ENERGY EFFICIENT INDUSTRIALIZED HOUSING RESEARCH PROGRAM

SUMMARY
FY 1989 RESEARCH ACTIVITIES

CENTER FOR HOUSING INNOVATION
UNIVERSITY OF OREGON

AND

FLORIDA SOLAR ENERGY CENTER

ENERGY EFFICIENT INDUSTRIALIZED HOUSING RESEARCH PROGRAM

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condensed from

VOLUME I - FY 1989 RESEARCH TASKS
VOLUME II - APPENDICES
MULTIYEAR RESEARCH PLAN

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MULTIYEAR RESEARCH PLAN

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SUMMARY OF FY 1989 RESEARCH ACTIVITIES

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ABSTRACT

This report summarizes three documents: Multiyear Research Plan, Volume I FY 1989 Task Reports, and Volume II Appendices. These documents describe tasks that were undertaken from November 1988 to December 1989, the first year of the project. Those tasks were: 1) the formation of a steering committee, 2) the development of a multiyear research plan, 3) analysis of the U.S. industrialized housing industry, 4) assessment of foreign technology, 5) assessment of industrial applications, 6) analysis of computerized design and evaluation tools, and 7) assessment of energy performance of baseline and advanced industrialized housing concepts. While this document summarizes information developed in each task area, it doesn't review task by task, as Volume I FY 1989 Task Reports does, but rather treats the subject of energy efficient industrialized housing as a whole to give the reader a more coherent view.

1.0 INTRODUCTION

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

This research program addresses the need to increase the energy efficiency of industrialized housing. Two 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.**

Project Funding

The project was funded by the states of Oregon and Florida for $100,000 in 1988, $230,000 in 1989, and is budgeted for $300,000 in 1990. Private industry funded $69,000 in 1989, and is expected to fund at least $100,000 of the work in 1990. U.S. Department of Energy funded the project for $630,000 in 1989 and is budgeted for $737,000 in 1990.

2.0 DEFINITIONS

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

(1) **HUD Code** Houses (mobile homes)
(2) **modular** houses
(3) **panelized** houses (including domes, precuts, and log houses)
(4) **production** houses (including builders 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 gives a different perspective on the energy use. Japan (Tatasumi) 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 its energy use.

Other methods of defining or categorizing housing exist which 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 utilizing 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 choices of components and the opportunity to purchase them 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

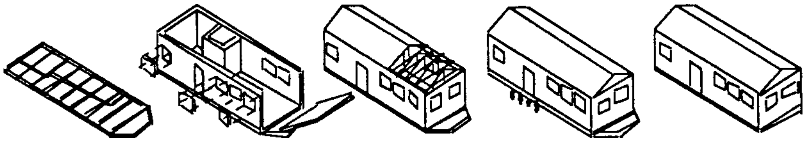


Figure 2.0-1
HUD Code House

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

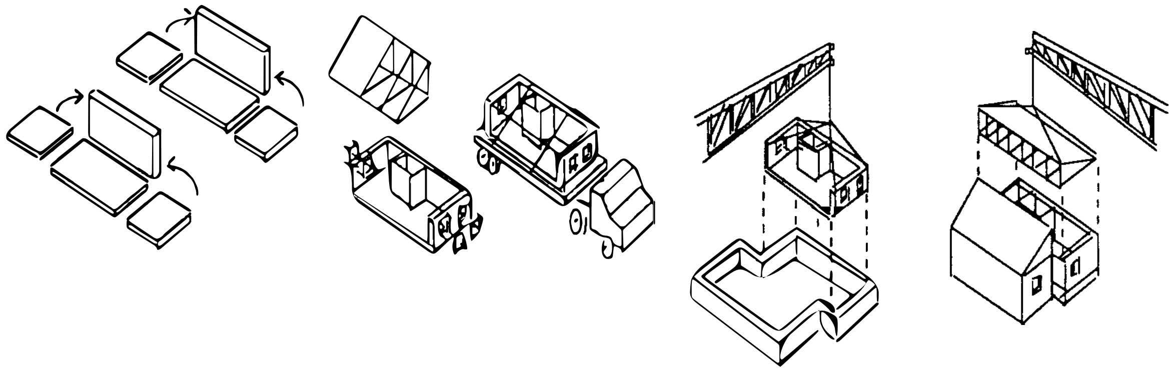


Figure 2.0-2

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

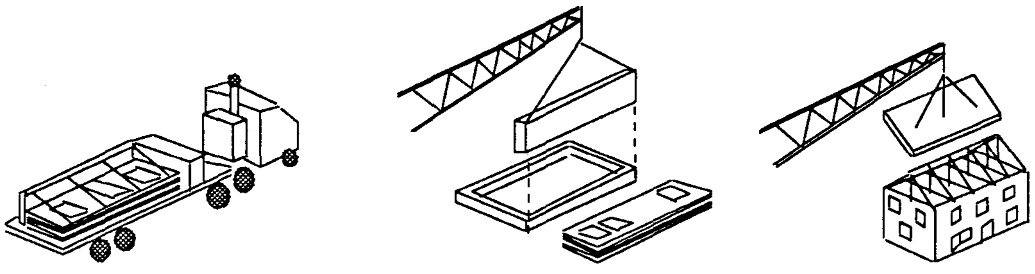


Figure 2.0-3
Panelized House

Panelized houses are whole houses built from manufactured roof, floor and wall panels designed for assembly after delivery to a site. Within this category several sub-categories exist. 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 finished on site (interior finishes, 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

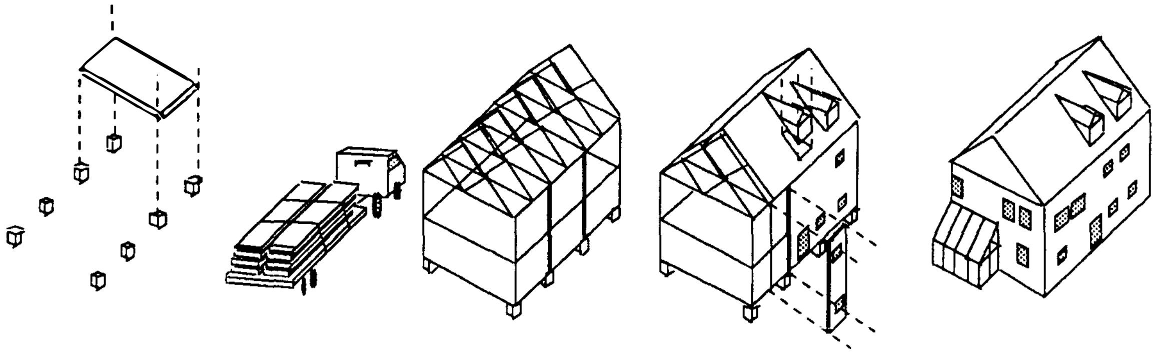


Figure 2.0-4
Production Built House

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 much the same as producers who are more commonly accepted as industrialized. In this instance, however, the factory is a building site which becomes an open air assembly line through which industrialized labor and materials rather than houses move.

3.0 INDUSTRIALIZED HOUSING COMPANIES AND THEIR MARKETS

This section reviews the history of industrialized housing in the United States, Japan, and Sweden. We studied Japan because it has the highest level of housing industrialization. Sweden was included because it produces housing that is both industrialized and highly energy efficient. This section also gives an overview of the U.S. industry with an analysis of trends across and within industry segments. It also contains a discussion of regional issues.

3.1 HISTORY -- UNITED STATES, JAPAN, AND SWEDEN

United States

Industrialized housing in the United States dates from panelized wooden houses imported by the English in the 1600's. In 1727, precut homes were exported from New Orleans to the West Indies. By 1850, 5000 houses had been shipped to California from England, France, and the East Coast of the U.S. to accommodate participants in the Gold Rush of 1848 (Kelley, pg. 9). Industrialized building has fascinated many Americans, including Thomas Edison, who in 1907 predicted the development of low cost homes of monolithic concrete (Bemis).

The period from 1900-1920 saw the development of mail order houses and the rationalization of construction including grading, cutting, marking, and packaging lumber; preassembly of doors and windows; standardization of parts; large scale estimating, collection of parts, and fixed prices for houses. Industrialized housing began to move from specialized markets like vacation homes to the mainstream housing markets (Kelley, pg. 13).

In contrast to western Europe, which began to *produce* industrialized housing, the U.S. continued to *experiment* with industrialization during the period 1920-30. Some notable developments were the Bemis cubical modular dimensional standard and Fuller's dymaxion steel house (Kelley, pg. 24-26).

During the 1930's, industrialization (prefabrication) attained the "status of a movement" (Kelley, pg. 28) due to a confluence of economic, social, and technical ideas. Developments included American Motorhomes integrated mechanical core, stress skin panel research by the U.S. Forest Products Laboratory, Tennessee Valley Authority use of modular housing for construction sites, and the formation of such companies as General Homes, Homes Inc., and Gunnison.

During the 1940's, the industry approached mass production, supplying 200,000 of the 1,600,000 homes completed during the war (Kelley, pg. 61). However, according to Kelley, the circumstances of the war probably did more to improve the efficiency of on-site construction than it did for prefabrication, and thus laid the ground work for the success of the production builder. After the war there were companies producing panelized wood frames, stressed skin, and machine made metal houses. During this period there was a rapid expansion, and then contraction, of the industrialized housing industry. The failure of some of these companies and the low quality of wartime construction resulted in a poor reputation for industrialized (prefab) housing.

In 1968 the Department of Housing and Urban Development launched Operation Breakthrough, based on assumptions that housing production was a technically backward industry, and that large investments in centralized plants could be justified by dramatic reductions in labor costs. This did not prove to be the case.

The trend toward industrialization has been growing irregularly over the past twenty years. While many home builders would not readily define their production as industrialized, industrialized components and processes are used on the vast majority of houses built. By the late **1980's, more than 1,000 home manufacturers were operating in 1,275 locations in the United States. Another 2,000 or more companies were mass-producing house components** such as floor, wall, and roof sections; prefabricated plumbing assemblies; and complete mechanical cores incorporating the main heating, plumbing, and electric assemblies of a house (LSI Systems). Items like doors, windows, and cabinetry are almost exclusively factory made in today's housing market.

Japan

Japanese industrialized housing has developed primarily since World War II (Kendall 1987, Coaldrake, Utida), in response to substantial housing shortages. In addition, there has been a population shift to major metropolitan areas such as the Tokyo-Nagoya-Osaka corridor. These factors, combined with a robust economy and increasing personal wealth, laid the foundation for a continuing housing demand.

The Japanese undertook research efforts during this time to address questions raised by these changes -- how to build houses rapidly, how to build them with materials suitable for urban areas, and how to deal with domestic wood shortages (Kendall 1987). These new questions, combined with traditional concerns about earthquake and fire hazards, produced answers which supported Japan's movement towards industrialized housing.

The industrialization of Japanese housing components took place within the context of a general industrialization of consumer products. There was considerable expertise shared from industry to industry. **Almost all of the major housing companies produce Western style housing that has been adapted to Japanese living patterns.**

Sweden

Sweden has a long history of prefabricated wooden house construction. During the mid to late 1800's, Sweden pioneered small solid wood panel construction technology which was utilized in modernized form until after WW II. Large suburban areas surrounding Stockholm were developed before and after World War II, using these early solid panel construction systems. The houses produced by these systems were of traditional Scandinavian style which utilized steep roof pitches, double wooden window systems, brightly painted board on board siding, with small gardens. The development of the housing export market of the early 1980's has led Swedish Factory Crafted (SFC) housing design to be adapted to many different building cultures around the world, including Japan, North Africa, and Central Europe.

The Swedish Factory Crafted housing industry produces almost all the single family houses built in Sweden today (Schipper, 1985) using two kinds of production systems -- panelized and modular. Modular systems, similar to U.S. modular housing, represent a small part of the Swedish housing market. Panelized systems, the larger segment of the market, come in two forms, small panel and large panel. Both systems are "closed panel" but with interior finishes (and sometimes exterior finishes such as brick) completed on site. Although plastic conduit is placed in the panels in the factory, electrical wiring is done on the site.

Figure 3.1-1 - Bromma Co. House

Prefabricated production includes floor "cassettes" (panels), exterior wall panels, gable end panels, and roof trusses. Cabinetry is provided as a prefabricated package for each house. Interior walls, plumbing, wiring, roofing, and interior finishes and paint are usually completed on site in conventional ways. **The amount of "value" produced in the SFC panel factory setting is less than 50% of the total cost of an SFC house. That portion of the SFC house that is produced in a factory setting is highly automated.**

3.2 CODES

The most striking difference in building codes between the United States and other nations we have studied is in their number. Japanese and Swedish builders have only one or two national codes to adhere to, while the United States housing industry must deal with codes and standards at many government levels, including regional, state, and municipal. One indication of the complexity of this problem is that there are over 40,000 local jurisdictions in the United States. Codes have been developed which are specific to the great variety of geographic and climatic conditions found in this country, and to a variety of location-specific energy and safety problems. HUD Code homes are currently the only building type which benefits from a national code, although there are and have been ongoing attempts to adopt national codes for the other industrialized housing segments. **The multitude of codes and standards impedes the introduction of new industrialized housing materials and processes.**

3.3 NATIONAL PERSPECTIVE

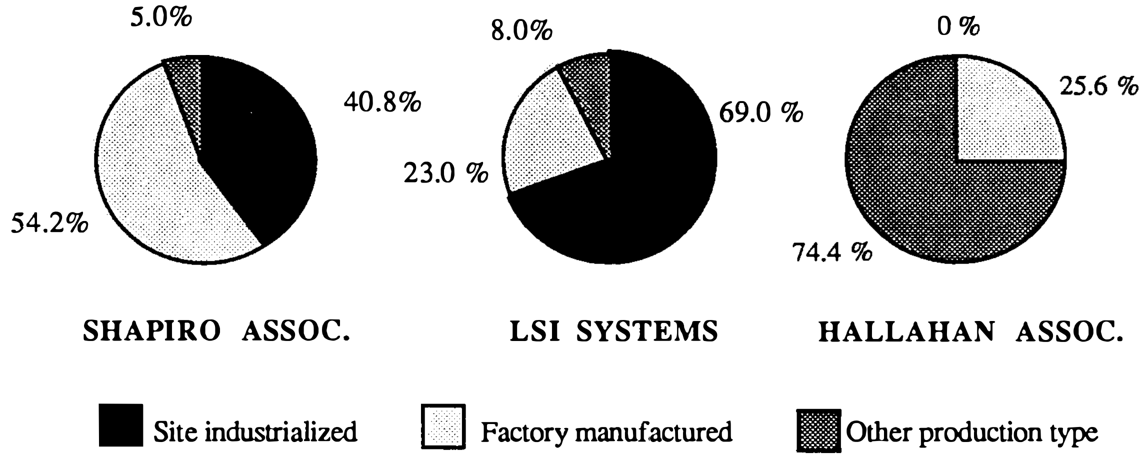
Industrialized housing involves thousands of manufacturers and builders who produce many kinds of houses and parts of houses, using a variety of industrialization strategies. Most of these manufacturers and builders, particularly those that build to conventional code standards, cannot be easily categorized and do not maintain reliable statistics on their production; consequently, the industry's statisticians disagree as to industry size, roster and production capability. Only the HUD code segment of the industry has an accepted definition and verifiable data collection procedure. All other segments such as precut, panelized, and modular share no universally accepted definition or data collection process or procedure.

Leo J. Shapiro Associates defines industrialized housing broadly, and includes companies that use manufactured components and industrialized processes in site building as well as companies that manufacture homes in plants and transport them to sites. According to Shapiro's definition, industrialized housing accounted for roughly 95% of 1987 national housing production that is not high rise.

LSI Systems' definition of industrialized housing acknowledges two degrees of industrialization within the industry -- 1) factory manufactured houses and 2) industrialized home builders. In this definition of industrialized housing there are two general categories: Home Manufacturers, who produce whole houses in factories, and Home Builders, who produce houses on sites sometimes using components, systems and techniques that are industrialized to varying degrees. These categories together account for approximately 93% of the 1987 national housing production that is not high rise. Whole manufactured houses alone account for only 21% industrialization (LSI Systems, 1988).

Unlike Shapiro and LSI Systems Inc, Hallahan focuses in considerable detail on only two industry segments, the manufacturers of panels and modules. Specifically excluded are HUD-code homes, log homes, precut homes, dome homes, and partially industrialized production builders.

Shapiro and LSI do not agree on the number of houses produced by industrialized manufacturers. Figure 3.3-1 shows a 29% variation in total production attributable to some level of industrialization, and a 30% variation in factory based industrialized production in 1987.



100% = 1,855,700 Department of Commerce total housing starts with HUD code

Figure 3.3-1
Comparison of Data Collectors and Total Industrialized Housing Production by Collector - (1987)
Source: Manufactured Housing 1988; The Red Book; Factory Built Housing in the 1990's

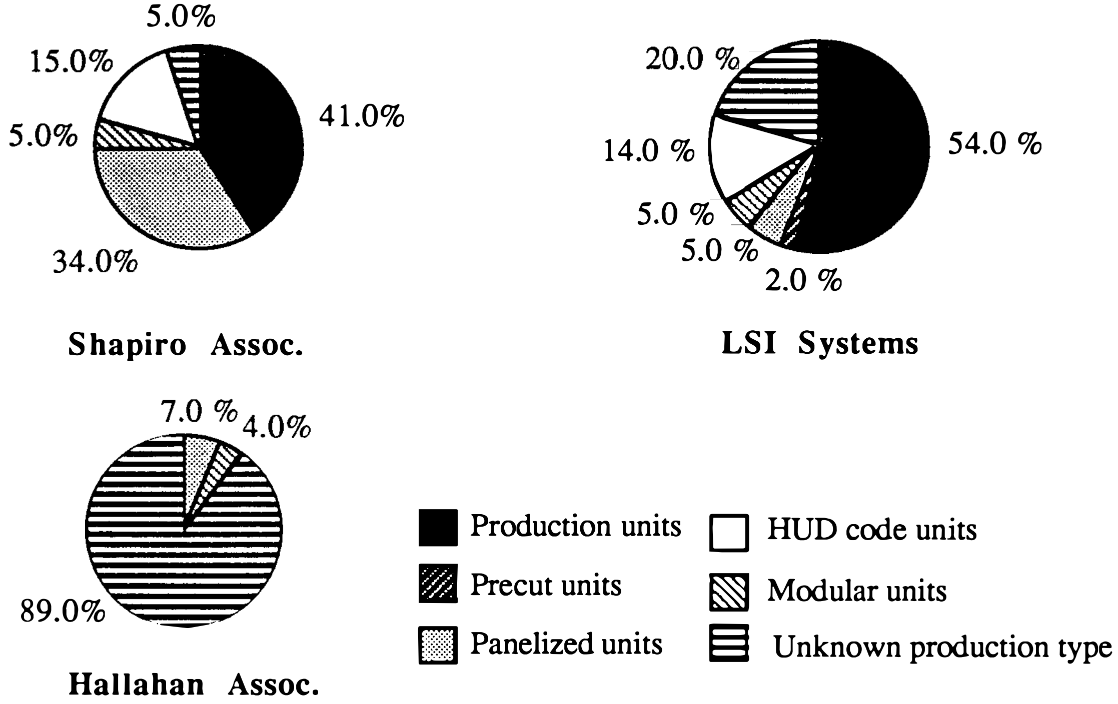


Figure 3.3-2
Comparison of Estimated Production by Industry Segment and as a Percentage of Total Industrialized Production, 1987
Source: Manufactured Housing 1988; Red Book; Factory Built Housing in the 1990's

Only Shapiro and LSI Systems attempted to quantify the whole industry, and ultimately agreed that **over 90% of all housing production was industrialized to a substantial degree.** More problematic, however, is the lack of agreement among all three data collectors (see Figure 3.3-2) as to which segments account for what proportion of industrialized production . An example is the 30% variation in reported production of panelized houses (Shapiro, 1988 and LSI Systems, 1988) and Hallahan contends that over half the units counted as modular housing are in fact commercial or institutional applications of modular construction (Hallahan, 1989).

3.3.1 Trends Across Industry Segments

Industry data collectors agree that the degree and nature of industrialization in housing is increasing as well as changing. Although industrialized houses comprised only a small percentage of U.S. housing stock through the 1960's, by the late 1980's well over half of all single family homes and low rise multifamily homes were produced in a factory using HUD code, modular and panelized construction (Shapiro Associates, 1988). Of the 1,858,000 new homes (non high-rise) built in 1985 for example, 307,000 were HUD code homes, 77,000 were modular and 565,000 were panelized or precut for production builders (Automated Builder).

While many home builders would not readily describe their production as industrialized, in fact today industrialized components and processes are used in the vast majority of houses built. There is now a likelihood of more than 90% that the average 'site built' house will have one or more major industrialized components.

While the general trend toward industrialization has held, the industry itself has evolved with time, economics and technology. **Both panelized and modular manufacturers have consistently increased market share over this time period (see Figure 3.3-3). Since 1980, both have increased production by more than 80%. Production builders have lost market share over the period and have equaled their 1980 production in only one year (1986) out of the eight. HUD-code production increased to a peak in 1983 and has slowly declined since that time.**

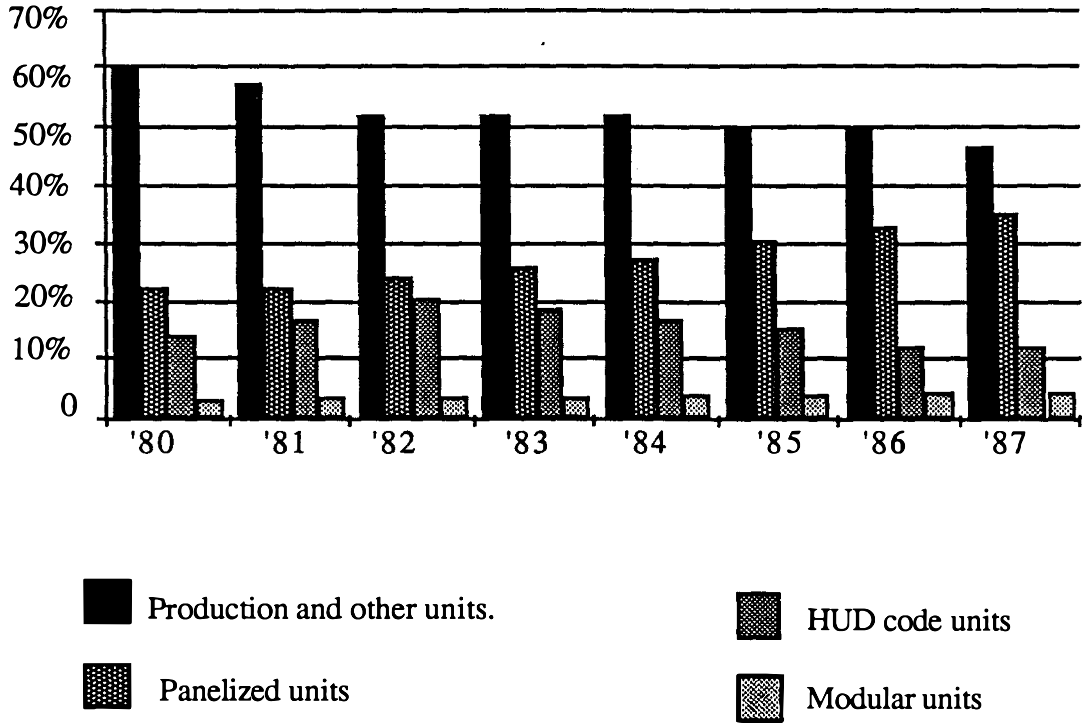


Figure 3.3-3
Industrialized Housing Production in Percent of Market Share: 1980-1988
Sources: U.S Department of Commerce; Manufactured Housing Institute;
Shapiro Associates and Automated Builder

3.3.2 Trends within Industry Segments

HUD Code

Since manufacture of houses under a preemptive HUD code began in 1976, production has ranged from a low of 221,000 units in 1980 to a high of 295,000 units in 1983 and 1984. Market share tends to rest at about 14%, however, market share peaks and lows do not coincide with production peaks and lows (see figure 3.3-4).

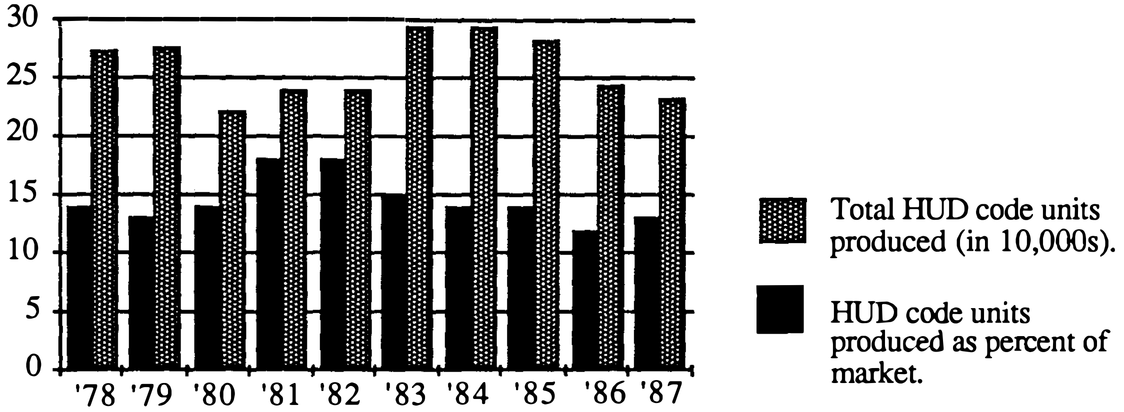


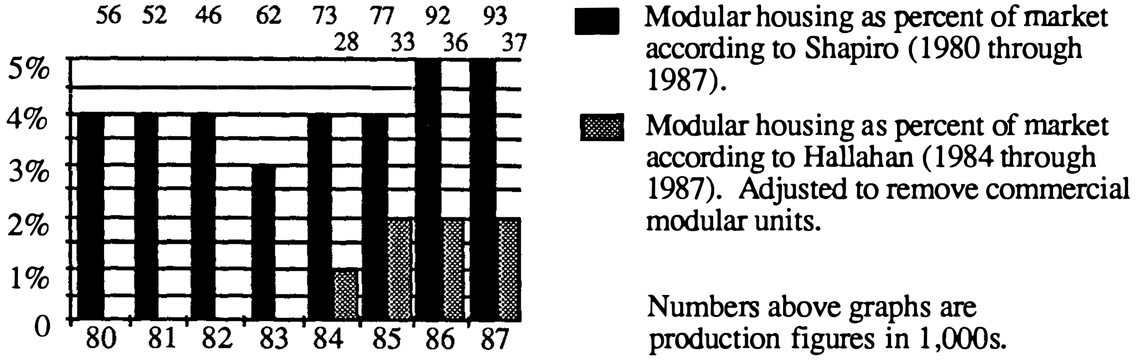
FIGURE 3.3-4
HUD Code Housing Production in thousands
and as Percent of Total Housing Production
Source: U.S. Department of Commerce and Manufactured Housing Institute

The HUD code industry segment has been declining in production since 1983 and in market share since 1982. This downward trend is even more dramatic when viewed in the context of the national statistics for single family house production. **In 1983, 32% of single family homes produced were HUD code. By 1987, the HUD code share of the single family market had declined 6% to 26%** (Manufactured Housing Institute, 1988). The size of HUD code homes sold within that time period however has changed more substantially. **In 1983, 73% of the HUD code homes sold were single section units of about 900 sq. ft. while the remainder were multisection units. By 1987, single wide units sold had decreased to 60%; the remaining 40% sold were multisection units** (Manufactured Housing Institute, 1988).

Modular

Shapiro records that modular production has grown steadily from 56,000 units in 1980 to 93,000 in 1987, increasing the modular share of national housing production from 3% to

5%. While other **data collectors generally agree that the modular industry segment has increased in total production and market share, the size of this growth and degree to which it can be attributed to residential applications is subject to some dispute and vary as much as 250%**, as shown in Figure 3.3-5.



Numbers above graphs are production figures in 1,000s.

Figure 3.3-5
Modular Housing Production in 1980-1987
Sources: Shapiro Associates and Hallahan Associates

Panelized

Panelized manufacturers can be categorized according to three scales of production (Hallahan, 1989, p.30): 1) high volume builders with panel manufacturing capability. (In 1988, approximately 12 companies built panels for about 1800 units each, for a total of 20,000 units.); 2) major panel manufacturers (In 1988, approximately 35 companies built about 800 units each, for a total of 29,000 units); 3) small panel manufacturers --the largest and most productive segment (In 1988, approximately 620 companies produced an average of about 125 units each for a total of 80,000 units).

The last 10 years show a slow but gradual increase in panelized production and market share that varies in magnitude depending on method of data collection. Shapiro describes a large segment with vigorous steady growth almost doubling in size since 1980. LSI Systems describes an industry segment as small as 1/9 the size of Shapiro's with a modest market share and no growth. Hallahan describes an industry segment about 1/5 the size of Shapiro's with a modest national market share of about 7%. Production growth has been flat or decreased somewhat from 1984 to present (Hallahan, 1989, p. 38).

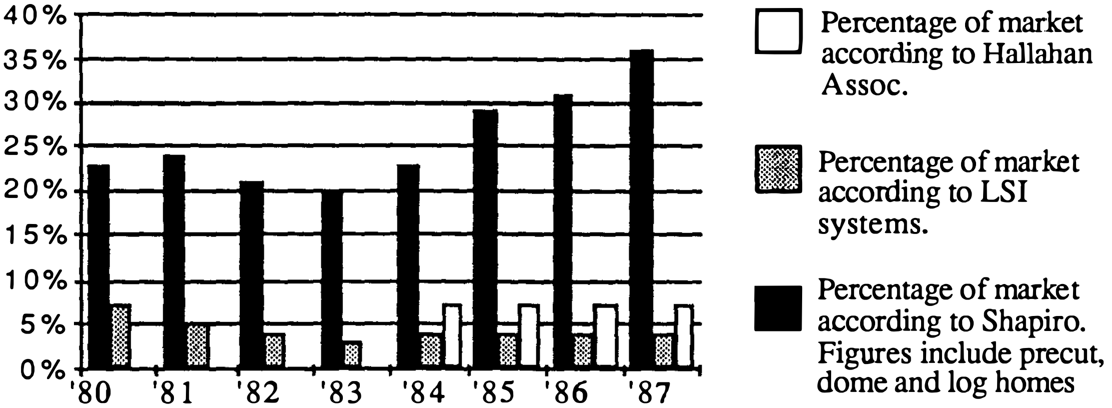


Figure 3.3-6
Panelized Housing Production, 1980-1987
Sources: U.S. Department of Commerce, Manufactured Housing Institute, Shapiro Associates, LSI Systems, Hallahan Associates

Production Builder

Production builders, as defined by Shapiro, include two types of industrialized site builders. **Most industrialized** (LSI's "Industrialized Builders") **are the few hundred developers and builders in the country's largest urban housing markets who built approximately 16% of 1987 housing production.** Less industrialized but more numerous are the tens of thousands of builders, developers and contractors who use one or more major industrialized components to supplement what is otherwise conventional site construction. These builders accounted for approximately 1/3 of 1987 housing production.

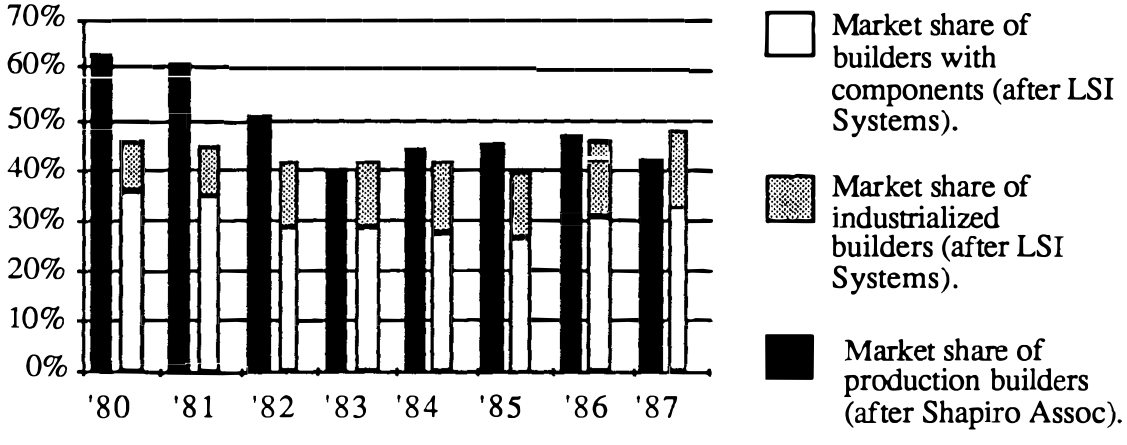


Figure 3.3-7
Production Builder Housing Production, 1980-1987
Source: U.S. Department of Commerce, Manufactured Housing Institute, Shapiro Associates, LSI Systems

3.4 REGIONAL PERSPECTIVE

Industrialized housing production is distributed unevenly in the U.S., and of course regional climates and therefore energy requirements vary widely as well. There is a continuing **pattern of population migration to the "sun belt" states, and a corresponding increase in housing starts in those areas.** These trends are depicted in Figures 3.4-1 and 3.4-2.

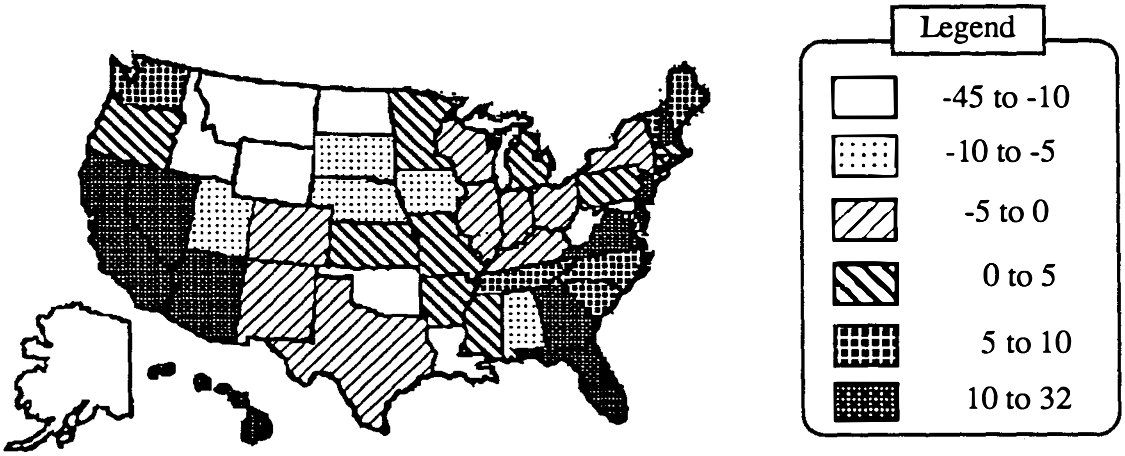


Figure 3.4-1, Net Migration Rate per 1,000 population, by State -- 1987
source: Framework for the Future: 1989-1991

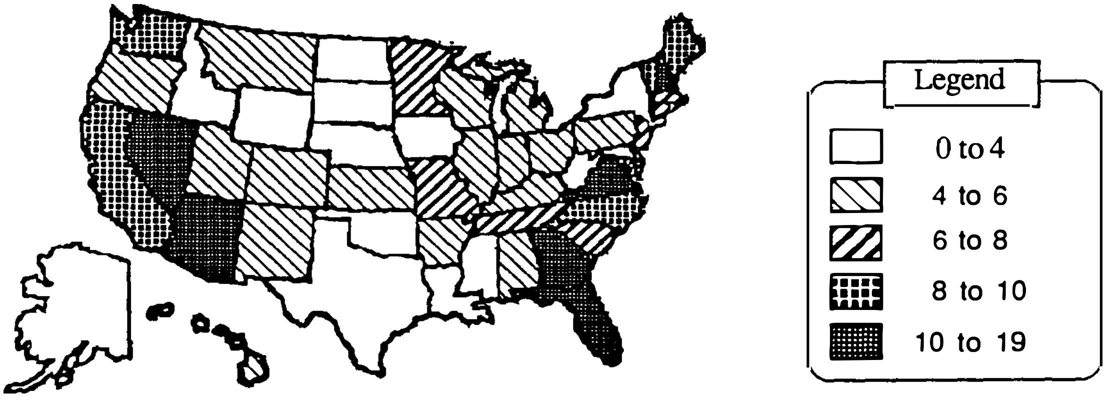


Figure 3.4-2, Housing Starts per 1,000 Population, by State -- 1987
source: Framework for the Future: 1989-1991

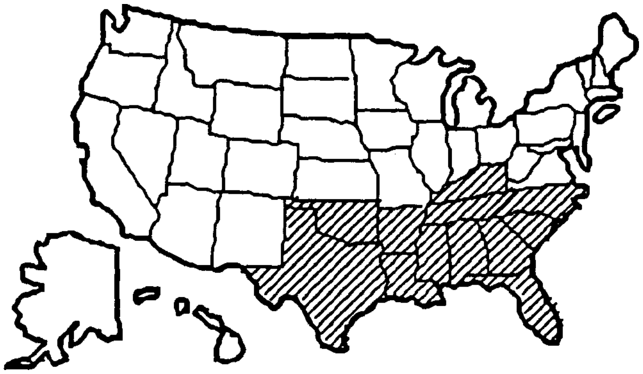


Figure 3.4-3, Geographic Concentration HUD Code Manufacturers

Although HUD houses are produced across the country, they comprise varying proportions of regional housing markets. **While HUD code market share is nationally about 14%, its regional market share in the South is about 24%;** in the Midwest, 15%; in the West, 10%; and in the Northeast, 9% (LSI Systems, 1988). The popularity of single and multisection units also varies in each region. **While the national average is 40% multisection, they are most popular (76%) in the West** and less common in other areas of the country: 38% in the South, 32% in the Northeast; and 31% in the Midwest (LSI Systems, 1988).

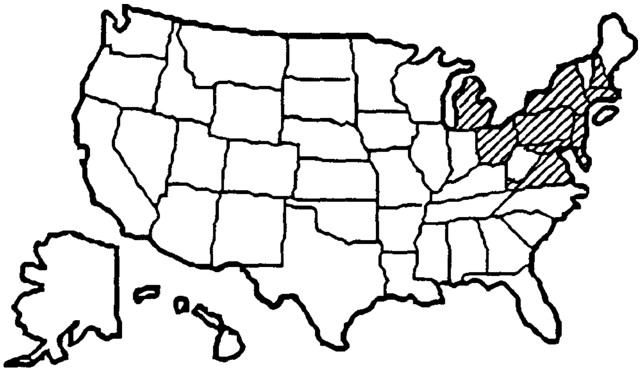


Figure 3.4-4, Geographic Concentration Modular Housing Production (1989)

More than other housing types, **modular housing is concentrated geographically among a few large manufacturers on the East Coast.** While the national market presence of modular housing has increased somewhat, geographic concentration has increased more dramatically. New England and the Mid-Atlantic markets have more than doubled, to more than 15,000 units per year. The South Atlantic and Midwest markets have been relatively constant. South Central and West markets have declined, and represent a very small fraction of modular production (Hallahan p. 11 and p. 12).

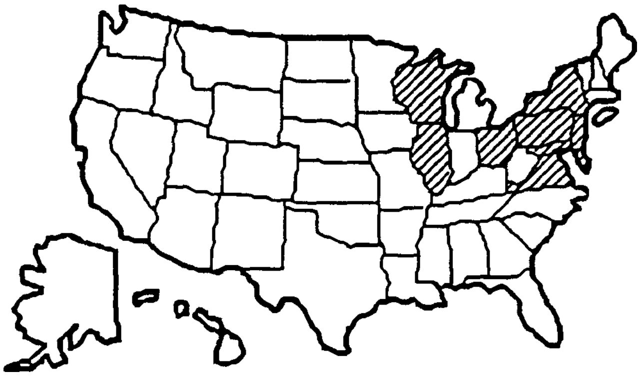


Figure 3.4-5, Geographic Concentration Panelized Manufacturers

The leading panelized housing manufacturers are located in the Mid Atlantic, Southeast and Midwest regions. According to Hallahan and LSI Systems, about half of panelized housing production is located along the East Coast with another one quarter located in East Northcentral states. While there has been a slight proportional shift from the Midwest to the East Coast, geographic concentration of panelized manufacturing has remained relatively constant, with the exception of West South Central states where there was a large proportional decline (Hallahan, 1989, p. 30). Mid-Atlantic and East North Central states sustained the only panelized manufacturing growth. Considerable growth was seen in Ohio, Pennsylvania, Virginia and Wisconsin. **Maryland has consistently been the most 'panelized' state,** although production has decreased slightly among builders with their own panel manufacturing capability (Hallahan, 1989, p. 32).

4.0 INDUSTRIALIZED HOUSING DESIGNS AND DESIGN PROCESS

This section reviews the nature of housing designs and the processes used to create them in the four industry segments. It concludes with a report on the use of computerized tools within the United States and Japan.

4.1 HUD CODE

HUD-code houses are marketed and sold, either with or without a lot, through a network of retail dealers and mobile home park operators who typically represent several manufacturers. Only a few manufacturers are large enough to create their own retail outlets. Unlike other segments of industrialized housing, the HUD code house is typically marketed inclusive of appliances and furniture. Units are usually offered at two or three price levels with varying size, design flexibility and amenity options. Prospective customers tour a display lot where current designs are shown. Customers electing to buy a house review and finalize options and arrange financing with a sales agent. Requested design adjustments, revisions or upgrades are noted on a plan and summarized on an order sheet, but plans are not customarily redrawn.

Large volume HUD code producers design prototype models at a centralized administrative office. Presentation and marketing drawings are prepared, assigned a model name or number and published in brochures for distribution. Production drawings and technical specifications are created, and most plants maintain working versions from which minor design or production changes are routinely made. Local plants and dealers report regularly to the centralized design office, commenting on local design and production, suggestions gleaned from customers, and observation of competitors' designs. From these reports, variations and modifications can be made to prototypes or new models commissioned.

Of the four segments, HUD code producers have the least design flexibility, because of the HUD code production process, transportation requirements, and regulations. With the exception of a reduction in number of interior walls and the subsequent possibility of larger, more open spaces in the plan, design refinement of the HUD code house has been more cosmetic than substantive. In recent years, manufacturers are increasingly finding themselves competing in a market that demands design flexibility and amenity. **These changes in HUD code marketing, design and manufacturing present a significant opportunity to incorporate site specific energy conserving design strategies and manufacturing procedures.**

4.2 MODULAR

In the U.S., modular houses are marketed through a combined dealer / builder network. Those marketed through dealers are sold individually to end users. Builders buy in quantity directly from manufacturers on a sub-contract or turnkey basis. Although potentially suited to being independent integrated housing companies, modular manufacturers are typically unaccustomed to acquiring land, financing, obtaining approvals, or marketing houses speculatively. They tend to collaborate with a developer or builder who may or may not use modular construction on other projects.

Although there is considerable variation among manufacturers, modular housing producers frequently have design and engineering capability within the company. Many plants work from a limited range of standardized plans for single family houses and custom designs for multifamily housing. Virtually every manufacturer maintains a plan book of standard models but encourages customers to pick and choose elements and features if standard models are not satisfactory. Recently, in multi-family and the higher end of market applications, developers bring architect designed projects to modular manufacturers, who then refine the design to their own production capability. Increasingly, the latter design strategy is becoming the norm.

While more flexible than HUD code, modular houses are also limited by module size, configuration, and other design limitations imposed by transportation requirements and regulations. Because units are stacked or placed side by side they must be overbuilt, resulting in duplication of floor, ceiling, or edge wall construction.

In Japan, there seem to be two primary types of sales locations for both panelized and modular builders: housing parks and sales offices. Housing parks are areas where several housing companies and smaller housing suppliers show their model homes. The parks visited ranged in size from 10 to more than 50 models. Sales offices are located in retailing areas within cities. Customers can walk in and be shown the various pictures, drawings of house models and options, and then develop a custom design for their own property, working with company sales personnel. Customer orders, whether developed at a park or at a sales office, are sent to the plant which supplies houses for that area. A large percentage of home sales seem to be to individual customers who own or are buying land. Few are sold to developers who speculate by selling completed homes on lots.

Sekisui Heim manufactures steel 3-dimensional modules with a maximum size of 5.6 m long x 2.46 m wide x 2.83 m high. These modules are clad with ceramic panels. The company has recently started building wood modules approximately the same size as its steel modules. Of Sekisui Heim's 26,000 unit sales, 90% are single family (they are the largest single family builder in Japan) and 10% apartments. Of the single family units, 90% are steel and 10% are wood modules.

Sekisui Heim's steel module production takes place in the most automated factory observed, where the **steel module framing is automatically positioned and welded.** The wood module production, on the other hand, is not automated significantly beyond that in the more advanced U.S. companies. Both module types are finished on an assembly line using methods similar to those found in the HUD code and modular manufacturers in the U.S. The modules are more than 90% complete when they leave the factory.

Misawa's newest product is a lightweight autoclaved panel (PALC) on a steel frame module (similar to Sekisui Heim). The steel frame and the concrete panels are produced on separate lines and then brought together for interior finishing, wiring, and plumbing. On the average there are 12 modules per house at about 100 sq. ft.. each. These are shipped to the site on six trucks. The crane is on the site for 2 to 3 hours and the roof is complete in 2 hours, for 5 to 6 total hours on the site.

4.3 PANELIZED

The following summarizes, for the United States, characteristics of "open" wood frame panelizers, the largest most technologically representative tier. The majority of panelized manufacturers market house shells to builders or developers who complete them with their own site construction forces. Fewer manufacturers market whole houses.

Panelized building systems are inherently flexible; therefore panel manufacturer are to some degree less restricted to standardized designs or models. Manufacturers, however, use a standard plan catalog of designs that can be customized to particular customers and applications. To the greatest extent possible, houses are designed in increments of a limited range of 'similar' panel components and sub-assembly placements. New designs and revisions to existing designs are initiated at a head office level in consultation with sales, marketing, finance and design personnel. The new design is created and refined to the level of manufacturing drawings and distributed to the plants that will ultimately produce it. While companies seek to build what the customer wants, they typically avoid major revisions or fully customized designs.

Panelizers have not yet been able to capitalize on the opportunity to add greater value and performance through the manufacturing process, and so considerable on-site construction is required to complete a house. The opportunity to factory integrate secondary components such as windows and doors precisely with walls, for example, has not been realized. Some companies however have managed to combine a well fabricated, energy conserving panel with quality installation procedures, andtherefore realized the opportunity to create a wide range of energy conserving houses of varying design, size and complexity.

In Sweden, each panel factory has a set of standard models that it produces. Virtually every standard plan is modified to some extent by customers to suit their needs. Designs are quite varied and offer a good range of choices of plan type, house form, and color. Exterior material choices are limited, with exterior siding being predominantly board on board solid wood material with clay tile roofing. Windows are triple glazed wood casement units.

In Denmark, composite concrete and wood panel systems are used to construct low rise, moderate density, multi-family housing. Composite construction systems are considered by the Danes to be less expensive, more energy efficient, and to produce a richer and more varied housing environment. **Concrete is used in interior applications where it can perform a thermal storage as well as structural role, while also reducing sound transmission between interior spaces.** Exterior infill wall panels are of wood frame construction, usually supplied by a "factory crafted wood" housing plant on sub-contract and built to the appropriate level of energy efficiency. Wall panels are unfinished -- both interior and exterior finish materials are site built.

In Japan, Sekisui House produces 60,000 units annually: 75% are apartments, and 25% single family. All the apartments and 90% of the single family units are steel frame with infill panels. The production of the lightweight steel frame and open panels is automated with some placing of materials in jigs by workers. The frame and panels are shipped to the site on four trucks, where it takes 90 days to assemble the house.

Misawa produces 40,000 units annually, of which 26,000 are single family. Of these 26,000, 90% are stressed skin wood panels. The stressed skin wood panel houses take about 40 days to assemble on site, where exterior finishes and roofing are applied.

4.4 PRODUCTION BUILDERS

Unlike other segments of industrialized housing, production builders do not typically market houses to order, but do so on speculation, and are thus very sensitive to consumer trends and changes. As a consequence, house size, character, and to a certain extent, form, are motivated by perceived market forces evaluated prior to design. In virtually all cases, production builders are also land developers who sell an integrated house and land package directly to the home buyer on a speculative basis. Units are typically constructed or partly constructed prior to sale. Model homes can be viewed on site.

Responsibility for design is centralized. Builders often have professional design staff and a traditional design process linked more directly to marketing than to production. Typically a few basic floor plans and elevations are designed and then varied for orientation, site conditions and owner requirements. Designs are sometimes standardized on a coordinated dimensional system.

Production builders have been successful at making the process of house building a flexible matrix of coordinated tasks and materials that they can quickly adjust to market, technological and economic conditions. They use industrialized materials, components, and processes when those products and processes perform better. As a consequence, **production builders are often the proving ground of innovative industrialized procedures and a litmus test for the components and materials ultimately adopted or adapted by the other three groups in the housing industry.**

4.5 COMPUTERIZATION OF THE DESIGN PROCESS

There is a multitude of software packages on the market for the general fields of architecture, building, construction, and manufacturing. Some of this software has potential for application within the field of industrialized housing. For example, software that incorporates estimating, materials and resource planning, and material lists is beginning to come into use because it gives housing manufacturers greater control over production costs earlier in the process. Project management and scheduling, integrated accounting, and marketing software give cost control to management in order to improve the efficiency of business operations.

Computerization in industrialized housing began with engineering software tools used primarily for component design and manufacture. This began with computer generated engineering calculations for truss design and progressed to automatic dimensional lumber cutting procedures and truss plate attachment.

Manufacturers have begun to computerize individual tasks in spite of incompatibilities in hardware and software, which inhibits the ability to data-share. A recent survey by Automated Builder magazine (June 1989) found that **61% of the panelized producers had CAD capabilities, with 24% of these also having CAM.**

In Japan, Misawa uses a laser disk system at its main dealerships to assist customers in selecting finishes and materials. The main menu items are: 1) exterior, 2) interior, 3) products, and 4) Misawa lifestyle images. Each main menu item has submenus. For example, the "interior" menu is divided into living room, Japanese room, children's room, kitchen, etc. Each of these room categories are illustrated with images of interior spaces. The Misawa sales person develops the plan on paper with the customer, using sample plans and photographs. Once the design has been developed it is loaded into the computer, using a tablet and stylus. The CAD system has a data base of Misawa products, so that when a wall is created the computer knows the specifications for the panels involved. The exterior walls are created by clicking on the module grid on the screen, using the stylus or a mouse, at the beginning and ending point of each wall. The system will check to see if floor panels have been mistakenly used for wall panels, etc. Interior room sizes and corridor widths are checked visually by the operator. The computer will print material lists and develop cost estimates for the customer.

Sekisui House is currently developing a computer system called SEPIAS which integrates the sales, design, and manufacturing process. This system is expected to be operational by 1991. In the SEPIAS system, initial drawings are developed at the sales office and a cost for the product quoted. These drawings are electronically sent to engineering where they are checked, modified, and then developed into manufacturing drawings. The step from architectural (sales) drawings to manufacturing drawings is expected to become highly automated. Once the drawings have been transferred to the factory they will be used for production control including direct input to machines, shipping control and buying control.

Drawings are updated as parts are acquired and produced and this information is relayed electronically to accounting and shipping. Some aspects of the SEPIAS system are currently operating.

We did not observe any Japanese computer systems that developed manufacturing data at the sales office, or that integrated structural design or energy design with drawings produced by a CAD system.

5.0 INDUSTRIALIZED HOUSING MANUFACTURING PROCESSES

United States

The industrialized housing industry is still based largely on a conventional site-built construction technology. The manufacturing process lacks any major process innovation. The efficiencies of labor use in an assembly line operation appear to be reasonably maximized, in that the amount of work performed by each person in the plant is far greater than what could be reasonably expected by a worker on a construction site. A typical manufacturing operation maintains between two week's and one month's supply of building materials at the plant. Home manufacturers justify this additional cost on the basis that it is offset by the cost benefits of volume purchasing of the materials, and by eliminating the vagaries of material delivery schedules.

HUD Code houses are built by unskilled laborers in a factory, assembly line fashion, from pre-approved floorplans and specifications. Most plants use a single main production spine with perpendicular subsidiary component assembly areas. Some plants employ two parallel production lines in order to test fit the "marriage" line of multiple section houses and correct misalignments on the factory floor.

Each HUD code house is constructed as a closed package with all plumbing and electrical equipment installed and inspected in the factory. The completed house section chassis is attached to a truck tractor unit and transported to the installation site. At the site, utility hook-ups and foundations have been prepared. The section is positioned, jacked, wheels are removed, and the unit gradually lowered onto the foundation.

Modular houses are manufactured in plants very similar to HUD code. Each module is constructed separately with all plumbing and electrical equipment installed and inspected in the factory. Completed house modules are lifted from the end of the assembly line by lift or crane and lowered onto a truck or transporter for shipment to the installation site. At the site, utility hook-ups and foundations have been prepared. The module is positioned by crane and gradually lowered into place, where it is connected to services and integrated with other modules.

Panel manufacturing plants are designed to produce panels rather than whole houses or parts of houses. Since the house assembly is not tested in the plant, considerable emphasis is placed on precision and quality control to minimize potential field installation problems.

Panels are manufactured individually and to order from a schedule of panels required to fabricate a specified house. A typical panel is hand framed on an adjustable jig with openings located and blocked for later installation. Exterior panels are then sheathed and fastened to the frame, usually by a stapling machine.

At the end of the production line, the panels, as well as other necessary components and materials, are gathered, sorted, and loaded onto an open trailer in the opposite order that they will be needed on the site. One trailer is frequently adequate to accommodate all the panels necessary to complete one single family house. The load is delivered to the site for panel installation and adjustment.

Production building occurs outdoors and is sequential in process. Separate construction trades follow one another through the site in a tightly scheduled linear sequence beginning with the foundation, then the floor, wall, and roof structures, envelope, doors and windows, and finally, finishes. Specific material and product selections are often fine-tuned or made in the field, based on availability and cost.

Production builders will purchase or subcontract for industrialized components to use in the field when appropriate. Many partially industrialize their production process and maintain their own panel and truss production facilities. Some sell the excess capacity of this panel or truss production to other builders.

Sweden

Swedish Factory Crafted (SFC) panel production technology is designed to produce exterior walls and floors. Roof trusses are similar in construction to those used in the U. S. and most wiring, plumbing and finished work is done in the field. Within this rather narrow range of industrialization, significant innovation has occurred.

SFC plants are highly automated but operate only one shift per day. Swedish labor laws make it virtually impossible to lay off workers, hence there is a considerable incentive for increasing production through improving worker productivity (Aho and Isacson, 1987). **The most recent innovations are the automated installation of insulation and a sheathing machine that fully automates sheathing including placing material, nailing and routing of panels for openings.**

SFC houses are required to have a 10 year unconditional warranty, with manufacturers held responsible for production defects over this period. Several plant managers stated that call-backs to repair faulty work are rare: less than 10% of all houses produced ever require any follow up service.

SFC plants have adopted the "just in time" inventory strategy for both suppliers and for production. Houses are built specifically for a customer on a presold basis. Suppliers of such products as windows, doors, cabinetry, etc., provide products on prearranged schedules generated from critical path scheduling of production capacity. Plants do not add shifts to provide more production. However, many plants are investing in additional plant capacity by adding production lines and increasing automation of parts of the production process that have been "under industrialized". Plant expansion has sought to increase capacity by improving worker productivity, thus using the same number of employees to produce more houses.

Japan

In Japan, once an order is received by a plant it is usually entered into a CAD system, which typically identifies all parts that are needed to produce the house. Material ordering, inventory, and shipping information are frequently computerized and usually have some level of interconnection with the CAD system.

Production is often highly automated, with each house being produced to individual order. The steel frame manufacturers employ various levels of robot welding and automated positioning of frames and modules as they move along the assembly line. Production of composite panels using steel frames and various facing materials, as well as autoclaved, lightweight concrete panels, are also highly automated. The assembly of panels on the frame is done by hand, in the field (Sekisui, Misawa) or on the assembly line (Sekisui Heim). The assembly line finish technique is similar to HUD code manufacturers in the U.S. The panels, 8'x8' or less, and the module, 10'x10'x10' or less, are smaller than their counterparts in the U.S. Houses are shipped to the site by truck, where installation is performed by company crews or independent contractors.

6.O INDUSTRIALIZED HOUSING AND ENERGY

Housing industrialization in the United States may result in increased energy efficiency, as it has in Sweden, or it may not, as in Japan. New research must be done to ensure that as U.S. housing becomes more industrialized, it also becomes more energy efficient. A strong foundation of new research will provide the information that the industry needs to exploit the energy efficiency opportunities that are unique to industrialization. It will also ensure that existing energy conservation strategies are modified to fit with industrialized production so that these strategies don't inhibit industrialization's potential to produce low cost, good quality, well designed housing.

Energy issues must be considered at all levels of the industrialized housing industry. In this section, we discuss six areas in which energy questions are especially pertinent:

1) climate
2) design
3) corporate structure
4) manufacturing
5) materials, components, and subassemblies
6) testing

6.1 CLIMATE

Climate is an important determinate of residential energy use. Energy conserving design strategies vary significantly with climate. In order to assess the importance of climate to energy conservation in industrialized housing, we looked at housing production and energy use by climate zone, as shown in Figure 6.1-1. We divided the U.S. into four climate zones: cool, temperate, hot-arid, and hot-humid.

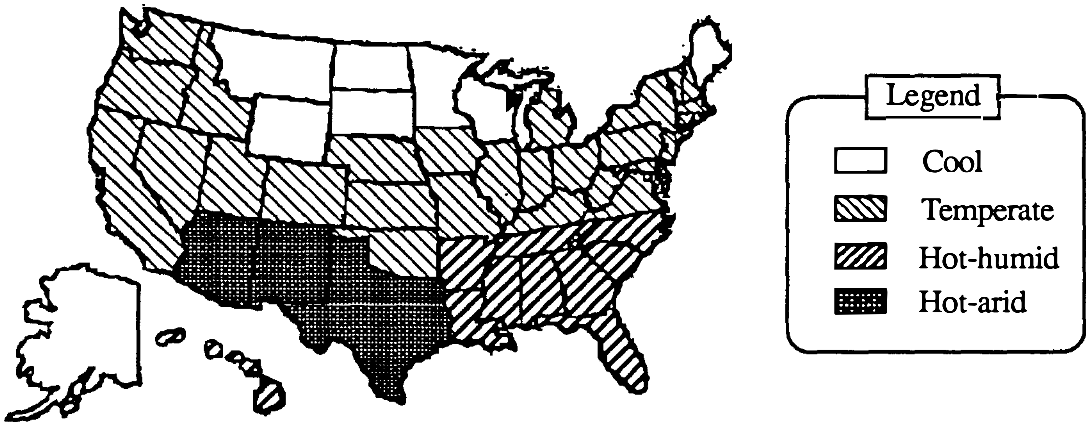


Figure 6.1-1, Climate Map

This map differs from its source (Drake, Solar Dwelling Design Concepts, 1977 p. 41) in identifying the entire states of California and Nevada as "temperate" regions --- a simplification responding to the fact that industrialized housing production figures are available only for entire states.

Total and per capita energy consumption figures are given in Figure 6.1-2.

Climate Region	Total Residential Energy Consumption, BTU's x 10^^{15} (quads)	Per Capita Residential Energy Consumption, BTU's x10^^{6}
Cool	934 (06%)	69.4
Temperate	10,229 (66%)	63.4
Hot-Arid	1,346 (09%)	61.5
Hot-Humid	3,069 (19%)	64.5

Figure 6.1-2, Climate Region Residential Energy Consumption -- 1987
source: EIA State Energy Data Report, 1987, p. 11

Two-thirds of U.S. residential energy consumption occurs in the temperate region, mainly because of its extensive area and large existing housing stock. Energy conservation strategies for retrofitting, therefore, are needed in this region. At the moment the temperate zone has the highest *number* of new housing starts, but the *rate* of new housing starts is highest in the Hot-Humid Southeast and in the western part of the Temperate zone. **In the future, then, national residential energy consumption patterns will very likely change. It will be as important to do research on energy efficiency for Hot-Humid climates as for Temperate climates.**

Climate	Housing Starts	
Cool	90,498	(06%)
Temperate	964,666	(60%)
Hot-Arid	116,137	(07%)
Hot-Humid	430,657	(27%)
Total	1,601,958	

Figure 6.1-3 Housing Starts - 1987
source: America's Changing Houses (LSI), 1988

As figure 6.1-4 shows, the production of houses by type is not uniform by climate zone.

Climate	Total Starts^	Production Type			
		Prod Built*	HUD Code^	Modular^	Panelized^
Cool	90,498 (06%)	69,444 (76%)	6,648 (07%)	2,207 (02%)	12,199 (13%)
Temperate	964,666 (60%)	772,280 (80%)	82,544 (09%)	40,429 (04%)	69,413 (07%)
Hot-Arid	116,137 (07%)	92,072 (79%)	17,944 (15%)	1,807 (02%)	4,314 (04%)
Hot-Humid	430,657 (27%)	272,765 (63%)	125,687 (29%)	6,264 (01%)	25,941 (06%)
	1,601,958	1,206,561	232,823	50,707	111,867

Table 6.1-4, Regional Industrialized Production -- 1987
^source data from America's Changing Houses (LSI), 1988
*taken here as all other starts

The most highly industrialized production types (HUD code, Modular, Panelized) dominate in different climatic regions:

Cool	Panelized houses
Temperate	Panelized and HUD code
Hot-Arid	HUD code
Hot-Humid	HUD code

From the manufacturers' perspective, the picture is different. Hot-Humid region sales are most important to HUD code producers, while Temperate Zone sales are most important for modular and panelized producers, even though they may not have the highest market share in that climate zone. **HUD code producers are therefore likely to be most interested in research that applies to Hot-Humid climates, while modular producers are most likely to be interested in climate research for Temperate zones.**

The climate suitability of each production type to particular zones is not necessarily matched by their popularity in those zones. Single wide HUD code houses, for example are most popular in hot-arid and hot-humid zones. The single wide is an ideal shape for cross ventilation in hot-humid zones, but its lightweight construction makes it difficult to incorporate the thermal mass which is desirable in hot-arid climates. Shading is important in both climates, but shipping dimension requirements all but eliminate overhangs.

6.2 DESIGN

HUD code

Many energy performance characteristics of the basic HUD code house form are established by transportation requirements. Typically these houses have a long and thin double loaded corridor plan with a relatively high surface to floor area ratio. This results in a higher heat loss coefficient per unit floor area.

Enclosure characteristics of HUD code houses observe minimum code standards, although this can vary in areas where utilities influence the market to request higher standards through incentive programs. Opening sizes and placements are determined at centralized design offices and only infrequently matched to regional climates or specific site orientations. Windows, doors and other installed components are selected at the plant on the basis of favorable cost, local distribution and service availability. Transportation height restrictions impose low roof pitches that allow little additional space for insulation, though recent innovations include 'flip-up' gable roofs with 3:12 or greater pitch. Overhangs and projections that offer shading are difficult to transport, but are sometimes applied on site.

The manufacturing process creates a number of continuous seams with inherent infiltration problems — floor to wall, marriage line along roof, walls and floors of sections. This potential energy problem is exacerbated by movement and vibration in transportation. Heating and plumbing services frequently installed in the floor are not insulated as well as possible. Unprotected material storage and the unskilled labor force common to HUD code manufacturers can pose quality control problems. Installation quality in particular varies from plant to plant, as does attention to installation procedures such as attachment of sections or checking of openings and seams that may have opened during transportation.

HUD code houses are commonly marketed and sold by retail dealers rather than developers or manufacturers and are rarely part of a comprehensive house and land package. Since they are typically installed on leased land, where tenure is uncertain, it is difficult to argue the life cycle value of energy improvements. Moreover, the small profit margins in the low end of the market occupied by many HUD code manufacturers leaves little opportunity for energy upgrades that increase costs.

Since energy conserving construction is frequently a function of quality, HUD code manufacturers may be convinced that energy conservation is also a means to the development of design and manufacturing procedures that result in a high quality, well constructed product.

Modular

Since all modular houses must comply with local codes, minimum energy standards are those prevailing where the house in installed. Design characteristics of modular houses also vary considerably with the size and number of modules as well as their method of connection. Modules can be stacked or aligned to reduce the exposed surface area of the house and the design adjusted to site opportunities. These decisions are left to the designer or developer, which are then drawn and specified for review by code authorities prior to manufacture.

Enclosure characteristics are also determined during design. Enhancements to code regulated standards are relatively easily accommodated and occasionally promoted in marketing. For example, many manufacturers offer more than one quality of window. Like HUD code houses, modular houses have potential infiltration problems along seams and marriage lines as well as considerable variation in installation quality. Some leakage problems and diminished insulation levels, however, can be alleviated by field insulating the interstitial space between modules.

Some manufacturers install electric resistance heaters instead of forced air systems to simplify field installation procedures and eliminate transportation damage to the heating system. With the exception of water heaters, appliances are selected on the basis of local service availability rather than energy efficiency. Heat pumps, if used, are typically added after installation by owners or installation contractors. Locations for heat pumps are roughed-in during manufacture.

Although the design portion of the production process is capable of adapting to regional climates and specific site conditions, manufacturing processes and transportation requirements frustrate opportunities to improve natural cooling or heating by passive means. **This production strategy can best conserve energy by regulating surface area and maintaining a tight, well insulated exterior envelope.**

Panelized

Panelized houses are typically built to prevailing regional energy codes, although some companies design and manufacture panels with higher efficiency levels. Design characteristics of panelized houses vary considerably with house size and method of panelization. The orientation, size and configuration characteristics of the house are established in standard plan catalogs at the marketing level of the company, with some refinement possible at the design stage.

Enclosure characteristics are also determined during design and enhancements to code regulated standards are relatively easily accommodated and occasionally promoted in marketing. Factory fabrication of panels does not necessarily produce a more energy efficient wall. The production strategy in and of itself produces many seams and joints in the enclosure that are susceptible to infiltration — a situation that is exacerbated by site adjustment and uneven fastening of panels by installation crews. Panels, doors and windows are factory framed but installed on site and insulation is cut and placed by hand, at best providing an opportunity to inspect and seal joints and penetrations against infiltration. **This opportunity is not taken consistently and the ultimate energy performance of a panelized house is subject to variation in installation skills and conditions.** Electrical and mechanical services are installed on site. The developer or end user usually chooses and installs major appliances.

Production Builders

Because production building tends to be applied to high numbers of houses on large tracts of undeveloped land, energy related decisions are made first and most significantly in the pre-design phase when the size, quality and approximate form of each house is determined. In later planning phases, the size, shape and orientation of lots establishes the orientation and proximity of houses. During the design phase, houses are placed on the site, their internal organization is established, the size and orientation of openings is decided, and basic construction characteristics such as the thickness of wall and roof cavities are established. Material, component and product decisions are often made in the field based on availability. Occupants often select appliances and secondary energy systems.

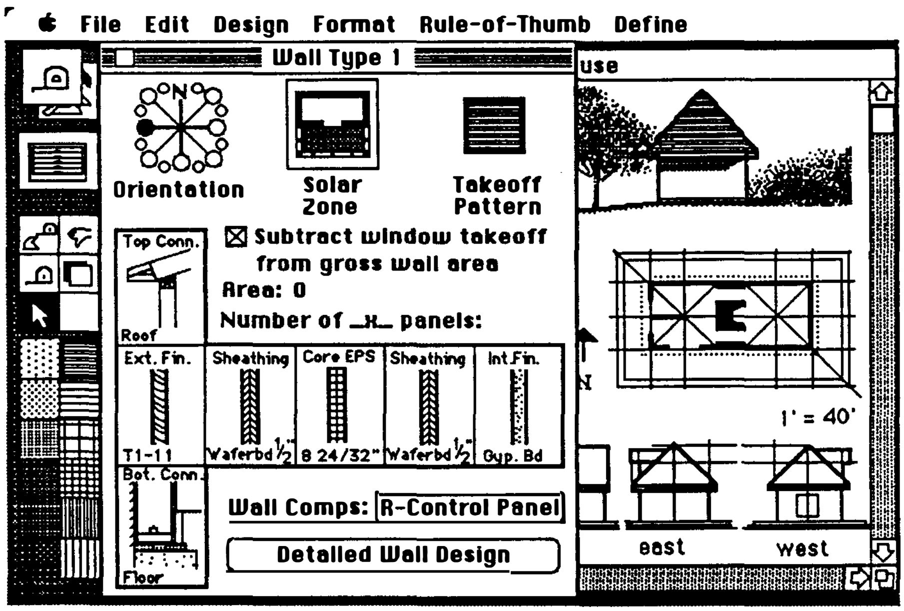
6.3 CORPORATE STRUCTURE

One potentially important way to differentiate between industrialized housing builders is corporate structure. It is an indication of who has control over design decisions which affect energy use. Once these key decision points are identified, we can determine what computerized design tools or other design aids are available to support these decisions, and how they should be improved.

We looked at energy decision-making from two perspectives: what design characteristics affect energy use, and how different industrialized housing types affect energy decisions. Design characteristics which affect energy use are: site, morphology, building fabric, equipment, construction methods, and operator/occupant preferences. Each category of industrialized house type category can be analyzed by corporate structure in a manner which reveals who makes energy decisions. For example, in terms of corporate structure, a large HUD code producer can be compared to a production builder on the basis of one decision -- siting. The HUD code producer has little control over the siting decisions, since s/he is at least two steps removed from the decision that is made by the purchaser. The manufacturer doesn't know in advance what the orientation of the unit will be, and therefore can't take advantage of either the sun for heating or the prevailing wind for ventilation cooling. It is easy to see why the manufacturer would opt for energy conservation strategies like insulation and reduced glazing area rather than for those strategies that are orientation dependent like solar heating or summer shading. By comparison, the production builder has more control of the siting decision. For example, in the case of a "spec" house, the builder makes the orientation decision him/herself. Design tools for the HUD manufacturer, then, might be directed at the dealer/customer (at least for siting issues) rather than at the manufacturer. Tools for the production builder, on the other hand, might be directed at the manufacturer/builder, with output that could be used as part of the sales process.

A Design Tool Example

We are developing a prototype computer design tool for a manufacturer who produces an energy efficient expanded polystyrene (EPS) core stress skin panel. This tool allows sales personnel to scan customer drawings into the computer, and then, using a graphic take-off method to do an energy analysis, create shop drawings, a bill of materials, and a cost estimate. This evaluation can be conducted at the customer's location by sales personnel during the preliminary stage, when people are just beginning to think about a house. This tool will help to increase manufacturers' sales by demonstrating the value of the energy features of their panel and its competitive cost when compared with 2x4 wall construction.



☒ Subtract window takeoff from gross wall area

Area: 0

Number of _x_ panels:

Wall Comps: R-Control Panel

Figure 6.3-1 Wall Specification Window

Figure 6.3-1 Shows a computer screen from this prototype design tool. The drawing in the background is a house which the user is evaluating to see how many wall panels would be required to build it. In the foreground, a wall specification window entitled "wall type one" is open. The wall specification window describes the orientation of the wall, its construction and the types of floor and roof assemblies to which the wall panels connect. The user could determine the number of panels in a wall by selecting the tape measure cursor from the palette on the left and using it to "take off" the wall by drawing a rectangle over the wall to be evaluated. The computer would then calculate the area of the wall and the number of panels needed to make the wall and displays that information in the center of the wall specification window. After the takeoff is complete, the computer has the information it needs to do an energy evaluation and to determine the materials needed to make the panels.

6.4 MANUFACTURING

The thermal performance of Swedish Factory Crafted (SFC) housing is extremely good due to a number of factors associated with the production of these houses. The thermal break wall system is very important to the high level of energy performance of SFC housing. Rubber gaskets around all wall openings and between floor-wall-roof systems greatly reduces infiltration. Advanced energy efficient heat pump technology also contributes to overall energy performance, as does residential heat exchange systems that utilize warm air return from heat producing elements such as cooking and hot water heating in the house. More advances are being made in window technology so that windows will not be an issue in heating system design, permitting the elimination of ducting or piping to exterior walls.

The most important technical advance which could have significant application to the U.S. energy efficient industrialized housing industry is the method of creating thermal breaks within building walls. SFC housing employs factory made wall framing members that virtually eliminate direct thermal contact between interior and exterior surfaces of the building wall. The energy efficient truss stud is a truly significant improvement to the thermal performance of wood frame construction. While a variety of hybrid studs are presently in use, the truss stud will probably become the dominant wall framing member in energy efficient industrialized housing because it is the most material efficient and can be "thickened" to accommodate increasing amounts of insulation. **The "truss stud" is too flimsy to be easily installed in the field, and therefore is a good example of energy efficiency that can be achieved only by industrial production.**

The newest industrialized process in SFC plants, designed and manufactured by Nordisk Karto in partnership with Myresjo Hus, **allows insulation to be automatically inserted into wall and floor panels.** Insulation materials are produced in sizes that fit the wall cavity width. These batts of insulation are inserted into the framing wall as panels move through the line. This system is not only very efficient, it also removes workers from a potentially hazardous environment working with rock wool or fiberglass materials.

While the mainstream of Japanese industrialized housing may not be energy efficient, some energy efficient houses are being built -- primarily using 2x4 construction. These techniques, borrowed from the U.S. and Canada, will become more interesting as the Japanese develop their own interpretations of the 2x4 system within a marketing context in which energy conservation is important. More innovative is the Japanese approach to the production of wood modules smaller than the average room dimension (Sekisui Heim). **The Japanese willingness to innovate, combined with their interest in energy efficient 2x4 wood construction, suggests that the Japanese will develop wood industrialization techniques that are energy efficient and also have application in the United States.**

A HUD code example

We looked in detail at one HUD code manufacturer's plant, and discovered several ways to increase the energy efficiency of the product without sacrificing manufacturing efficiency. We would expect that similar sets of recommendations could be made for most of the other plants we visit.

A through study of the different phases of the production process has revealed four opportunity areas for improving energy efficiency. These major areas are, in order of the greatest to the least beneficial increase in energy efficiency, 1) the roof systems, 2) air distribution systems, 3) floor systems, and 4) wall systems.

Roof Systems

Areas of low or no added cost energy improvements are: (a) roof radiant energy control, (b) roof ventilation, (c) air circulation, and (d) roof thermal insulation.

If a radiant barrier is installed in the roof system during construction, and is coupled with adequate roof ventilation, the peak cooling loads of the house can be cut by 9%. This can be accomplished by installing the presently utilized type of roof decking in the same manner, but with a radiant barrier material attached to the decking prior to its installation on to the roof trusses. The decking should be installed with the reflective face of the material facing the "attic space". The radiant barrier material could readily be stapled to the decking in the plant prior to the decking being placed and attached to the roof trusses at a cost of less than 12¢/sq. ft. Increasing the amount of air intake vents, increasing the amount of attic air exhaust vent area, and eliminating any conditions that might block air circulation will increase roof ventilation. Increasing the intake area can be accomplished by revising the perforated soffit vent used to increase the vent free area available, or by increasing the soffit overhang by one or two inches, which would allow increased vent free area with the same perforation configuration as presently used. Incorporating either of these two strategies should not result in any increases in labor or material cost.

Exhaust vent area can be increased through the installation of a continuous vent at the ridge of the unit. On a double wide unit, the ridge vent would be installed in the field in-lieu-of the ridge shingles, without requiring additional labor either in the plant or in the field. On single wide units which have a roof ridge configuration, the vent would be installed in the plant in place of ridge shingles. Installation of a continuous ridge vent typically requires less labor than ridge shingles in the same configuration. The additional cost to a home for the continuous ridge vent material is minimal.

Conditions that could prevent good circulation of air in the roof space were noted in the construction of some of the units. For example, the insulation that was being blown into the roof space was also being blown around and over the HVAC ducts. When the roof decking was subsequently placed on the trusses, the insulation at the ducts was compressed up against the decking, thus preventing circulation of air in those areas.

Roof thermal insulation installed in the homes consists of blow-in mineral wool insulation. The insulation is placed by an installer walking along one side of the unit on a scaffold with a nozzle attached to a remote blower. Since the insulation is usually blown in from only one side of the unit, any obstructions in the roof system (such as air distribution ducts), prevents proper placement of the insulation. This problem could be remedied by enabling the installer to walk around the entire unit.

Air Distribution Systems

Recent studies have shown that there is a potential for significant energy loss when conditioned air distribution systems are located outside the thermal envelope of the home. When either an air handler or the supply and/or return air ducts are located outside the conditioned space and a leak occurs in the air distribution system in the non-conditioned areas, the result can be a loss of over 50% of the total energy efficiency of the house. The design and placement of ducts within the conditioned space would eliminate the potential for such problems, since no energy wastes would then occur if a duct should leak within the conditioned space. Due to the design and configuration of the units being manufactured, routing of ducts inside the conditioned space of the units would not pose a problem. Ducts could be run above closets and cabinet spaces and along the side wall of bedrooms and similar spaces with a furred coffer to conceal the duct. Air distribution grilles would be wall rather than ceiling mounted, which would not disrupt the vaulted ceilings in the living room, dining room, or other spaces where this amenity is especially desirable. It would add only minimal cost to the unit, most of which would be in construction and installation of soffits to conceal ducts.

Locating air handlers within the conditioned space can greatly reduce the potential for energy waste. This can be accomplished by designing for split HVAC systems which will allow the air handler to be located inside the home. Compact air handlers of the required capacity are available, so that this option should not affect the usable area or layout of the homes. It would not be necessary for the manufacturer to install the air handler at the plant. All that is necessary is the air handler closet with supply and return air ducts in place, a chase for the refrigerant piping, and the electrical disconnect switch for the air handler. The actual installation of the HVAC system could be accomplished in the field. This strategy would add little or no additional cost.

Floor Systems

Three areas of opportunities for improving the energy efficiency of the homes are 1) side wall insulation, 2) floor plenum baffling or insulation improvement, and 3) hot water supply piping insulating.

The inclusion of floor space side-wall insulation can improve energy efficiency by reducing heat losses and heat gains around the floor perimeter. This can be accomplished by attaching batt insulation at the side-walls between joists prior to installation of the floor decking. The cost for additional labor and materials is minimal.

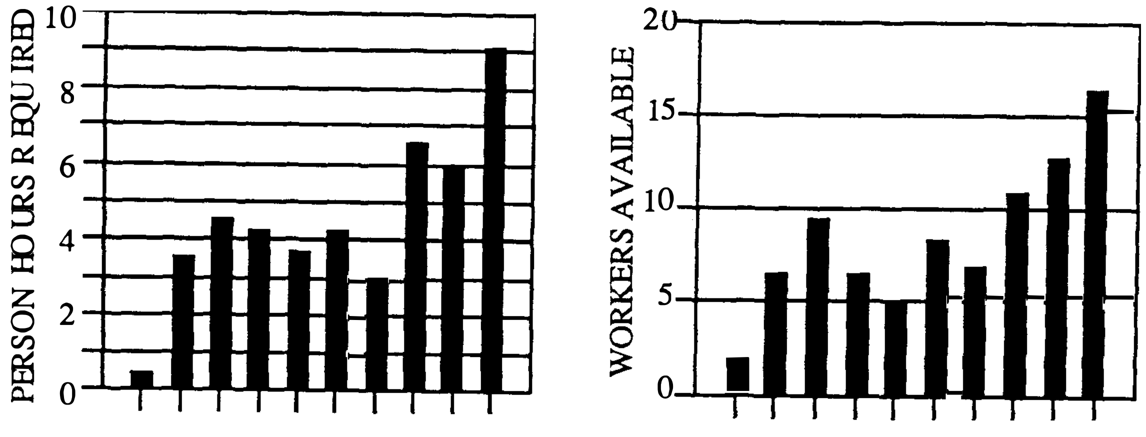
If the scrim cloth and insulation are torn anywhere under the floor during construction, air entering through the tear could circulate freely throughout the floor plenum. A simple way to eliminate this problem would be to staple the scrim and insulation to the underside of each of the joists, in effect baffling the space between each joist space individually. Then if an air leak occurs in one area of the floor, it is contained in that area. This strategy would require no additional materials, and add only a few minutes labor time for the additional stapling.

Wall Systems

There are two main opportunities to improve the thermal performance of the walls: 1) air infiltration/exfiltration reduction strategies, and 2) thermal insulation enhancements. These opportunities also occur in the floor and roof construction.

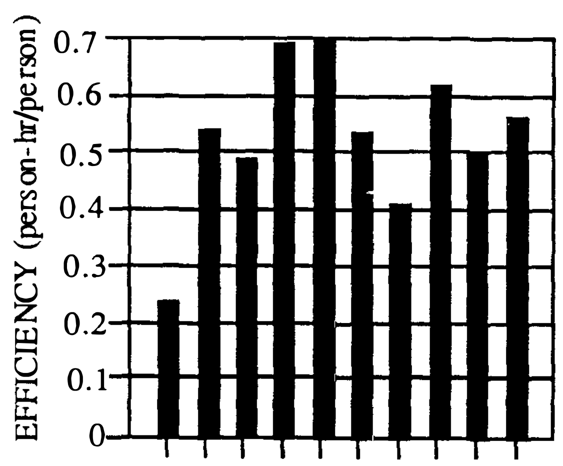
Manufacturing Process

We used the HUD code manufacturer to provide base line data that can be used to develop a generic simulation model. This model will be used to evaluate incremental changes to the manufacturing process that are needed to increase the energy efficiency of currently produced houses. It can also be used to evaluate the cost effectiveness of changes proposed to manufacturing processes for the 21st Century house. Without this information, manufacturers can not evaluate the cost effectiveness of proposed design changes intended to increase the energy efficiency of the house.



a. station number

b. station number



STATISTICS:
Total person-hr/unit = 44.5
Total workers = 81.96
Possible units/day = 14.1
Average efficiency = 52.6 %
Probable units/day at average efficiency = 7.4

KEY:

Station #1:	Truss fabrication
Station #2:	Chassis fabrication
Station #3:	Floor fabrication
Station #4:	Exterior wall frames
Station #5:	Interior wall frames
Station #6:	Wall installation
Station #7:	Roof frame
Station #8:	Roof finish
Station #9:	Exterior finish
Station #10:	Interior finish

Figure 6.4-1 Analysis of HUD code manufacturing plant requirements (a), resources (b) and efficiency (c) by station

The processes that take place in the manufacture of HUD code have a great deal in common with both modular and panelized manufacturing processes. A HUD code manufactured product can be viewed as a combination of modular and panelized housing types. All of the structural components are assembled in the factory. Components are prefabricated using a process that is almost identical to the one used by panelized builders.

Detailed time studies were conducted at each of the ten production work stations. Activities, number of personnel, and the manufacturing time required of the ten manufacturing stations were documented.

Figure 6.4-1 shows a graphical analysis of the data. Figure 6.4-1a shows the person hours required for one production unit (12'x60') and Figure 6.4-1b gives the available worker hours per station. The process efficiency can then be determined by the ratio of person-hour requirements to worker availability at each station. This data is shown in Figure 6.4-1c. This type of analysis pinpoints the work stations at which productivity can be improved. For example, there are opportunities in the roof finish station (#8) to improve the unit's energy efficiency by applying insulation more evenly. The analysis shows that station #8 is reasonably efficient already, so extra time spent at that station for this improvement will not slow the line. Instead, it will result in a higher quality and more energy efficient product.

6.5 MATERIALS, COMPONENTS, AND SUBASSEMBLIES

A number of products are being developed that have the potential to change the nature of materials, components, and processes used to manufacture houses.

Windows with very high R values and switchable glazings offer the potential for increased performance of industrialized housing because in addition to reducing heat loss, they have the potential to shade within the plane of the windows -- a feature that is important because of transportation size limits that currently make the addition of external shading devices difficult. Currently, the thermal weakspot of high performance windows is the frame. **Panel producers working with window manufacturers may have the potential to integrate the windows and the wall, thereby eliminating the frame and improving the window's thermal performance.**

There is continuing development of composite materials for wall, roof, and floor construction, such as glass fiber reinforced cement, magnesium oxyphosphate bonding of wood fibers, rye grass straw, and plastics to improve the performance of our traditional building materials. These factory made materials have the potential to increase energy efficiency, either when used in conjunction with other materials such as expanded polystyrene to make stress skin panels, or with materials which are inherently resistant to thermal transfer, as are some plastics formations. General Electric is currently publicizing the use of plastics in house production. We have developed a conceptual design for a plastic panel manufacturing facility for General Electric, and are exploring how this combination of material and production process could produce energy efficient designs. The GE manufacturing facility was designed to produce 2600 2500sq.ft. houses per year. It had a maximum capacity of 1000 panels per day, using three shifts working on two assembly lines -- one for wall panels, the others for roof, floor, and foundation panels. The plant is highly automated, electronically transferring data from design and engineering to automated equipment on the factory floor.

There are also a number of projects directed at developing improved heat pump systems. These systems, combined with improved control systems and "smart house" concepts, may increase the marketability of an industrially produced "wet mechanical cores" that can be used with modular, panelized, or production built houses.

6.6 TESTING

We have created three environments to test the energy performance of component assemblies and whole houses in the field and in the laboratory. 1) An artificial sky and 2) a boundary layer wind tunnel have been assembled and data collection equipment is being installed and calibrated. This equipment will be used to test models of proposed housing designs for daylighting and ventilation performance. 3) At our field test pad, we are currently testing two wall constructions -- a styrofoam and oriented strand board stressed skin panel, and a concrete and polystyrene stressed skin panel, for comparison to a baseline structure. These tests have been supported by material donations from manufacturers.

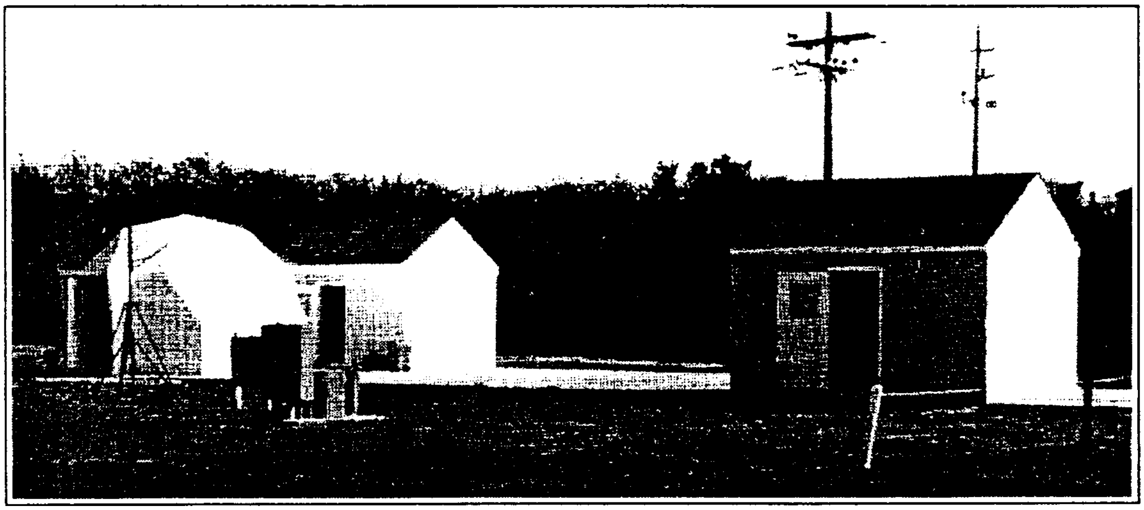


Figure 6.6-1 Test Houses

Most of the effort on these tasks went into construction of three small (approximately 200 sq. ft.) side-by-side structures. One is a conventional 2x4 structure with R-11 wall and R-19 attic insulation which will be used as the baseline structure, and which can be seen in the foreground, to the right on figure 6.6-1. The structure on the left, behind the dome, is made of styrofoam sandwich panels. In this construction scheme, wall and roof panels are made in the factory and shipped to the site for assembly. The panels were donated by

DOW Chemical Company, which is interested in seeing the energy performance of their product against the competition. They are also interested in knowing the shingle temperatures over their unvented roof panels. The third structure is a geodesic dome which was site erected out of innovative factory made triangular and rectangular panels. These R-28 panels have an expanded polystyrene core with a lightweight concrete shell. These are made by the American Ingenuity Co. of Melbourne, Florida, and were selected because of the potential energy efficiency and low cost of this housing system.

In 1989, 90% of the construction was completed on these structures. Instrumentation for the structures was also procured, and some calibration were completed . In 1990, instrument installation will be completed and cooling season performance will be monitored in the presence of typical occupancy loads.

7.0 MULTIYEAR PLAN

During FY1989 we developed a multi-year research plan in conjunction with an industry steering committee and representatives from US DOE.

7.1 GOAL

In this plan we identified our research goal, which is to develop new knowledge and technologies that will produce energy efficient, affordable, industrialized housing. We seek **to conduct research that will develop techniques to produce marketable industrialized housing that is 25% more energy efficient than the most stringent U.S. residential codes now require, and that costs less.** The designs and technologies developed through research will improve the quality and livability of housing, especially that of low and moderate income individuals. The new knowledge, capabilities, and designs resulting from this effort will be widely communicated to industry and to the public in an effort to promote their widespread adoption.

7.2 TASKS

We identified three areas of energy concern -- 1) energy conservation, 2) industrial production, and 3) housing design -- these established the scope and direction of the plan. Each area is critical to the overall success of the research effort.

The rate of energy consumption in houses is the consequence of interactions between location, design, quality of production, and patterns of use. Accordingly, this plan approaches the problem of energy efficiency in industrialized housing from an integrated point of view rather than one that isolates energy from design or production. A further advantage of undertaking energy efficiency research in conjunction with housing design and industrial process is that the energy knowledge, capability, and products acquired can be made accountable to the market and production criteria used by consumers and manufacturers.

In Figure 7.2-1, the major research areas are shown as circles, and the tasks as rectangles:

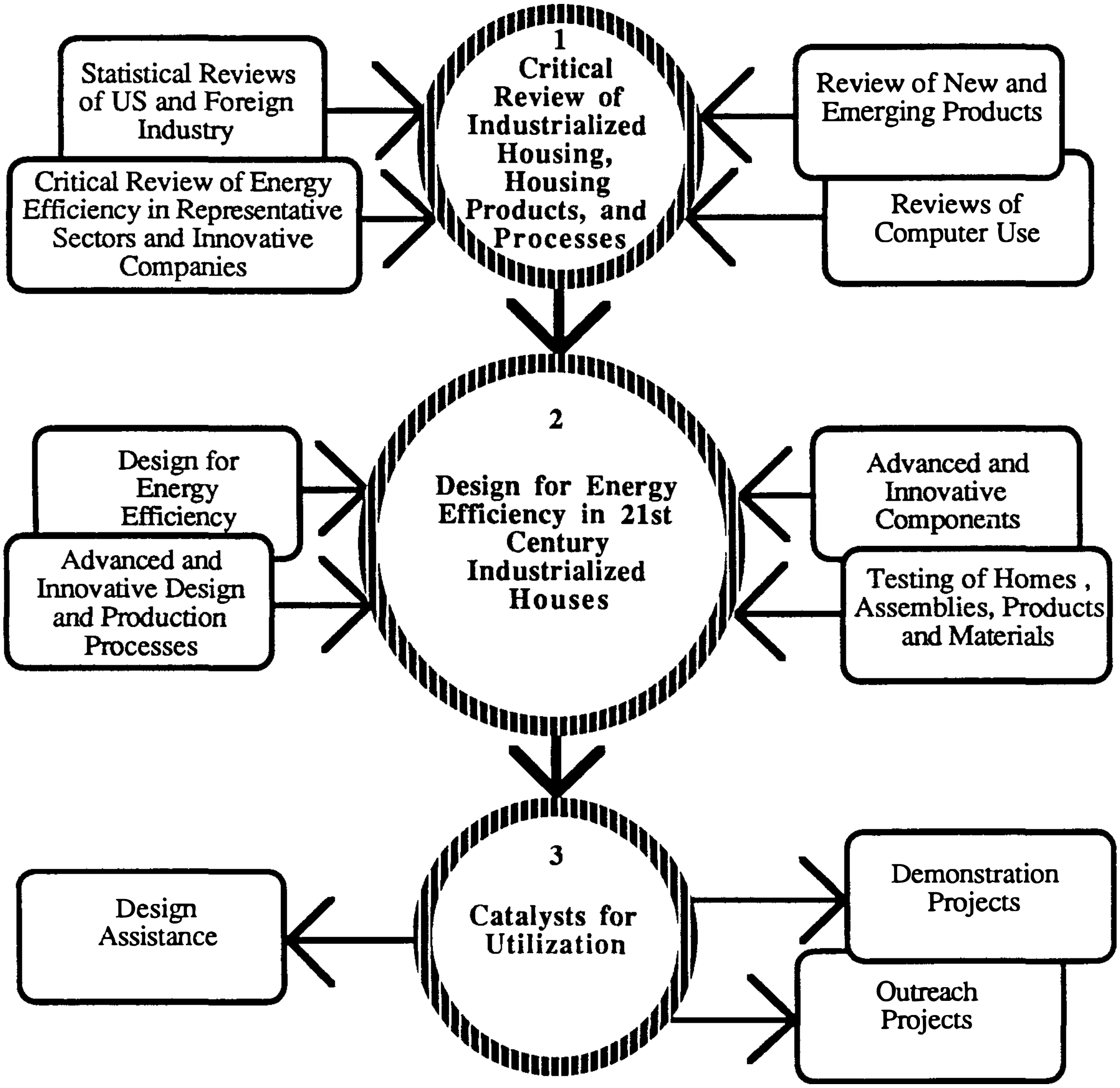


Figure 7.2-1

The research plan focuses on establishing a research base from which the housing industry will be able to develop and produce marketable, energy efficient houses through industrialization. To reach that goal, the plan is structured to investigate the interaction of these primary concerns -- energy, industrial process, and housing design -- within three key *research areas*: 1) Critical Review of Industrialized Housing, Housing Products and Processes, 2) Design for Energy Efficiency in 21st Century Industrialized Housing, and 3) Catalysts for Utilization. Each research area includes a number of *tasks* supporting the overall goal.

Area 1: Critical assessment of the industrialized housing industry, both domestic and foreign. Data from this research will be critical in the development of strategies for improving energy efficiency in U.S. industrialized housing. Research tasks include the following:

- Statistical reviews of U.S. and foreign industry data
- Site visits and process analyses of representative manufacturing plants
- Assessment of new and emerging products
- Reviews of the state of the art in computer use.

Area 2: Development of 21st century industrialized housing concepts. This element is the core of the research plan. It consists of research to develop advanced design, engineering, and production capabilities that are required to assure the future competitiveness of U.S. industrialized housing. Research tasks include:

- Develop software to increase the sophistication of energy design in industrialized housing. The software will be integrated with the house sales and manufacturing processes.
- Develop industrialized housing production process simulation software using existing factory simulation tools. This phase will identify bottlenecks and suggest improved manufacturing methods.
- Develop, through a cost shared government/industry collaboration, advanced and innovative components such as improved air distribution systems, integrated wet cores, and radiant barrier systems.
- Design, construct, and test energy efficient single and multi-family prototypes, optimized for industrialized production.
- Provide side-by-side field trials of small test structures using baseline and innovative construction systems, such as stressed skin sandwich panels and metal stud framing.
- Perform post-occupancy evaluations to validate test assumptions regarding occupancy, and assess market value and user perceptions of energy features.

Area 3: Development of catalysts for utilization of the designs and technologies of energy efficient industrialized housing. Design concepts and technologies developed by the program are meaningless unless they are put to use. This element will promote the use of the research findings. Direct industry involvement in the research through steering and technical committees will be of the utmost importance. Research tasks include:

- Provide design assistance to manufacturers, builders, and client groups.
- Develop housing demonstration projects in collaboration with industry.
- Develop an outreach program including reports, articles, newsletter, awards, and an annual conference for researchers and manufacturers.

8.0 ACKNOWLEDGEMENTS

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