ENERGY EFFICIENT
INDUSTRIALIZED HOUSING
RESEARCH PROGRAM

SUMMARY
FY 1992 RESEARCH ACTIVITIES

CENTER FOR HOUSING INNOVATION
UNIVERSITY OF OREGON
AND
FLORIDA SOLAR ENERGY CENTER

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SUMMARY OF FY 1992 RESEARCH ACTIVITIES

ABSTRACT

This report summarizes research results from tasks conducted from March 1992 to February 1993, the fourth year 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 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 "Integration of Computerized Energy Analyses with Existing and Planned CAD Software Used by the Industry" section describes two 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, ASG. ASG's software package "Architecture" runs on top of AutoCAD. Architecture 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 Fall 1993.

The other project in this section is the Sales to Marketing 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.

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 "Concurrent Engineering of Wall Panels" 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. Based on preliminary data the stressed skin insulating core panel house demonstrated 19% better performance.

In the "Student Family Housing Demonstration" section we describe six housing units to be built and tested on the University of Oregon campus. These units will demonstrate good energy performance, available methods of industrialization, high levels of architectural quality and low cost.

We have completed the design of the stressed skin insulating core (SSIC) panel demonstration house and will start construction in Springfield, OR, in June. 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 November, 1994, issue of *Better Homes and Gardens*.

1 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 research centers have responsibility for the program: the Center for Housing Innovation (CHI) at the University of Oregon and the Florida Solar Energy Center (FSEC), a research institute of the University of Central Florida (UCF). which has teamed up with the Department of Industrial Engineering at 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 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

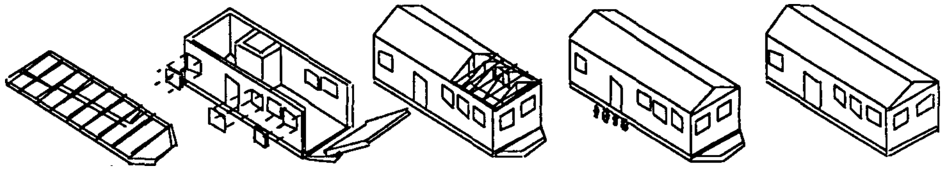


Figure 2 - 1
HUD Code House

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

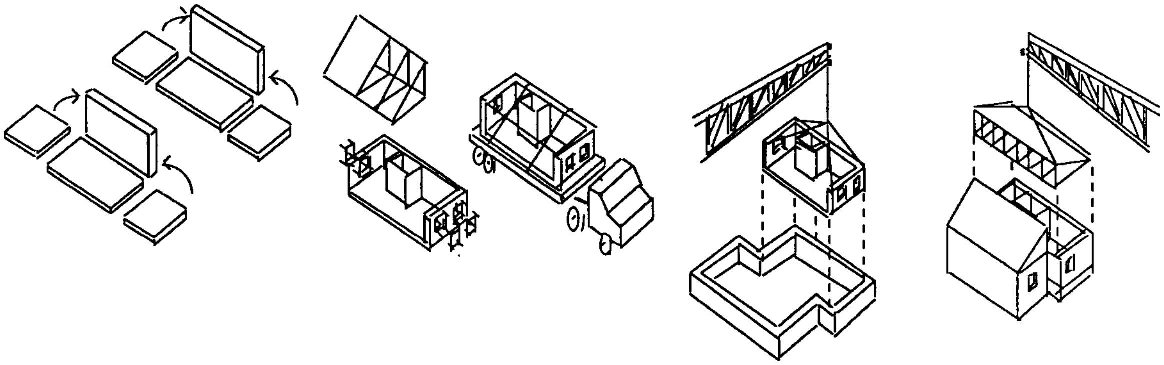


Figure 2 - 2
Modular House

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

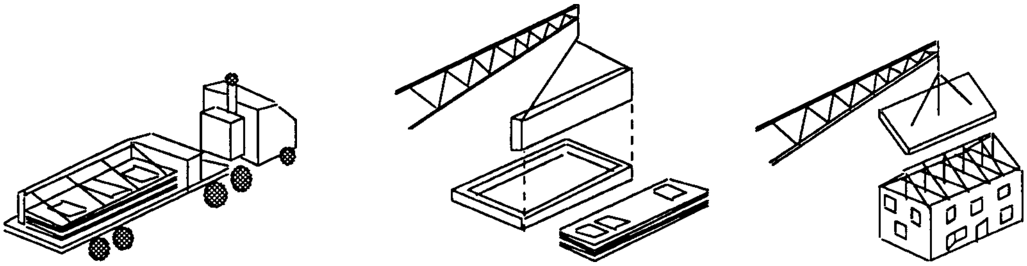


Figure 2 - 3
Panelized House

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

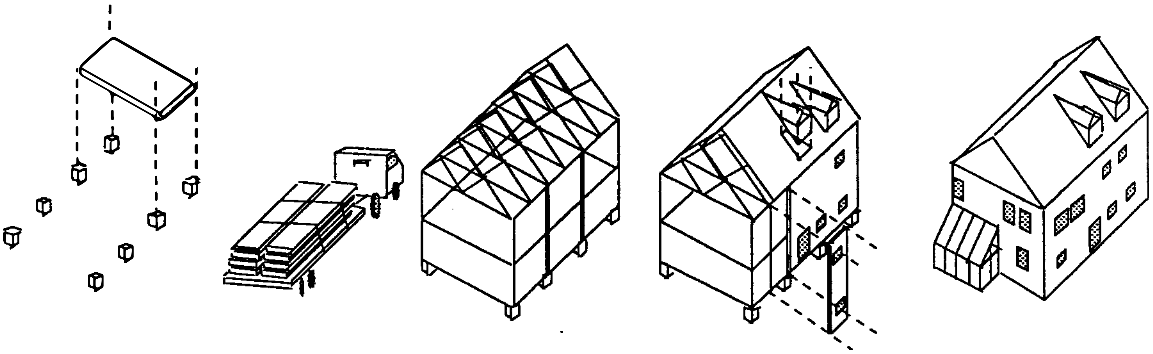


Figure 2 - 4
Production-Built House

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

Objective

The objective of this research is to develop an agenda of energy-related research needs from visions, or scenarios of “zero-energy” industrialized housing systems for the year 2030. The intended outcome is to make energy efficiency an integral part of the agenda of research and development leading to the new materials, processes and designs the housing market, housing industry, its supply and service sector and regulators will adopt in the future. Task products are a roster of short, medium and long term research needs to pursue in collaboration with industry, universities and the national laboratories under the direction of the Department of Energy.

Rationale

Any housing system integrates many process and product technologies that continuously evolve as the opportunity and need for cost-effective improvement and innovation are identified and implemented. This process of improvement and innovation, however, has historically been slow and incremental in mature industries such as housing and construction. As many as 45 or 50 years (Ventre, 1980) may pass between awareness of an innovative product or process and its ultimate availability and adoption as common practice. Current technologies in the early stages of research and development that are most amenable to influence toward greater energy efficiency may not become a part of the housing mainstream until 2030. For energy efficiency to be an integral part of the housing mainstream of the future, research must seek opportunities to improve energy performance in parallel with design, construction and economic factors anticipated to motivate housing demand and supply at the point at which innovations are likely to be adopted.

Background

Over the past two years, researchers in the program have defined a series of industrialized scenarios for zero energy houses for the year 2030. Each scenario presents energy goals within performance specifications for building systems (from foundation to roof) and delivery processes (from sales to design to manufacturing and assembly).

Several methods and phases of work (illustrated in Figure 3-1) were undertaken to identify and rank these research needs. Early in 1990, team members set out to define a context for housing and energy conservation in the future. Literature surveys were undertaken in seven areas of anticipated influence. Fifty-five trends were identified. From them, four housing design scenarios or problem statements were compiled. Eight architectural design studies were then commissioned, developed and evaluated.

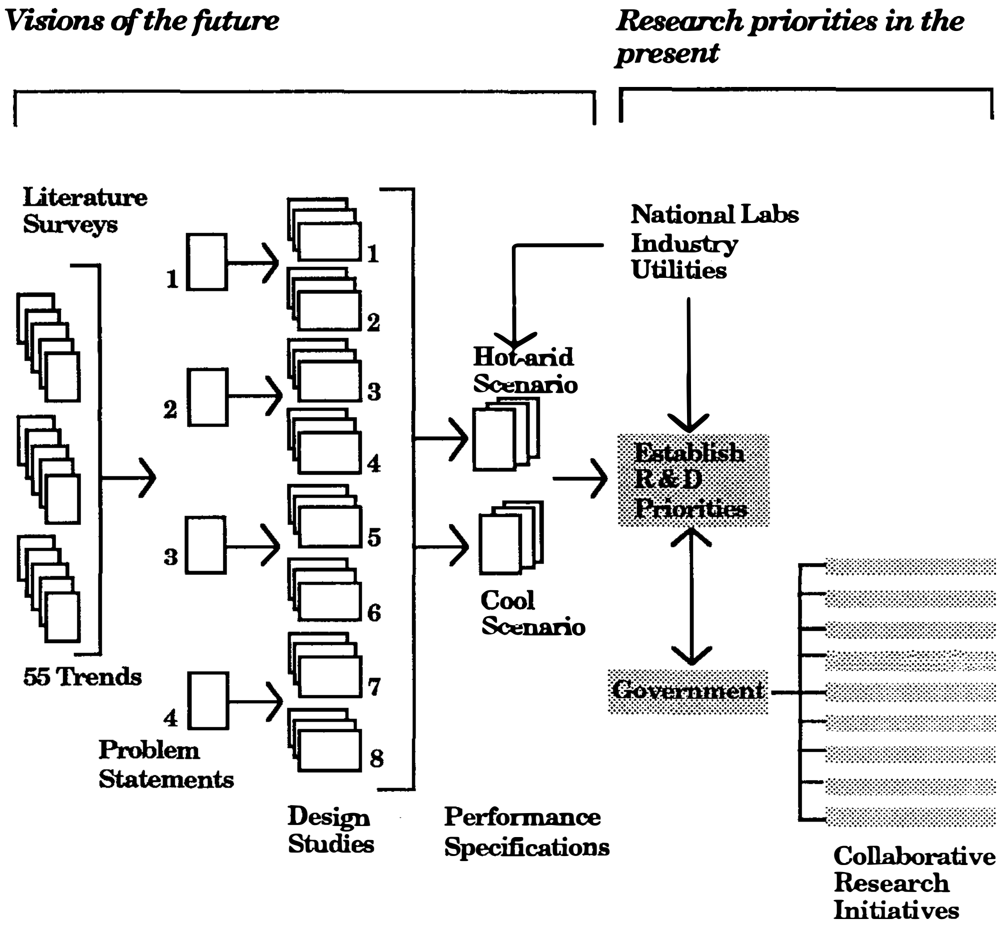


Figure 3-1
Organization and Method
Design for Energy Efficiency Task Area

By 1992, the focus narrowed to systems development (structural, mechanical, manufacturing, etc.) for two scenarios — one for a hot-arid climate and the second for a cool climate. Specifications were developed that quantify projected and desired advances in the performance characteristics of the systems and technologies that make up each scenario were developed.

"Whole House Performance Specifications" quantify performance goals for overall house energy use, cost, architectural design, and regulatory systems. "Building Systems Performance Specifications" quantify performance goals for envelope systems (walls, roofs, floors, foundations and apertures), and service systems (heating, ventilation and air conditioning; water and waste; power, lighting and communications). "Process Performance Specifications" quantify performance goals for design and manufacturing systems. From these specifications, a roster of priorities has been proposed for research and development by collaborations of government, industry, universities and utilities.

Performance Specifications for Two Housing Scenarios

The two scenarios developed in detail in FY92 — a concrete panel system for multifamily housing in hot, arid climates, and a wood composite frame and thin insulation panel system for single-family housing in cool climates — match national residential energy conservation needs with industrialized housing opportunity. The hot-arid climate scenario investigates a very first cost sensitive market in a cooling energy demand area, while the cool climate scenario investigates a median cost market in a heating energy demand climate.

Both scenarios represent areas anticipating strong sustained demand for new housing into the next century. The materials and construction systems explored — manufactured panels of engineered wood composites, thin insulations and concrete composites — are representative of the design and installation flexibility that will be sought in future industrialized housing systems.

The Single Family Wood Composite Frame and Thin Insulation Panel House for a **Cool Climate Scenario** explores technological advances anticipated in wood composite and insulating materials (illustrated in Figure 3-2) and integrates them with scattered site and infill housing.

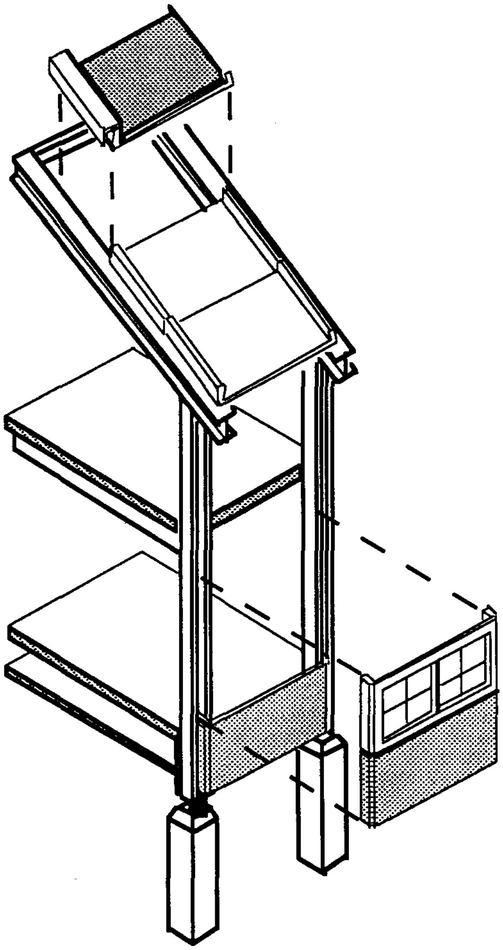


Figure 3-2
Cool Climate Scenario
Enclosure Systems

In this scenario, computerized marketing, design and engineering processes make possible retail "house stores" where prospective homeowners can define their housing needs and develop a design that integrates their expectations with a budget and energy performance. Designs would be based on the significant design and engineering capabilities of wood composites such as laminated veneer lumbers and high energy performance thin insulation technologies such as vacuum or powder evacuated panels that promise R-values greater than 20 per inch.

Systems Performance Specifications from the Cool Climate Scenario

Whole House Performance Goals

Energy

- Zero net annual energy.
- 100% of cooling load by natural ventilation.
- Zero losses from air distribution systems.

Design

- Detached houses of 1, 1 1/2, and 2 stories.
- Diverse densities, house sizes, configurations and styles.
- Detailed for assembly and disassembly for re-use or recycling.

Cost

- Affordable at 100% median household income.

Building Systems Performance Goals

Enclosure Systems

- Structural frame: Two-way system of laminated sections of wood veneer and wood composite materials. Compressive and bending strengths greater than 3000 lbs/in^2. Interior partitions are non load bearing.
- Exterior wall, roof and floor cladding: Evacuated panels 1 - 2.5" thick. Assembly thermal resistance rated R-50 with an infiltration rate of 0.15 air changes per hour.
- Windows and doors: Door assembly thermal resistance rated at R-25. Window assembly thermal resistance rated at R-10.
- Floor systems: Stressed skin honeycomb core panels.
- Foundation systems: Point bearing over ventilated crawl space.

Service Systems

- Conventional air conditioning unnecessary with fan ventilation.
- Passive solar heating by direct gain with electric fuel backup.
- Power distribution systems surface mounted.

- Water and waste systems include heat recovery, greywater recycling and conserving fixtures.

Process Performance Goals

Design Process Systems

- Network links housing provider with financial and regulatory institutions, manufacturers and suppliers.
- Interactive, three-dimensional descriptions of project marketing, sales, design and development. Analysis and optimization of design against customer-defined design, energy and cost parameters.

Manufacturing Process Systems

- Principles of total quality, just-in-time inventory, flexible manufacturing and modular automation.
- Project management, procurement "kitting" and assembly systems managed with computer-aided process and resource planning.

The Multifamily Concrete Panel House for a Hot-Arid Climate Scenario explores advancing technology in concrete materials and panel systems and anticipates its application to dense, low-cost, multifamily housing that is naturally cooled and heated. In it, vertically integrated housing companies concentrate a full range of planning, design, construction and financial services. Advancing concrete material and panel manufacturing technologies combine with wood composites to improve design flexibility, field assembly and thermal performance. Planning and design systems enable designers to evaluate energy performance from on-site sources early in the design process.

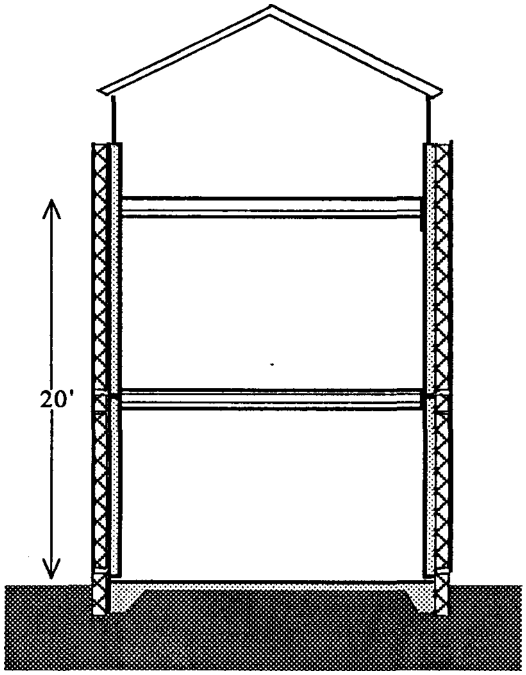


Figure 3-3
Hot-Arid Climate Scenario
Enclosure System

Systems Performance Specifications from the Hot-Arid Climate Scenario

Whole House Performance Goals

Energy

- Zero net annual energy budget over all uses.
- Reduced peak cooling/heating loading.
- Zero losses from thermal air distribution systems.
- 96% of cooling load handled by ventilation (natural & mechanical) and evaporative cooling.

Design

- Multifamily attached houses (16 to 20 units per acre).
- Shared service core.
- Factory manufactured concrete panel system.

Cost

- Affordable at 60% of median household income.

Building Systems Performance Goals

Enclosure Systems

- Roof system: Metal shading and mounting frame.
- Walls: Load- bearing concrete panels with fiberglass reinforcement, insulation, finishes and electrical and mechanical conduits designed into panel.
- Floor system: Wood composite structural panels.
- Foundation system: Slab on grade for ground floor.

Service Systems

- HVAC: Common services center; integrated whole-house ventilation with heat recovery (0.7 ACH); Thermal storage heat pumps.
- Water and waste: End-use conservation; xeriscaping; grey water recycling; heat exchangers.
- Power, lighting and electronic communications: Site-based PV and DHW; high daylighting factors.

Process Performance Goals

Design Process Systems

- Integrated network decreases planning and design time and cost by linking marketing, sales, design, engineering, and management with suppliers,and regulatory and fiscal institutions.
- Site energy evaluation during project definition.

Manufacturing Process Systems

- Principles of total quality, just in time inventory, flexible manufacturing and modular automation.
- Project management, procurement, and assembly systems managed with computer aided process and resource planning.

Research Needs Identified by the Hot-Arid Scenario

The performance specifications for the hot-arid climate scenario have generated 23 potential research needs representing gaps between present knowledge and that required to realize systems and technologies anticipated or desired in the scenario. These research needs have been categorized by type-product development, process development, and data or research methods– and by time frame–short term (one to two years), medium term (two to four years), and long term (over four years).

Product development research needs are directed toward development of materials or systems prototypes. Examples from the hot–arid scenario include:

- A lightweight, low-cost and high thermal storage concrete sandwich panel, which is a medium-term research need generated from the Enclosure Systems performance specification.
- A flexible, low-cost service center for space conditioning, water, waste, and power for multifamily housing densities,which is a medium-term research need generated from the Services Systems performance specification.
- Augmented interior finishes to improve thermal and moisture storage, which is a long-term research need generated from the Enclosure Systems performance specification.

Process development research needs are directed toward design, manufacturing and assembly process improvements. Examples from the hot-arid scenario include:

- A computerized design tool to evaluate site scale energy conservation strategies at early stages of design process, which is a medium-term research need generated from the Design Processes performance specification.
- A factory-based process to measure whole house energy comfort and indoor quality during manufacturing, which is a medium-term research need generated from the Manufacturing Processes performance specification.

- A smaller, less costly device or system than a crane to place thermally massive materials in assembly processes, which is a long-term research need generated from the Manufacturing Processes performance specification.

Data or research methods needs are directed toward acquisition of test data and methodologies necessary to evaluate new processes and products. Examples from the hot-arid scenario include:

- An evaluation method that integrates cost, energy and design quality to ensure the products developed are not only inexpensive and energy efficient but also meet homeowners needs, which is a short-term research need generated from the Whole Building performance specification.
- A refined model to simulate the performance of peak demand from shifting finishes and materials, which is a short-term research need generated from the Enclosure Systems performance specification.

Task Future and Completion

Figure 3-4 illustrates task status at the end of FY 1992. Performance specifications in both hot-arid and cool climate scenarios are substantially complete. Research needs inventories and evaluation criteria have been established, and priorities are being developed.

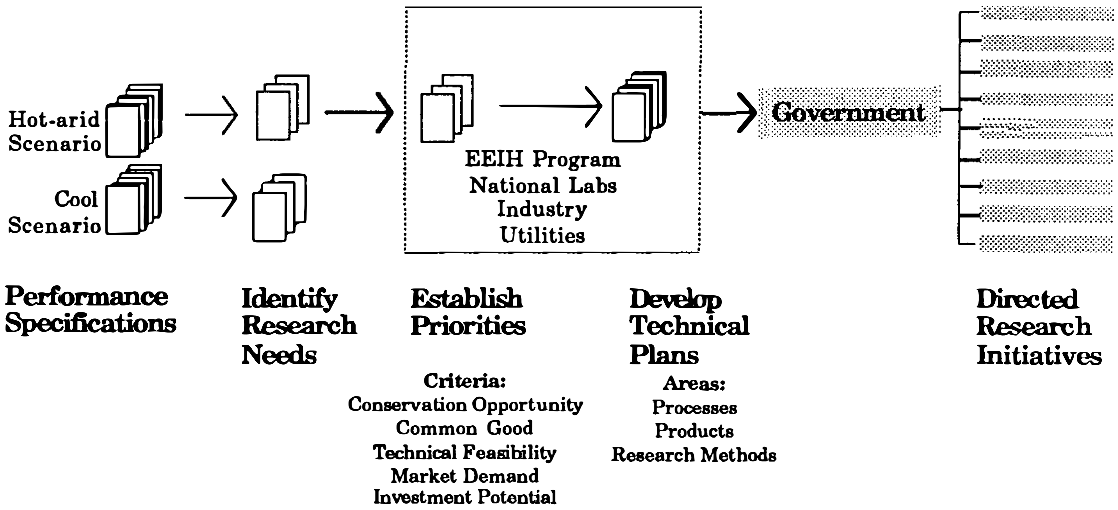


Figure 3-4
Task Completion Overview

In FY 1993, we will complete performance specifications, research needs inventories, and priorities in a working report for each scenario. We will review these working reports and their proposed research priorities with representation from the National Laboratories, industry, utilities and universities. From this consultation we will develop recommendations to the Department of Energy. Also in FY 1993, we will conclude all activities in this task area and publish a concise summary document reviewing research findings from this task for a broad audience inclusive of interested parties outside housing and energy research specialties.

4 INTEGRATION OF COMPUTERIZED ENERGY ANALYSIS WITH EXISTING AND PLANNED CAD SOFTWARE USED BY THE INDUSTRY

We believe that the U.S. industry 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). The U.S. is already trailing in this movement. Japan has taken a lead 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.

We are currently working on two tasks that use computers to enhance processes within the industrialized housing industry. The first task aims to improve design and plan production by injecting energy analysis tools into the normal CAD drawing process. The second task is oriented towards the front end of the business –the initial sales and design contact between potential buyers and manufacturers.

Energy Module For an Industrialized Housing CAD System

The objective of the first task is to develop an energy analysis program that will work from within an existing Computer-Aided-Design (CAD) tool. This program would be used by housing manufacturers to evaluate the projected energy use of their building while it is still on the drawing board. Since all the geometric data is contained in the CAD drawing, the user would not be required to laboriously enter in building data in order to get an energy analysis, as all other energy analysis tools currently require. An additional goal of the project is to display the results graphically so that visually-oriented architects and non-technical people will be able to easily interpret the results and so improve the energy efficiency of their designs.

A Collaborative Research and Development Agreement

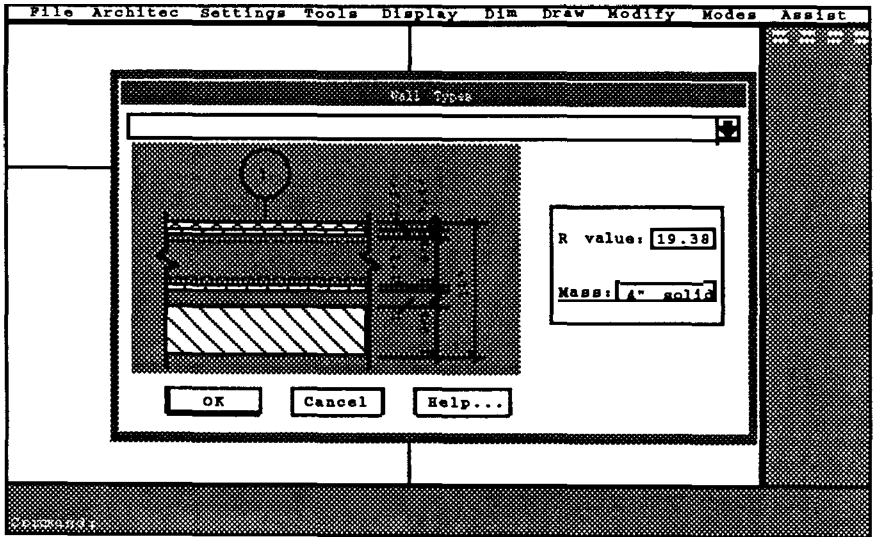
The first phase of this project involved finding an appropriate CAD tool and negotiating an agreement to develop software for the product. This process has been completed and AutoCAD by AutoDesk with Architecture for AutoCAD by ASG were selected. A Collaborative Research and Development Agreement (CRADA) has been signed by the Archsoft Group (ASG) in Sausalito, California; Pacific-Northwest Labs (PNL) in Richland, Washington; and the University of Oregon. PNL will develop the energy analysis engine for this product; ASG will supply training, software, and marketing; and the University of Oregon will develop the user interface and the CAD-geometry interpreter for the product, as well as provide expertise on energy and architectural issues.

History

Twenty-three CAD packages were evaluated before selecting ASG/AutoCAD (Meacham, et al 1991). Although some of the CAD products had more modern software organization that would have simplified the addition of the geometry interpreter and energy analysis engine, AutoCAD had a good score in most areas, with the highest score in market penetration. AutoCAD, a product of AutoDesk, Inc., is the largest selling PC-based CAD tool in the world with an installed base of over one million users worldwide. Being a generic CAD tool, however, AutoCAD had no support for handling of architectural and industrialized housing constructs. Therefore we looked at companion products that would tailor AutoCAD to architectural and industrialized housing applications. We selected ASG, a Registered Developer with AutoDesk that has developed more than 20 products that work seamlessly with AutoCAD, including Architecture, their most popular companion tool to AutoCAD. ASG is a strong company, with an installed base of over 30,000 for Architecture alone. The final decision factor was that ASG was eager to work with us on our new product.

The Character of the Tool: A User Scenario

Users of this program are not expected to be energy experts. It is important therefore that the program make it easy to input data for the energy analysis, and that the results be interpretable by non-technical users. These goals are met by creating a graphical interface, integrating the energy description process with the building description process, and by relying whenever possible on the existing ASG Architecture/AutoCad interface.



R value: 19.38

Mass: 4" solid

Figure 4-1
Wall Types Specification

There are certain types of information required by the energy engine that are already known by the designer and appear on the drawings. These include areas, construction materials, building orientation, etc. For example, the ASG Architecture program has a means to create walls in the plan by specifying the type of construction ie: metal stud, concrete block, etc. This sets wall thicknesses for purposes of drafting. Our tool will extend this interface convention by attaching thermal properties to these types—as shown by the mass and R value readings in Figure 4-1. This information, in addition to the area of the wall as determined by the geometry interpreter, forms the input passed to the energy engine for analysis of the walls. The other parts of the building shell will be handled in a similar fashion.

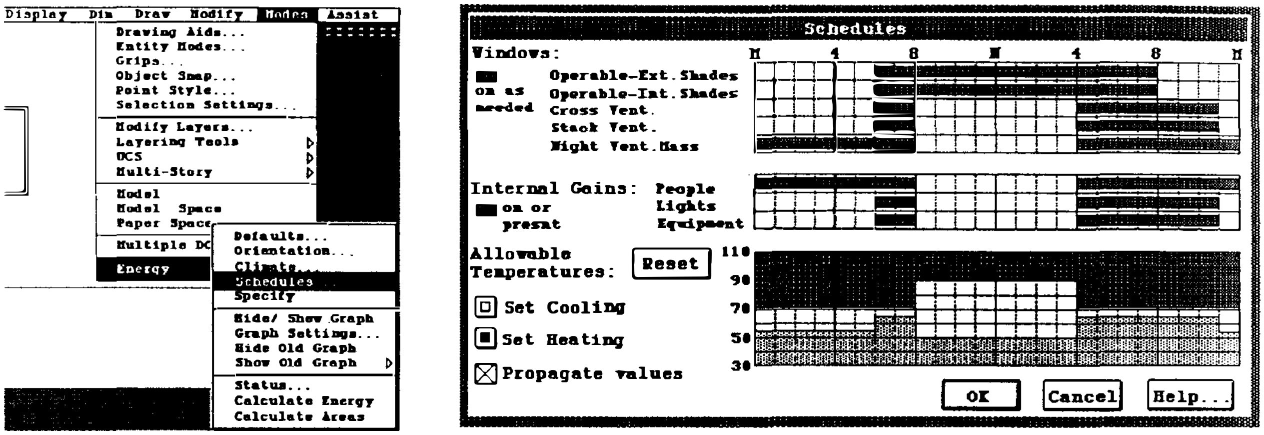


Figure 4-2
Setting Building Schedules

Other kinds of information, such as climate or occupancy schedules, are not readily available from the CAD model. For these the user goes to an "Energy" menu, which provides the means to provide this information to the energy engine. For instance, as shown in Figure 4-2, choosing "Schedules" brings up a dialog box where the user graphically sets schedules for such things as windows, occupants, lighting, and thermostat.

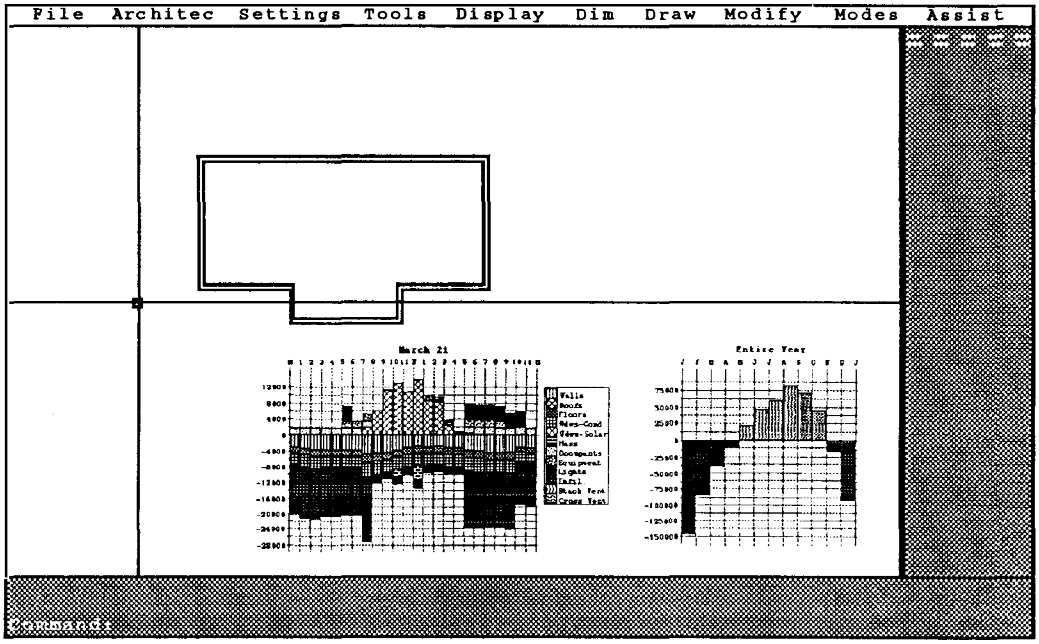


Figure 4-3
Graphic Report

Interpreting the numeric and textual results of most energy analyses is a time-consuming and difficult process even for people who have a technical background. For non-technical people, which can include the designer and client, such an array of numbers is confusing and will likely be ignored. We have previously developed a graphical presentation format (Brown, et al 1992) that successfully makes analysis results accessible to those without the technical knowledge to understand the underlying data. Figure 4-3 shows the output that will be presented to the user of this program.

Future Work/Completion Date

The project is currently in the code development stage, with completion of code and test for the Phase I product planned for September 1993. The Phase I product will provide the essential core capabilities such as geometry recognition of the CAD drawing, and user specification of materials, climate, orientation, occupancy and thermostat schedules and will produce graphical display of loads and gains. Future phases will develop engines that will calculate the effects of thermal mass, allow daylighting specification, and provide for more sophisticated user access to library or template development for materials, climates, and schedules.

Sales to Manufacturing Tool

The second task, 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 are the people with 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 factory-produced industrialized housing, improve energy performance, and enhance customer satisfaction.

While there are substantial gains to be made through increased computerization of existing processes, the greatest promise for improvement is in the ways increased systemic computerization provides previously unavailable options for selling, designing, and manufacturing homes. An example of this is the way computer-based systems can help home buyers customize a manufacturer's standard house plan, visualize the changes made, and then pass this 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. The user interface will employ intelligent "agents" to assist the buyer in navigating the program. A graphic interface and a full range of hypermedia will insure ease of use.

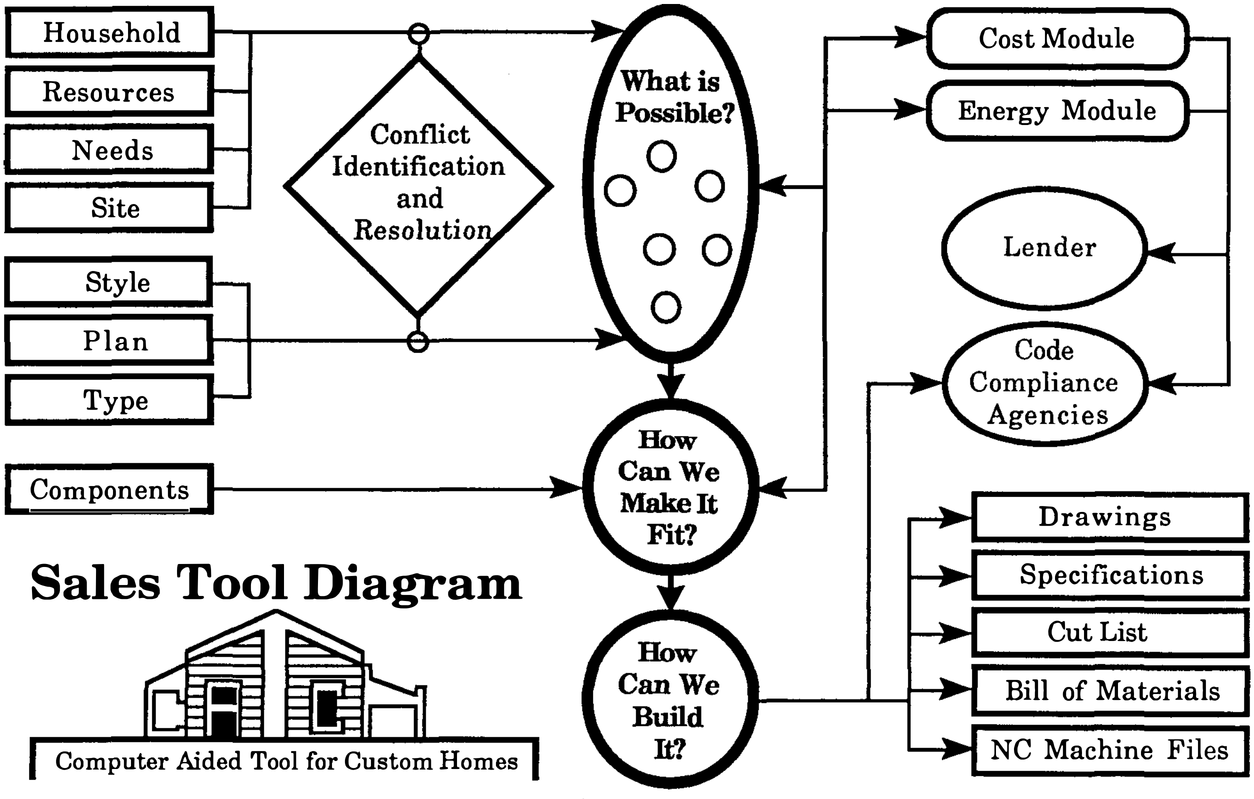


Figure 4-4
Sales to Manufacturing Tool Scenario

Figure 4-4 illustrates a conceptual scenario for the application. As the buyer makes choices about plans, size and style of dwelling, the Sales Tool stores those facts and starts creating a composite design program. In designing a home there are an enormous number of decisions to make, and the range of choices can be overwhelming to the buyer. Based on decisions made by the buyer and on the answers to specific questions put to the buyer, an expert system can make inferences about the kind of dwelling desired, and thus filter the immense quantity of data that the user would otherwise be presented with. The expert system also analyzes the various choices that have been made and identifies problem areas or conflicting decisions. It then passes this information to the agents who advise the buyer in resolving the problem.

Energy efficiency leads to lower annual heating and cooling costs, and lowers the total cost of the house over its lifetime. Many lenders also provide a mortgage credit if the energy features lower utility bills, thus allowing the buyer to purchase more house. Among the interface agents will be ones devoted to energy design, building and operating costs, and financial analyses. They present information from the energy and cost engines in a graphic format that allows the buyer to immediately see the financial and environmental benefits of improved energy efficiency, and that also provide lenders with an analysis in support of a mortgage credit.

The process of designing a house generates data in many forms: textual, numeric, graphic, and geometric data, to name only a few. In order to produce a factory-built house a manufacturer needs specific types of data. Our program will automate the flow of data from sales and marketing through construction. It will provide a direct electronic means for manufacturers to produce drawings, specifications, bills of material, cut lists, numeric-controlled machine files, and code compliance reports.

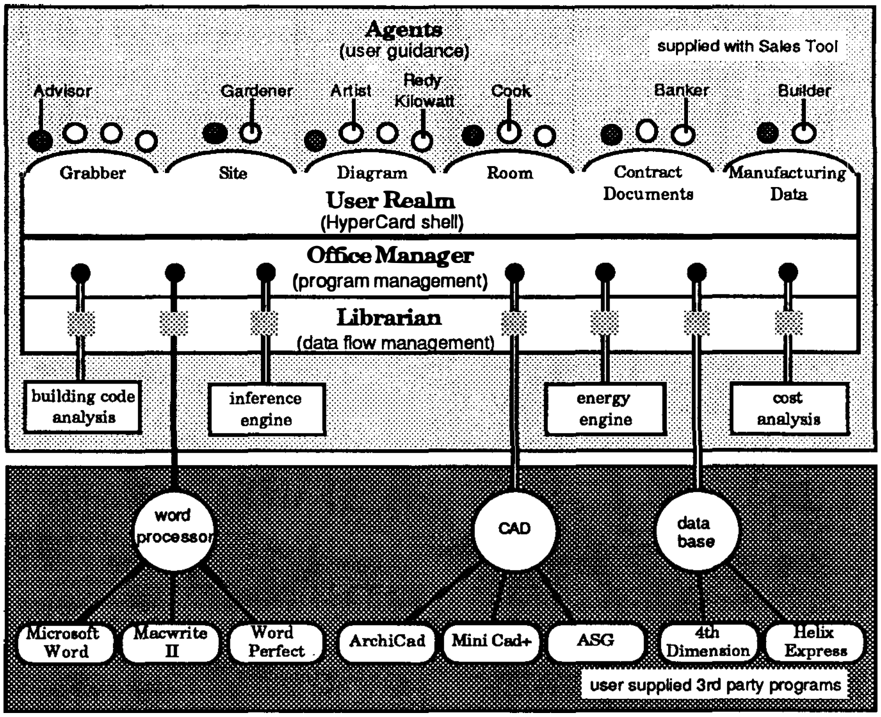


Figure 4-5
Sales Tool Development Strategy

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 4-5. In order to reduce the development requirements the tool will rely heavily on existing software applications that run on Macintosh, DOS, and UNIX systems. Inter-application communication allows one program to interact with another, provided both support this technology. 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.

Additionally, there will be several modules or sub-programs 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. Examples of these are the energy, cost, and inference engines, and the advising agents.

Future Work

Currently we are completing a working report that presents a conceptual description of the tool and examines several key technical issues related to implementation. We will soon begin development of a working prototype that uses inter-application communication. We expect to receive extensive support from hardware and software vendors as well as from the industrialized housing industry. The backbone will be completed and marketed in 1994, with successive special modules added each following year. The final product will provide a level of automation that the U.S. needs to become competitive in the world housing industry, at the same time decreasing residential energy consumption.

5 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 Computer-Aided Engineering modeling tool which can assist housing manufacturers (both existing and new entrants) in planning for and assessing the impact of innovative manufacturing technologies. Entitled GIHMS (for Generic Industrialized Housing Manufacturing Simulator), the CAE tool 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 FY92.

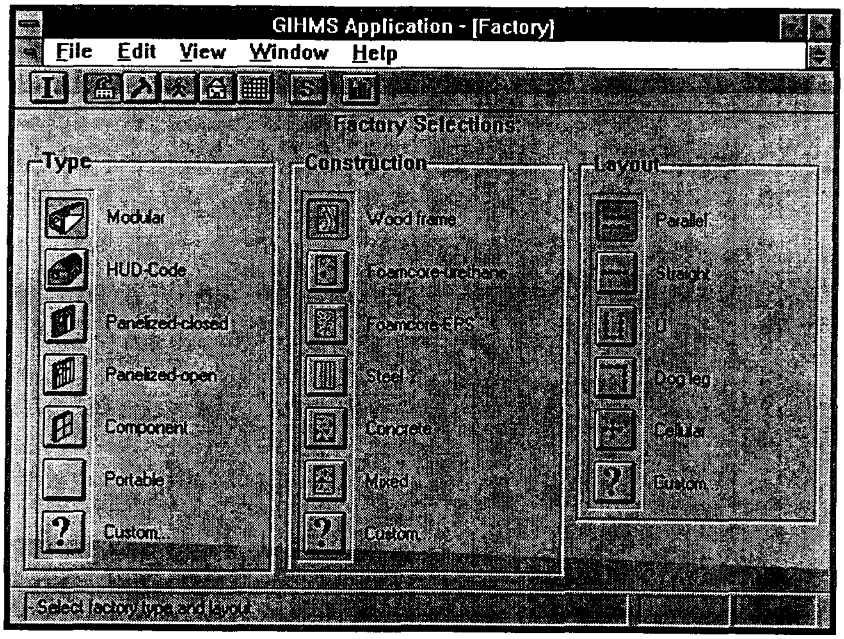
- A functional specification for GIHMS was developed, with a focus on stressed skin insulating core (SSIC) panel manufacturing.
- A working prototype simulation model of a generic SSIC manufacturer was developed. This prototype is serving as the test-bed for developing and testing GIHMS modeling constructs.

GIHMS Specification

In FY92 a functional specification for GIHMS was developed, focusing on SSIC manufacturing. The specification is being used to guide the ongoing software development effort. The specification addresses the following functional areas:

general characteristics, product line definition, order definition, factory definition, operations management and control, and output analysis. The following sections summarize key GIHMS functions and features in each functional area.

General Characteristics: GIHMS is being designed for use by personnel who are PC literate and have housing industry experience but not necessarily computer simulation experience. To accommodate this user, GIHMS will allow models of an industrialized housing manufacturing facility to be developed and evaluated using a WINDOWS-based, "point and click", icon-oriented environment. A typical user WINDOW is shown in Figure 5-1.



Select factory type and layout

Figure 5-1
Typical GIHMS User Interface

Product Line Definition: The product line is the list of products that can be manufactured by the simulated factory. GIHMS will allow the user to define the company's product line at several levels of detail. At the highest level the user will be able to select (from a database) specific house plans for which the simulated factory will be able to manufacture applicable components. The user will be able to narrow the range of search using database query commands. At a lower level, the user will be able to define specific product-related characteristics associated with a house plan. These characteristics, which might include panel depth, spline configuration, and electrical chase requirements (for SSIC technologies), will differentially impact the manufacturing process.

Order Definition: A customer order consists of all components (panels) required for a house plan. Each order consists of sub-orders, one for each unique panel type required by the house plan. GIHMS will allow the user to specify a specific stream of customer orders or develop a random stream of orders.

Factory Definition: The physical configuration of the factory will be specified in several stages, including equipment selection and factory layout. The user will select process, load/unload and material handling equipment in much the same way as she/he selects house plans, using a relational database. Factory layout will be interactive using CAD representation of the factory floor and will consist of: 1) moving icons that represent process equipment to their desired locations and 2) defining material handling flow paths.

Operations Management and Control: Operations management and control consists of the following tasks: production scheduling, labor/machine scheduling, shift scheduling, inventory management, and flow control. The library of operations management and control options will be expanded as research progresses. It is expected to include various operations research algorithms as well as expert systems to optimize factory operations within a given physical facility.

Output Analysis: GIHMS will allow the user to review simulation results in a variety of formats including factory animation, quantitative tables and graphs. Quantitative results will include both factory operational performance measures (throughput, delays, etc.), and capital cost analysis that includes facility and equipment costs. An animated segment is shown in Figure 5-2.

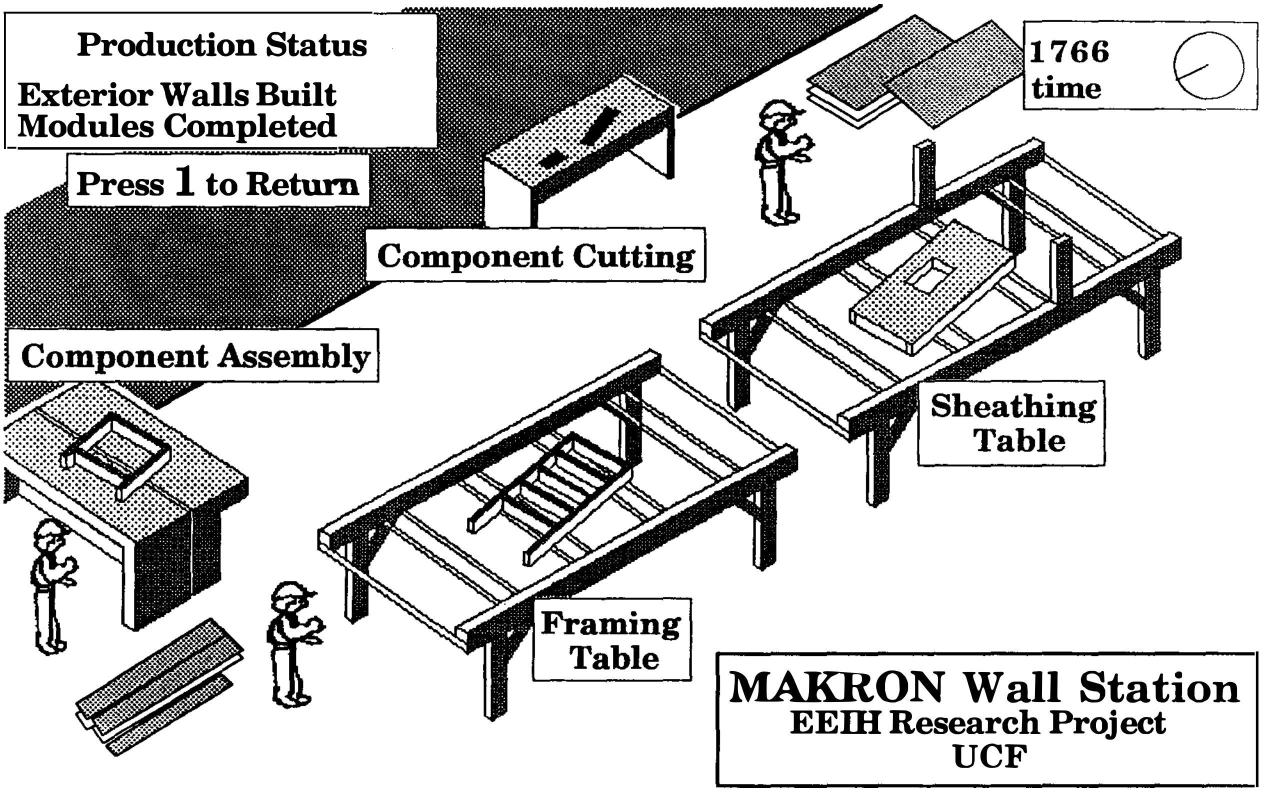


Figure 5-2
Typical GIHMS Animation Scene

Prototype Simulation Model

A working prototype simulation model of a generic stressed skin insulating core panel manufacturer was developed. This prototype provides most of the complex functionality associated with the real SSIC manufacturing process and serves as the test-bed for developing and testing various GIHMS modeling constructs. A schematic of the manufacturing operation is shown in Figure 5-3.

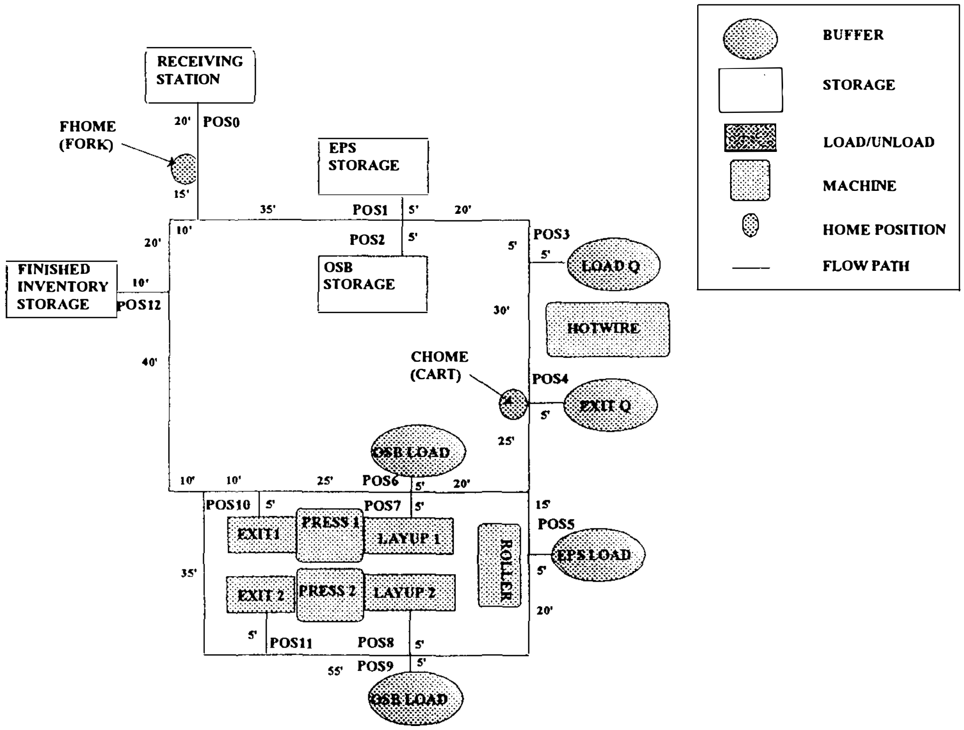


Figure 5-3
Schematic of SSIC Manufacturing Operation

6 CONCURRENT ENGINEERING OF WALL PANELS

While much can be done on the manufacturing floor to improve the energy efficiency and cost of housing, the real opportunities lie in the design of the product itself, both from an architectural and manufactured component perspective. In FY92 this task researched wall producibility and investigated the use of Quality Function Deployment to industrialized housing.

Wall Producibility

The goal of this task is to better understand the impact of the manufactured component on the producibility of a house. Producibility is defined in the broadest sense to include factory manufacturing of the component, shipment of the component to the construction site and site erection and finishing.

The task focuses on the exterior structural wall. The wall is an ideal candidate for analysis since it significantly impacts both the cost and energy performance of new housing. Given the real potential for long-term energy savings, this task seeks to resolve conflicting cost perceptions by addressing the following specific objectives:

- To assess the producibility of a "standard" residential exterior structural wall using various innovative manufactured building components.
- To identify key cost drivers.
- To create a practices database documenting current practices and capable of supporting future product/process design efforts

The "standard" wall used in the producibility analysis is 40' long by 8' high, contains 3 windows and 1 door, and is standing on-site, fully assembled and finished. The interior is specified as 1/2" sheetrock, finished and painted. Vinyl siding is used as the exterior surface. A schematic of the standard wall for a wood frame option is shown in Figure 6-1. Specific construction technologies considered for building the standard wall included: 2x4 stick-built, 2x4 wood frame manufactured panels (2 manufacturers), 2x6 wood frame manufactured panels and 4" SSIC panels (2 manufacturers).

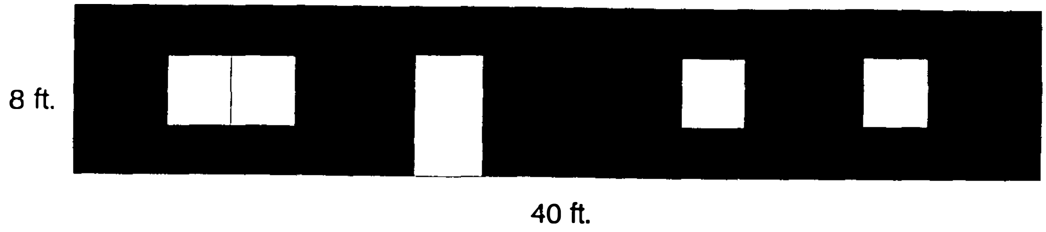


Figure 6-1
Standard Wall for Wood Frame Construction
Wood Frame Construction Specifications: 2x4 frame, studs at 16" O.C., 7/16" OSB exterior sheathing, 1/2" sheetrock interior sheathing, wiring and rough electric completed, windows, and door installed, R11 batt insulation installed, taping and spackling completed, interior painting completed.

A fundamental assumption used throughout this analysis is that producibility can be measured by the resources required to produce the wall: labor, materials, capital items, (facilities, equipment and inventory) and indirect operating expenses. Resource usage is measured in the factory, during shipment and on the construction site. Costs serve as the common denominator for comparing resource requirements. Cost estimates were developed with the following assumptions:

- Labor is estimated at a common rate of $10/hr. in the factory and $15/hr. on site, including fringes.
- Materials are estimated at prices effective March 1989. The prices are thought to be generally representative of prices through mid 1992. The cost of wood products has risen approximately 90% since then. The impact of this recent price increase is addressed in a sensitivity analysis.
- Factory floor space is estimated at common rates depending on type of construction.
- Capital costs for facilities and equipment are amortized over current production levels and a 10-year planning horizon at a 20% internal rate of return.
- Cost estimates for panel factory and site operations do not include mark-ups to recover non-production costs and profit. Therefore relative production costs may not be a true estimator of relative pricing, depending on the degree of vertical integration and levels in the distribution chain.

The methodology used included the following steps:

- Visits were made to each factory and construction site. Production operations were observed and documented on video tape. Production management and staff were interviewed. Inventories were taken of production equipment and floor space.
- Video tapes were analyzed to document production processes and estimate labor content. A process/practices database was prepared using Boothroyd-Dewhurst's Design for Manufacturing and Assembly (DFMA) software. The database included Operations Process Charts, labor and materials information.

- Capital costs were estimated from inventories developed during the site visits, and amortized using an EXCEL spreadsheet.

Results are shown in Table 6-1. Key findings include:

- Conventional wood framed construction costs are similar for both stick-built and factory panelized construction. Although capital costs are higher for panelized operations, they result in corresponding reduction in labor. 2x6 wall construction is about 7% more costly than 2x4 construction.
- SSIC panel costs vary greatly. Cost differences are primarily the result of management decisions regarding inventory levels and manufacturing facility costs, as opposed to differences in production processes.
- For the current scenario (shown in the "Total" row), SSIC panel construction costs are 25-55% higher than 2x4 construction and 17-45% higher than 2x6 construction. For the 2x4 comparison, this difference is driven almost equally by increased costs for material and labor. In addition capital facilities are running at only 33% of their capacity, while the frame panelizers are running at virtually 100%.

	4" Stick Built	6" Stick Built (16" OC)	6" Factory Frame #2	4" Factory Frame #2	6" Factory Frame (24" OC)	Stress Skin #2	Stress Skin # 1
Material	970	1060	970	940	1040	1060	1090
Labor	380	390	330	380	350	440	450
Capital & Indirect Operating	0	0	60	40	60	600	150
Total	1350	1450	1360	1360	1450	2100	1690
Sensitivity Analysis							
Normalized	1350	1450	1370	1360	1450	1600	1590
Lumber Price Increase	1520	1680	1550	1470	1670	1740	1740
Optimistic Cost Reductions	1520	1680	1550	1470	1670	1700	1700

Table 6-1

Standard Wall for Wood Frame Construction

Three sensitivity analyses were performed to assess the sensitivity of results to various assumptions. Each builds upon previous assumptions.

- A "normalized" scenario assumes that all operations are managed equally well and that production volumes are at 100% of capacity. Results indicate that SSIC construction costs might be no more than 18% higher than 2x4 construction and only 10% higher than 2x6 construction.
- An optimistic scenario assumes that it will be possible to cut all SSIC factory manufacturing costs (except materials) by as much as 50%. One recent data point (Florida Solar Energy Center, 1993) suggests that at least one SSIC manufacturer may already be near this level. Results indicate that SSIC construction costs might be no more than 12% higher than 2x4 construction and 1% higher than 2x6 construction.

The primary conclusion from FY92 efforts is that although SSIC construction costs are currently greater than those of conventional wood frame construction, there are likely future scenarios under which their costs may be only slightly higher than 2x4 construction and roughly the same as 2x6 construction.

Quality Function Deployment

The goal of this task is to better understand what customers expect from manufactured building components and how these requirements can be incorporated into component design. The primary focus has been on evaluating the feasibility of innovative concurrent engineering methodologies for industrialized housing applications, specifically for manufactured building components used in the construction of exterior structural walls. In FY 1991, we demonstrated that the structure of Quality Function Deployment (QFD) appeared to be a promising mechanism for capturing the voice of the customer (identifying customer requirements) and deploying those results to the technical engineering characteristics for a wall. One important aspect of applying that methodology was the meaningful prioritization of the customer requirements. Using this methodology we examined a refined approach to the use of QFD for the development of a wall panel, examined the role of QFD in the context of an overall product development process for industrialized housing, and initiated the development of an integrated systems benchmarking approach to stimulate continuous improvement in industrialized housing manufacturing practices.

In FY92 we completed the analysis of a survey using the Analytic Hierarchy Process to determine the relative importance of customer requirements for the wall. Although the method was sound, it was found that the customer characteristics needed further refinement before they would yield meaningful results. The initial set of criteria was distributed throughout the EEIH project to solicit additional criteria. The refined criteria formed the basis for identifying appropriate (measurable) engineering characteristics. After additional distribution and review, further changes were made, and the resulting requirements/characteristics are included in Tables 6-2 and 6-3. It remains to be verified that the application of the House of Quality will be useful for industrialized housing application. Because QFD and the House of Quality provide an effective mechanism for competitive benchmarking, the analysis of the House of Quality continues in the FY 1993 task.

CUSTOMER REQUIREMENTS: Qualities or characteristics of an exterior structural wall or characteristics of a room or house that impact or are affected by an exterior structural wall.

- Comfortable environment
  - Physical comfort
    - Maintain comfortable room temperature
    - Maintain proper room humidity
    - Provide weather tightness
    - Control fresh air
  - Auditory environment
    - Isolate outside noise
    - Isolate outside vibrations
    - Sound will not leak out
  - Visual environment

Table 6-2

Customer Requirements

        - Variable window styles
        - Variable window locations
        - Good lighting effect
        - No visible seams/joints where not desired
- Flexibility and adaptability
    - Adapt to change of lifestyles
        - Can reposition
        - Can relocate door opening
        - Can reconfigure/enlarge room
    - Flexibility to customize to own taste
        - Easy to design with
        - Can choose own exterior wall finish/covering
        - Can choose own interior wall finish/covering
        - Easy to hang heavy objects
- Performance
    - Easy to maintain
        - Easy to clean
        - Minimum interior maintenance
        - Minimum exterior maintenance
        - Easy to locate utilities
        - Easy to repair
    - Durability
        - Does not decay or degenerate
        - Does not corrode
        - Resistant to puncture/damage
- Safety
    - Safe against artificial mishap
        - Hard to set on fire
        - Can not get sick from panel
        - Components do not harm environment
    - Strong
        - Will not collapse easily in fire

Table 6-2 (Continued)

Customer Requirements

    - Strong against heavy wind
    - Strong against earthquake
- Ease of site assembly
  - Connectability
    - Easy to connect to foundation
    - Easy to connect at corner panels
    - Easy to connect to adjacent panels
  - Handling
    - Easy to position
    - Easy to orient
  - Quality
    - Straight and true
    - Not affected by moisture during construction
    - Acceptable appearance
- Supplier factors
  - Availability
    - Panels readily available
    - Punctual delivery
  - Service
    - Honors warranty claims
    - Offers longer warranties
  - Cost
    - Initial cost
    - Maintenance cost
    - Disposal cost

Table 6-2 (Continued)
Customer Requirements

- Livability
  - Indoor environment
    - Reaction to freeze exposure
    - Reaction to humid exposure

Table 6-3
Technical Characteristics

    - R-value
    - % R-value reduction over time
    - Blower door test
    - Seal Quality
    - Sound transmission
    - Sound absorption
  - Style
    - Surface roughness
    - Surface absorption
    - Surface porosity
    - Maximum depth of cracks
    - Number of visible seams
    - Maximum length of visible seams
    - Number of cracks
    - Maximum depth of visible seams
    - Maximum hanging weight
    - Available hanging surface (x < 30 pounds)
    - Available hanging surface (x > 30 pounds)
- Safety
  - Fire prevention
    - Load strength in fire
    - Surface burn characteristics
    - Load strength and containment
    - Strength of corner in fire
  - Structural strength
    - Transverse loading strength with windows
    - Vertical compressive strength
    - Racking shear strength
    - Combined axial and bending strength
    - Wind proof
    - Vibration insulation
  - Utility safety

Table 6-3 (Continued)
Technical Characteristics

        - Water resistant
        - Electrocution proof
- Durability
    - Durability
        - Corrosion
        - Fade proof
        - Chemical proof
- Constructability
    - True to fit
        - Squareness/trueness
        - Deformation
    - Standardized components
        - Number of components
        - Number of standard parts
    - Ease of assembly
        - Time to install full wall
        - Time to join adjacent panels
        - Site installation time (non-standard window)
        - Factory installation time (non-standard window)
        - Sealant insulation time
        - Panel vulnerability to sealant
        - Time to secure to panel
- Enterprise reliability
    - Service quality
        - Length of warranty
        - Frequency of claims (number of claims/number sold)
        - Average length of time to resolve warranty claims
    - Stability of manufacturer
        - Number of years in business
        - Number of panels sold
        - Annual volume of business
    - Availability to order

Table 6-3 (Continued)
Technical Characteristics

        - Number of suppliers
        - Delivery lead time
- Cost
    - Operation cost
        - Cost to maintain
        - Annual pest control cost
    - First cost
        - Site installation cost
        - Factory manufacture cost (labor)
        - Retail price of panel
        - Wholesale price of panel
        - Extra cost of material to install non-standard windows
        - Sealant costs
        - Manufacturing equipment costs
        - Site equipment costs

Table 6-3 (Continued)
Technical Characteristics

7 FIELD TESTING OF WHOLE HOUSES AND COMPONENTS

Introduction

A side-by-side evaluation to assess the energy benefits of using stressed skin insulating core (SSIC) panels in residential construction was conducted in Louisville, KY, U.S.A. One house was constructed as a conventional 2x4 stud-frame (SF), and the other was constructed with stressed skin insulating core panels. Both houses were constructed by the same builder who has experience with both types of construction. Each two-story house has a 1200 sq. ft. floor area and has the same floor plan, elevations, and orientation, and nearly the same exterior colors. Both houses are heated by a natural gas furnace, and all of the air distribution ducts are within the thermal envelope of the building. A comparison of the basic building parameters for the two houses is given in Table 7-1. The houses were constructed between October and December of 1992. Energy testing and unoccupied monitoring was conducted from January 12 through March 5, 1993.

Component	House Type	Construction Type	R-value
Foundation	Both	Block stem wall and slab	R-10 to 2 foot depth
Walls	SF	2x4 stud	R-13 fiberglass batt
	SSIC	3-5/8" EPS core panel	R-14 EPS core
Windows	Both	Double glazed, wood frame, aluminum cladding	R-2.0
Second floor ceilings	SF	2x4 truss	R-30 blown-in
	SSIC	Flat 7-3/8" EPS core panel	R-29 EPS core

Table 7-1

Basic Parameters of the Stud-Frame (SF) and Stressed Skin Insulating Core (SSIC) Panel houses

Both houses were designed to have a conductive thermal transmittance (UA) equal to each other. Calculations using as-built values show that the SSIC conductive UA equals 265 Btu/hr-°F and the SF conductive UA equals 271 Btu/hr-°F, a difference of only 2%.

Five days of building diagnostic testing were performed on each house. The testing evaluated: thermal insulation quality by infrared imaging; building envelope and air distribution system air-tightness by fan pressurization and tracer gas; pressure effects inside the house due to interactions of the air distribution system; calculated versus measured building load coefficients by co-heating; and building thermal capacitance by cool-down.

Four weeks of short-term energy monitoring were conducte–two weeks of electric heating energy-use monitoring and two weeks of gas heating energy-use monitoring. The houses were unoccupied during monitoring but internal heat gains due to people and equipment were simulated by computer control. In addition to house energy-use data, data from house dry bulb temperature, mean radiant temperature, south wall surface temperature, and relative humidity were continuously monitored. Passive perfluorocarbon tracer gas sources and samplers were deployed to measure the time-averaged house air exchange rates. A weather measurement station was installed on top of one of the houses. A photograph of the two houses, with the weather station on top of the SSIC house, is shown in Figure 7-1.

Initial Results

Results from the building diagnostic testing portion of the project are presented here. Analysis of the monitored data is still on-going, so those results will be presented at a later date. Infrared scanning indicated that the thermal insulation quality of both houses was high. Few defects were found which would have a significant impact on energy use. The stud-frame house had two insulation defects that are worth noting. One defect involved a ceiling area over the stairwell, approximately 6 sq. ft., where the blown-in insulation was missing. The other defect became apparent only after infiltration was forced by blower door -an air leak occurred where an exhaust duct in the first-floor bathroom penetrated the band joist and was not sealed well.

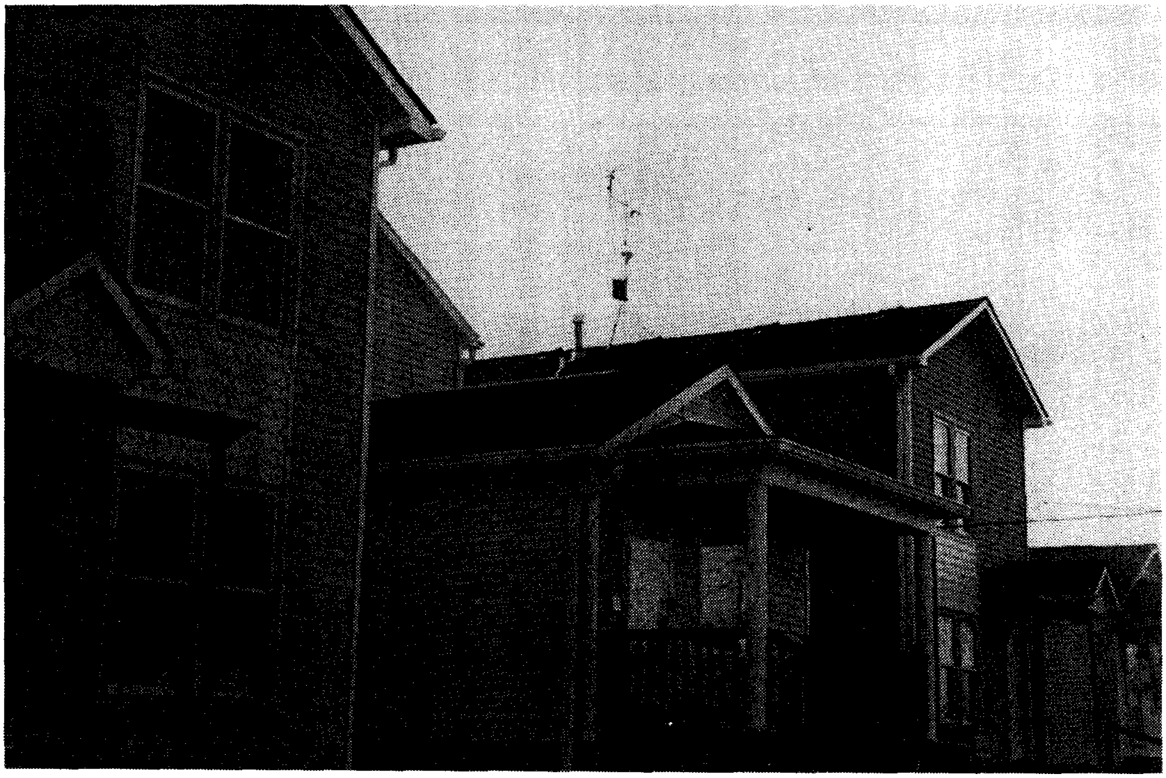


Figure 7-1
Photograph of the two test houses; weather station installed on top of the SSIC house.

Air-tightness was evaluated for both building envelopes and the air distribution systems. Blower door and tracer gas tests indicated that the envelope of the SSIC panel house was more air-tight. Tracer gas tests, using SF_6 and a specific vapor analyzer, showed that both houses had an increase in air infiltration when the air distribution system was operating. However, duct leakage to the outdoors was less than the blower door could measure accurately. Figure 7- 2 gives a summary of these results.

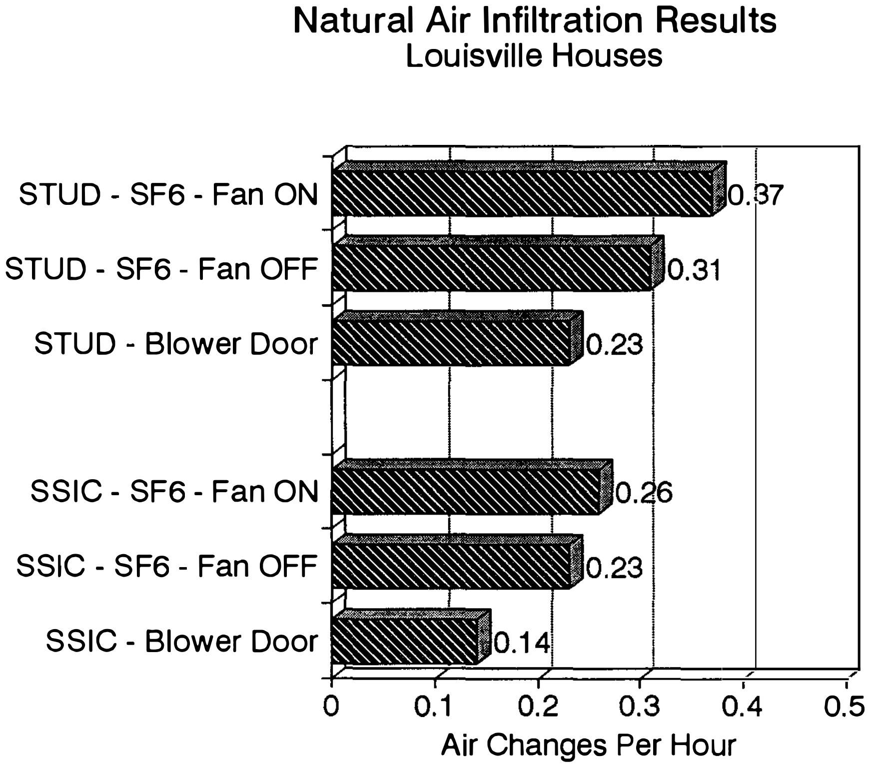


Figure 7-2
Natural air infiltration results for Louisville houses: blower door and tracer gas.

A series of measurements were taken to evaluate pressure differentials within the building and between the building interior and the outdoors. The impact of building pressure differentials can affect occupant health and safety, building durability, and energy use. Since both houses have gas furnaces inside the conditioned space, occupant health and safety could be affected if negative pressures caused the furnace to back-draft. Pressure measurements taken between the utility closet and the outdoors showed pressures between -2.0 Pa and -5.7 Pa. These measurements were taken with the furnace fan on, and the kitchen and bath exhaust fans on. A clothes dryer, which will be installed inside the house, would have increased the exhaust flow. Since the utility closet has two 6” ducts connecting it to the ventilated attic to provide combustion air and dilution air, a recommendation is made that the utility closet doors be weather stripped to better seal the furnace and gas hot water heater from the main body of the house. Additional pressure differential measurements taken between closed rooms and the main body of the house, with the furnace fan and exhaust fans on, showed that the main body depressurized to about -5 Pa while the closed rooms pressurized to between 3 and 10 Pa. These pressure differentials would cause increased energy use. In a cold climate, if warm moist air is forced through the building shell due to pressurized rooms, moisture may condense inside the building shell and cause material degradation. A recommendation is made to allow for more return air flow from closed rooms by separate return ducts or transfer grilles.

In order to determine the as-built building heat loss coefficient, a co-heating test was performed. Figure 7-3 displays the inside to outside temperature difference of each house and the energy used to hold that temperature. For the one night co-heating test, the measured UA for the SSIC house was 19% lower than that of the stud-frame house.

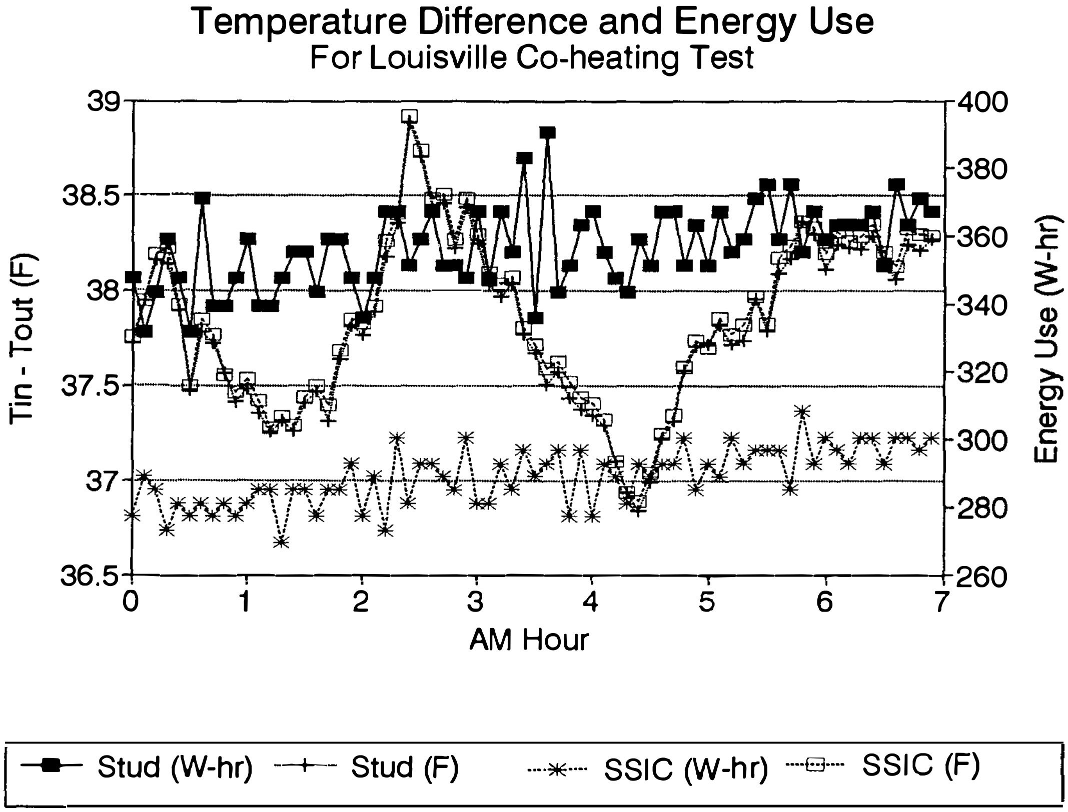


Figure 7-3
Inside to outside temperature difference and heating energy use for one night of co-heating.

An evaluation of the bulk thermal capacity of each house was made, starting at sundown, by letting the house temperature fall with no internal heat source. The two buildings have nearly the same thermal capacitance. The drop in the inside temperature as a function of time is shown for each house in Figure 7-4. The time constant for the stud-frame house was 4.7 hours compared to 5.6 hours for the SSIC house. The SSIC house cooled more slowly since it has a lower heat loss coefficient. In a follow-on test, where the houses were heated up at the same energy input rate, the SSIC house also heated up more quickly due to its lower concurrent heat loss rate.

Conclusion

Preliminary building diagnostic testing indicated that the SSIC house would have better thermal performance than the conventional house. More detailed information will be available following analysis of the monitoring data.

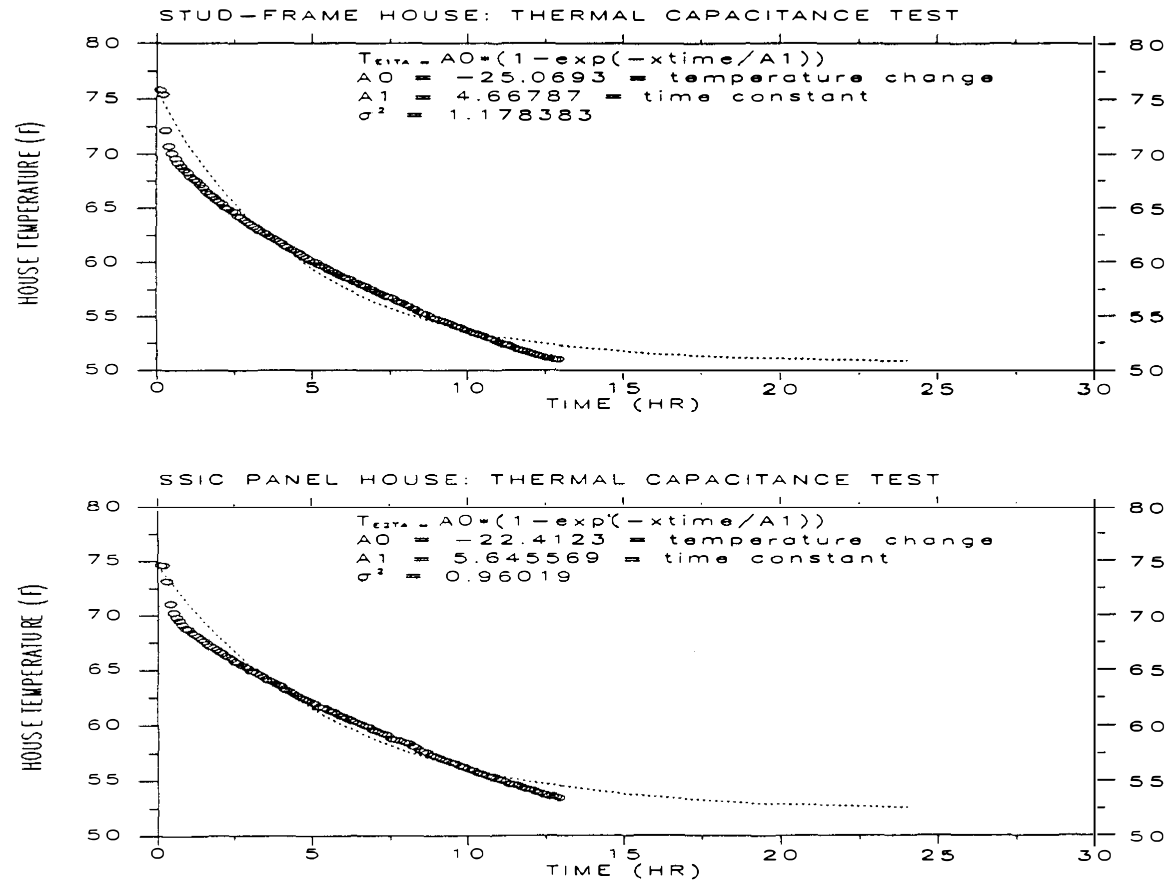


Figure 7-4

House temperature decay during thermal capacity cool-down test.

8 STUDENT FAMILY HOUSING DEMONSTRATION

Objective

The objective of this task is to provide energy analyses and expert advice in the development of three duplexes of student housing to be built on the University of Oregon campus. The development of the six housing units is being undertaken by a Center for Housing Innovation design team, under the direction of Don Corner. These units are to meet BPA's Super Good Cents energy performance levels, incorporate industrialized housing technologies, exhibit high levels of architectural quality, and be low cost.

Description

All units were initially analyzed as being constructed with an insulated concrete slab, R26 wood frame walls, and wood framed roof systems with R38 insulation and vaulted ceilings. Each unit was also analyzed for a particular alternate construction type, and with mass and glazing areas optimized for the base construction type.

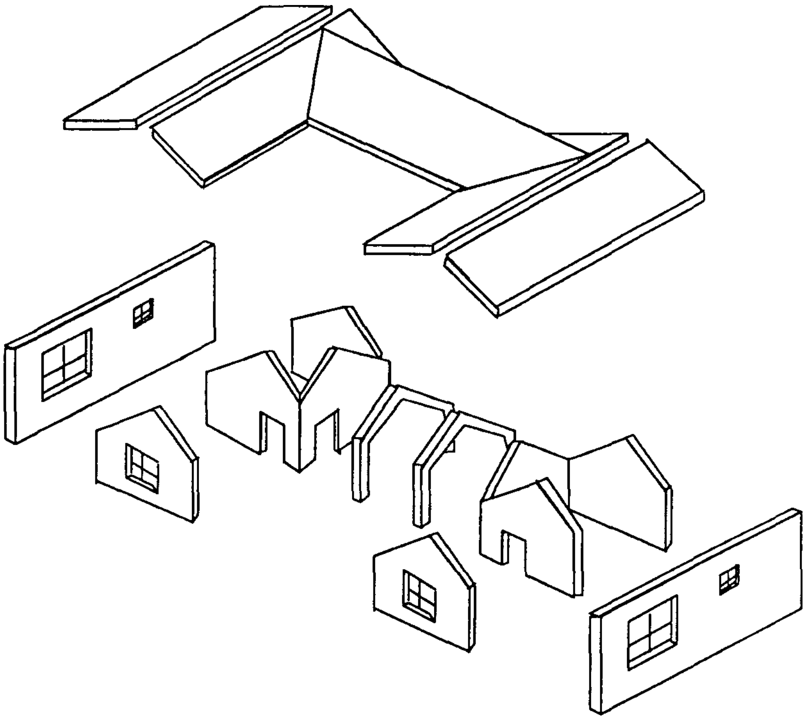


Figure 8-1

1 Story Unit Pair (1488 s.f. total)

The first duplex is one story, with a brick party wall and additional mass in the form of brick wing walls attached to the party wall. The alternate construction analyzed consisted of R23 stressed skin insulating core panels for the walls.

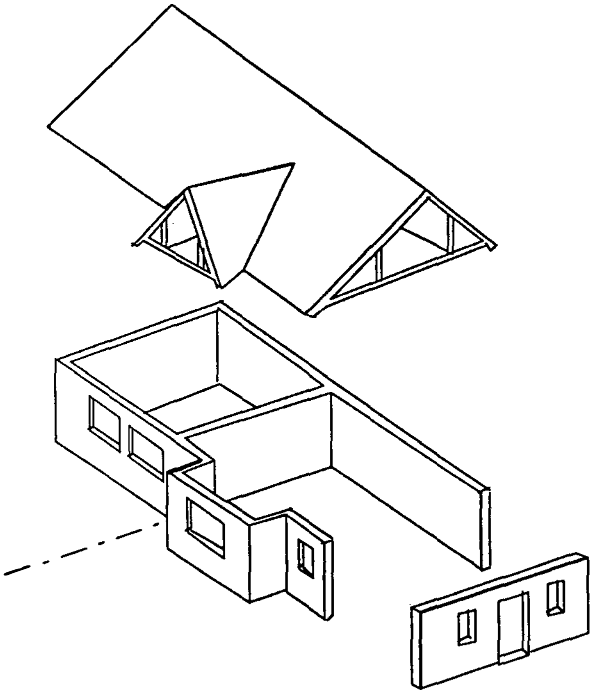


Figure 8-2
1 and 1/2 Story Unit Pair (2093 s.f. total)

The second duplex is one and one-half stories, with a wood framed party wall. The alternate construction analyzed was the base case with insulation reduced to R21.

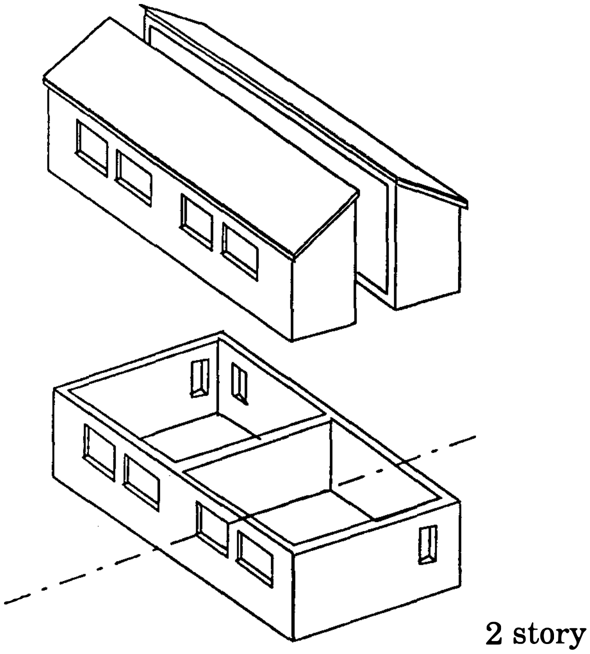


Figure 8-3
2 Story Unit Pair (1590 s.f. total)

The third duplex is a full two stories with a concrete block party wall. It was also analyzed with concrete block and R21 outsulation lower floor walls.

Methodology and Findings

A first round of energy evaluations was completed in 1991 using the software Energy Scheming, with the report completed in early 1992 (Brown, Harmon 1992). This round of analysis was done using Calpas3 software.

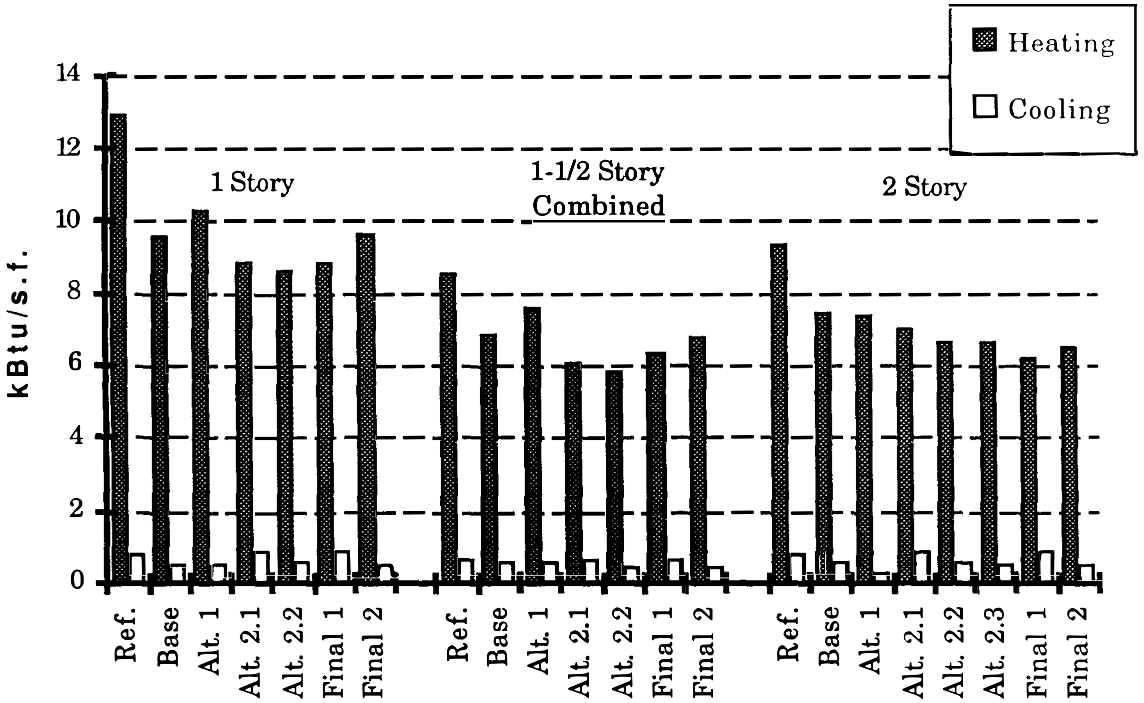


Figure 8-4
Summary of Space Conditioning Loads based on Floor Area

Figure 8-4 is a summary of our findings. Initially we analyzed the units and respective alternates in order to aid the design team in deciding which construction types to use. We also did a reference trial that modeled the units as if they were constructed to meet the 1992 Oregon Residential Energy Code. We found that generally the alternate constructions did not perform as well. Performance, however, was improved by increasing mass and glazing to their optimum levels. Since cost was an issue, we were asked to determine the performance of the units if glazing were optimized based on the mass areas as originally designed. We found that equivalent or better energy performance could be had by reducing the glazed area.

Status

The University of Oregon has agreed to build six units of experimental housing which have been designed by the Center for Housing Innovation. Construction of the project will be carried out by 2-G Construction of Eugene, Oregon, acting as construction manager/general contractor. The deadline for acceptance of a "guaranteed maximum price" by the University is April 29, 1993 with construction to begin immediately following.

Competitive bids by subcontractors and building systems producers were opened April 15. Firms specializing in modular construction, open wood stud panels, closed wood stud panels, insulating core panels, and conventional framing were invited to bid on the three buildings containing two units each. After a period of clarification, construction scenarios for the six units were developed as follows:

1 and 1/2 Story Unit-Pair (1710 sq. ft. total)
Low bidder on this building was a firm specializing in open panel wood stud construction. This was the anticipated outcome since this unit was designed around the merits of this form of construction. The upper floor will include attic trusses erected by the general contractor.

2-Story Unit-Pair (1600 sq. ft. total)
This building was designed with the expectation that the upper floor would be produced as a two part modular structure with the lower floor produced on site. Bids received from panelized builders and conventional frame builders were comparable while the bids from modular producers were considerably higher. This seems to reflect the fact that all the subcontractors other than the modular builders were bidding more than one part of the total project. They viewed the additional work on the second floor of this structure as a relatively inexpensive extension of the scope of work they anticipated across the site. For the modular producers this portion of the work was their entire involvement and thus had to bear all the relevant overheads.

Given several nearly equal alternatives it was decided to build this structure as a closed panel wood stud building with prefabricated floor cassettes. Truss roofs will be erected by the general contractor.

1-Story Unit-Pair (1500 sq. ft. total)
Bids received for this structure from wood stud panelizers and site builders were comparable. Bids for the preferred scenario, insulating core panels, were considerably higher on a relative basis. However, the actual cash difference was

not great since the exterior walls represent only a portion of overall cost and other systems were not affected by the choice of alternatives. It was decided to build one half of the unit using wood stud closed panels and the (mirror image) second half using insulating core panels. This will permit a direct comparison of these two techniques. Currently roof trusses are to be placed over both units by the general contractor, however further negotiations are underway to see if it might be possible to substitute insulating core roof panels over that half of the structure to extend the performance comparison.

9 STRESSED SKIN INSULATED CORE LOW-INCOME DEMONSTRATION HOUSE

Objective

Working with a stressed skin insulating core (SSIC) panel manufacturer, we will design, build and test a prototype low-income dwelling 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., three bedroom, 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 prescriptive Long Term Super Good Cents standards (Roof - R 49, Wall - R 26, Floor - R30, Window - U.35) However it will be built at the cost of a comparable home designed to meet current Oregon Code standards (Roof - R38, Wall - R21, Floor - R 25, Window - U.35). The SSIC 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.

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. Thus panelized construction is an important potential source of energy savings, with SSIC panels at the cutting edge of this opportunity.

While Northwestern regional market demands are well suited to panelized construction, contractors in this traditionally lumber-rich region have resisted panelization until recently. Consequently there is a large latent market for energy efficient panels. Additionally the Bonneville Power Administration has collected extensive cost data on achieving the Super Good Cents energy performance criteria in the Northwest for conventional construction. These are data we can use for comparison. Consequently we will build the first SSIC demonstration house in the Northwest.

Project Background

The demonstration house project began in 1991. Several sources of support were identified — 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 expanded to include the following firms and contributions:

AFM Corporation	Exterior building panels
Bonneville Power Admin.	Funding
Cadet Manufacturing	Electric heaters
DEC International	Envirovent HVAC/water heating unit
Lights of America	Lighting fixtures
Malarkey Roofing Co.	Roofing
Owens Brockway	Glass cullet as structural fill
Simpson Strong-Tie	Connectors
Stimson Lumber Co.	Duratemp siding
Studor International	Internal plumbing vents
St. Vincent dePaul Society	Land and construction costs
Super Struct Systems	Honeycomb core interior wall panels
Trus Joist MacMillan	Engineered framing products

Viking Industries	Windows
Viscor, Inc.	Building gaskets

Participation by manufacturers of roofing materials and skylights has also been solicited. A strategy to integrate the clothes dryer with the exhaust air heat pump is also under investigation. Candidate builders for construction of the building shell have been contacted; their input helps insure that regional construction and market-related issues are treated realistically.

Early efforts focused on finding an optimum house design for panel construction, and on locating potential sources of energy and cost savings. Studies examined ways to optimize thermal performance and reduce panel cost; the interaction of panel R value and window quality, the cost impact of alternate foundation systems, and the consequence of roof complexity on panel cost effectiveness were all studied. Schematic designs and comparative cost analyses (panel vs. conventional construction) were developed for five versions of the house.

1992 Progress

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/sq. ft. -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 and other strategies, such as HVAC system and windows, essential to support the goal of an affordable, high energy performance house.

Demonstration House Features

A number of innovations have been 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 and foundation system, using the 2-way spanning capability of the 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 increase of 28 square feet (2% of floor area).
- The panel system replaces sawn lumber with a variety of plentiful wood resources.
- Site labor is reduced by half.
- Project length is reduced by one week.
- Because only three consecutive days are required for shell construction, this system extends the building season.
- The demonstration house is projected to save 43% of the heating and cooling energy of a conventional, Oregon Code-compliant house.
- Flush-mounted skylights eliminate thermal bridging due to curbs.

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 the skin area for structural, thermal, and cost performance.
- Structural siding laminated directly to the insulation core eliminates a layer of OSB.
- 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%, improve air tightness

and reduce fasteners by 50%.

- Offsetting building corners reduces the impact of dimensional variations in long walls and floor panels.
- Reducing the quantity of dimensional lumber in the floor and roof lessens 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 and increase overall R-value. Reduces installation cost by 5%.

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 and shutters shade east/west glazing.

Cost Comparisons

A summary of cost estimates for the SSIC demonstration house and conventionally built reference house is shown in figure 9-1.

		Demonstration House			Reference House		
				Time*			Time*
		Comp. Cost	$/SF	Days	Comp. Cost	$/SF	Days
+	Roof	$7,406			$6,757		
+	Floor	$3,927			$3,592		
+	Exterior Walls	$6,279			$5,187		
	(Shell Total)	($17,612)	$13.98		($15,536)	$12.33	
	Intermediate Floor	$3,230			$3,230		
+	Interior Walls	$1,727			$1,165		
	Misc.	$10,010			$10,010		
-	Foundation	$1,474			$2,794		
-	Sheetrock	$2,100			$3,243		
	Painting	$1,826			$1,826		
-	Electrical	$2,465			$2,670		
	Plumbing	$4,190			$4,190		
	AAHX-Mech	$3,879			$3,879		
	Garage	$4,989			$4,989		
	Site Improvements	$2,194			$2,194		
	Land Cost	$12,000			$12,000		
	Plans, Survey, Eng. & Specs	$700			$700		
	Initial Financing Cost	$1,500			$1,500		
+	Equipment Rental	$1,730			$ 1,500		
	Builder's Profit	$7,151			$7,151		
-	Builder's Admin.	$2,238			$3,032		
-	Site Insurance	$145			$186		
-	Holding Cost	$874			$1,121		
	Title Insurance	$395			$395		
	House Sales Commission	$2,594			$2,594		
	System Development Fees	$1,521			$1,521		
	Utility Connection	$1,450			$1,45		
	Credit Report	$65			$65		
	Underwriter	$200			$200		
	Escrow	$150			$150		
	Builder Credit Report	$130			$130		
	Draw Inspections	$300			$300		
	Recording Fees	$75			$75		
+	Contingency	$2123			$2108		
	Total House Cost	$91,487	$72.61	35	$92,354	$73.30	42
	Cost Difference	$867					

Figure 9-1
Estimate Summary – Eugene, Oregon, March 1993

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

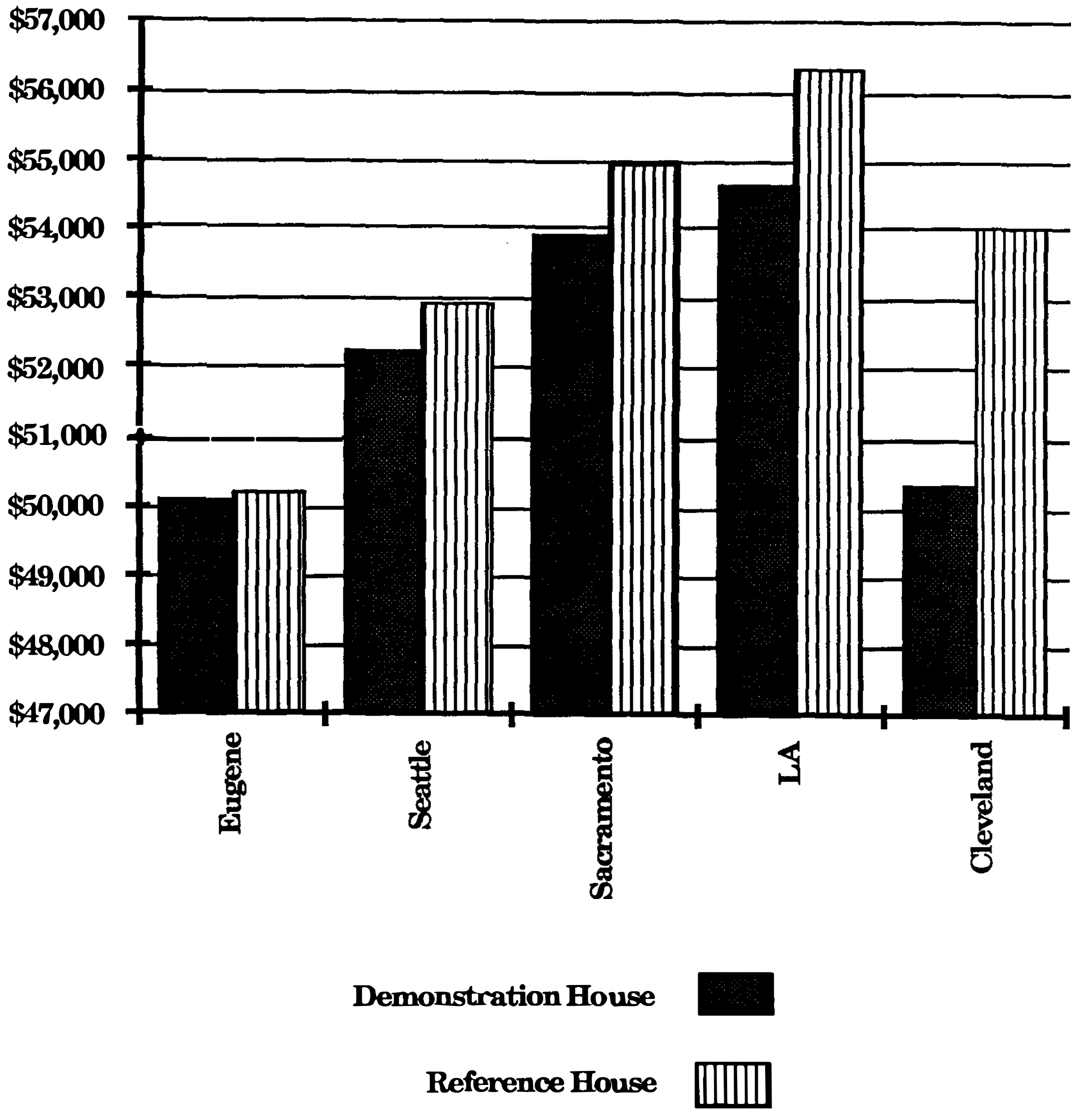


Figure 9-2
Shell Cost Including Other Systems That Are Affected by Panel Construction

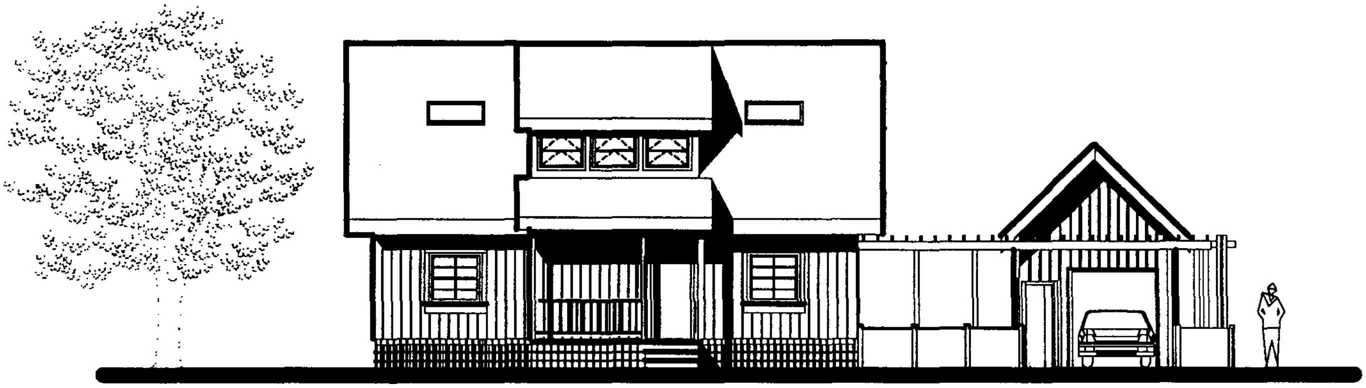


Figure 9-3
South Elevation

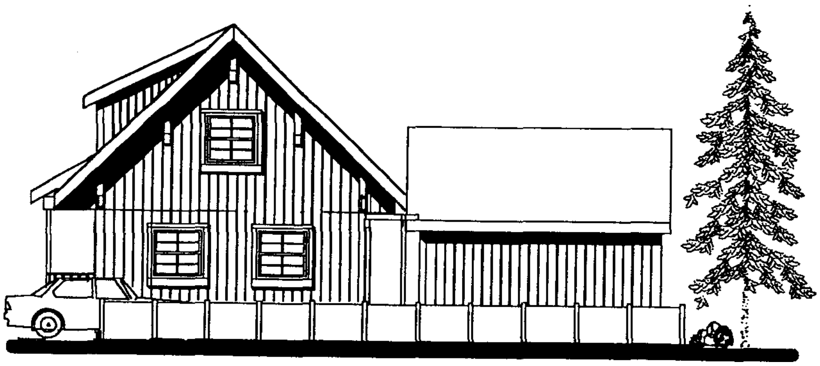


Figure 9-4
East Elevation

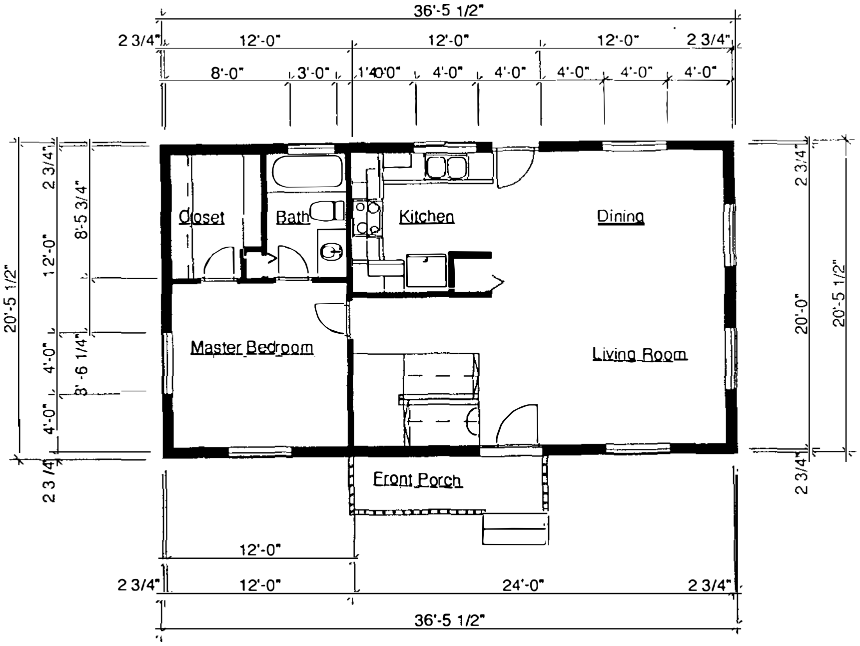


Figure 9-5
First Floor Plan

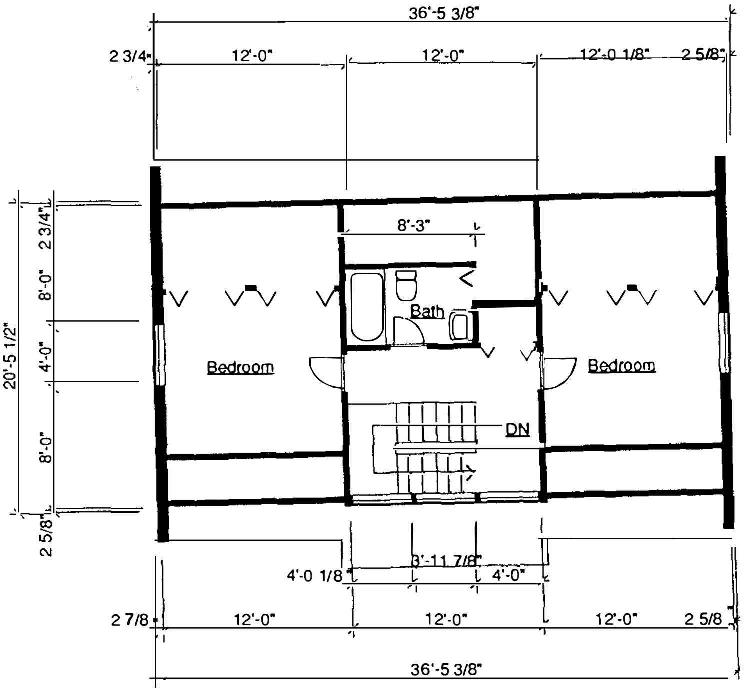


Figure 9-6
Second Floor Plan

Future

We will build the house and begin thermal testing this spring. The construction process will itself be an important part of the research, and will be monitored through time and motion studies and detailed time accounting in order to document present construction approaches and suggest areas of improvement. There will be a year-long energy testing program, once construction is completed.

A number of ideas developed thus far invite further exploration. One involves the composition of the panels themselves, which would appear to save roughly $2000 in the 1260 sq. ft. demonstration house, and may offer further savings of up to $600. Improvements in floor and foundation rank next, in which the SSIC panel version with pier foundation would appears to save $1300 over the cost of a conventional building floor and foundation. Strategies to minimize panel waste offer savings of as much as $1300, offset by a smaller but so far uncertain increase in assembly labor. Joinery changes also offer savings, possibly as great as $1100 for a house this size, but this is dependent on other factors such as the choice of large vs. small panel construction.

Energy Testing Plan

The testing will involve two brief 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 areas of thermal bypass. A blower door will be used to determine the 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. The following measurements will be recorded:

Number of Channels	Channel Type	Measurement Description	Units
1	voltage	indoor air temperature	^{o}F
1	voltage	indoor air relative humidity	%
1	voltage	indoor mean radiant temperature	^{o}F
2	voltage	wall surface temperatures	^{o}F
2	voltage	roof temperatures	^{o}F
4	voltage	relative humidities at the inlets and outlets of the exhaust and indoor coils	%
4	voltage	dry bulb temperatures at the inlets and outlets of the exhaust and indoor coils	^{o}F
1	voltage	domestic hot water flow rate	gpm
2	voltage	inlet and outlet water temperatures of the hot water tank	^{o}F
2	voltage	exhaust and conditioned air flow rates	cfm
1	pulse	lighting energy use	kw-hr
1	pulse	electric resistance air heating energy use	kw-hr
1	pulse	electric resistance water heating energy use	kw-hr
1	pulse	exhaust air heat pump operating energy use	kw-hr
1	pulse	whole house energy use	kw-hr

Occupied monitoring will be conducted taking the same measurements as described above. Long-term occupied monitoring by monthly manual reading of sub-meters will follow to verify the values recorded by the data acquisition system. This long-term monitoring will provide data on how much energy use varies as a function of the occupants and if there is any degradation of energy performance over time.

In addition to the house monitoring system and the co-heating system, a complete meteorological measurement system has been included in the testing plan. Measurements will include:

Number of Channels	Channel Type	Measurement Description	Units
1	voltage	ambient air temperature	^0F
1	voltage	ambient mean radiant temperature	^0F
1	voltage	ambient air relative humidity	%
1	voltage	horizontal solar radiation	w/m^2
1	voltage	wind speed	mph
1	voltage	wind direction	deg.

The specifications of all sensors and the data logger have been carefully examined to ensure that accurate data will be obtained.

Stressed Skin Insulating Core Demonstration House Promotion

The goal of the demonstration house promotion plan is to publicize the project to a range of audiences, including builders, architects, building industry members and interested lay people, and to reach them at the local, regional and national level. The strategy is to use a variety of occasions and media, from print coverage to information sessions and exhibits to events that mark the significant public moments of the project, the ground–breaking and grand opening.

In the first stage of promotion, information on the design phase and goals of the house has been sent to a wide range of publications and has generated strong interest. Articles have been published in the following places this Winter:

Housing Research Center Newsletter, National Consortium of Housing Research Center (distributed at the NAHB 1993 annual convention)

Building Systems Builder, March issue

Glass Magazine, March issue

The Register Guard, Eugene city newspaper

Architecture and Allied Arts Review, University of Oregon alumni newsletter
On the Level, Lane County HBA newsletter

Articles will be appearing soon in the following publications:

Automated Builder
Popular Science
ARCC Newsletter
Oregon Business Magazine
Arcade, SW Oregon chapter of AIA newsletter
BPA Circuit, Bonneville Power Administration Newsletter
Inside Oregon, University of Oregon newspaper
Springfield Utility Board Newsletter
Centerline, Center for Housing Innovation newsletter
Professional Builder and Remodeler

There are also a number of magazines and newsletters that are following the project into the construction and monitoring phases and have expressed interest in publishing an article, including:

Sunset Magazine
Fine Home Building
Construction Specifier
Building Products
Architectural Record
Emerald People's Utility District Newsletter
Builder

In addition, we have sent project information to several other publications, including:

Progressive Architecture
Journal of Light Construction
House Beautiful
Walls and Ceilings
Nation's Building News
Home Energy, The Magazine of Residential Energy Conservation

Several in-house brochures are also in progress, which will cover the design phase of the project and will advertise the industry donors and the materials/products they are supplying for the house, as will the site sign. In addition, three technical reports will be published: on the design phase, on construction and evaluation, and on monitoring.

The major events planned for the project are the ground-breaking and grand opening. These will be occasions to invite significant guests and to generate television coverage. At these times news releases will be sent to local, regional and national newspapers, including the *NY Times*, *LA Times*, *Wall Street Journal* and *Washington Post.* After construction there will be tours available.

The project was also exhibited at the NAHB Building Systems Council Showcase 1992 in Orlando, Florida. In addition, an information session was held for the Lane County HBA in March, and there is another one scheduled for the SW Oregon chapter of the American Institute of Architects this April.

10 INDUSTRY ASSISTANCE

In FY92 we conducted industry assistance activities which included PEER visits to Premier Building Systems, and Regional Building Systems. Blower door tests were provided for Ryland Building Systems. An exhibit and presentation was delivered for the National Association of Home Builders Building Systems Councils Showcase. Infrared camera inspection was completed of the Resource Conservation House for the National Association of Home Builders National Research Council.

Premier Building Systems - PEER Visit: Premier, located in Kent, WA, is the largest of 35 partners of American Foam Manufacturers and produces R-control brand stressed skin insulating core panels. The PEER (Process and Energy Efficiency Review) visit was conducted by seven members of the EEIH team and included energy testing of three homes, a review of manufacturing methods, and a review of energy efficiency considerations in marketing and design processes. Significant findings are not presented here because despite repeated written and verbal requests we did not receive authorization from Premier to disseminate the results.

Regional Building Systems (RBS) - PEER Visit: RBS is a major modular manufacturer located in Columbia, MD, with two plants: one in Northeast, MD and the other in Fredericksburg, VA. The PEER visit was conducted by eight members of the EEIH team. It included testing of two model homes, a review of manufacturing methods at the Northeast plant and a review of the sales and marketing processes. RBS cost shared the PEER visit.

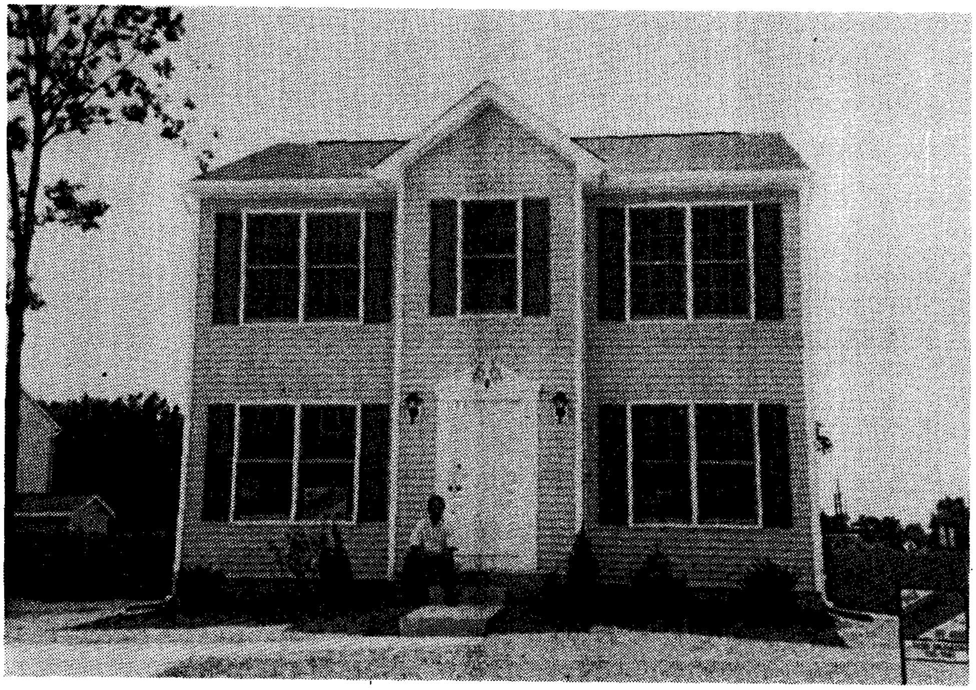


Figure 10-1
Regional Building Systems Model House MILESTONE at the Northeast Plant

Figure 10-2
RBS Model House (for sale) DORSEY in Essex, MD

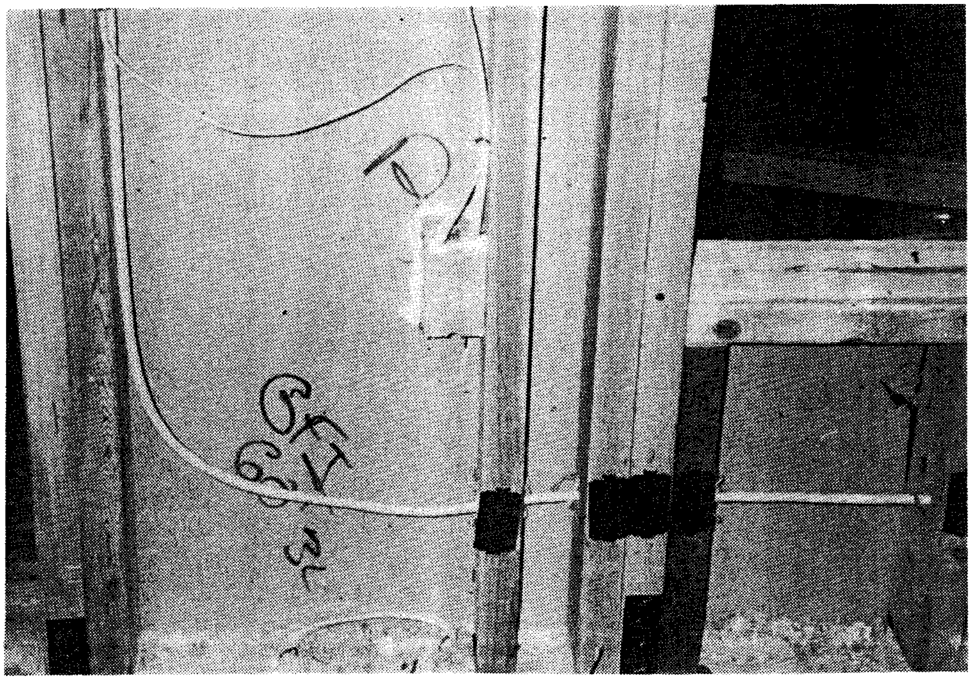


Figure 10-3
Electrical penetrations are well sealed during the RBS manufacturing process.

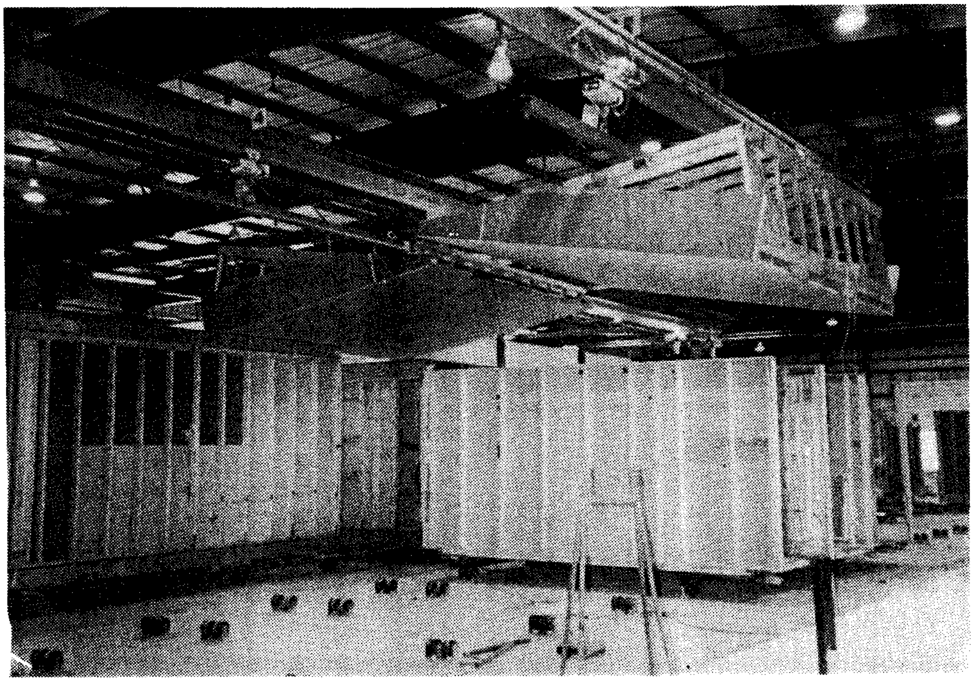


Figure 10-4
Continuous ceiling drywall over the wall top plate assures air tightness of RBS house envelopes.

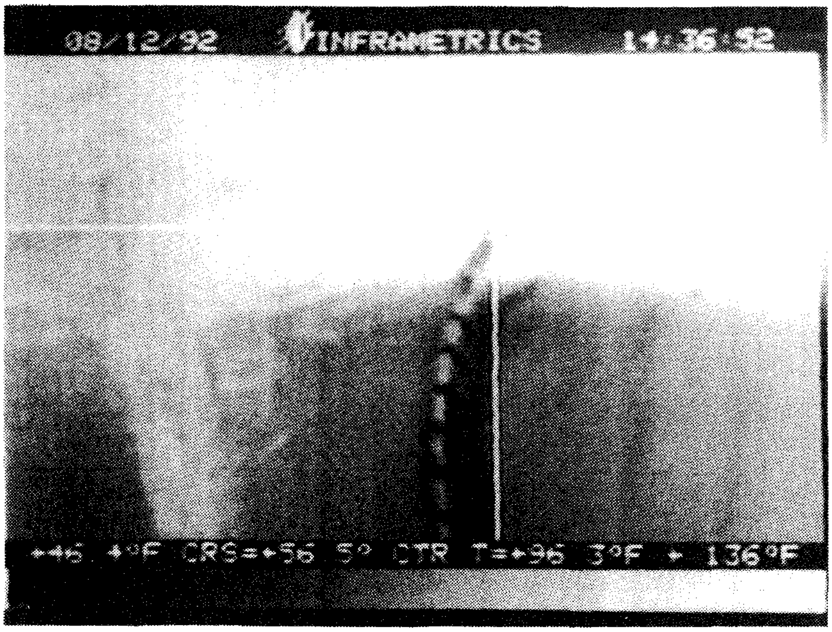


Figure 10-5
Cold air (56.5°F) leaking out of the ductwork in the attic of the DORSEY model,while the attic air temperature was measured to be 111°F.

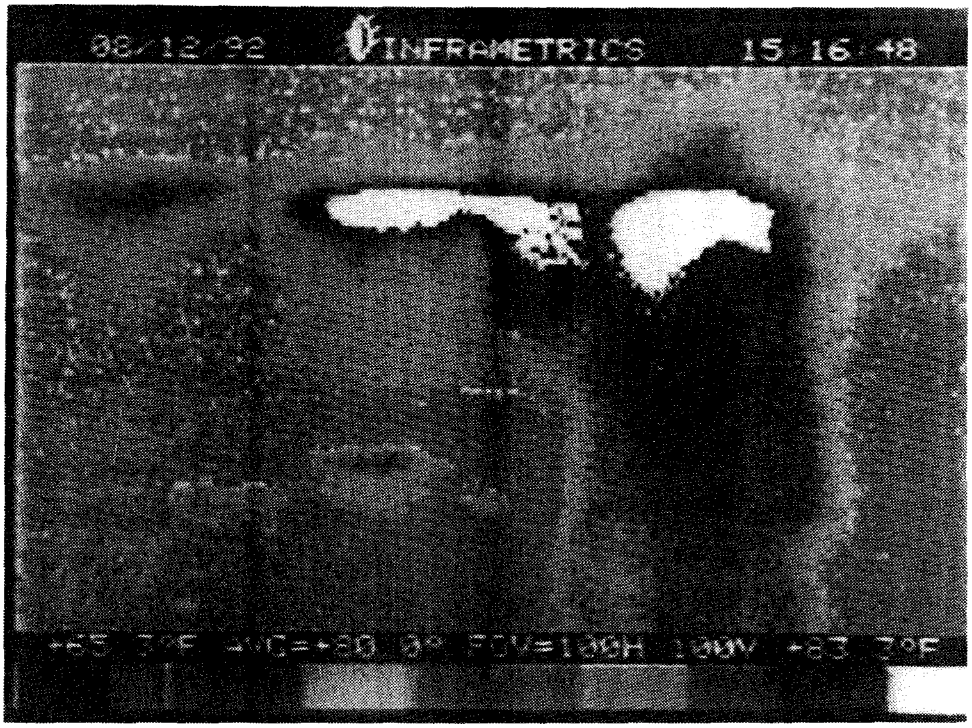


Figure 10-6
IR photo of air leak at the marriage wall in the master bedroom of the DORSEY model. The red areas indicate hot outside air intrusion.

Figure 10-1 and 10-2 show the two model homes tested with infrared camera, blower door and pressure gauges during the cooling season (August, 1992). The envelopes of the houses tested to be quite airtight because of care in sealing the penetrations in the wall (Figure 10-3) and the nature of construction, where the whole ceiling acts as an air barrier (Figure 10-4). However, we found significant leakage in the air distribution system (Figure 10-5) and between two modular units (Figure 10-6).

The manufacturing methods review identified two key strengths–adoption of TQM (Total Quality Management) at the corporate level and workplace safety. Opportunities were identified in the following areas: a) TQM on the factory floor b) Systemization of Operations c) Engineering/Manufacturing interface.

In the design area it was noted that energy was not high on the list for RBS customers (i.e. builders) and that the ability to modify designs quickly was important. Recommendations were made to a) improve staff awareness of energy issues, b) emphasize energy efficiency as a key indicator of quality and make it more visible in sales and marketing, and c) explore hybrids of modules and panels to increase design flexibility.

Ryland Building Systems - Blower door tests. Blower door tests were conducted on two models. The air distribution duct system was found to be very air tight. Some problems were noted during pressure differential measurements and were pointed out to Ryland. Ryland cost shared in the study.

NAHB Building Systems Councils Showcase - Exhibits and Presentations. The EEIH display booth was updated and exhibited at the 1992 Showcase in Orlando, October 31 - Nov. 2, 1993. In addition, presentations were made by EEIH researchers during the program.

NAHB NRC - Infrared camera inspection of Resource Conservation House: During the DOE program review meeting in February 1993, we cooperated with NAHB - NRC and tested their resource conservation house with our IR camera. Despite steel studs and trusses, the preliminary short-term tests showed good thermal integrity of the walls and ceilings except in one area near the garage. This is because of the innovative insulation system. The IR camera was also useful in locating the studs and identifying appropriate areas of the walls where NAHB - NRC staff could conduct additional thermal measurements.

11 SPIRIT OF TODAY HOUSE DEMONSTRATION

The Concept

This is a “demand pull” (as opposed to “market push”) concept to increase the market share of energy efficient housing in the U.S. We have teamed up with the *Better Homes and Gardens* (BHG) magazine (readership - over 30 million) to design, build and monitor a series of high quality homes where energy efficiency is integrated with other driving concerns of today–viz. excellent indoor air quality and comfort, environmental responsibility, handicapped adaptability, high wind resistant construction, and, last but not the least, marketability.

A series of homes will be designed, encompassing a size range of 1500 - 3500 sq. ft. BHG will be featuring the first home in its November 1994 issue. This home will be completed in February 1994 and will be monitored till summer of 1994. Visitors will be admitted for $1/person with the proceeds going to the BHG foundation for the homeless and an Orlando area home for children. It is expected that by the time of publication, several other Spirit of Today houses will be built around the nation.

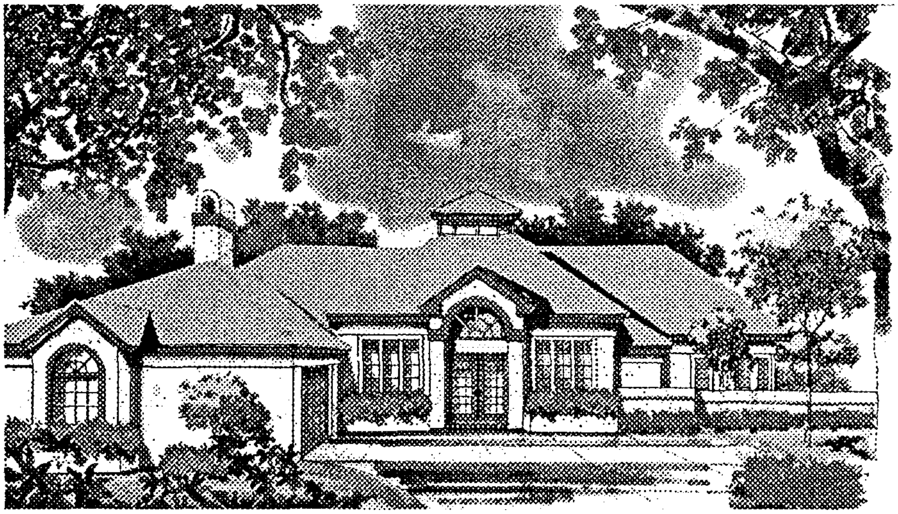


Figure 11-1
The First Spirit of Today House in Orlando, Metrowest

Figures 11-1 and 11-2 show the elevation and preliminary floor plan of the first house to be built in Orlando in the community of Metrowest, near Universal Studios.

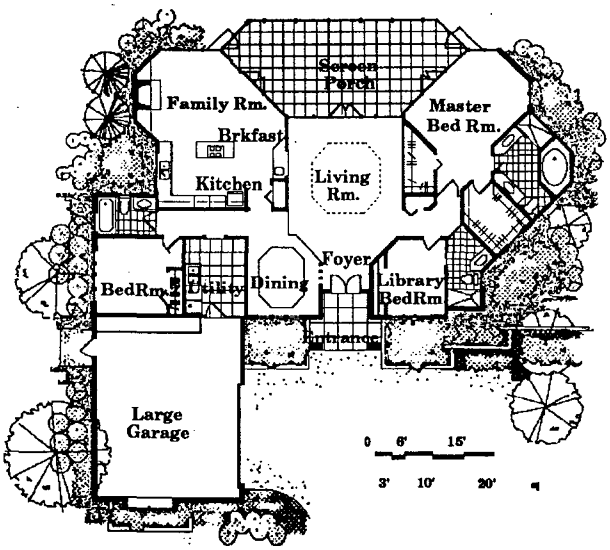


Figure 11-2
Spirit of Today House Floor Plan

This 4 bedroom, 3 bath house, approximately 3000 sq. ft., will be marketed at about $300,000 in the Palma vista subdivision, which is a subdivision of about 100 homes of similar price range. Planned energy and environmental features of this house include:

- Use of very high SEER/high COP heat pump unit
- Large portion of ductwork in conditioned space even in this 1 story design
- Ceiling fans
- Use of dampers so that the air handler unit can function as a whole house fan for ventilative cooling
- Motorized cupola windows for ventilative cooling
- Choice of indoor materials to use recycled components and to emit little volatile organic compounds
- Outside fresh air intake for excellent indoor air quality
- Cleanable ductwork liner
- High efficiency pleated filter or integrated air cleaner
- Energy-efficient appliances and indoor lighting
- Energy-efficient windows
- Solar water heating (passive system)
- Low water use appliances
- Xeriscaped landscaping
- Shade trees

Because of the BHG involvement many product donors will be donating equipment, furnishings and material for this house. Clint Design will be the builder and Donovan Dean the architect of this house. Project coordinators are Bill Nolan of Orlando, a NAHB director, and William Nolan of Better Homes and Gardens. Andy Pughe, the developer of Metrowest, is the incoming chairman of the Home Builders Association of Mid Florida for 1994.

We plan to monitor this home and compare its energy and water usage to neighboring homes. It is planned to involve Orlando Utilities Co. in this effort.

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