ENERGY EFFICIENT INDUSTRIALIZED HOUSING RESEARCH PROGRAM

SUMMARY
FY 1991 RESEARCH ACTIVITIES

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

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CONTENTS

SUMMARY OF FY 1991 RESEARCH ACTIVITIES

ABSTRACT

This report summarizes research results from tasks conducted from April 1991 to February 1992, the third year of the Energy Efficient Industrialized Housing research program. Detailed descriptions of tasks, methods, and results are available in the reports listed in section 14 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 will be 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 Analysis with Existing and Planned CAD Software Used by Industry" section describes an analysis of existing CAD systems used by industrialized housing producers. We identified three programs that have the capability to add an energy analysis module so that energy considerations can be more easily integrated into the manufacturer's product design process. We also analyzed energy codes in five western states and determined that it isn't financially feasible to add an energy code compliance module to a CAD system because of the differences between codes and their continual evolution. 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. However, substantial barriers to the development of such software derive from the nature and structure of the housing industry.

The "Optimizing the Integration of Electrical and Mechanical Systems with the Structural and Enclosure Systems in Modular Construction" section describes a

conceptual electrical subsystem designed to overcome the substantial energy loss that results from the compression and crumpling of insulation in current practice. We also describe the importance of developing protocols among component producers.

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 the manufacturing facility for Integri Homes, a division of Penn Lyon Homes.

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 focus group investigations with architects, manufacturers, inspectors, builders, financiers, real estate agents, and home owners, and have developed seventy-six desirable panel attributes ranked by their importance.

The “Testing of Subassemblies” section describes comparative thermal testing of two industrialized building systems compared to a conventionally constructed base case and six roofing systems. The industrialized systems demonstrated superior performance. These tests are valuable third-party verification of manufacturers’ claims of superior energy performance, which has helped them market their products.

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.

The "Stress Skin Insulated Core Low Income Demonstration House" section describes a project to design, build and test a low income house using stressed skin panels that achieves high levels of energy performance at a lower first cost than conventional construction.

The "Exhibition" section describes an exhibit we created for the National Association of Home Builders/Building Systems Council show to test this method of conveying research information to the industrialized housing community. The exhibit was ranked among the best in the show, generated numerous requests for more information, and captured the sustained interest of several senior executives from major housing producers.

In the "Industry Assistance" section we describe several Process and Energy Efficiency Review (PEER) visits to housing manufacturers. In a PEER visit, six to eight architecture, energy and industrial process experts conduct a thorough two and a half day review of the manufacturing and design methods and the products of the manufacturer. In addition, houses are tested for air tightness and insulation defects. On the last day, recommendations are made to senior management with a written report following later.

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 at the University of Oregon and the

Florida Solar Energy Center, a research institute of the University of Central Florida. The two organizations provide complementary architectural, systems engineering, 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 will enable researchers to solve energy problems in such a way that they can assist industry to improve its product and compete with foreign companies, 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 that 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** 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), 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 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 means 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

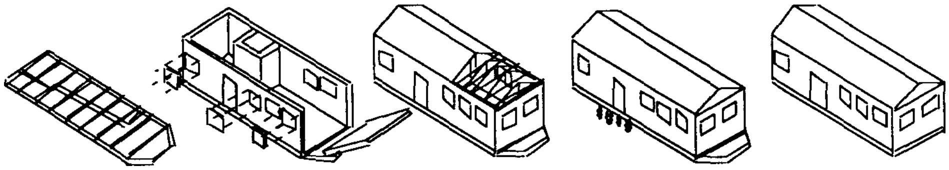

Figure 2 - 1
HUD Code House

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

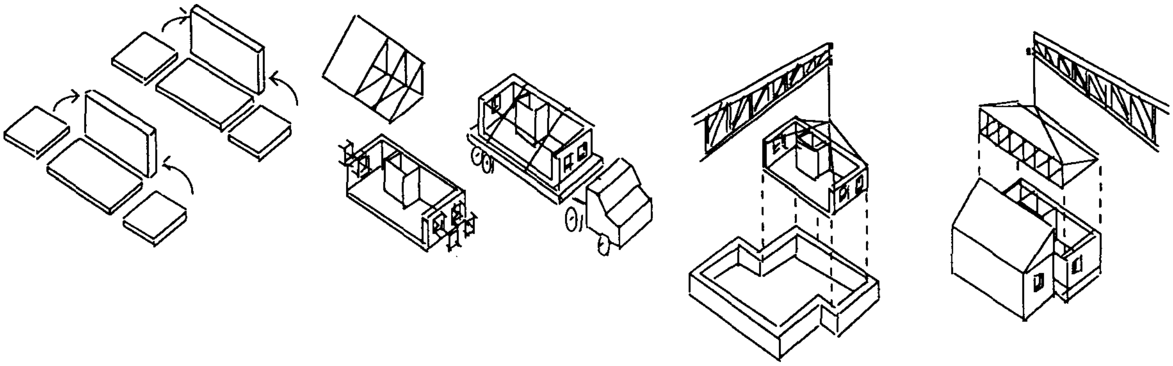

Figure 2 - 2
Modular House

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

Panelized Houses

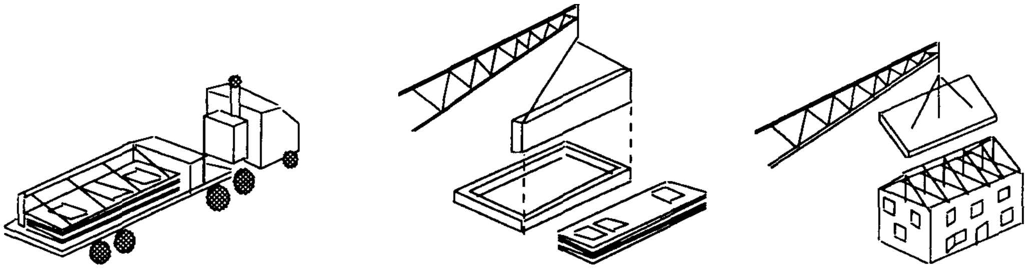

Figure 2 - 3
Panelized House

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. Stress-skin panels are typically foam filled, carrying structural loads in the sheathing layers of the panel only.

Production Built Houses

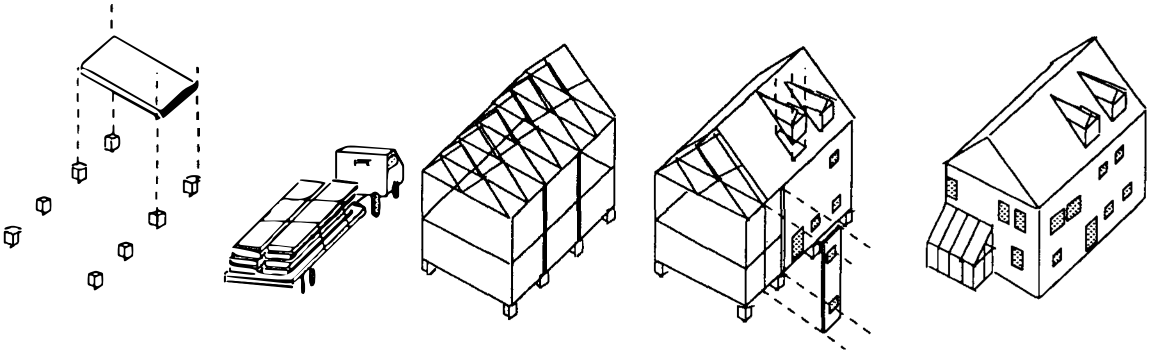

Figure 2 - 4
Production Built House

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

The objective is to develop advanced technology single family and multifamily housing systems that optimize projected and desired advances in computerized design processes, materials, components, and manufacturing automation to achieve high levels of energy performance at reduced first cost. These systems will be developed to allow proposed housing designs to be compatible with future demographic, economic, environmental, and regulatory changes.

Historically, the record of design and technological change in industry suggests that the diffusion of innovation takes a long time. An estimated nine years goes by between awareness of innovation and its recognition and ultimate adoption (Rogers, 1986). In mature industries such as housing and construction, delay may be as long as 45 or 50 years (Ventre, 1980). In order to significantly affect housing in the future, we must start developing new products and processes now.

Once a vision of future energy efficient industrialized housing has been established and the performance of the required housing systems defined, we will work with industry and national laboratories to establish a series of short to medium term goals that are valuable to industry now, but also lead in the direction of future high performance, economical industrialized housing.

To be systematic and substantive about the future, the research team asked specific questions. What are the forces that will significantly influence design, energy and manufacturing priorities for housing through the beginning of the next century? Who will live in the houses? Where will they be? How will they be sold and financed? How will they be made? Of what materials? By what processes? and so on.

Literature surveys were completed in design processes; manufacturing processes; materials, components and constructions systems; energy and environment context; demographic context; economic context, and planning policy and regulatory context. Findings were compiled, compared, cross-referenced and distilled to a list of fifty-five trends over the seven research areas (Kellett, 1991).

In defining the problem of this work, we established areas of convergence among trends by looking for points where opportunity or innovation in energy conservation paralleled anticipated trends in housing demand, design and manufacturing across a range of house types, markets, construction systems and climates.

Of the many future scenarios that could result, we identified the four likely to yield high levels of energy savings and market success: Starter House for a Hot-Arid Climate; Move-up House for a Hot-Humid Climate; Extended Family House for a Cool Climate; and Renewable House for a Temperate Climate.

The "Starter House for a Hot-Arid Climate" captures energy conservation opportunities that result from trends anticipating strong demand for small, minimum cost multi-family houses in sun-belt suburbs, diversifying household composition, declining wood resources, advancing concrete technology, increasing site density, and increasing competition for cooling energy.

The "Extended Family House for a Cool Climate" captures energy conservation opportunities that result from trends anticipating demand for median cost infill single family housing in northern metropolitan suburbs, improved performance of insulated panels, decreasing availability of dimensional lumber, increasing engineering capabilities of wood composite materials, and increasing computer coordination of design and engineering processes.

The "Move-up House for a Hot-Humid Climate" captures energy conservation opportunities that result from trends anticipating demand for above median cost single family houses in Florida, increasing demand for custom design flexibility and quality, increasing competition for peak period energy, miniaturization of variable air volume distribution systems and increasing utility participation in energy conserving construction programs.

The “Renewable House for a Temperate Climate” captures energy conservation opportunities that result from trends anticipating strong future demand for remodels, additions and upgrading of existing houses, increasing sophistication of “do-it-yourself” building materials and components, increasing computerization of design, engineering and construction management processes, decreasing availability of dimensional lumber, and increasing recycling and regulation of toxicity levels in building materials.

Following evaluation of the housing scenarios, we concluded that two housing scenarios had the most promise. The two selected were a multi-family lightweight concrete panel house for a hot-arid climate; and a single family wood composite frame and thin insulation panel house for a cool climate. Both represent regions anticipated to sustain strong housing demand into the next century. Their materials and construction systems – engineered wood composites and lightweight concrete in manufactured panels – are representative of the design and installation flexibility sought in industrialized housing systems.

A cycle of performance specifications has been completed to quantify the projected and desired advances in computerized design processes, materials, components and manufacturing automation necessary to realize each housing system. Included are performance specifications in areas of design and manufacturing process, whole building performance and building components and systems.

Later in 1992 a second generation of design and evaluation will assess implications and opportunities of these specifications, and identify a roster of technologies, design strategies, and production processes for short and medium term research and development by joint effort between USDOE and industry.

What follows is a summary of the performance specifications for the Hot-Arid concrete panel multifamily housing shown in figure 3 - 1.

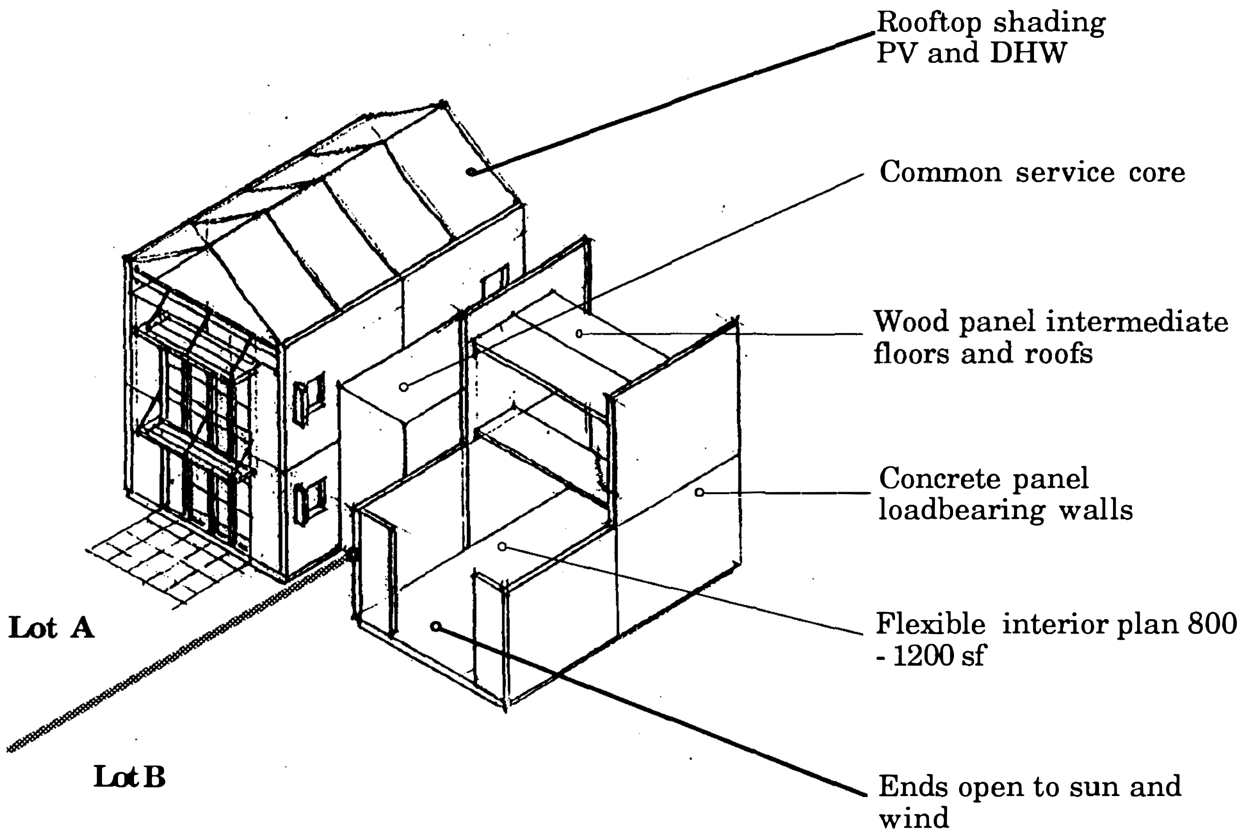

Figure 3 -1

Architecture

- 800 to 1200 sf of conditioned space
- 12 to 16 dwelling units per acre
- Multi-family, attached (duplex minimum)
- Shared service core

Energy

- Zero net annual energy consumption for all uses
- Emphasize renewable sources
- Reduce off-site fuel use to 18 kBtu/yr
- Reduce cooling peak loading to 1 ton
- Reduce heating peak loading to 1 ton
- Zero losses from thermal air distribution systems

Space Conditioning Strategies	• 98-100 % solar savings fraction for heating • 40 % of cooling load by natural ventilation • 35 % of cooling load by mechanical ventilation • 23 % of cooling load by evaporative cooling • 2 % of cooling load by mechanical cooling

Enclosure

Exterior Wall	• Lightweight concrete/rigid insulation/cementitious coating; 8"-10" thick x 8' - 10' high x 10' - 30' long panels • R 30
First Floor Slab	• 4" thick concrete; 3000 psi; fibrous reinf. admixture • Fiberglass fabric reinforcement
Second Floor and Roof	• 4' x 8' to 8' x 30' wood stressed skin panels • R40
Daylighting	• Kitchen/office 3% Daylight Factor/30 footcandles • Living/dining/bedrooms 2% Daylight Factor/ 20 footcandles
Windows	• 90 - 135 sf of glazing • 7% of floor area for ventilation inlets • Transmittance .70 • UV transmittance .05 • Emissivity - .05 • Transmission loss 32 dB • R -10 • Infiltration 37 cfm/lf

Shading coefficient (summer/winter)	• N – .77 / .46 • S – .77 /.46 • E – .40 / .12 • W – .40 / .12
Doors	• R -25 • Infiltration 5 cfm/lf

Heating, Ventilation, and Air Conditioning

Systems	• Common services core • Mechanical HVAC as back-up • Integrated whole-house ventilation w/heat recovery ventilation and possible evaporative cooler • Range of mechanical system alternatives • Solar DHW w/plant-integrated back-up
Ventilation rate	• 0.7 ACH - 107-125 cfm

Water and Waste

Systems	• End use conservation, including irrigation • Limited landscape area; Xeriscape • Rain water collection and storage • Grey water recycling and storage • Performance-sized piping

Power, Electric Lighting, and Communications

Electricity	• Systems -Site based PV and DHW -120/220 V AC core-based circuits -775 V AC core-based circuits -12V DC distributed, surface mount circuits -Automated electric demand control

Electric Lighting	• Systems -Fluorescent general and task lighting -12 V DC accent lighting -Dimming/motion sensors / daylight-integrated controls -Peak load of 0.8 - 1.1 kW
Communications	• Systems -Coordinated services distribution/hybrid cables -Distribution center & modular service entrance -Decentralized occupant interface

Computerized Design Process Performance Specifications

Processor	• Silicon based • Terra IPS (instructions per second)
Graphics	• 2048 x 2048 pixel resolution with 24 bit color
Memory/Storage	• 10 to 50 giga bytes
Language/Operating Systems	• Expert systems • Industry wide standards for object-oriented programming of building components • Integrated software languages and operating systems
Human Interface	• Voice and optional virtual reality apparatus
Network	• Universal network interface • Fiber optic 100 megabits per second • Wireless 10 megabits per second

Manufacturing Process

Manufacturing Strategy	• Total quality • Just in time • Out-sourcing low margin, noncritical components • Cellular manufacturing • Pragmatic modular automation
Pre-manufacturing Activities	• Computerized Architectural Design (CAD) • Computer Aided Process Planning (CAPP) • Manufacturing Resource Planning (MRP)
Manufacturing Activities	• Plant capacity – 5 houses per day • Site or factory cast concrete • Framed reinforcing is mold for concrete infill • Make walls, ceiling, roof, and interior partitions • Buy roof frame, core components, appliances • Bought parts shipped with house
Manufacturing Facility	• Sheathing table with bridge mounted keyhole saw • Gluing assembly table with automated glue dispenser and press • Manual assembly table • Mold and re-bar fabricating station • Limited inventory • Working stock stored on line • Operations grouped in cells • Long haul materials handling by fork lift bridge mounted pick and place robots
Operations Control System	• Direct control of automated equipment • Driven by information from the CAPP and MRP systems • Indirect control, three computer terminals • Real time location of materials and work orders

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

Japanese, Swedish and Norwegian housing companies are more industrialized and more computerized than U.S. companies. The Japanese lead the U.S. in computerizing the sales through design processes and the Swedes and Norwegians the design through production processes. These foreign examples are illustrations of what U.S. industry must do to remain competitive in the world housing market and to improve its domestic productivity. Given these foreign examples and what is currently taking place in the U.S. in software development and housing production, we believe the U.S. industry is on the brink of extensive computerization.

Two objectives of this task are to develop an energy module that can be integrated with existing industrialized housing CAD software and to develop a prototype industrialized housing sales tool that features energy efficient design as a primary sales feature.

We have completed two studies that underpin the development of an energy module for a CAD system. The first was an investigation of the feasibility of incorporating an energy code compliance feature as part of the software. The second was an evaluation of CAD systems to see which could support the addition of an energy module.

Our investigation of codes in Oregon, Washington, Idaho, Montana and California determined that the general approach to regulating energy consumption in buildings is consistent across the codes investigated. All have a prescriptive method for simple compliance where the proposed design must meet the prescribed heat transfer coefficient value (U) for each component. All except Montana allow for more flexibility through a performance option that depends on an envelope heat transfer rate (BTU / Hr. F) for the whole building. This method allows for adjustments to the individual component 'U' values as long as the overall heat transfer rate for the building remains below the target. Additionally, most codes offer an energy budget method that uses engineering calculations and computer programs to determine an overall energy performance similar to the performance method. This is the most flexible compliance method that allows incorporation of design issues such as solar gain and thermal mass.

Further investigation into the specific requirements for the individual components reveals a more complex situation. The various codes have unique methods for evaluating the many energy consuming aspects of residential design. Below grade walls and slabs, for example, are considered as one component in the 1987 Northwest Energy Code. The Washington code, however, treats the below grade walls and slabs separately. In another example, some codes consider walls as a system, including windows and doors, while others consider these components separately prescribing individual thermal performance requirements. Climate considerations are also significant in the comparisons of the many codes. While Oregon has only one zone throughout the state, Washington has two, the Northwest Energy Code three, and California employs sixteen.

Another significant consideration is the maintenance required for a code compliance tool. The program must be current with respect to the many code revisions and jurisdictional changes. New technology in such areas as HVAC systems, stress skin panels, and glazing must be interpreted and incorporated in a timely manner. The necessity of prompt and thorough communication throughout the building industry increases when one considers the dynamic nature of the energy code environment. While most codes appear to be on three year revision cycles, these cycles do not run concurrently and are dependent on state legislative mandate. As energy concerns increase, these revisions are becoming more, rather than less, complex. To illustrate this observation, just compare the highly developed California energy code with some of the less developed energy codes in states which have not yet grappled with this issue.

Computer based energy code compliance tools are now available. The <u>Wattsun</u> program, developed and maintained by the Washington State Energy Office, serves as a residential energy code compliance tool for building inspectors throughout the Northwest. In California, energy performance programs have become integral to the certification process. <u>Calpas</u> and <u>Sunday</u> are two programs frequently used. With this proliferation of computer applications throughout the building industry, it is a short conceptual step, but a substantial implementation step, to combining different computer applications in one program. The costs of implementing and maintaining a comprehensive code compliance tool for the U.S. are significant, probably well beyond the reach of software vendors, and not feasible within the Energy Efficient Industrialized research program budget.

We evaluated twenty-three CAD packages to determine the feasibility of adding an energy module to them. Few CAD packages available presently have all the features desirable to support an energy module and to be marketable to industrialized housing producers.

While many of the surveyed CAD tools could accommodate the energy module, they would require intensive programming efforts to create the requisite data structure, and would still need industrial housing capabilities. Another area in which many CAD packages failed to meet the criteria was in not having true three-dimensional capabilities that are required for the energy module to account for things like solar incidence, shading and stack ventilation.

The two most highly ranked CAD packages are SoftPlan and SolidBuilder. Both programs have the kind of data structure that allows extensive thermal definition of a buildings components and can generate bills of materials, cut lists, framing diagrams, elevation, sections and in the case of SolidBuilder, three dimensional views of the building or sub-assemblies (like stick framed roof structures). A third program, ASG, currently does not provide requisite data structure, but is expected to release a new version in early 1992 that does. ASG does currently have features appropriate to the industrial production of housing.

SoftPlan is an architecturally specific CAD package created for light frame construction. It generates the third dimension (currently elevations only) from plan views and information entered by the user. One of its most attractive features is that it can run on a very simple PC and does not require a math coprocessor.

SolidBuilder is an architecturally specific front end for a general purpose 3D solid modeling CAD program (SilverScreen). SolidBuilder allows the user to focus on sets of design or drawing issues specific to architecture and light frame construction. It requires a slightly more sophisticated hardware platform, and the additional CAD program.

We are currently negotiating with software vendors to develop an agreement to develop an energy module for their software.

Three conclusions of our analysis of the industrialized housing sales process and ensuing implications for software development deserve mention. First, based on our analysis, there is currently an inverse relationship between a manufacturer's sales volume and their willingness to allow buyers to customize their products during the sales process. Large volume manufacturers typically generate a smaller profit per home sold and achieve desired total profits by standardizing the homes they sell and maintaining strict control over the manufacturing and delivery process.. They are generally less willing to allow buyers to customize. Small volume manufacturers typically generate a larger profit per home sold and welcome customers who see the potential to design their own home as one of the compelling qualities of owning an industrialized home.

Given that end users (i.e. home buyers) are the people with the largest stake in the energy performance of housing products, we believe sales processes that allow and encourage buyers to customize within manufacturer-specified guidelines have great potential to improve energy performance, enhance customer satisfaction, and increase the market share of factory-produced industrialized housing.

Second, there is an industry-wide reluctance to 'gamble' on increased efficiencies (and the accompanying cost savings) through large scale, system-wide computerization. Several of the manufacturers interviewed made reference to the "reality gap" they have discovered between what a software vendor *says* their software will do and what the manufacturer is able to *get* it to do once it is installed on the manufacturer's computer system. This is further complicated by the need for any software or hardware purchases to be backwardly compatible with all software and hardware currently in use. We believe this leads to a cycle in which manufacturers will not commit to new computer-based techniques until they have been tested in the market. Yet such techniques are not tested in the market because manufacturers are reluctant to be the first to try them. The investment inertia of this problem will be with the industry at least until a new generation of non-hardware specific software and the computer hardware on which it operates becomes the norm within the industry. RISC (reduced instruction set chip computers) and object oriented software programming may promise such a circumstance in the latter half of the decade.

Third, 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. Conclusion two above presents a very real hurdle to achieving this type of promise.

There are important software development implications that arise from the decentralization of housing industry. There are few large companies that can underwrite the cost of sustained research and product development, or vertically integrated companies that can coordinate the development of products and processes necessary to fully exploit computerization. Therefore there is very little software and hardware development in the industry.

What is needed is a software development environment that can bring together manufacturers. material and equipment suppliers, software developers and university researchers to further the computerization of the entire industry. This new coordinated approach to software development can employ a strategy sensitive to the diversity of the housing industry, the qualities that impede investment in new computer-based techniques, and the advantages to be gained from systemic approaches to enhanced computerization.

5 OPTIMIZING THE INTEGRATION OF ELECTRICAL AND MECHANICAL SYSTEMS WITH THE STRUCTURAL AND ENCLOSURE SYSTEMS IN MODULAR CONSTRUCTION

The objective of this task is to develop the methods and means to optimally integrate electrical and mechanical sub-systems into the structural, insulating, and sheathing systems of industrialized housing in a more energy-efficient and cost-effective manner than current methods allow.

Sub-systems compromise energy efficiency in two ways as documented in consumer home energy-efficiency guides. Sub-systems are responsible for most energy inefficiencies due to compression and crumpling of insulation (Coe, et al. 1984 and Wilson, 1990) and to air leakage pathways (Coe, et al. 1984). These inefficiencies result from the physical presence of sub-systems in the insulated shell as well as ineffective methods of sub-system installation.

Current sub-systems installation methods inhibit otherwise effective assembly techniques used in the HUD Code, modular, and panelized sectors of industrialized housing. The technique of producing structural floor, wall, and roof components with insulation and sheathing at sub-assembly stations is stifled because factory workers install electrical and mechanical sub-systems with conventional methods that must occur after the components are assembled. To optimize the use of and thermal properties of materials and assembly techniques, manufacturers need sub-system elements to incorporate at the time of component sub-assembly.

Of sub-systems elements, electricity and communications wiring are the largest threat to both the effectiveness of insulation and the air tightness of the house interior (Coe, et al 1984) since wiring must be routed through all exterior walls and the attic, where insulation is located. Additionally, the wiring requirement is likely to increase more than any other sub-system not only because of the expected increased availability of home electronics to homeowners such as computers and security systems, but also to advances in home automation(HA).

Wiring will be of particular concern if any home automation systems, such as

Smart House, Elan or systems developed in the future, become candidates for industrialized housing. These systems provide improved control over a homeowner's environment and decreased effort to insure a safe and efficient home. However, these may require extra wiring and service points that could amplify the crumpling and compression of insulation. Thus, this task seeks ways to better integrate (rather than replace) wiring systems of the future into the building envelope.

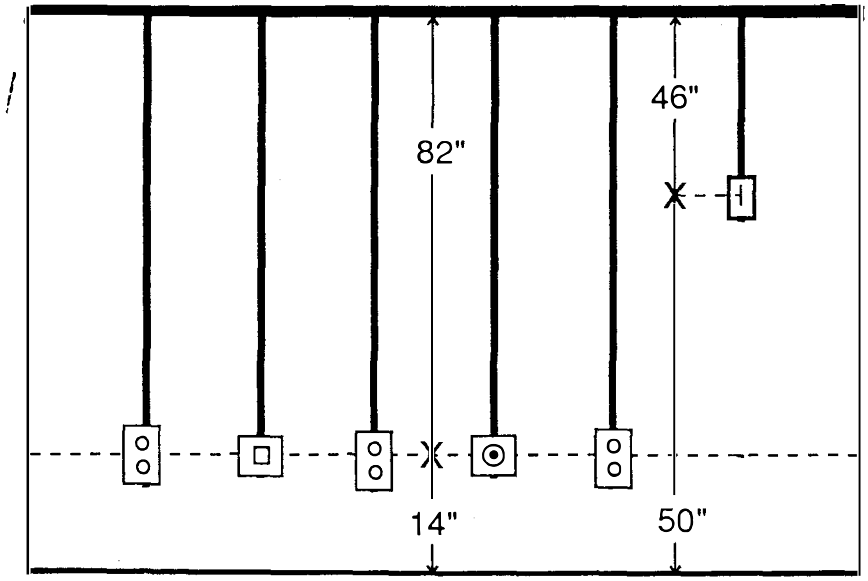

Figure 5 - 1
Vertical Locations of Service Points
Top plate functions as structural/electrical/communications element; service points are supplied through pre-terminated "key" connectors and appropriate wiring.

From an analysis of sub-systems, general characteristics reflect that the electrical sub-system must be isolated from contact with water, metals and combustible substances, must be routed to multiple service points on every wall of living spaces in the conventional vertical locations, and must be routed to every ceiling surface requiring lighting or a fan. The communications sub-system requires the same, except the number of service points is limited to several in each living space according to potential need. Additionally, the quality of both electrical and communications services can diminish over the length of a run, or circuit. Both of these sub-systems could potentially require expansion in the number of service points or the number of circuits available.

To help optimize use of materials as well as simplify component assembly, the wiring could be coupled with or embedded in a structural component. Inherent in this idea is moving the wiring from the insulated cavity of the component into the boundaries that define that cavity. This would eliminate most compression and crumpling of insulation that is nearly unavoidable in today's installation methods where wiring and insulation share common physical space. The logical structural candidate for housing electrical and communication services would be the top plate of wall components, since all the potential service points are found within walls or ceilings, both of which are in direct contact with wall components' top plate. Such a structural/ electrical/communication element (S/E/C Element) could provide service throughout the house without the significant difficulty of navigating around doors from which base board or bottom plate strategies suffer. However, since the top of a wall is not the conventional location for an electrical outlet or any other service point, a connection to various service points in conventional locations from the S/E/C element would be necessary to complete the delivery of services. One design for conquering that connection would be pre-terminated service point units that include a service point (i.e. wall switch, coax plug, etc.), the length of wiring required to reach the S/E/C element and a designated termination, or "key", to mate the unit with the proper circuit inside the S/E/C element. The shape of the "keys" should make it impossible to improperly connect a service point unit. The number and type of circuits within one S/E/C element would be limited by the physical properties of the material, manufacturing methods used to produce the element and code requirements. The number of connection points (penetrations in the S/E/C element) would limit the number of service point units a given circuit inside the S/E/C element could accept.

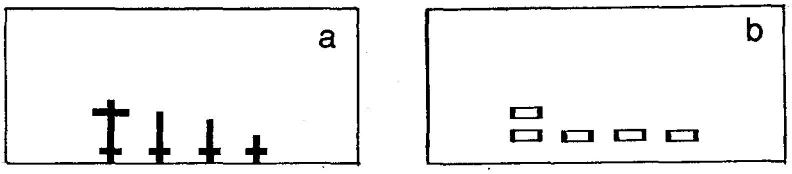

Figure 5 - 2
Section through structural/electrical/communications element (S/E/C). a.) At point of penetration that allows entrance of "keys" to circuits b.) At all other points along the length of the S/E/C element.

The S/E/C element and the pre-terminated service point units represent two elements in the set of elements necessary to accomplish structural and distribution functions. Tracing back from service-point to point-of-supply, the additional function of forming the structural and distribution connections between two components is required. That connection, between two S/E/C elements, constitutes the most technically complex and significant requirement of the set of elements. Every type of component-to-component joint must be accommodated by the set.

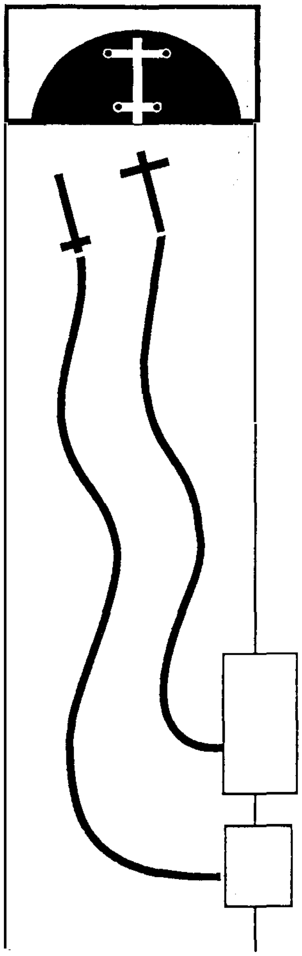

Figure 5 - 3
Section showing service point units (outlet, jack, etc.) and appropriate length of wiring with “key” termination.

A survey of common home assembly methods revealed 4 prevalent joint configurations for components:

1.) "straight"- between two vertical or horizontal components forming one plane,
2.) "L"- between two perpendicular, vertical and/or horizontal components (FIG 4c),
3.) "T"- between two or three horizontal and/or vertical components forming two perpendicular planes (FIG 4b), and
4.) "cross"- between three or more vertical and/or horizontal components which form two perpendicular planes (FIG 4c).

Additionally, angles not conforming to a 90^0 configuration would require accommodation as a separate joint type or as a hybrid of types 1-4.

Currently, no protocol exists to help the industry standardize this phase of the assembly process. As long as the required functions of structural integrity are satisfied, and the joint is properly sealed for fire protection a variety of assemblies are acceptable for each joint type. If no protocol can be developed to reduce the number of "accepted" joints, the array of elements required to accommodate the total range of "accepted" joints and their respective S/E/C connections will overwhelm any potential economies of scale. Additionally, the possibility of complex crossing of the various circuits housed in the S/E/C elements lead this research effort to the following directives for additional development of the S/E/C concept with industry representatives in both the Industrialized Housing sector and the Electrical Elements and Electronics sector, such as the Home Automation Association, General Electric Corporation, and selected manufacturers interested in advanced technology for the 21st century.

1. The number of joint scenarios required of the integrated Structural/Electrical /Communications must be minimized within each joint type defined according to a rational joint protocol to maintain an acceptably low number of elements for production and stocking.

2. The S/E/C joints at points intermediate to the ends of a component must accommodate routing of circuits in two or more directions, as exemplified by (a) and (b) in Fig.4 where a plan view of five walls illustrates three of the joint types (Cross, "T", and "L"). The thin lines in (a), (b), and (c) represent the path of circuits in the S/E/C element.

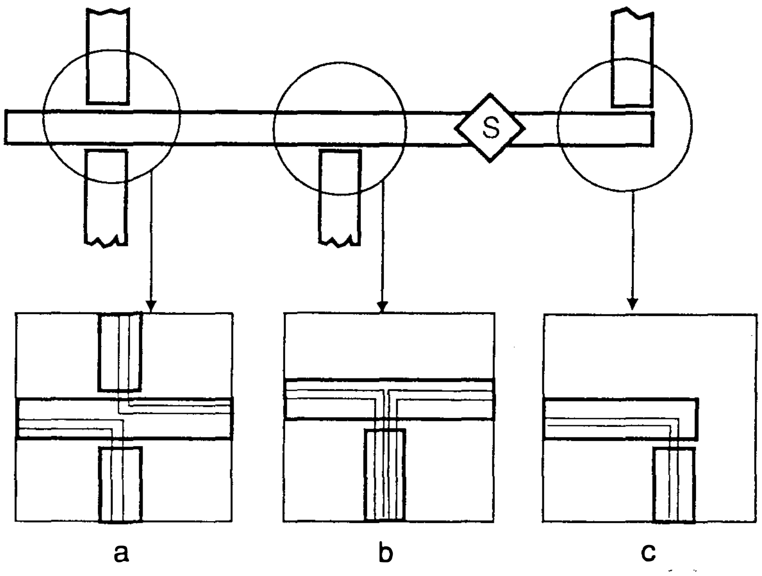

Figure 5 - 4
Plan view of five walls illustrating three types of joints: (a) cross, (b) "T", and (c) "L". The thin lines represent circuits in the top plate S/E/C element of the walls.

6 MANUFACTURING PROCESS SIMULATION

Industrialized housing manufacturers currently have few tools to assess the impact of implementing new manufacturing technologies to produce innovative energy efficient designs. This task seeks to provide such a tool to assist current manufacturers as well as new entrants to the industrialized housing industry. GIHMS (for Generic Industrialized Housing Manufacturing Simulator) integrates computer simulation, animation and data base technologies. Several milestones in the design and development of GIHMS were reached in FY91.

- The user perceived "look and feel" was established
- The overall modeling environment was defined.
- A working prototype model of a modular housing manufacturer was developed and exhibited to industry for comments.

GIHMS "Look and Feel"

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 a manufacturing facility to be built and evaluated using a WINDOWS-like "point and click" icon. A typical user WINDOW is shown in Figure 6 - 1. More specifically, the user will be able to select from a range of generic factory types to customize the generic factory design.

Specific elements that might be customized include:

- Manufacturing processes and associated equipment.
- Material handling methods and associated equipment.
- Facility layout.
- Labor availability by trade.
- Work schedules.

For example, to model the Integri modular manufacturing facility with an automated wall panel extruder, the user would simply:

1. "Click" on the icon corresponding to a modular manufacturer with parallel lines.
2. "Click" on the section of the resulting factory corresponding to the Wall process.
3. Scroll through the available wall panel equipment to the desired equipment.
4. Review the associated equipment specs, such as floor space requirements, production rate, cost, etc. and view a picture of the equipment.
5. "Click" on the automated equipment to replace the generic manual wall panel manufacturing process.

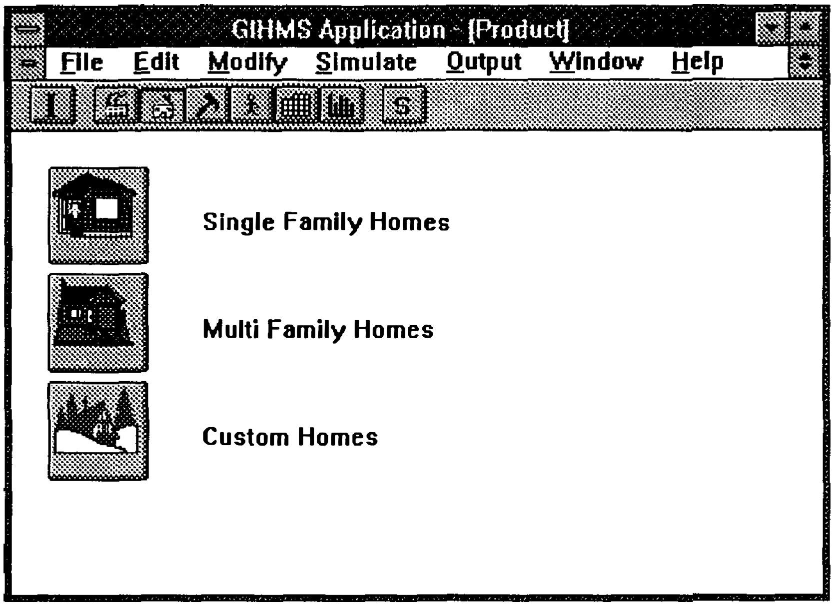

Figure 6 - 1
The user windows are designed to look and feel familiar to PC literate persons using "point and click" access to files, models and applications.

Manufacturing performance depends greatly on the specific houses being built. Therefore, the user will be able to select from a range of common house plans and then customize them. The "look and feel"of this product definition and production scheduling process will be similar to the factory definition process described earlier. Finally, to assist the user in analyzing model output, GIHMS will allow the user to select from a wide range of manufacturing and financial performance measures and define output formats (such as tables, histograms, pie charts, weighting schemes, etc.). Of course, model output will also include a computer animation of the factory in operation. A sample screen is shown in Figure 6 - 2.

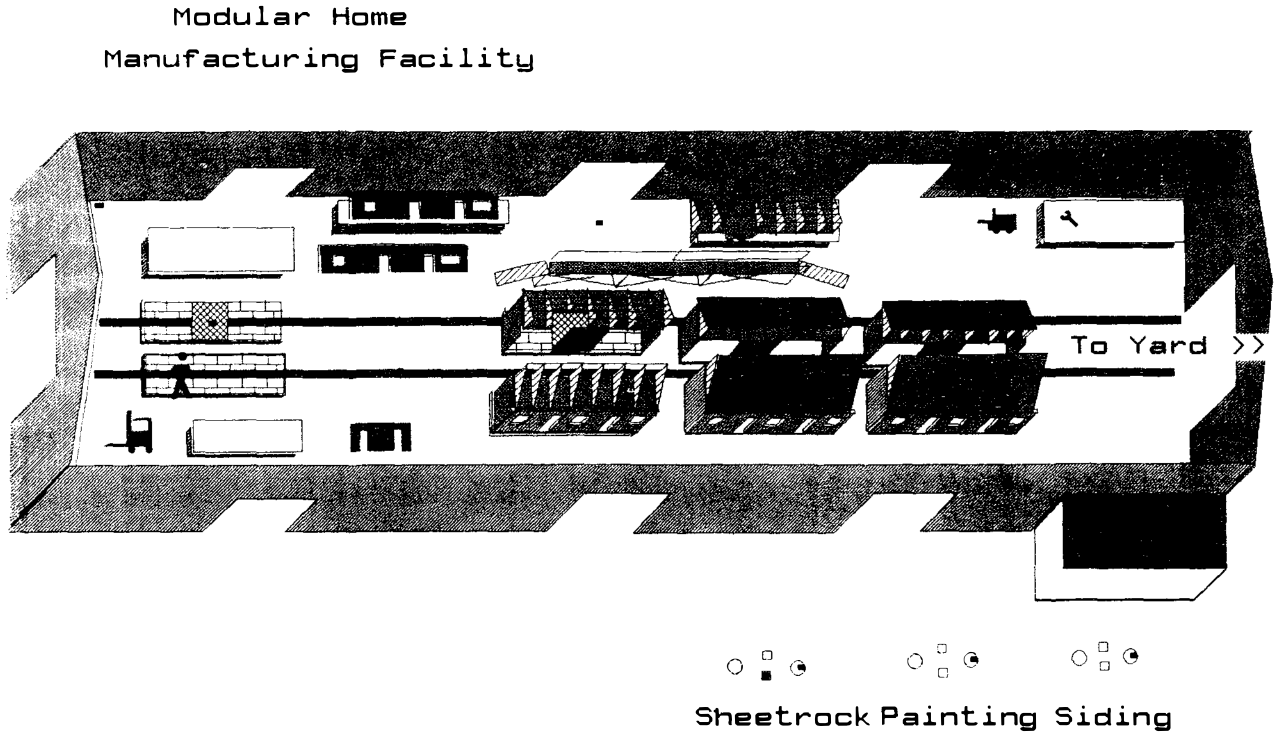

Figure 6 - 2
A sample screen of the computer animation included in the GIHMS model output showing work stations, components, the main assembly line and modules in a modular home factory.

Modeling Environment

To accomplish the user-perceived "look and feel" described in Section 1, GIHMS will use the structure shown in Figure 6 - 1. All communication between the user and GIHMS will be accomplished through the WINDOWS-based User Interface. The interface will communicate user modeling wishes to the other elements of GIHMS through the GIHMS Integrator, which will be written in QUICKC. A broad range of house plans, factory types and process and equipment options will be provided to the user through a number of data bases developed using SUPERBASE. SUPERBASE allows the storage and display of both text and graphics information to support the user's selection of these options. The Factory Simulator will provide the actual computer simulation and animation capability to GIHMS.

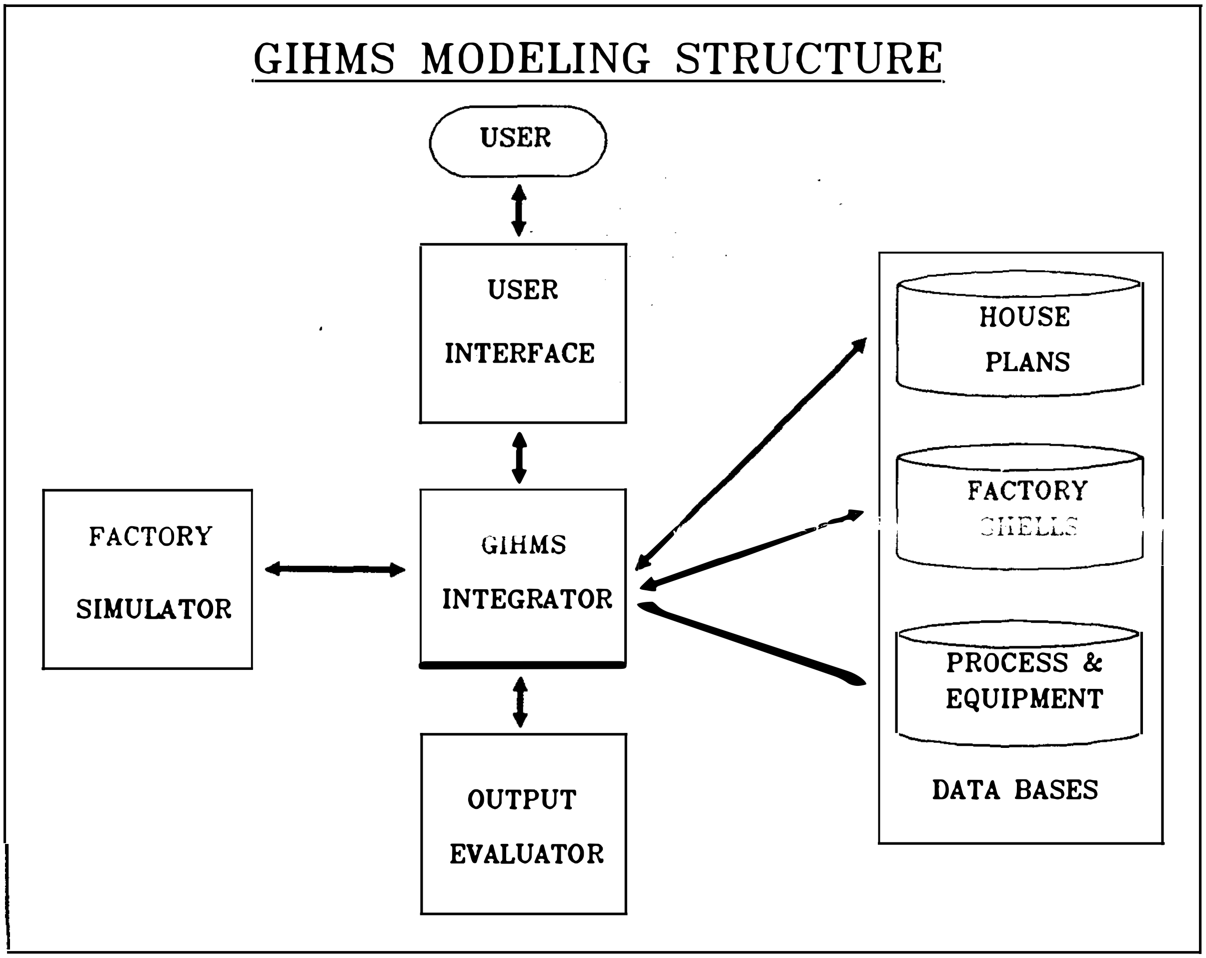

Figure 6 - 3
The user interface with the GIHMS integrator will be accomplished using WINDOWS-based software.

The SIMAN/CINEMA simulation modeling/animation packages were selected for prototype versions of the Factory Simulator. Note that the Factory Simulator must be reconfigurable, driven by factory and product definitions provided by the user. User defined output analyses will be provided by the Output Evaluator. The evaluator will be written in EXCEL, a WINDOWS-based spreadsheet package.

Prototype Modeling

A prototype model of the Integri modular manufacturing facility (a division of Penn-Lyon Homes) in Leesburg, Florida, was developed. The facility was modeled in two languages, SIMAN and SIMFACTORY. The objectives of the simulation modeling effort included:

- To identify unique modeling complexities associated with industrialized housing.
- To evaluate the relative strengths and weaknesses of SIMAN and SIMFACTORY for use in developing the Factory Simulator
- To showcase simulation capabilities to the housing industry and solicit industry comments.

Model results were reported by Haas (Haas, 1992). The modeling effort succeeded in its objectives:

- A number of unique modeling complexities were identified. SIMAN was selected as the preferred development language for the Factory Simulator.
- The Integri model was demonstrated at the BSC trade show in Atlantic City and at various other meetings with housing industry personnel at the UCF campus in Orlando.

7 CONCURRENT ENGINEERING OF WALL PANELS

While much can be done on the manufacturing floor to improve both energy efficiency and cost of housing, the real opportunities lie in the design of the product itself, both from an architectural and engineered component perspective.

The Industrialized Housing industry uses site-built housing designs and construction techniques. It typically does not take advantage of the factory manufacturing environment. Very few resources are devoted to research and development to remedy this situation. Recent advances in concurrent product and process design methodologies are likely to yield significant design improvements.

The objective of this task is to demonstrate how concurrent engineering design methodologies can be brought to bear on the design of major engineered components to improve energy efficiency, manufacturing cost, quality, customer appeal, and architectural design flexibility. An exterior structural wall panel was chosen as the product focus of this research. FY91 efforts have focused on the use of two concurrent engineering techniques, Quality Function Deployment (QFD) and Design for Manufacturing and Assembly (DFMA).

Quality Function Deployment

Akao defines QFD as "converting customer requirements into substitute characteristics, establishing the design quality of the product, and the deployment of relationships systematically starting with the quality of each functional component to the quality of each part and process" (Akao, 1987). QFD product development is unique in that it focuses directly on the customer, so design is not driven exclusively by innovation (Bossert, 1991).

QFD is being used in the wall panel design effort to bring customer requirements to bear on the design process:

- Facilitating identification and resolution of potential design conflicts
- Providing a means for comparative assessment of product performance (competitive benchmarking).
- Allowing the design team to prioritize product improvement efforts.

FY91 QFD efforts have focused on determining customer requirements. Customers were initially defined in the broadest sense as all primary stakeholders in the homebuilding industry. These included architects, manufacturers, builders, inspectors, financiers and real estate agents, as well as homebuyers. A focus group composed of these stakeholders was convened to determine customer requirements. The group generated 76 requirements and structured them into a value tree. A follow-up survey of focus group members solicited relative preferences. The completed value tree is shown in Figure 7 - 1.

ATTRIBUTE	CRITERIA	SUBCRITERIA
Style (.123)	Surface Characteristics (.091)	Easy to Paint (.017)
		Smooth Final Finish (.011)
		Textured Final Finish (.006)
		Decorator Friendly (.029)
		No Observable Seams or Joints (.028)
	Options (.032)	Built-in Security System (.006)
		Prewired for Electric & Phone (.021)
		Built-in Security System (.006)
Process Technology (.143)	Manufacturing (.084)	Doors & Windows of Standard Size (.008)
		Minimum # of Components (.011)
		Easily Available Materials (.014)
		Minimum Utilities in Wall (.009)
		Easy to Install Utilities (.016)
		Easy to Manufacture (.027)
	Transport & Assembly (.058)	Straight & True Frame (.015)
		Quick/Easy Assembly on Site (.013)
		Good Fit to Foundation & Roof (.013)
		Easy to Use Connectors (.010)
		Easy to Transport Walls (.008)
Materials (.132)	Basic Structure (.065)	Concrete Block (.017)
		Wood Frame (.024)
		Metal Studs (.026)
	Exterior Materials (.067)	Brick (.023)
		Solid Sheathing (.022)
		Vinyl Siding (.009)
		Stucco (.013)
Performance Features (.275)	Maintenance (.092)	Easy to Repair/Replace (.025)
		Easy to Locate Utilities (.020)
		Min Interior/Exterior Maintenance (.046)
	Durability (.183)	Resists Rot/Decay (.089)
		No Condensation on Windows (.016)
		Resists Puncture (.039)
		Resists Wear (.039)
Functionality (.328)	Structural (.219)	Air Comes in & Rain Stays out (.083)
		Horizontal Backing Top & Bottom (.021)
		Sound Barrier (.034)
		Animal & Insect Proof (.055)
		Easy to Modify/Add on/Mount items (.025)
	Energy (.109)	Good Insulation (.040)
		Insulated & Tinted Windows (.020)
		Radiant Barriers (.015)
		Maintains Thermal Properties (.034)

Figure 7 - 1

Customer Requirements for an Exterior Structural Wall Panel

Customer requirements for an exterior structured wall panel were collected from a focus group of representing major facets of the homebuilding industry and the resulting responses were structured into a value tree. Each attribute, criterion, and sub-criterion was ranked according to relative importance by individual focus group members.

Note that customer requirements do not include all functional requirements of the wall. Although not voiced by the customer, these requirements are expected of the product, both by the customer and by regulating bodies. Examples include state and local building codes. Functional requirements (including building codes) will be required of any new product design.

Design For Manufacture and Assembly

Design for manufacture and assembly (DFMA) is both a philosophy for design and a specific set of design tools that alert design engineers to the manufacturing implications of their work (Hall, 1991). DFMA tools supply quantitative data to the designer that reflects the time and cost involved in manufacturing a specific design, while it is still early enough to consider options (Boothroyd & Dewhurst, 1991). In a more proactive mode, guidelines are also offered to help steer the design in the best direction (Anderson, 1990).

DFMA is being used in the wall panel design effort to bring manufacturing and site-assembly issues to bear on the design process:

- Providing a means for comparative assessment of product designs
- Offering guidelines for the design effort

FY91 DFMA efforts have concentrated in two areas. First, a review of DFMA guidelines was completed. The primary conclusion from this effort was that existing guidelines were oriented toward machined parts, small electro-mechanical assemblies and electronic circuit boards. Therefore, they held little direct value for wall panel design. Guidelines would need to be redeveloped based on specific manufacturing and assembly processes common to the industrialized housing industry. This effort is ongoing in FY92.

The second area was to begin an effort to document the manufacturing and assembly processes and equipment used in wall panel production, especially for foam core panels. This effort is ongoing.

8 TESTING OF SUBASSEMBLIES

The objective of this task was to establish baseline heating and cooling performance data on industrialized construction systems available currently. Such testing develops strong ties with industry as it directly benefits sales and marketing.

In 1991, testing continued on the three prototype room scale structures at the FSEC site on Cape Canaveral, FL. (Figure 8 - 1) Preliminary data was also obtained on roofing tiles using small scale roof models shown in the foreground of Figure 8 - 1. Complete results are available in Chandra and Moalla (1992).

The prototypes tested were a) Basecase, b) DOW, c)Dome (Anti-clockwise from right in Figure 8 - 1). The basecase construction is conventional 2x4. The DOW is made from foam core stress skin panels made from DOW STYROFOAM. The Dome is made of triangular and rectangular panels of expanded polystyrene sandwiched between a thin concrete exterior and a gypsum wall board on the interior. These were made by American Ingenuity, a manufacturer in Melbourne, Florida. Table 8 - 1 compares the three prototypes:

	Base	Dow	Dome
Floor area, ft^2	192	192	251
Interior volume, ft^3	1370	1710	2000
Wall/ceiling (roof) insulation, R-value	11/19	20/30	28
Air leakage at 50 Pa depressurization, ACH	3.9	2.4	1.7
Overall thermal transmittance, Btu/ft^2-^oF-day	7.3	5.0	3.6

Table 8 - 1
Prototype Characteristics

Figure 8 - 1
Three Prototype rooms and six small scale roof models tested.

Heating season tests were conducted by simulating occupancy loads with light bulbs and measuring the backup electricity consumption. As expected, the industrialized prototypes (DOW and Dome) saved between 45% and 56% in heating energy when compared to the Basecase. The peak heating electrical demand savings were slightly less (39% to 42% compared to the basecase).

Figure 8 - 2 shows the results of testing the tile roofs against standard shingles. The data is for the roof deck temperatures as measured in three warm, sunny February days (The ambient temperatures ranged between 62 and 75 °F). The performance of all four types of roofing tiles is surprisingly good in keeping roof deck temperatures cool. This may be due to interstitial ventilation between the barrel shaped tiles rather than to the tile mass. Although innovative tile installation (with double battens rather than single -- marked db in the plots) and radiant barriers (marked rb in plots) improved performance, the installation is not more cost-effective than the standard practice concrete barrel tile over single

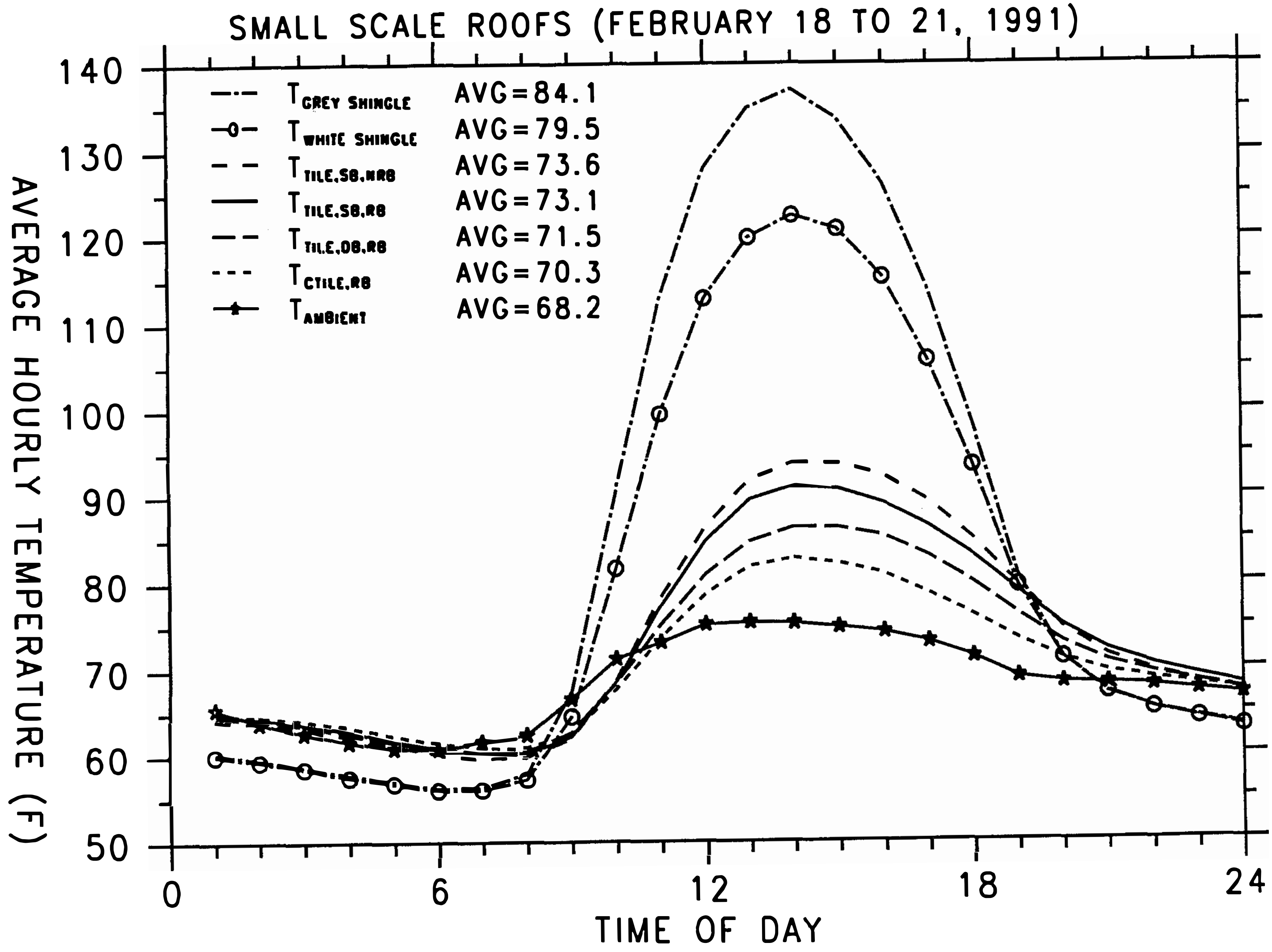

Figure 8 - 2
South Deck Temperatures of Small Scale Roof Models

battens (the curve labeled sb, nrb). As a result, the DOW was reroofed with these types of tiles and the cooling season tests were repeated in the same methodology as that in 1990.

The 1990 cooling season tests had shown the DOW performance to be slightly inferior to that of the Dome (Chandra and Moalla, 1992). The 1991 test showed that with a tile roof the DOW not only looked better but also improved its cooling performance similar to that of the Dome.

Conclusions

These tests have been valuable to industry because they provided performance data for DOW on roof shingle temperatures and assisted American Ingenuity in its marketing efforts in Israel. These tests were also appreciated by Penn Lyon Homes and the Structural Insulated Panel Association. As a result, the EEIH team is planning to conduct field tests of a full scale foam core and base case home in 1992.

9 STUDENT FAMILY HOUSING DEMONSTRATION

The objective of this task is to assist a Center for Housing Innovation design team, under the direction of Don Corner, in the development of six units of student housing units planned to be built on the University of Oregon campus in 1992. These units will demonstrate energy performance levels consistent with BPA's Super Good Cents program, available methods of industrialization, high levels of architectural quality, and low cost.

Production Concepts

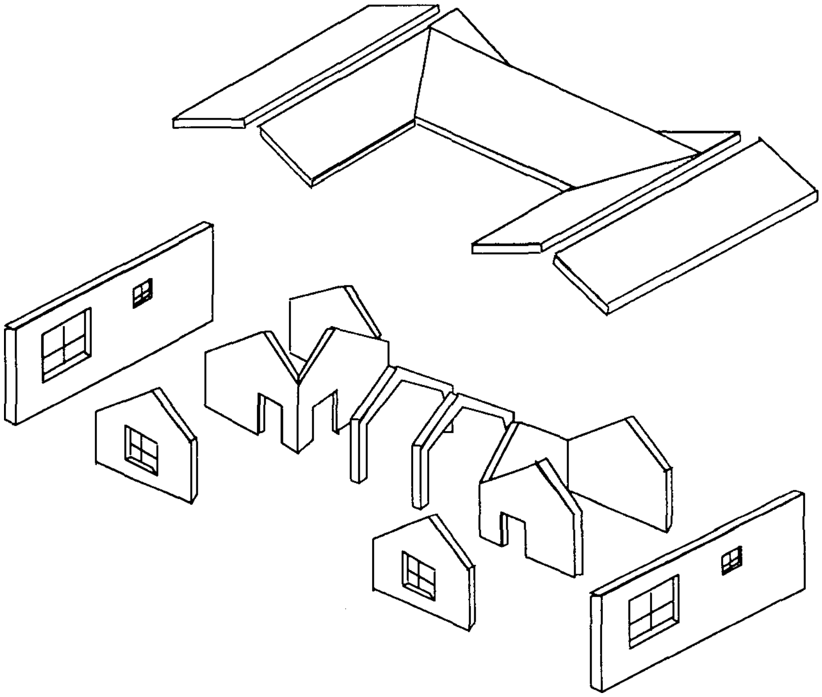

Figure 9 - 1
1 Story Unit Pair (1500 sq. ft. total)

The one story unit pair (Figure 9 - 1) is constructed over a concrete slab, with closed and completed wall and roof panels as large as possible, incorporating the maximum amount of finish work both for exterior and interior surfaces.

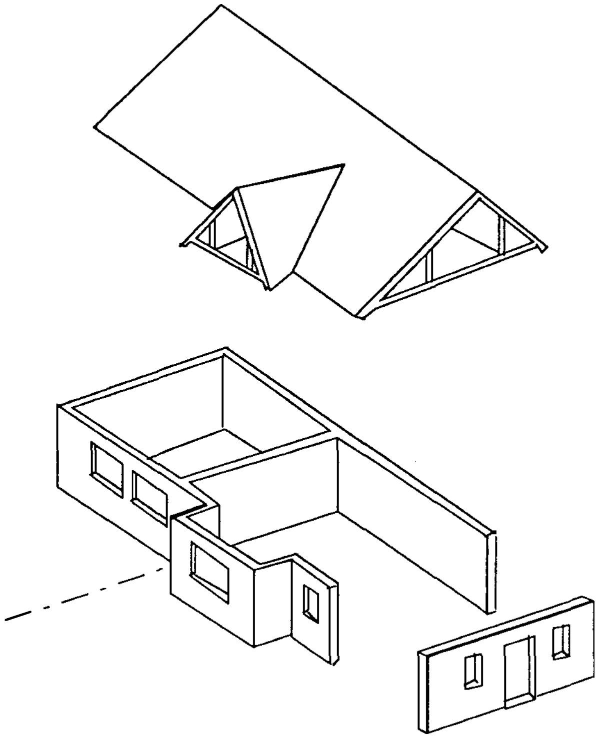

Figure 9 - 2
1 1/2 Story Unit Pair (1710 sq. ft. total)

The 1- 1/2 story unit pair (Figure 9 - 2) is constructed over a concrete slab, with open panel wall systems and trusses or a composite lumber framed roof. Wall panels are partially assembled off site, including the framing and exterior sheathing. The attic/roof volume is occupied space. One unit represents the unexpanded mode, while the other unit represents the expanded mode. Expansion can occur either upstairs or down, each independent of the other.

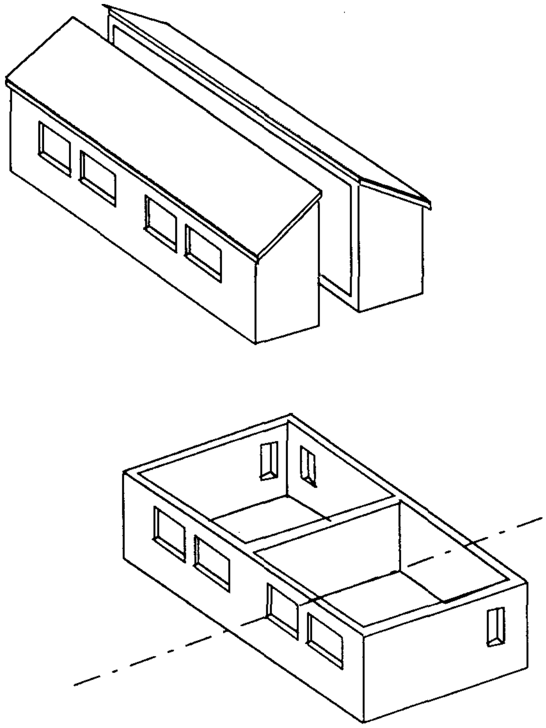

Figure 9.0 - 3
2 Story Unit Pair (1600 sq. ft. total)

The two story unit pair (Figure 9 - 3) is constructed over a concrete slab, with the lower story site built of concrete masonry unit walls with exterior insulation. One framed interior wall contains the plumbing tree for the kitchen and for supply to upstairs. The upper floor consists of two preassembled UBC modulars that have arrived on site completely finished. A solar mass exists both in the slab and in the CMU walls.

We have completed a first round of energy evaluations using the software Energy Scheming. This analysis revealed potential insulation, shading, inadequate mass, and cross ventilation problems.

Energy Testing Plan

An energy testing plan developed for this task is the same as for the stressed skin insulated core (SSIC) low income demonstration house (see section 10 for more details). In this case, the six student family houses will be tested. Preoccupancy tests will verify the design envelope performance goals and air tightness by blower door, infrared scanning, and co-heating. Unoccupied monitoring will occur in the heating season and in the cooling season with simulated occupancy. Short term, occupied monitoring will also be conducted. Long term occupied monitoring by sub-meters will be done as well.

The monitoring equipment will be the same for the married student houses as for the SSIC panel house. Most of the equipment needed to complete the energy testing has been procured and is being set up and debugged. A practice house is being used at FSEC for the purpose of system check-out.

10 STRESSED SKIN INSULATED CORE LOW-INCOME DEMONSTRATION HOUSE

Working with a Stressed Skin Insulated Core panel manufacturer, we will design, build and test a low income prototype dwelling that showcases energy efficient technology and demonstrates that panelized construction delivers good quality homes with high levels of energy performance at a lower first cost when compared to conventional construction.

The initial demonstration project will be a 1200 sf three bedroom, two story house built on a 50' x 160' lot in an existing single family neighborhood. It will employ a stressed skin panel construction system using R-Control panels supplied by AFM Corporation. It is designed to equal the annual energy performance of an architecturally equivalent conventional home built to BPA's prescriptive Long Term Super Good Cents standards (Roof - R 49, Wall - R 26, Floor - R30, Window - U.35), but will be built at the cost of a similar home designed to current code standards (Roof - R38, Wall - R21, Floor - R 25, Window - U.35).

We will build the first prototype in the Northwest because the design complexity that this regional market demands is easily achieved using panelized construction, yet contractors in the Northwest have resisted panelization until recently. Consequently there is a large latent market for energy efficient panels, and 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.

Panelized construction uses industrialized techniques to produce panel elements, typically sized from 4' x 8' to 8' x 28', which are used to form walls, roofs and floors. Within panelized construction, there are two approaches to transferring loads -- one uses a combination of studs and sheathing and the other sheathing and a core material. The latter, called stress skin panels, are highly energy efficient when the core is made of insulating material. Because of this characteristic, stress skin insulated core (SSIC) panel manufacturers aggressively market energy efficiency as a product feature.

The panels have not been fully exploited, however, because designers and builders have been reluctant to depart from practices, dimensions and modules derived from conventional framing. The thickness of the SSIC panels has in general not been optimized to combine structural <u>and</u> thermal performance, resulting in energy overkill and unnecessary cost.

In addition, the SSIC panels are "closed" by virtue of their construction, making wiring and plumbing in exterior walls problematic. These problems can be addressed by establishing planning modules that reduce wiring and plumbing runs, perimeter floor chase details as is done in Sweden, and surface mounted wiring. The areas around window and door openings are less thermally efficient than the opaque wall, as a result of the framing required for conventional windows and doors. This can be addressed by revised window design. Current joinery details rely more heavily than necessary on lumber inserts to transfer loads at wall/roof and wall/floor junctions, introducing thermal weaknesses.

Panelized construction is the strongest housing industrialization trend in the U.S. Panelizers increased their market share from 29% in 1980 to 37% in 1991. We believe that the increase in market share is partly due to cost savings in comparison to conventional framing techniques. We expect this trend to continue, making panelized construction an important potential source of energy savings. SSIC panels appear to be the cutting edge of this energy efficiency opportunity.

Participation of project partners St. Vincent dePaul Society and AFM Corporation has been secured. AFM has agreed to furnish panels for the building, and St. Vincent dePaul has agreed to supply the site, finance construction and act as general contractor for the project. Engineering, cost and fire test data have been received from AFM and are under review. Two Oregon builders with panel construction experience have been contacted, as possible candidates for construction of the building shell. Their input helps insure that regional construction and market related issues are treated realistically.

Participation of window, lighting and other manufacturers is pending. Two window manufacturers, one door manufacturer and one lighting distributor have been contacted. Contact has been established with manufacturers of oriented strand board and gypsum board products for help with performance optimization of the panels themselves.

Consultation with the Structural Insulated Panel Association has been maintained through presentations at two SIPA meetings, in order to establish the project's connection with real needs and capabilities of the panel industry. An extensive product library has been assembled to familiarize us with the range of products and techniques presently in use.

Schematic design studies have been completed for one single-story, three 1-1/2 story and two two-story versions of the demonstration house. Construction cost estimates for panel and conventionally framed versions of these designs have been made.

Preliminary analyses of energy performance for these alternates have been completed, using the WATTSUN program. More detailed energy modeling using DOE 2 will be employed when the house design is finalized.

Studies have been performed to optimize cost and thermal performance of the structural insulated panels as presently configured and in alternative configurations. Similar studies have examined the interactive energy performance of panel R value and window quality, in order to optimize energy performance relative to cost.

Other studies have investigated the cost impact of alternate foundation systems that make better use of the panels' structural capabilities, and the consequence of roof complexity on panel cost effectiveness. Alternative joinery details have also been examined for their impact on cost and energy performance.

Detailed manufacturing and code analyses have begun, with the help of University of Central Florida project researchers and other consultants.

We are currently examining the SSIC house in comparison to conventional construction. We expect to complete construction and begin thermal testing this summer. So far the most promising improvement is in the composition of the panels themselves, which seems capable of saving roughly $2000 in a 1200 sf house. Improvements in floor and foundation rank next, in which the panel version with pier foundation 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 offer smaller savings, possibly as great as $1100 for a house this size, but dependent on other factors such as the choice of large vs. small panel construction.

Energy Testing Plan

An energy testing plan has been developed for the SSIC low income demonstration house. The testing will involve both short term monitoring by low cost data acquisition system, and long term monitoring by monthly manual reading of sub-meters. The purpose of this field monitoring is to verify design performance goals. Recent literature on field data acquisition for residential building energy-use monitoring has been surveyed and the findings incorporated into the energy testing plan.

Preoccupancy tests for the SSIC house will be conducted using infrared scanning, blower door, and co-heating techniques. 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 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 (UA) will be possible.

Preoccupancy 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 time frame will depend on the quality of data obtained on changes in weather. The simulated occupancy will provide inputs for a building energy analysis model such as DOE 2. The following measurements will be recorded as six minute averages of six second datalogger scans:

Number of Channels	Channel Type	Measurement Description	Units
2	pulse	heating/cooling system energy use	W-hr
1	pulse	hot water heater energy use	W-hr
1	pulse	whole house energy use	W-hr
2	voltage	house air temperature by thermocouple	^{o}F
1	voltage	wall surface temperature by thermocouple	^{o}F
1	voltage	mean radiant temperature by thermocouple	^{o}F
1	voltage	relative humidity by bulk polymer sensor	%

Occupied monitoring will be conducted taking the same measurements as described above. Long term monitoring by monthly manual reading of sub-meters will follow. 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
2	voltage	ambient air by TC and thermistor	°F
1	voltage	relative humidity by bulk polymer sensor	%
1	voltage	horizontal solar radiation by pyranometer	W/m^2
1	pulse	wind speed by cup anemometer	mph
1	voltage	wind direction by vane	deg.
	voltage	soil temperature by thermistor	°F
1	pulse	rain accumulation by tipping bucket	in

Most of the equipment needed to complete the energy testing has been procured, and the systems are being set up and debugged. A practice house is being used at FSEC for the purpose of system check-out.

11 EXHIBITION

One goal of the EEIH project is to solicit industry participation in the design, process and testing by communicating potential benefits to industry members. Because the industry is so fragmented and diffuse, it is very difficult to communicate with all the players individually. In addition, industry comments during EEIH Steering Committee Meetings confirmed that industry members have little time for the intense study and review needed to digest voluminous research reports.

Consequently, it was decided to present the EEIH project during the Building Systems Council Showcase, the annual industry association convention, which most industry members attend. It was also determined that communicating the results of the project to date would be best accomplished using highly visual media, and as little verbiage as possible while still communicating the major points.

Two principal communication tools were prepared: a free-standing exhibit and a self-explanatory videotape program.

The exhibit employed colorful graphic images of each of the major task areas: energy testing, energy design, and process efficiency. In addition, the exhibit integrated an infrared video camera and monitor, demonstration of process engineering software. Another part of the exhibit presented a five-minute, continuous-play video program about the project.

Virtually every convention delegate visited the exhibit. Some of the principals in larger industrialized housing companies spent up to an hour perusing the exhibit and conversing with EEIH project team members at the conference. A survey distributed after the conference resulted in several requests for additional EEIH services and input. The exhibit itself was rated second in overall quality at the convention.

12 INDUSTRY ASSISTANCE

Through this task, a number of activities were conducted to assist the industry. These include:

- Penn Lyon Homes - PEER (Process and Energy Efficiency Review) visit and an additional energy evaluation.
- Acorn Structures, Inc. - PEER visit.
- Schult Homes - Energy evaluation in conjunction with NREL
- ABACoS - Subcontract to obtain data.
- NAHB Building Systems Councils - Subcontract to conduct focus group of industry executives.

Penn Lyon Homes (PLH)

The EEIH team conducted a PEER visit to PLH facilities in Selinsgrove, Pennsylvania. In a PEER visit the EEIH team of six to eight experts conduct a thorough 2 - 1/2 day review of the manufacturing and design methods of the firm. In addition, two nearby model or occupied homes are tested for air tightness (by a blower door) and insulation defects (by an infrared camera). On the last day, recommendations are made to senior management. A written report is provided later. The PEER visit uncovered many areas where manufacturing methods could be more efficient (eg. better material handling using transfer cars, more off-line assembly). It also suggested opportunities for energy improvement (re-routing electrical wiring, air sealing ducts and recessed lighting fixtures) and design (Energy efficient model design in plan book, computerized "what if" tools, adding site and orientation information in design book, increasing homebuyer input at design stage). Details may be found in Chandra, et al (1991).

Later, energy evaluations were performed for a new line of homes PLH started constructing using foam-core panels. Figure 12 - 1 shows the foam core model home, a conventional 2x4 model home and Figure 12 - 2 thermograms obtained from the infrared camera. The thermogram is of the wall ceiling corner in both houses and the marked areas show heat loss pathways. The much smaller heat loss pathways for the foam core panels is evident. This information was presented to approximately 100 PLH dealers.

Acorn Structures

A PEER visit was conducted for Acorn in Acton, Massachusetts, in late 1991. Acorn is undergoing a transformation in response to the depressed New England real estate market. Energy testing of two Acorn homes revealed opportunities to improve duct system integrity and reduce air convection in the ceiling insulation near the wall junction. Wintertime overheating was noted and opportunities for thermal mass were identified. The air tightness of the homes was excellent. The manufacturing review concentrated on inventory management, design review on the design and marketing process. Suggestions were made in both areas. Manufacturing recommendations included better inventory control and tracking, consideration of multiple vendors for long lead time items, and closer look at all the factors to make buy/manufacture decisions. Design recommendations include conducting energy analysis and goal setting and publishing them in marketing literature, making energy assets of the open airy designs more explicit in the literature and reconsidering computers to increase productivity as the clientele increasingly demand totally custom solutions.

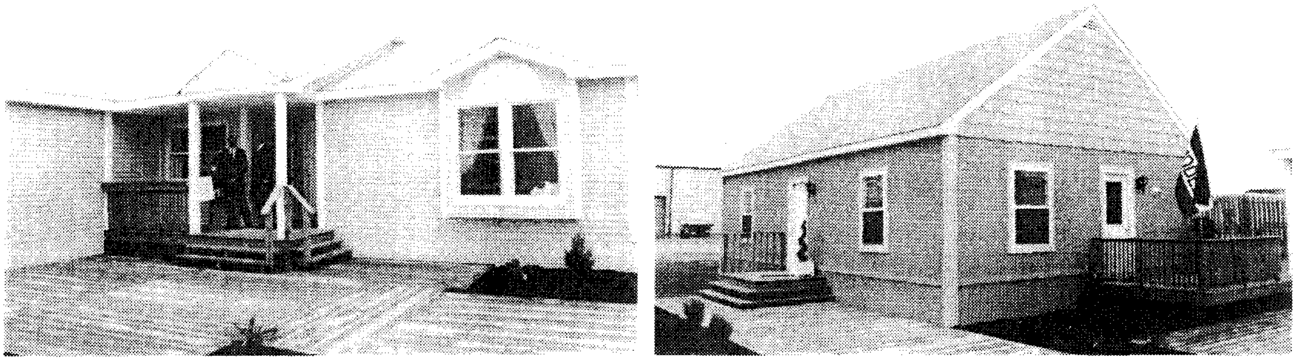

Figure 12 - 1
Penn Lyon Homes: a foam-core panel house (left) and a 2x4 wood-frame house.

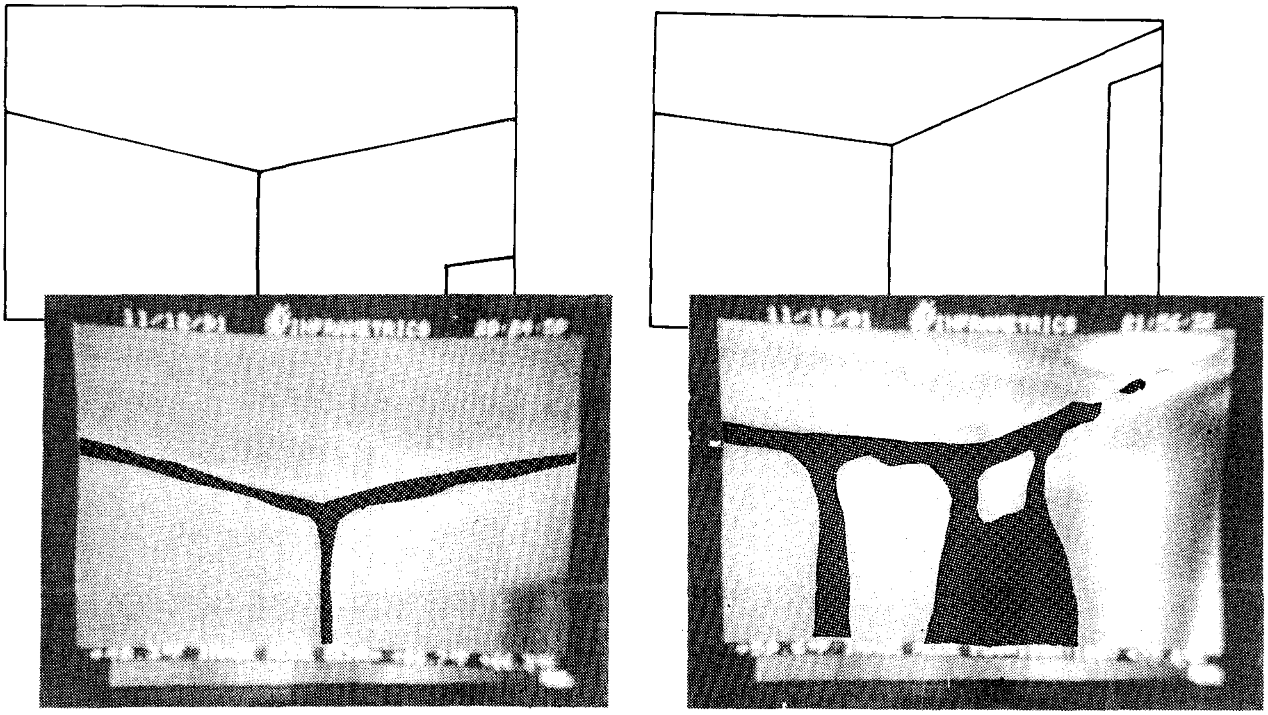

Figure 12 - 2
Infrared scans comparing foam-core panel construction (left) and 2x4 frame construction (right).

Schult Homes

Schult homes are a leading manufacturer of high end HUD Code homes and are located in Plainville, Kansas. The EEIH team and NREL jointly performed blower door and Infrared camera inspections of two homes at the factory as well as at NREL facilities in Denver, Colorado, after the homes were transported 300 miles over rough interstate highways. Testing revealed some insulation settling due to transport and leaky supply ducts. Although NREL co-heating tests show that the homes generally met the new HUD energy code, the EEIH team recommended that the ducts be better constructed and the interior doors be undercut more to improve air distribution system efficiency and energy performance.

ABACoS

ABACoS is an industry alliance led by GE Plastics that is attempting to develop integrated building systems. The goals complement EEIH's. As a result we are cooperating by sharing data, reports and ideas. EEIH awarded a subcontract to ABACoS to facilitate this process.

National Association of Home Builders/ Building Systems Council

The National Association of Home Builders/ Building Systems Council is the industry trade group representing many members of the industrialized housing industry. The EEIH team has participated in the annual conventions of the NAHB/BSC as well as BSC meetings at the NAHB annual meeting since 1990. In 1991, BSC was awarded a subcontract to increase the industry/EEIH interaction and awareness. As part of that subcontract, BSC conducted a focus group of eight senior managers of the industry to determine industry needs and how increased funding from the Department of Energy might meet that need. The salient results were:

- Views were from a small sample, not necessarily representative of the industry. Attendees from large and small companies all had similar viewpoints.
- They did not suggest long term research needs. Their main long term focus was consumer behavior and trends in energy prices.

- They suggested a large number of homes be field monitored for energy performance. Such data would have a "phenomenal" effect on sales if results validated superior performance of innovative construction shells. This would supply the "proof" consumers need beyond manufacturer claims.
- Participants felt that consumers are concerned about energy efficiency but are unwilling to pay for it. Buyers of low to moderate cost homes were more interested in energy than buyers of custom high priced homes.
- They felt that while energy concerns may be transitory, "Green" concerns would be prevalent throughout the 90s.
- Several felt that if energy efficiency could be achieved through quality control and more effective combination of materials, cost would not increase.
- DOE had a name recognition problem. The public is more familiar with HUD and EPA as government agencies.
- Promotion and educational activities were suggested as suitable government activity.

Conclusions

The EEIH team has significantly increased the interaction with industry and the project results are directly benefiting the industry. It is hoped that this type of activity will increase in future years.

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