air tightness of the building and to assist in locating areas of thermal bypass while conducting the infrared scanning. A low cost data acquisition and control system has been developed to perform the co-heating test. Through this test, a determination of the “as built” building load coefficient will be possible.

Unoccupied monitoring will be conducted with simulated occupancy for one to two weeks in the heating season and one to two weeks in the cooling season. The simulated occupancy will provide inputs for a building energy analysis model such as DOE 2.

10.0 INDUSTRY ASSISTANCE

Objective

The objective of this task is to work with industry to enhance the energy efficiency and/or productivity of their product or process.

Progress this year

In addition to testing efforts described in section 7, the following activities were conducted this year:

- IBACoS Testing Report
- NAHB/BSC Showcase demonstration by M. Mullens, *GIHMS* Software in *Computer Integrated Manufacturing* BSC exhibit and PEER discussions with BSC in Cincinnati
- Palm Harbor Homes testing

IBACoS Lab Home Construction Monitoring

The objective of this research task was to benchmark the constructability of the innovative structural panel technologies used in the IBACoS Lab Home Construction Program. The two primary analyses compared: 1) the innovative MIT roof system against conventional truss construction, and 2) the innovative Superior foundation system against conventional poured concrete/concrete block construction. Both innovative systems can be classified as "net shape" panel technologies, which promise improved constructability and thermal performance through increased factory "value-added" prefabrication. The study is based on empirical results obtained during the recent construction of two architecturally identical homes, IBACoS Lab Home A, built using conventional construction technologies (including a truss roof system and a poured concrete/concrete block foundation system), and IBACoS Lab Home B, built using innovative technologies (including the MIT roof system and the Superior foundation system). Figures 10-1 and 10-2 show Lab Home B under construction. The house observed was a 2,250 square foot, two-story design with basement. The construction took place during Summer and Fall 1993 in a suburb of Pittsburgh.



Figure 10-1
Superior Foundation Panel is Positioned



Figure 10-2
MIT Roof Panel is Hoisted in Place

Two measures are used to characterize the constructability of competing structural systems. *Cycle time* is defined to be the clock time between the start and finish of assembly. It measures the speed in which the system can be installed. Estimates are expressed in continuous working hours, uninterrupted by breaks, lunch or end of day. Timing starts when the first component is readied for hoisting and ends when the last component is permanently attached. *Labor content* is defined to be the total man-hours required by the construction crew over the course of the construction cycle. Note that neither interior nor exterior finish is included in the analysis. The assumption is that these finish activities are similar for competing technologies. All estimates were normalized to equalize observed differences in construction crew capability and component quality. Results developed in *Benchmarking the Constructability of Innovative Homebuilding Technologies Used in the IBACoS Lab Home Construction Program* are shown in Table 10-1 (Armacost, et al 1994).

Performance Measure	Conventional Truss Roof	MIT Roof	Conventional Foundation	Superior Foundation
Cycle Time (hr.)	2.2	1.8	54	25
Labor (man-hr.)	7.4	8.9	106	68

**Table 10-1
IBACoS Lab Home Constructability Analysis**

MIT Roof System Results: The MIT roof system is in the early stages of development and has yet to be commercialized (Crowley, et al 1993). It employs prefabricated, insulated, stressed skin panels which utilize oriented strand board (OSB) as both the skin and rib core. Panels are supported by a triangular structural ridge beam, also made from OSB. The system was used in Lab Home B above the garage and family room, representing approximately 430 square feet of roof area. Results indicate that while the MIT roof can speed construction, it may require additional labor. Several factors suggest that these estimates may significantly understate the potential of the MIT roof. First, insulation of the conventional roof is not considered in the analysis, since no insulation was required over the garage area. Note that the MIT roof comes from the factory

with insulation installed. Data obtained from construction labor tables indicate that insulating the ceiling of the truss roof would require 3.7 man hours. Therefore, if insulation was included in the analysis, total labor for the truss roof could be as high as 11.1 man hours, significantly greater than the 8.9 man hours estimated for the MIT roof. Second, the MIT roof was installed on a single, short, non-complex section of Lab Home B. The MIT roof is likely to be even more competitive in a more realistic construction application. Third, the analysis compares highly refined conventional construction methods against early prototype methods for the MIT roof. This ignores the obvious potential for improving construction site methods for the MIT roof. Finally, the MIT roof provided enhanced architectural design flexibility, including a cathedral ceiling and over 100 square feet of usable bonus space above portions of the garage and family room.

In summary, observed results suggest that the MIT roof is still in an early prototype stage of new product development, suffering from minor quality problems and a poorly trained crew. Key steps toward commercialization must include an increased focus on manufacturing processes, site construction processes, quality and training.

Superior Foundation System Results: The Superior foundation system is a commercial system utilizing factory precast, high density concrete panels, complete with expanded polystyrene foam insulation. The system rests on compacted gravel placed in shallow trenches and requires no poured concrete footings. The system was used throughout Lab Home B to replace the poured footings/concrete block foundation used in Lab Home A. Results indicate that the Superior system can cut both construction cycle time and labor by 50%. These positive results are driven primarily from the elimination of poured concrete footings which reduce or eliminate site operations such as excavation, rebar placement and pouring. The inherent technological delays associated with poured concrete (e.g., waiting for concrete delivery, waiting for inspection and waiting for concrete curing) are also eliminated. Several factors suggest that these estimates may significantly understate the potential of the Superior system. First, the system is likely to be less susceptible to weather-related delays. Second, exterior sealing is not included in the analysis. The Superior system requires no

sealant, while conventional technology requires that sealant be applied after block construction is complete. Finally, interior insulation and the addition of furring strips to the conventional foundation is not considered in the analysis. The Superior system is delivered with these items preinstalled, while conventional technology requires that they be added after block construction is complete. In summary, the research results indicate that the Superior system offers superior constructability when compared to conventional technologies.

Building Systems Council Interactions

There was active interaction between EEIH researchers and the National Association of Home Builders Building Systems Council (BSC) in FY94. In May 1993 Barbara Martin, Executive Director of BSC, attended the FY93 EEIH Steering Committee Review Meeting and made a number of valuable recommendations. In September 1993 EEIH representatives met with the BSC Board of Directors in Cincinnati to discuss future directions for the EEIH PEER review process. As a result it was agreed that BSC supported the PEER review concept and that informal discussions regarding potential enhancements should continue. However, this momentum was lost as FY94 funding was eroded. The EEIH exhibit was completely updated for BSC 1993 Super Showcase in New Orleans. EEIH representatives attended Showcase and manned the exhibit. The exhibit was highly successful, winning the *Best in Show* awarded by the BSC Board of Directors (see Figure 10-3). At Showcase, EEIH representatives also demonstrated *GIHMS* software in a Computer Integrated Manufacturing seminar and attended the BSC Board of Directors Technical Interest Focus Group meeting.

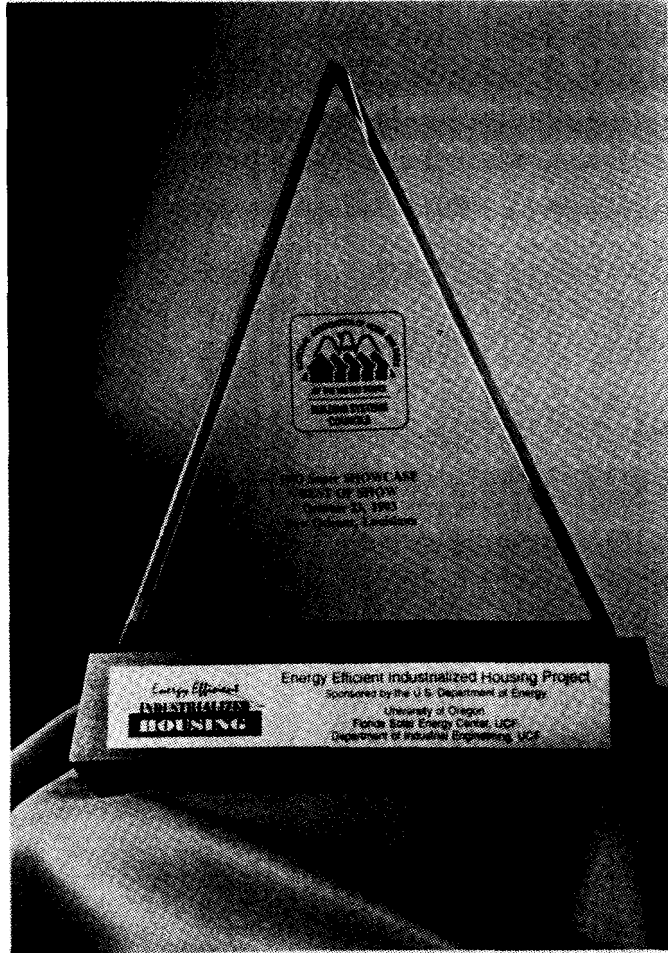


Figure 10-3
Best in Show Award

Palm Harbor Homes

Palm Harbor is a major manufacturer of HUD code homes in FL, AZ, TX, AL, NC and OH. They operate two factories in Plant City, FL and have 20 model homes on display adjacent to the manufacturing facilities. The homes range between 1000 and 2000 square feet and are made from two or three sections.

Palm Harbor prides themselves on their high quality. Their homes appeared to fare much better than other manufacturers in hurricane Andrew. Palm Harbor also sells their homes on the basis of superior energy efficiency. Typically, their EnerGmiser Florida homes will have R-30 in ceilings, R-11 in walls and floors, tinted windows, ducted air returns and air transfer ducts in ceilings.

We conducted blower door, duct blaster and pressure differential tests to test the air tightness of the house and air distribution systems. We also conducted surveys of thermal integrity with a color infrared camera. Two model homes were tested. Senior management of Palm Harbor was present with us during all testing.



Figure 10-4
Infrared testing at a Palm Harbor Home. Jim Tyson of FSEC conducts the test while Bert Kessler, engineering manager of Palm Harbor observes the results.

Because the model homes were on a temporary setup the results would not be typical of field installations. Even then, the homes appeared to be of high quality

with two minor defects. The engineering manager could readily see them in the infrared camera and immediately thought of small changes in the manufacturing process to assure better quality control in those areas. At the end of our visit we were cordially invited to test several of their homes in the field.

11.0 SPIRIT OF TODAY DEMONSTRATION HOUSE

Objective

The objective is to increase the market share of energy efficient housing (50% better than codes) in new construction by creating a market demand for such housing. The homes utilize currently available products and technology and meet other driving concerns of today—excellent indoor air quality, handicapped accessibility, high wind resistant construction, resource efficient materials, security, comfort, convenience, exciting design and curb appeal.

Rationale

We are attempting to achieve our objective by creating a "demand pull" as opposed to a "technology push." A key barrier appears to be that a large majority of the home buyers and home builders are not aware that products and technology to achieve Spirit of Today goals already exist in the marketplace. Another barrier appears to be the perception that energy efficient housing is architecturally dull. To remove these barriers, we have entered into a partnership with *Better Homes and Gardens* magazine to inform millions of readers that it is indeed practical to have attractive, high quality, energy and water efficient housing today.

Progress this year

The magazine will feature a large luxury home in a multi page story. An additional page will be devoted to featuring a smaller home with Spirit features. The large home is currently under construction and is about 90% complete. The smaller home (approximately 1800 sq. ft. plus a basement) is currently being designed. Current schedule calls for the magazine article to be published in October 1994. Just as high quality Japanese cars created a demand for high quality cars in every price range, it is expected that with appropriate follow up, the publication of the Spirit of Today magazine article will create a demand for energy and water efficient housing.

The First Spirit of Today House

The first house is a 3467 sq. ft. design with 3 bedrooms, 3 bathrooms, a den and a large bonus room over the garage. It also features an in-ground swimming pool.

Figure 11-1 shows a frontal view of the house. The house faces North. Note the wide 4 ft. overhangs, the interesting roof design and the cupola. The cupola has 4 motorized awning windows to enhance natural ventilation. Figure 11-2 shows the rear of the house. Note the casement windows with a fixed transom for additional daylighting. A solar water heater is installed on the roof. Figure 11-3 shows the floor plan. The kitchen, the bathroom between bedrooms 2 and 3, the wide hallways, electrical switch heights, high traction floor tiles and carpets and the high contrast finishes are designed to accommodate the needs of the handicapped. The ceiling is 12 ft. high with coffered ceilings in the master bedroom, bath, study and all living areas. This allowed us to lower the hall ceilings to 10 feet and place supply and return ducts in the conditioned space. The air handler is in the large closet in the laundry room. The balcony and the bonus room over the garage creates a nice recreational space.



Figure 11-1
Front view of the first Spirit of Today House



Figure 11-2
Rear view of the first Spirit of Today House

House Features

Construction: The house features panelized 2 x 6 studs on 24" center construction. The wall panels and roof trusses were engineered and manufactured by Shelter Systems Limited in the Baltimore, MD area and shipped to Florida. The engineering reduced costs by streamlining the roof trusses, allowing 24" on center construction and strong wind resistant overhangs. Panelization assured high quality and strong construction to American Plywood Association's Code Plus standards. The roof decking was nailed to trusses with 8 penny ring shank nails averaging 6" on center to resist high wind loads. Oriented Strand Board, engineered wood beams and finger jointed studs were used as much as possible to reduce the use of large dimensional timber.

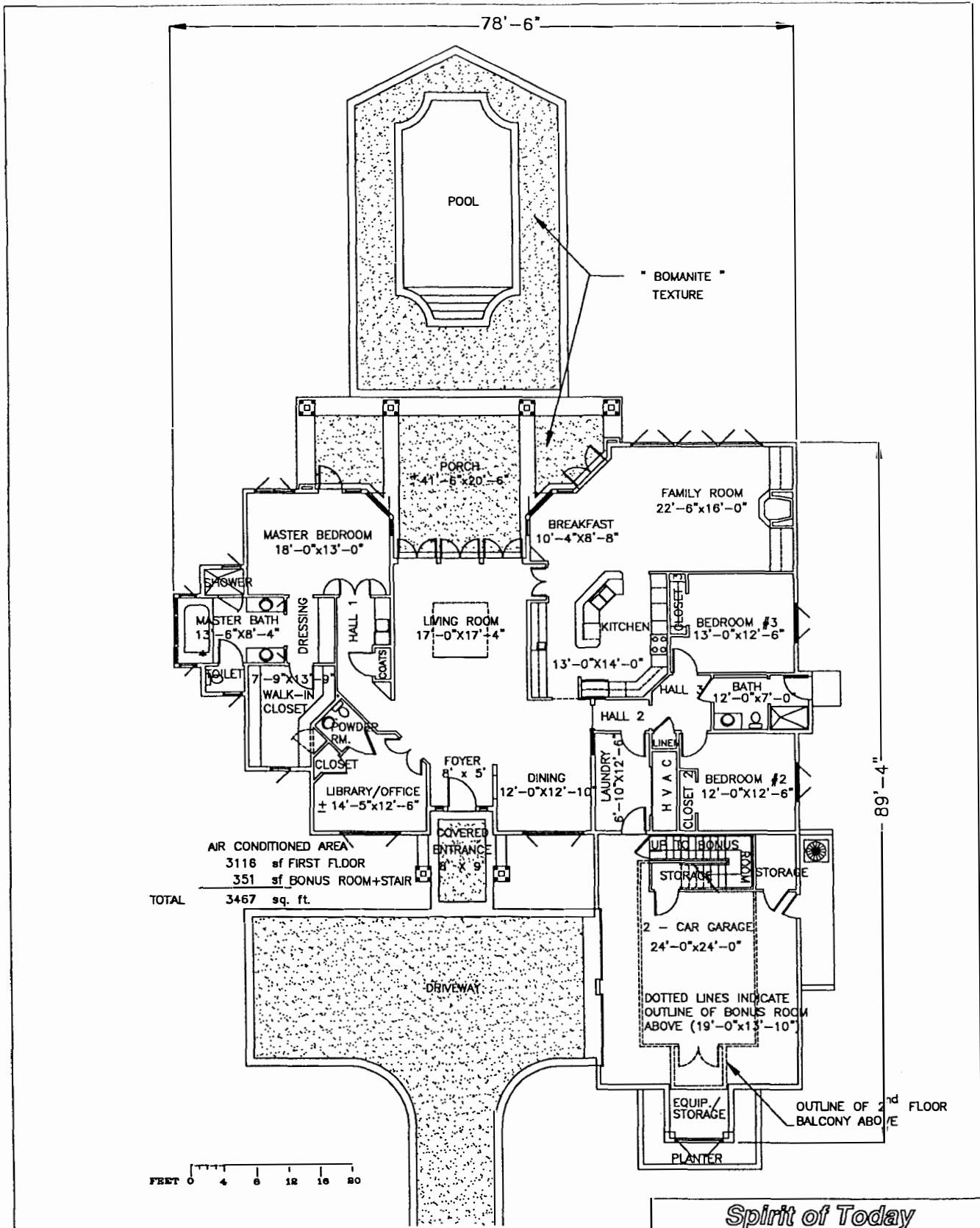


Figure 11-3
Spirit of Today Floor Plan

<i>Spirit of Today</i>		
AS BUILT FLOOR PLAN		
FLORIDA SOLAR ENERGY CENTER <small>300 State Road 401 Cape Canaveral 32920 Tel. (407)783-0300</small>		
ARCHITECT: DONOVAN DEAN ARCHITECTS INC.		
AutoCad Dwg. <i>P. Robinson/R. Thomas</i>		Drawing no.
Date: May 5, 1994	Rev. 4	5-01-0002

Energy, Comfort and Convenience: The house features energy efficient Argon filled windows with low emissivity coating designed for southern climates. 4 feet overhangs over all windows reduce solar gain. Casement windows and motorized cupola windows enhance natural ventilation. Security system is integrated with window screens such that the windows can be opened without activating the alarm. Concrete tiles on the roof reduce solar heat gain into the attic by about 50% compared to dark colored shingle roofs. The ceiling has R-30 cellulose insulation. The walls use a CFC free foam insulation and air sealing system (average R - 19). The air handler unit and over 85% of ductwork are in conditioned space, even in this mostly one story design. Return air transfer ducts permit comfortable cooling and heating even when bedroom doors are closed. A high efficiency heat pump with separate humidity and temperature controllers provide optimal comfort at a low energy cost. The heat pump has two compressor speeds delivering 3 or 5 tons of cooling to take care of normal and party loads (high occupancy). Ceiling fans with remote controls increase comfort and convenience. Efficient appliances and fluorescent lighting reduce energy costs. The direct vent propane fireplace does not require a chimney and enhances the ambiance without sacrificing indoor air quality. A passive solar water heater with electric backup provides reliable water heating. Low water use landscaping and fixtures decrease water use. The HVAC system with a programmable thermostat, the security system, lighting and motorized windows can be controlled by a cellular telephone.

Ventilation and Indoor Air Quality: 200 cfm of continuous ventilation (about 0.3 airchanges per hour) is provided with heat and moisture recovery through a desiccant wheel. In addition, exhaust vents to the outside in all bathrooms and kitchen have motors mounted in the attic for quietness. Use of heating and cooling ducts with a cleanable hard coat and fungicide, sheet metal ducts for ventilation systems, high efficiency electronic air cleaner, tiles on the floor and carpets certified by the green label program of the Carpet and Rug Institute assures excellent indoor air quality.

Future Plans

Contrasted to one of a kind demonstration programs, the Spirit of Today program is designed to spawn the construction of many houses. The name Spirit of Today

as well as the house designs are being copyrighted. It is planned that builder training and quality assurance will be a part of the program. The energy and water use performance of the first few will be monitored to document the benefits. In these ways the Spirit of Today is expected to increase the market share of energy efficient housing through an industry-academia-government partnership.

SPIRIT OF TODAY INDUSTRY PARTNERS

Company	Product
American Olean Tile	Ceramic Floor and Wall Tiles
American Plywood Association	Structural Wood Products
City of Orlando, Leu Gardens	Landscape Design
Eljer	Fixtures and Faucets
Fantech	Bath and Kitchen Vents
Georgia-Pacific	Roof and Wall Sheathing
Gibraltar Solid Surfaces	Countertops
Glidden	Paints
Heatilator	Fireplace
Honeywell	Totalhome Automation and Security System
	Electronic Air Cleaner, Energy recovery ventilator
Hunter Douglas	Window Blinds
Hunter Fans	Ceiling Fans
Icynene	CFC-free foam insulation
Johnson Hardware	Pocket door frame kits
Kwikset	Lever latch and lock sets
Lee/Rowan	Closet systems
Lennox Industries	Heat Pump system
Louisiana-Pacific	Finger Jointed Studs
Merillat	Cabinets
Monier	Roofing Tiles
Peachtree Windows and Doors	Windows and Doors

RCA	Custom Home Theater/VCR
Real Frye	Gas Logs
Rosboro Lumber Co.	Glulam Structural Beams
Shaw Industries	Carpets
Shelter Systems Limited	Wall Panels and Roof Trusses
Smyth Lumber	Building Materials
Stanley Garage Doors	8' high Garage Doors
Thermal Conversion Technology	Solar Water Heater
Thomasville Furniture Industries	Furniture
Waverly	Fabrics
Whirlpool Corp	Major Appliances

We would like to take this opportunity to express our heartfelt gratitude to *Better Homes and Gardens* magazine. Without their sponsorship and proactive role the Spirit of Today would not be a reality today.

12.0

REFERENCES

Work described in this summary is excerpted from the following working reports and publications of the Energy Efficient Industrialized Housing Program:

Armacost, R.L., M.A. Mullens and W.W. Swart. "The Role of Object Oriented CAD in a Generic Simulator for the Industrialized Housing Industry," Working Paper, Univ. of Central Florida Dept. of Industrial Engineering, Orlando, FL, March, 1994.

Armacost, R.L., M.A. Mullens and W.W. Swart, "Benchmarking the First Cost of Innovative Homebuilding Technologies," Working paper, Univ. of Central Florida Dept. of Industrial Engineering, Orlando, FL, January, 1994.

Armacost, R.L., M.A. Mullens and W.W. Swart, "Benchmarking the Constructability of Innovative Homebuilding Technologies Used in the IBACoS Lab Home Construction Program," Working Paper, Univ. of Central Florida Dept. of Industrial Engineering, Orlando, FL, January, 1994.

Center for Housing Innovation (various authors), *Problem Statements for the 21st Century House*, Report for U.S. Department of Energy, Energy Efficient Industrialized Housing Research Program, October, 1990.

Center for Housing Innovation (various authors), *Progress Report Design for Energy Efficiency Task Area*, U.S. Department of Energy, Energy Efficient Industrialized Housing Research Program, 1991.

Center for Housing Innovation (various authors), *Working Report Task 2.1: Design for Energy Efficiency—Performance Specifications for Systems and Technologies of a Multifamily Concrete Panel House in a Hot-Arid Climate*, U.S. Department of Energy, Energy Efficient Industrialized Housing Research Program, 1993.

Center for Housing Innovation (various authors), *Working Report Task 2.1: Design for Energy Efficiency — Performance Specifications for Systems and Technologies of a Single-Family Thin Insulation and Wood Composite Panel House in a Cool Climate.*, U.S. Department of Energy, Energy Efficient Industrialized Housing Research Program, Forthcoming, 1994.

Crowley, J., et al. "Reinventing Wood Frame Construction: Development of an Innovative Roof Component System," *Forest Products J.*, 43(7/8) (1993) 27-35.

Mullens, M.A. and D. Conlan, *CE Technology Characterization for Structural Insulated Panels*, Report prepared for U.S. Department of Energy Office of Conservation and Renewable Energy (CE), major revision submitted December, 1993.

13.0 PUBLICATIONS

Armacost, R.L., M.A. Mullens and W.W. Swart. "The Role of Object Oriented CAD in a Generic Simulator for the Industrialized Housing Industry." Working Paper. Univ. of Central Florida Dept. of Industrial Engineering, Orlando, FL, March, 1994.

Armacost, R.L., M.A. Mullens and W.W. Swart. "Integrated Systems Benchmarking for Industrialized Housing." Deborah A. Mitta, Laura I. Burke, John R. English, Jeanne Gallimore, Georgia-Ann Klutke and Gregory L. Tonkay, eds. Paper for 1993 2nd Industrial Engineering Research Conference Proceedings, Institute of Industrial Engineers, Norcross, Georgia, 1993, pp. 649-653.

Armacost, R.L., M.A. Mullens and W.W. Swart. "The Role of Object Oriented CAD in a Generic Simulator for the Industrialized Housing Industry." Paper submitted to and accepted by The Eleventh International Symposium on Automation and Robotics in Construction, Brighton, England, May, 1994.

Armacost, R.L., M.A. Mullens and W.W. Swart. "Benchmarking the First Cost of Innovative Homebuilding Technologies." Working Paper. Univ. of Central Florida Dept. of Industrial Engineering, Orlando, FL, Jan., 1994.

Armacost, R.L., M.A. Mullens and W.W. Swart. "Benchmarking the Constructability of Innovative Homebuilding Technologies Used in the IBACoS Lab Home Construction Program." Working Paper. Univ. of Central Florida Dept. of Industrial Engineering, Orlando, FL, Jan., 1994.

Armacost, R.L., M.A. Mullens, W.W. Swart and S. Chandra. "Operations Research in Industrialized Housing." Paper presented at XIII World Conference on Operations Research, Lisbon, Portugal, July, 1993.

Armacost, R.L., M.A. Mullens and W.W. Swart. "An Energy Equivalencing Approach to the Justification of Innovative Home Building Technologies." Paper presented at 1994 Energy Efficient Building Association Conference, Dallas, February, 1994.

Brown, G.Z. and R. Kellett. "Methodology of Task 2.1: Design for Energy Efficiency - A futures task of the Energy Efficient Industrialized Housing Research Program." Paper presented at Future Buildings Forum Workshop, Gabriola Island, British Columbia, Canada, June, 1993.

Brown, G.Z., C. Baxley, R. Berg, J. Briscoe, M. Elliot, P. Gay, R. Kellett, B. Mitchell and S. Pierce. "Stressed Skin Insulating Core Panel House - Design Phase." Paper presented at Innovative Housing '93, Vancouver, B.C., June, 1993.

Brown, G.Z. and S. Pierce. "SSIC Component Evaluation." Report for Center for Housing Innovation, University of Oregon, October, 1993.

Brown, G. Z., K. Aires, R. Berg, L. Braun, C. Christensen, M. DeKay, R. Kellett, P. Larocque, B. Muller, D. Peting and S. Pierce. "Performance Specifications for Systems and Technologies of a Multifamily Concrete Panel House in a Hot-Arid Climate." Report for Center for Housing Innovation, University of Oregon, October, 1993.

Brown, G.Z. and M. Meacham. "Predicting Architects' Plan Preferences." Report for Center for Housing Innovation, University of Oregon, December, 1993.

Brown, G.Z., D. Hubbard and M. Meacham. "Building Massing Intelligent Design Tool, Volume III, Analysis, Verification and Critique for the Building Massing IDT." Report for Center for Housing Innovation, University of Oregon, December, 1993.

Brown, G.Z., C. Baxley, R. Berg, J. Briscoe, R. Kellett, J. Kline, P. Kumar, T.K. Lei and T. Sekiguchi. "Stressed Skin Insulating Core Panel House - Design, Construction and Evaluation." Paper presented at ASES-Solar '94, San Jose, CA, June, 1994.

Kellett, R., K. Aires, L. Braun and P. Larocque. "High Performance Insulations and Future Housing Systems." Paper presented at ASES-Solar '94, San Jose, CA, June, 1994.

Kellett, R., M. DeKay, B. Muller, K. Aires and L. Braun. "A Vision of Energy Efficient Industrialized Housing Systems for 2030." Paper presented at Innovative Housing '93, Vancouver, B.C., June, 1993.

Mullens, M.A. "Generic Industrialized Housing Manufacturing Simulator." Paper presented at the 1993 Annual PROMODEL Users Conference, Park City, UT, August, 1993.

Mullens, M.A. "Using the Generic Industrialized Housing Manufacturing Simulator to Evaluate New Manufacturing Technologies." Paper presented at the National Association of Home Builders - Building Systems Council Super Showcase 1993, New Orleans, October, 1993.

Mullens, M.A. "Improve Your Bottom Line." The PROMODELLER, PROMODEL Corp., Orem, UT, Winter, 1994.

Mullens, M.A. and D. Conlan. *CE Technology Characterization for Structural Insulated Panels*. Report prepared for U.S. Department of Energy Office of Conservation and Renewable Energy (CE), major revision submitted July, 1993.

Mullens, M.A. and D. Conlan. *CE Technology Characterization for Structural Insulated Panels*. Report prepared for U.S. Department of Energy Office of Conservation and Renewable Energy (CE), major revision submitted Dec., 1993.

Rudd, A. and S. Chandra. *Side-By-Side Evaluation of a Stressed Skin Insulating Core Panel House and a Conventional Stud Frame House*. Final report. FSEC-CR-664-94. January 14, 1994. Florida Solar Energy Center.

Rudd, A., N. Moyer, S. Chandra and A. Hodgson. *IBACoS Testing Report—Final*. FSEC-CR-707-94. June 9, 1994. Florida Solar Energy Center.

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