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**ENERGY EFFICIENT INDUSTRIALIZED HOUSING
RESEARCH PROGRAM**

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**VOLUME 1
FY 1989 TASK REPORTS**

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ANALYSIS OF THE U.S. INDUSTRIALIZED HOUSING INDUSTRY

ASSESSMENT OF FOREIGN TECHNOLOGY

ASSESSMENT OF INDUSTRIALIZATION APPLICATIONS

COMPUTERIZED DESIGN AND EVALUATION TOOLS

**ASSESSMENT OF ENERGY PERFORMANCE OF BASELINE AND
ADVANCED INDUSTRIALIZED HOUSING CONCEPTS**

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CONTENTS

VOLUME I

1. **ABSTRACT**
2. **INTRODUCTION**
 - 2.1 Research Context
 - 2.2 Research Goals
 - 2.3 Overview of FY89 Research
 - 2.4 Project Team
 - 2.5 Industry Participation
 - 2.6 Project Funding
3. **ANALYSIS OF U.S. INDUSTRIALIZED HOUSING**
 - 3.1 Definitions and Characteristics of Industrializing Housing
 - 3.2 Statistics and Trends in Industrialized Housing
 - 3.3 Field Observations of HUD Code, Modular and Panelized Housing Manufacturers
 - 3.4 Case Study: Fleetwood Homes
 - 3.5 Current Status of Energy Efficiency
 - 3.6 U.S. and Foreign Building Codes
4. **ASSESSMENT OF FOREIGN TECHNOLOGY**
 - 4.1 Current Status of Design, Manufacturing, Marketing and Installation in Industrialized Housing in Sweden
 - 4.2 Current Status of Design, Manufacturing, Marketing and Installation in Industrialized Housing in Other Western and Northern European Countries
 - 4.3 Current Status of Design, Manufacturing, Marketing and Installation in Industrialized Housing in Japan
5. **ASSESSMENT OF INDUSTRIALIZATION APPLICATIONS**
 - 5.1 Statistical Analysis of Industrialized Housing Production by Climate Zone
 - 5.2 Climate Response of Industrialized Housing by Climate Region
 - 5.3 Analysis of Domestic and Foreign Industrialized Housing Costs and Energy Performance
 - 5.4 Towards 21st Century Manufacturing: the GE Plastics Panelizing Plant for the Future
 - 5.5 Emerging Components and Subsystems

produced by industry. Nine out of ten site-built homes, for example, use manufactured roof trusses. Industrialization has the potential to increase energy efficiency by utilizing factory production processes and materials that may not be usable or cost effective in the field. However, the U.S. housing industry is not pursuing research and development activities to improve energy efficiency through industrialized manufacturing processes. Their motivation for industrialization appears to be cost savings from volume purchasing and utilization of low wage labor.

b) *Many foreign industrialized housing companies use more advanced production processes and more energy efficient designs and components than do U.S. companies.* Some of these foreign companies are currently exporting to the U.S.; an increase in this process could threaten the U.S. housing industry.

c) *Demand for energy continues to escalate in the United States.* Reduced energy consumption in residential buildings, the focus of this research, is a cost effective way to make energy available for other uses and reduce the need for additional generating capacity and imported oil.

d) *United States building codes and standards impede technological innovation.* Local officials, often reluctant to support legitimate deviations from local practice, sometimes take highly individualistic approaches to code enforcement. Standardization and industrialization of materials, modules, and processes may expedite the development of uniform code and enforcement practices, encouraging progress in housing technology.

e) *The cost of home ownership has become prohibitive for many.* The percentage of average household income that must be allocated to purchase a house has increased, and the price of land as a percentage of total housing cost has increased dramatically (Hoben, 1987). The 1980's is the first decade since the depression in which the rate of home ownership declined. Housing and land costs are changing housing designs and presenting new opportunities and challenges for energy efficiency in industrialized housing production.

Industrialized Housing Definitions

Industrialization of new U.S. House production varies from modular builders who ship furnished houses to the site, to production builders who assemble factory produced components on the site. Industrialized housing can be divided into four major categories: modular houses, HUD-code

1.0 ABSTRACT

This document describes the research work completed in five areas in fiscal year 1989. 1) The analysis of the U.S. industrialized housing industry includes statistics, definitions, a case study, and a code analysis. 2) The assessment of foreign technology reviews the current status of design, manufacturing, marketing, and installation of industrialized housing primarily in Sweden and Japan. 3) Assessment of industrialization applications reviews housing production by climate zone, has a cost and energy comparison of Swedish and U.S. housing, and discusses future manufacturing processes and emerging components. 4) The state of computer use in the industry is described and a prototype design tool is discussed. 5) Side by side testing of industrialized housing systems is discussed.

2.0 INTRODUCTION S. Chandra

In fiscal year 1989, the Department of Energy began a multiyear research program to improve energy efficiency in industrialized housing. Congress appropriated \$700,000 for FY 1989. Two research centers share responsibility for this 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 complementary capabilities of these two organizations will provide the architectural, engineering, and industrial process expertise necessary to establish a successful research program. These institutions are committed to assuring that additional funding for this five year program is provided by non-DOE participants including private industry, state governments, and utilities. The program is guided by a steering committee composed of industry and government representatives.

This report summarizes the research conducted from November 1988 through December 1989, with the exception of the multiyear plan, which is described in a separate document.

2.1 RESEARCH CONTEXT

Two related challenges -- providing needed housing and conserving energy -- form the context for this work. In response, this research program seeks to address several issues of growing importance to the U.S.:

- a) *Housing construction is becoming increasingly industrialized.* The market share of HUD code, panelized, and modular builders continue to grow. Today their market share has grown to between 38% and 56% of all single family homes and low-rise apartments. Furthermore, more of the components used in site construction are

produced by industry. Nine out of ten site-built homes, for example, use manufactured roof trusses. Industrialization has the potential to increase energy efficiency by utilizing factory production processes and materials that may not be usable or cost effective in the field. However, the U.S. housing industry is not pursuing research and development activities to improve energy efficiency through industrialized manufacturing processes. Their motivation for industrialization appears to be cost savings from volume purchasing and utilization of low wage labor.

b) *Many foreign industrialized housing companies use more advanced production processes and more energy efficient designs and components than do U.S. companies.* Some of these foreign companies are currently exporting to the U.S.; an increase in this process could threaten the U.S. housing industry.

c) *Demand for energy continues to escalate in the United States.* Reduced energy consumption in residential buildings, the focus of this research, is a cost effective way to make energy available for other uses and reduce the need for additional generating capacity and imported oil.

d) *United States building codes and standards impede technological innovation.* Local officials, often reluctant to support legitimate deviations from local practice, sometimes take highly individualistic approaches to code enforcement. Standardization and industrialization of materials, modules, and processes may expedite the development of uniform code and enforcement practices, encouraging progress in housing technology.

e) *The cost of home ownership has become prohibitive for many.* The percentage of average household income that must be allocated to purchase a house has increased, and the price of land as a percentage of total housing cost has increased dramatically (Hoben, 1987). The 1980's is the first decade since the depression in which the rate of home ownership declined. Housing and land costs are changing, housing designs and presenting new opportunities and challenges for energy efficiency in industrialized housing production.

Industrialized Housing Definitions

Industrialization of new U.S. House production varies from modular builders who ship furnished houses to the site, to production builders who assemble factory produced components on the site. Industrialized housing can be divided into four major categories: modular houses, HUD-code

(mobile) homes, panelized houses, and production houses. There are many hybrids of these categories. The results of this research will be applicable to all forms of industrialization whether the homes are primarily built in the factory or on the site.

Modular houses are built at a factory and moved to a permanent foundation at a residential site. They may have three or four walls, the floor, and the ceiling in place. In some cases carpeting and drywall finishing is done on site. Modules may be stacked to make multi-story structures or attached in rows.

HUD-code (mobile) homes are the traditional U.S. factory produced houses. Unlike modulars they are subject to a national preemptive building code administered by the Department of Housing and Urban Development (HUD). HUD-code homes incorporate a frame on a chassis and wheels so they can be towed on the highway. HUD-code homes can be 100% finished in the factory. Once on site, the wheels and axles are usually detached and recycled to the factory.

Panelized houses arrive at the site as preconstructed wall, floor, and ceiling components that workers erect and join together. These panels may be either "open" or "closed." In open panel construction, all electrical and plumbing work as well as all code inspections are completed on site, as is most interior finishing. In closed panel systems, electrical and plumbing work is done at the factory and enclosed within panel surfaces. Interior and exterior finishes are also largely completed. Variants such as domes, precuts, and log homes have been included in the panelized category.

Production houses are usually built in large numbers on tracts near metropolitan centers. Because they use a large number of factory made components (trusses, plumbing cores, etc.,) and systematic management of construction sequences, their process is frequently referred to as "bringing the factory to the site." Small scale site builders who may use only one or two industrialized products like roof trusses or windows have been included in the production builder category.

Roughly 1000 companies now manufacture houses in the U.S. at over 1000 locations. Plant capacities can be as great as 4,000-5,000 units annually. The process used in most factories, however, resembles traditional wood-frame construction brought indoors. The design, raw materials, and construction sequencing are closely modeled on the "site building" approach. This is largely intentional and is used for marketing the homes to customers. The economic advantages of industrialization are underused. The primary economic benefit is achieved by using less skilled labor, purchasing large volumes of raw materials, using building components, and shortening construction time.

Japanese industrialized housing companies are much more automated than their American counterparts. They have applied new technologies to home building as they did to the production of cars and other consumer products. Japanese manufacturing uses different levels of automation, depending on what is needed to solve particular production problems. When the demand for homes exceeds the capacity of a firm's employees, the firm introduces high-tech production techniques to maintain a balance between its commitment to staff and its production requirements.

The Scandinavians have a highly evolved system for producing manufactured housing that results in lower initial unit costs and reduced energy consumption. Factory-crafted houses that cost 25%-40% less to build than their site-built counterparts dominate Scandinavian housing markets.

2.2 RESEARCH GOAL

The goal of this research project is to develop new knowledge and technology that will produce energy efficient, affordable, and marketable industrialized housing. Housing that is 25% more energy efficient than the strictest U.S. residential codes require, yet less costly than current homes. The designs and technologies developed will improve the quality and livability of housing, especially that of low and moderate income individuals. The new knowledge, capability and designs resulting from this effort will be widely communicated to industry and the public to promote its utilization.

This goal will be reached by pursuing three major approaches:

- a) ***Develop and improve new ideas for design, construction, materials, and components of energy efficient industrialized housing.*** The quality of design is particularly important for achieving both energy efficiency and market acceptance. Consumers often assume that the quality of industrialized housing is comparable to that of low quality mobile homes, the type of manufactured housing with which they are most familiar. Any new industrialized housing must be designed to be responsive to climate and regional house form traditions, and be attractive to consumers. Unless these houses attract consumers, their energy savings will remain theoretical.
- b) ***Improve the industrialized process used by the housing industry.*** Currently, industrialized housing in the U.S. is largely site-built housing that is constructed under a roof to protect it from the elements. The Office of Technology Assessment (OTA, 1986) has noted, however, that advanced "manufacturing technologies, including a variety of numerically controlled production systems, which have been developed for other manufacturing industries. . . could be adapted for use in factory and field housing

construction". At present, these technologies are not employed by the U.S. industrialized housing community.

- c) *Work with the building industry on research that would not otherwise be attempted.* Responsibility for housing research tends to fall to the federal government because even the largest housing firms cannot or do not conduct basic research. The OTA notes that the federal government "does support such research in health and agriculture, both of which are based on small establishments that lack the resources to conduct independent research". The positive response of the Program Steering Committee has shown that industry is interested in pursuing joint research activities.

2.3 OVERVIEW OF RESEARCH TASKS

This five year research project is organized around three major research and technology utilization elements. Following the five year overview, a summary of research performed in FY'89 is provided.

Overview of 5 year Research Elements

Critical assessment of the industrialized housing industry, both domestic and foreign. This element of the research plan is basic. Data from this research will be critical in the development of strategies for improving energy efficiency in U.S. industrialized housing. Approximately 60% of the first two year's effort and 10% of the next three years' effort will be devoted to these tasks. 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

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. About 30% of the first two years' and 60% of the remaining years' efforts will be devoted to these tasks. These research tasks are included:

- 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 a "modular language" for design and construction. This language consists of a set of rules and protocols which permits flexibility in design yet enables low cost automated design and manufacturing processes.
- 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.

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. About 10% of the first two years' and 30% of the next three years' work will be devoted to these tasks, including the following:

- Provide design assistance to manufacturers, builders, and clients 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.

2.4. OVERVIEW OF FY89 RESEARCH

Analysis of the U.S. Industrialized Housing Industry (Chapter 3)

A thorough literature review, site visits to over 30 manufacturing facilities, visits and telephone conversations with industry leaders formed the foundation of this task.

Different sources of data on industry statistics were reviewed and the data summarized to identify historical and regional trends in the industrialized housing industry. The salient features of each industry segments were identified and contrasted with each other. This was followed by an assessment of existing shortcomings in the energy area.

Fleetwood Industries, a typical HUD code producer, generously opened its doors and let the project team study their design office (in Riverside, CA) and a manufacturing facility (in Haines City, FL). A considerable effort was made to perform an industrial engineering assessment of the production processes and the energy features. Preliminary recommendations were developed in each area.

Finally a short assessment is made of U.S. Building Codes and how they impact industrialized housing.

Assessment of Foreign Technology (Chapter 4)

Site visits and literature reviews were conducted of industrialized housing in Sweden, other western and north European countries and in Japan.

The current status of design, manufacturing, marketing and installation of industrialized housing in these countries were assessed. The points of similarity and departure were identified. The applicability of foreign technology, areas of cooperative research and export possibilities for U.S. technology were assessed in the areas of energy efficiency and housing.

Assessment of Industrialization Applications (Chapter 5)

This chapter is composed of five disparate parts. The first, a statistical analysis of industrialized housing by climate zone, characterizes production in terms of climate zone so that matches between production types and energy conservation strategies can be identified. The second part identifies the climate implications for industrialized housing at several levels: siting and orientation, configuration, envelope, openings, and equipment. The third section compares the cost and energy performance of U.S. and Swedish factory crafted housing. The fourth part is a study conducted for GE Plastics. This study defined a futuristic manufacturing factory for a panelized plant. This plant accepts large (8 ft x 40 ft) multifunction panels made out of plastic composites. These large panels are cut to size, doors and windows installed in them by automated production machinery. The panels are then shipped to site for site construction. The final part identifies emerging component concepts and prototypes in order to determine how they might be used to increase energy efficiency in industrialized housing.

Computerized Design and Evaluation Tools (Chapter 6)

This task began with an evaluation of computerized tools used by industrialized housing manufacturers. Included are a taxonomy of software types and a description of where tools are used in the U.S. and Japanese industries. We also began an analysis of the energy decisions making process. A prototype tool under development for a stress skinned EPS core panel is also described.

Assessment of Energy Performance of Baseline and Advanced Industrialized Housing Concepts (Chapter 7)

Three testing activities were initiated in FY89:

1. Side-by-side testing of small prototype structures at FSEC
2. Calibration of artificial sky at Oregon
3. Assembly of wind tunnel at Oregon.

In the side-by-side testing activity three small (approximately 200 sq ft) structures have been constructed. These are: 1) a conventional 2 x 4 structure; 2) a structure made of factory-made panels consisting of styrofoam (R) sandwiched between two sheets of oriented strandboard. These panels were donated by DOW-Chemical; 3) A geodesic dome system composed of 7 inches of expanded polystyrene foam panels with an exterior concrete coating, made by American Ingenuity. The test plan is to test the cooling performance of the two energy efficient factory made panelized structures to that of the conventional structure. This testing will be performed in 1990.

2.5 Project Team

The prime contractor for the project is the Center for Housing Innovation (CHI) at the University of Oregon. The Florida Solar Energy Center (FSEC) is a major subcontractor to CHI. FSEC is assisted by the Department of Industrial Engineering of the University of Central Florida (UCFIE) in the manufacturing process analysis task.

The Center for Housing Innovation is a research institute within the University of Oregon and reports directly to the Vice President for Research. The University has nearly 1000 full time faculty, more than 600 part time faculty members, and 1500 graduate teaching and research assistants to serve 18,000 undergraduate and graduate students. In the past year faculty members and students engaged in active research programs have secured for the University \$62.7 million in research grants.

The Center for Housing Innovation is a multidisciplinary group. Its members are nationally

recognized for housing design and research. Members of the staff have completed award-winning housing projects for both public and private clients. Innovative projects have also been carried out in Puerto Rico, Mexico, Colombia, Israel, Jordan, and Turkey. Careful attention to climate and energy consumption has been characteristic of all this work. This experience is invaluable in the design of housing that has market acceptability in both domestic and foreign locations, which is vital for improving the competitiveness of the U.S. housing industry.

Faculty from the Center, along with colleagues from the Oregon Solar Energy Center are nationally recognized for the work in computerized design tools, energy efficient design methods, daylighting, solar heating and cooling, and energy efficient building design.

FSEC is an off-campus research institute of the state university system of Florida and is administered by the University of Central Florida. FSEC has an annual budget of approximately \$6 million and a staff of over 100. FSEC conducts research and technology transfer activities in a variety of building and solar energy areas including research on radiant barriers, moisture adsorption and desorption in buildings, ventilative cooling, air-conditioning systems, demand-side management technologies, photovoltaics, hydrogen and power electronics applications.

FSEC is nationally known for its innovative buildings research, especially in the areas of radiant barriers, moisture and air distribution systems. FSEC researchers serve on ASHRAE and ASTM committees and have attracted over \$6,000,000 in buildings related funding in the last five years from government, utilities and private industry.

The industrial engineering department at UCF has substantial research experience. Its \$1.2 million research budget ranks 4th nationally in research per faculty and 8th nationally in total funded research. Inclusion of industrial engineering (IE) expertise serves to complement the design and energy expertise of CHI and FSEC. This IE expertise is crucial to the success of the project as many improvements in cost and quality can result from improved manufacturing processes.

2.5 Industry Participation

The project has attracted strong industry support and involvement. Senior managers from Acorn Structures, BBH Enterprises, Charles Wayne Group, Fleetwood, GE Plastics and Weyerhaeuser participated on the project steering committee. American Ingenuity and DOW Chemical have cost shared in the construction of test structures. Fleetwood has given complete access to perform an industrial engineering study of its manufacturing process in a Florida plant and to meet with their designers in California. GE Plastics has established a strong working relationship with the project

team and has provided funding to the UCF Industrial Engineering Department to design a prototype industrialized housing plant of the future. In addition, a grant was received from Bohemia Corporation to investigate glulam applications in buildings, and discussions have been held with AFM Corporation to assist in development of design tools for stress skin panels.

2.6 Project Funding

Table 2-1 below shows the funding for the project for FY88, 89 and 90. The FY90 funding numbers are estimates. Table 2-2 below shows the funding from industry in FY89.

Source	Fiscal Year		
	1988	1989	1990
DOE	0	\$630,000.	\$737,000.
States of Oregon and Florida	\$100,000.	\$230,000.	\$300,000.
Industry & Others	0	\$ 68,600.	\$100,000.
Totals	\$100,000.	\$928,600.	\$1,137,000.

Table 2-1
Project Funding

Steering Committee Participation	\$15,000.
Donation of Time and Materials for IH Structures	
DOW Chemical	\$10,000.
American Ingenuity	4,000. 14,000.
Grant from GE Plastics	10,000.
Grant from Oregon Community Foundation	19,000.
Grant from Bohemia Corporation	10,600.
Total, Industry	\$68,600.

Table 2-2
Project Co-Funding From Industry in FY89

3.0 ANALYSIS OF U.S. INDUSTRIALIZED HOUSING

Work completed in FY 89 under this task area reviewed the current status of industrialization in U.S. housing. The industry's scope, production, circumstances and characteristics were reviewed to assess conditions and research opportunities to improve energy efficiency. Five parallel investigations of varying scope, detail and methodology were undertaken.

The first was a review of the principal segments of industrialized housing in the U.S. Section 3.1 Definition and Characteristics of Industry Segments defines and summarizes the design, production and marketing processes of HUD code, modular, panelized and production builder industry segments. This information is gathered through observation of representative manufacturing plants in each segment, supplemented by reviews of literature and reports. Conclusions focus on characteristics of each segment's house and production process that affect energy performance.

Section 3.2 Statistics and Trends in Industrialized Housing reviewed existing industry data collected by LSI Systems Inc., Leo Shapiro and Associates, and Hallahan Associates. Following an introduction to the purpose and methodologies of each data collector, this section summarizes the size and composition of each segment of the industry, identifying trends that may influence energy efficiency of its houses.

The foregoing general analysis of industry segments was augmented by a series of comprehensive field analyses. Representative companies were selected, visited and analyzed to gain a detailed understanding of their particular manufacturing, design and marketing procedures. Section 3.3 Field Observations of HUD code, Modular and Panelized Housing Manufacturers, reports on the status of tools and manufacturing methods, facilities planning, quality control, computer usage, inventory control, distribution systems, marketing, installation, labor and economic factors concluded from these field analyses.

One HUD Code manufacturer was studied more extensively and in greater detail. Section 3.4 Case Study: Fleetwood Homes, presents a sustained field examination of Fleetwood's marketing, design and manufacturing processes. This analysis concludes with specific recommendations to improve the energy efficiency, manufacturing and design of its houses.

Section 3.5 Current Status of Energy Efficiency reviews and summarizes significant energy efficiency shortfalls and variations gleaned from site visits and field analyses. The last section, 3.6 United States and Foreign Building Codes, examines regulatory issues and barriers affecting innovation and energy efficiency in industrialized housing.

3.1 INDUSTRIALIZED HOUSING -- DEFINITIONS AND CHARACTERISTICS

R. Kellett

3.1.1 HUD Code

Figure 3.1-1
HUD Code House

Definition: 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 (implemented in 1976). Each unit is manufactured and towed on its own chassis, connected to a foundation and utilities. A HUD code house can consist of one or more units shipped separately but designed to be joined into one unit. Individual units and parts of units may be folded, collapsed or telescoped when shipped.

Applications:

HUD code houses are designed, manufactured and marketed as three dimensional modules to create single, double, and triple-wide detached single family units one story in height. Floor areas typically range from approximately 950 sf for single wides to 1,300 - 1,800 sf for double wides and 1,100 - 2,500 sf for triple wides. Maximum module size is established by state transportation regulations, typically 14' wide, 14' high and 60' long. The HUD code house has traditionally been a low end market product sold complete with furnishings, and is popular among first time home buyers. Prices start at approximately \$30,000.

Representative Companies:

The nation's highest volume HUD code manufacturer is Fleetwood Enterprises of Riverside CA, one of the largest house building companies in the country with annual sales over \$1 billion. In 1988, Fleetwood produced 36,700 floors (16 % of total HUD code production) in 26 plants throughout the country (Automated Builder, October 1989, p. 40). Other large manufacturer's include Skyline Corporation of Elkhart IN (22,064 floors), Redman Homes of Dallas, TX (22,933 floors) and Champion Enterprises of Dryden, MI (13,519).

Market / Design / Manufacturing Synopsis:

Marketing:

HUD-code houses are marketed and sold 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. The overwhelming majority of HUD code houses are marketed without a lot, legally classified as personal property and financed with conditional sales contracts much like an automobile or major appliance purchase. When marketed with a lot, the HUD code house is real property that can be financed through long term mortgage instruments including FHA programs.

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 can be shown. Customers electing to buy a house review and finalize options as well as financing with a sales agent. Requested design adjustments, revisions or upgrades are noted on a plan and summarized on an order sheet. Plans are not redrawn.

Design:

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 to dealers and plants. Production drawings and technical specifications are created for distribution to plants and most maintain working versions from which minor design or production changes can be made. Plants and dealers report local design and production feedback comments and suggestions gleaned from customers and observation of competitors to the centralized design office. From these reports, variations and modifications can be made to prototypes or new models commissioned.

Manufacturing:

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.

and 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 modules; checking of openings and seams that may have opened during transportation.

Assessment:

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 HUD code houses are typically installed on leased land, it is difficult to argue the life cycle value of energy improvements when tenure is uncertain. Moreover, the low profit margins in the traditional low end of market niche met by many HUD code manufacturers leaves little opportunity for energy upgrades that increase costs.

Arguably, the considerable cost advantage of HUD code houses cannot be attributed to industrialization. It is instead attributable to certain material purchasing advantages and the substitution of unskilled labor trained to execute a discrete low technology task for more adaptable skilled labor or automation. Attempts to substitute technology or automation for unskilled labor have been fraught with difficulty. [Robinson 1988 p.5-10] As a consequence, design changes and manufacturing innovations motivated by market or energy considerations involve retraining and are costly, time consuming and cumbersome to achieve.

HUD code production process, transportation requirements and regulations permit the least design flexibility of the four industrialized segments. With the exception of a reduction in 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. Pressure to become flexible in design led to the opening of the plan and has more recently led to other marketing and production innovations. Such innovations include better interior plan choice and flexibility [Automated Builder, July 1988, p. 38]; a hybrid of HUD code interior and shell with site finished exterior [Automated Builder, November 1987, p. 40 and October 1989, p. 28] and house with land developments [Builder, February 1989, p. 60]. A significant opportunity is presented by these changes in HUD code marketing, design and manufacturing to incorporate site specific energy conserving design strategies and manufacturing procedures.

Finally, the inherited image of a poorly built mobile home has been difficult to overcome and market perception of the HUD code house continues to be negative. [Builder, February 1989, p. 58] As a consequence, HUD code houses remain primarily the choice of low income buyers just entering or leaving the housing market and rarely a second purchase choice given other alternatives. Energy

example is typically 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.

Unless specifically directed otherwise 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 national design offices and infrequently tuned 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 field applied.

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

	PREDESIGN	DESIGN	MANUFACTURE	INSTALL'N
DESIGN CHARACTERISTICS				
Size	X			
Configuration		X		
Interior layout		X	X	
Site orientation				X
ENCLOSURE CHARACTERISTICS				
Walls		X	X	
Floors	X			
Roofs		X	X	
Openings				
Location / size		X		
Product / installation			X	
SERVICES				
Electrical and mechanical				
System engineering		X		
Product / installation			X	
Appliances	X		X	

Table 3.1-1
Location of Energy Related Decisions
By Production Phase
HUD Code Manufacturer

and 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 modules; checking of openings and seams that may have opened during transportation.

Assessment:

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 HUD code houses are typically installed on leased land, it is difficult to argue the life cycle value of energy improvements when tenure is uncertain. Moreover, the low profit margins in the traditional low end of market niche met by many HUD code manufacturers leaves little opportunity for energy upgrades that increase costs.

Arguably, the considerable cost advantage of HUD code houses cannot be attributed to industrialization. It is instead attributable to certain material purchasing advantages and the substitution of unskilled labor trained to execute a discrete low technology task for more adaptable skilled labor or automation. Attempts to substitute technology or automation for unskilled labor have been fraught with difficulty. [Robinson 1988 p.5-10] As a consequence, design changes and manufacturing innovations motivated by market or energy considerations involve retraining and are costly, time consuming and cumbersome to achieve.

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Finally, the inherited image of a poorly built mobile home has been difficult to overcome and market perception of the HUD code house continues to be negative. [Builder, February 1989, p. 58] As a consequence, HUD code houses remain primarily the choice of low income buyers just entering or leaving the housing market and rarely a second purchase choice given other alternatives. Energy

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

3.1.2 Modular

Figure 3.1-3
Modular House

Definition:

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.

Applications:

Modular manufacturing is applied to both single family and multi-family housing. Modular design and construction is somewhat flexible. Modules can vary significantly in size from 12' - 14' in width to 24' - 60' in length and can be stacked, cantilevered, placed side by side or otherwise configured into one to three story buildings. Most houses are built from 2, 3 or 4 modules, although some luxury applications have required as many as 14. In addition to single family houses, modular construction is applied to condominiums, apartments, offices, motels and other commercial buildings. There is considerable variation in size, appearance, quality, design sophistication and accordingly, cost.

Representative Companies:

In 1987, the top ten modular builders built approximately 20,500 houses. In 1987, the segment was dominated by one large manufacturer Cardinal Industries, Columbus, Ohio producer of approximately 1/4 of the modular market share. Since then Cardinal has been forced into bankruptcy. Other major modular manufacturers in 1987 included Spear's Engineering of

Richmond, Virginia, producing 2,250 units. Muncy Homes, of Muncy Pennsylvania, producing 2,000 units; and Ryland Modular Homes of Columbia, Maryland, producing 1950 units (LSI Systems, 1988 p.vii).

Marketing, Design and Manufacturing Synopsis:

Marketing:

Modular houses are marketed through a combined dealer / builder network. Those marketed through dealers are sold individually to end users. Those marketed to builders are sold in quantity directly to builders on a sub-contract or turnkey basis. Although potentially suited to being independent integrated housing companies, modular manufacturers are typically (there are important exceptions, i.e. Benchmark) unaccustomed to acquiring land, financing, regulatory approvals or marketing houses speculatively and collaborate with a developer or builder who may or may not use modular construction on other projects.

Design:

Although there is considerable variation among manufacturers, modular housing producers tend to have design and engineering capability within the company. Many plants work to 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 none are satisfactory. Recently in multi-family and higher end of market applications, developers have brought architect designed projects to modular manufacturers to refine a design to a manufacturer's production capability. Increasingly, the latter design strategy is becoming the norm.

Manufacturing:

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. Many modular manufacturers work in an 'L' shaped plant configuration with the house skeleton moving through the leg of the 'L' where floor, exterior walls and roof are constructed and onto the shorter leg where other elements, services and assemblies are fabricated and installed. There are other viable plant configurations.

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.

Figure 3.1-4

Modular Plant Schematic

source: Robinson, Manufactured Housing, p 14-6

Energy Decisions:

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

Enclosure characteristics are also determined in design and enhancements to code regulated standards are relatively easily accommodated and occasionally promoted in marketing. Like HUD code houses there are 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. Many manufacturers offer more than one quality of window.

Some manufacturers install electric resistance heaters instead of forced air systems to simplify field installation procedures and obviate 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, when desired, are typically added by owners or installation contractors at roughed in locations after manufacture.

	PREDESIGN	DESIGN	MANUFACTURE	INSTALLN
DESIGN CHARACTERISTICS				
Size		X		
Configuration	X	X		
Interior layout		X		
Site orientation		X		
ENCLOSURE CHARACTERISTICS				
Walls		X		
Floors		X		
Roofs		X		
Openings				
Location / size		X		
Product / installation			X	
SERVICES				
Electrical and mechanical				
System engineering		X		
Product / installation			X	
Appliances			X	X

Table 3.1-2
Location of Energy Related Decisions
by Production Phase
Modular Manufacturer

Assessment:

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 and ceiling or edge wall construction. 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 derive improved natural cooling or heating from passive means. This production strategy can best conserve energy by regulating surface area and maintaining a tight well insulated exterior envelope.

3.1.3 Panelized

Figure 3.1-5
Panelized House

Definition:

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.

Applications

Panelized building systems can be applied to single family detached or lowrise multifamily attached housing developments. Panels are typically 8' high and between 4' and 40' in length. Since all plumbing and electrical connections are made on site, open panel systems are more easily accepted by building officials and unions. As a consequence, open panel packages are frequently used by production builders for their easy integration with other forms of site construction. Closed panel building systems on the other hand have encountered opposition from building officials and labor unions and have declined in popularity. Panelized houses can cost between approximately \$ 70,000 and \$ 300,000.

Representative Companies:

In 1988, NVR Building Products of Pittsburgh, PA was the top company producing 8,500 wood frame houses out of 7 plants, reporting gross sales (panels) of \$ 126,000,000. Other companies include National Enterprises Inc. of Lafayette, IN with production of 6,000 wood frame houses, Davidson Industries Inc. of Indianapolis, IN is an expanded polystyrene panel producer with production of 3,500 houses. Acorn Structures Inc. of Concord, MA, an innovative energy

sensitive panelizers ranked 20th with annual sales of \$14,000,000 and production of 200 wood frame houses. [Automated Builder, June 1989, p. 22]

Marketing / Design / Manufacturing Synopsis:

The size and scope of the panelized industry segment is a matter of considerable disagreement among data collectors and is an issue discussed elsewhere in this report. Because of the number of potential sub-categories and production tiers within this industry segment, the marketing, design and manufacturing characteristics are particularly difficult to 'generalize' meaningfully. Rather than stretch or dilute characteristics to be inclusive of more than one category, the following summarizes characteristics of 'open' wood frame panelizers, the largest most technologically representative tier.

Marketing:

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.

Design:

Panelized building systems are inherently flexible and panel manufacturer are to some degree less restricted to standardized designs or models. All manufacturers have a standard plan catalog 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, major revisions or fully customized designs are typically avoided. Customers can make minor modifications to the catalog design or propose major additions or modifications that must be reviewed by the manufacturer's design and engineering staff. A few manufacturers offer custom design services or will adapt their product to designs by others. Computerized design procedures have been more readily made a part of the manufacturing process.

Manufacturing:

Among industrialized housing producers, panel manufacturers use them most sophisticated equipment and technology at the highest rate of capital investment of the four segments studied. 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 field installation problems.

Figure 3.1-6
Panel Plant Schematic

Source: Robinson, Manufactured Housing, p 14-2

Factories are typically organized in straight production line configurations, with panels produced in linear sequential steps moving from station to station in a straight line. Separate production lines for different types of exterior and interior panels operate in parallel. Sub-assemblies and components are constructed at adjacent work stations and moved to main lines. 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 panel necessary to complete one single family house. The load is delivered to the site for panel installation and adjustment. Some trucks are designed to incorporate a small crane to unload and place panels, and a compressor to run field tools. Once the house shell is enclosed, interior panels are placed and finished.

Energy Decisions:

Panelized houses are typically built to prevailing regional energy codes although some companies have options to upgrade the design and manufacture of panels to higher energy efficiency. Basic

design characteristics of panelized houses also vary considerably with house size and method of panelization, decisions left to the discretion of the designer or developer prior to manufacture. The orientation, size and configuration characteristics of the house are established in standard plan catalogs usually at the marketing level of the company with some refinement possible in design.

Enclosure characteristics are also determined in 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. The opportunity is not always 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. Major appliance choices and installation are typically the domain of a developer or end user.

	PREDESIGN	DESIGN	MANUFACTURE	INSTALLN
DESIGN CHARACTERISTICS				
Size		X		
Configuration		X		
Interior layout		X		
Site orientation		X		
ENCLOSURE CHARACTERISTICS				
Walls	X	X		
Floors	X	X		
Roofs		X		
Openings				
Location / size		X		
Product / installation			X	X
SERVICES				
Electrical and mechanical				
System engineering		X		
Product / installation			X	
Appliances				X

Table 3.1-3
Location of Energy Related Decision
by Production Phase
Panelized Manufacturer

Assessment:

Panelized construction offers great design flexibility to designers and manufacturers. The ability to work with relatively small, discrete construction components renders handling and transportation requirements less onerous than those experienced by modular and HUD code manufacturers. Moreover, panelized plants tend to be newer and technologically more advanced and adaptable than other segments of the industry.

At the same time panelizers have not yet been able to capitalize on the opportunity to add greater value and performance through the manufacturing process and considerable on-site construction of uneven quality and precision 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 and realized the opportunity to create a wide range of energy conserving houses of varying design, size and complexity.

Panel manufacturers are not typically large vertically integrated housing companies. Instead, they often smaller specialized companies working independently in small market niches or collaboratively with larger volume builders or developers. As a result panelizers present an opportunity to focus resources on the development and refinement of a component that while relatively simple compared to the complexity of a whole house could be very influential on the energy performance of many houses.

3.1.4 Production Builder

Figure 3.1-7
Production Built House

Definition: Production building refers to the mass production of whole houses 'in situ'. While housing built by production builders is not inherently industrialized or involve highly industrialized

technologies, this large and influential industry segment regularly employs rationalized and integrated management, scheduling, and production processes as well as factory made components much the same as the more traditionally accepted industrialized housing producers. 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.

Applications:

Production building methods are commonly applied in the construction of large numbers of houses that are similar in construction methods and repetitive in form. Houses produced range from single family detached (single and double story) to multifamily. Production methods are not inherently limited to a particular material or scale although it is most frequently applied to single family detached houses of wood frame construction.

Representative Companies:

In 1987, the top four production builders in the country alone built 3% of the housing starts or 38,000 houses valued at \$ 4.74 billion. The largest, Lincoln Property of Dallas, TX built 7,727 units; NVRyan Homes of McLean, Virginia built 8,389 units; Ryland Group of Columbia, Maryland built 9,465 units; and Trammel Co-Res of Dallas, Texas built 12,307 units (Automated Builder, August 1988). Kaufman and Broad of Los Angeles, California, built 4,664 units in 1988 (Automated Builder, August 1989, p.20).

Marketing, Design and Manufacturing Synopsis:

Marketing: Unlike other segments of industrialized housing, production builders do not typically market houses to order but do so on speculation and are very sensitive to trends and changes in consumers. Many find it necessary to work directly with potential customers or independent market research groups to target projects and assist in development and refinement of models and design. As a consequence, house size, character and to a certain extent form are determined by perceived market forces evaluated prior to design investigations. 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.

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

Manufacturing: Production is outdoors and 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 deemed appropriate. Many partially industrialize their production process and maintain their own panel and truss production facilities. Some sell the excess capacity of this production to other builders.

Energy Decisions:

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

	PREDESIGN	DESIGN	MANUFACTURE	INSTALLN
DESIGN CHARACTERISTICS				
Size	X			
Configuration		X		
Interior layout		X		
Site orientation		X		
ENCLOSURE CHARACTERISTICS				
Walls		X		
Floors		X		
Roofs		X		
Openings				
Location / size		X		
Product / installation			X	
SERVICES				
Electrical and mechanical				
System engineering			X	
Product / installation			X	
Appliances				X

Table 3.1-4
Location of Energy Related Decision
by Production Phase
Production Builder

Assessment:

A decade ago, production builders started work on a site with truckloads of lumber, and industrialized housing manufacturers were in direct competition. Today these same builders start work on a site with truckloads of increasingly larger pieces of houses in the form of trusses, floor cassettes, wall panels, utility cores, and pre-hung window units. This industry segment is the major consumer of industrialized components, increasing use of industrialized components from 11.4% in 1977 to 20.5% in 1987. (LSI Systems, 1988 b)

Production builders have been successful making the process of house 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 process when they work better. As a consequence the segment is often the proving ground of innovative industrialized procedures and a litmus test for the components and materials ultimately adopted or adapted by the housing industry. The recent and growing trend among large volume production builders to collaborate with panel manufacturers is a contemporary case in point. Some builders have gone so far as to significantly reduce their own construction forces and subcontract the building portion of their projects to industrialized builders on a turnkey basis.

Production builders construct approximately 44% of national housing starts. [Automated Builder 1989] Although comprised of literally thousands of different companies, the segment has the largest and most capitalized housing builders as well as the many small and intermediate builders among their ranks. Many of these are integrated development and construction companies and present the opportunity to integrate site planning decisions with house design and construction. Whether independently or in aggregation, this segment of the industry is critical to create the demand for energy conserving design procedures, construction materials, components and techniques that will motivate and sustain research and development.

3.2 STATISTICS AND TRENDS IN U.S. INDUSTRIALIZED HOUSING

R. Kellett

Introduction

Industrialized housing involves thousands of manufacturers and builders, producing many kinds of houses and parts of houses via a variety of industrialization strategies and hybrids. Most of these manufacturers and builders, particularly those that build to conventional code standards, cannot be simply categorized and do not maintain reliable statistics on their production; consequently, the

industry's statisticians disagree as to its size, roster and production capability. Effective and well focused research, however, must identify and characterize those constituencies that need and benefit from its findings.

Objectives

The objectives of this part of the research, then, are these:

- Determine and summarize the basis of data variations.
- Determine an appropriate data base for this project.
- Create a statistical 'snapshot' of industrialized housing at a national scale.
- Profile trends that characterize the industry's form and direction.
- Identify constituencies upon which to focus this research.

Comparison of data collectors

Consensus and reliability are difficult goals to achieve in any review of production and related statistics relevant to industrialized housing. Only the HUD code segment of the industry, for example, 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. To complicate matters further, those public agencies and institutions that compile generally reliable housing production statistics do not distinguish industrialized and factory made housing because they are built to conventional codes and standards (Robinson, 1988, pp.6-1,2).

Data on industrialized housing has been collected and analyzed for about 10 years by Leo J. Shapiro Associates and LSI Systems Inc. More recently, Hallahan Associates has generated modular and panelized industry data for the Building Systems Councils of the National Association of Home Builders. Between these authorities are substantive differences in definition, data categories and methodology with significant impact on the numerical summaries produced and the conclusions that can be drawn from them.

Leo J. Shapiro and Associates

Leo J. Shapiro and Associates, an independent survey research firm in Chicago, IL has collected data on industrialized housing since 1979 for the publisher of what is now Automated Builder magazine. The firm annually updates its general analysis of industrialized housing and periodically updates its detailed analysis of individual segments.

Shapiro 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. This definition of industrialized housing accounted for

roughly 95% of 1987 national housing production that is not high rise.

Shapiro's version of the industry is subdivided into four categories or industry segments without distinction between single family and multi-family units. A production builder builds single family and low rise multi-family houses in subdivisions or 'tracts' near major metropolitan centers. These builders supplement conventional site building with a wide variety of industrialized components and processes. A panelized home manufacturer is one of several kinds of factory builder including open and closed panel manufacturers, precut house kit manufacturers and packagers, and producers of kits for log houses and domes. A modular home manufacturer makes fully assembled sections of single and multifamily houses in a factory. A HUD code home manufacturer builds what were once called mobile homes in one or more sections to a national preemptive building code administered by HUD.

A sample of approximately 55 companies per segment is drawn from the subscription files of Automated Builder and supplemented with companies that do not subscribe to Automated Builder when suggested by members of the subscriber sample. In 1987, this sample included 118 producers in the production, panelized and modular categories and 38 HUD code manufacturers. Within each segment, the sample is stratified according to annual sales figures and interviews are conducted within each stratum. Data are collected in telephone interviews with executives from representative companies within each industry segment, updated with follow-up interviews. Data collection typically takes place in the fourth quarter of a production year and is based in part on a projection to the end of the production year.

LSI Systems Inc.

LSI Systems Inc. has been collecting data on the industrialized housing industry for over 11 years and is the primary source of data for The Red Book of Housing Manufacturers and Where the Action Is. LSI Systems is primarily engaged in market research for the building components and materials industry and produces housing production summaries as a corollary to that work. Because of this interest, LSI Systems also collects and publishes data on the many building components manufacturers and construction systems suppliers who serve a full range of industry segments.

LSI Systems' definition of industrialized housing acknowledges two degrees of industrialization within the industry -- factory manufactured houses and industrialized home builders. Combined, both categories account for approximately 93 % of 1987 national housing production that is not high rise; and at its narrowest, 23 %. This version of industrialized housing is subdivided into 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 to varying degrees industrialized. Each major category is further subdivided into segments.

Within the Home Manufacturer category are four sub-categories or segments defined by the following distinctions. A 'precut house' is a sales package for which many parts are precut but not preassembled. A 'panelized house' is a sales package that includes preassembled closed or open wall panels and may include other preassembled roof systems, floor systems etc. A 'modular/sectional house' is a non-HUD code three dimensional housing unit produced in a plant (usually in two or more sections) for erection on a permanent foundation with a minimum of on-site labor. A 'mobile home' is a three dimensional housing unit manufactured to HUD mobile home standards. Statistics for these four industry segments are thorough and comprehensive.

The Home Builder category has three sub-categories of segments distinguished by the degree to which they use industrialized components, systems and procedures. A 'major industrialized home builder' is production builder in a large metropolitan market who uses industrialized building components and techniques when they are cost effective. A 'conventional home builder with components' is a site builder who uses one or more industrialized major building components. These two segments are the largest and represent one half the total of all national housing production. The last and smallest segment, the 'conventional home builder without components', refers to small scale builders using primarily site fabricated materials, assemblies and techniques.

LSI Systems' data are collected for single family as well as multifamily housing from a sampling of companies reported in a detailed mail survey of managers. Industry-wide estimates are extrapolated from a sample of manufacturers who respond to the survey within publication deadlines. These data are accurate to the extent that respondents are honest and forthcoming, able to describe themselves in the aforementioned data categories and meet publication deadlines. In 1987, 587 house manufacturing companies and 214 production builders comprised the base sample from which a statistics for the industry were extrapolated (LSI Systems, 1988, p vii).

Hallahan Associates

Hallahan Associates is a Baltimore, MD management consulting firm commissioned by the Building Systems Councils (BSC) of the NAHB in 1988. Hallahan's study, Factory Built Housing in the 1990's: A Study on Modular and Panelized Housing from 1984 to 1994, was commissioned to establish industry size, production and growth patterns relevant to the strategic planning efforts of BSC's modular and panel producing membership. Unlike Shapiro and LSI Systems Inc, Hallahan focuses in considerable detail on only two industry segments, the manufacturers of "... residential units that leave a factory as either three dimensional modules or two dimensional panels and are built to conventional building codes." Specifically excluded were HUD-code homes, log homes, precut homes and dome homes and partially industrialized production builders.

Data were collected using several methods. Published industry data were reviewed and a survey mailed to known manufacturers. These data were in turn supplemented with interviews with selected manufacturers and compiled to establish production levels from 1984 to 1988. Key factors influencing growth and change in these production levels were identified and used to quantify potential production levels through 1994.

Methods used to collect data on modular manufacturers varied from those for panelized manufacturers. Information on modular manufacturers relied primarily on data collected by the 36 states with Industrialized Housing Acts; quantity and quality varied considerably from state to state. Information on panelized manufacturers relied primarily on a survey of over 1000 potential and probable panelized manufacturers. From 165 survey responses, published data and interviews a universe of 670 panelized manufacturers was developed and data projected. Panelized manufacturer information, therefore, is based on estimates difficult to cross-reference and check conclusively.

The resulting 125 page study completed in mid 1989 presents data on unit production levels over a five year historical period as well as over a five year projection into the mid 1990's. Compared to Shapiro and LSI, Hallahan's production data is finely focused, broken down between modular and panelized units, and analyzed over five major regions and state by state where possible.

Comparison of data collectors

Comparing these primary collectors and compilers of industry data, it is difficult to achieve a consensus as to the size, scope and character of US industrialized housing. Important differences in the nature of the sponsor and audience for which the data are intended, the definition and classification of industry segments and the methodology of data collection and analysis create problematic numerical differences in the conclusions reached. Table 3.2-1 summarizes and compares data collected by Leo J. Shapiro Associates, LSI Systems and Hallahan Associates.

Size of the Industry

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

Production by Industry Segment

Other disagreements are noted in the definition and categorization of industry segments, numbers of companies within them and production attributable to them.

<u>Data Collector</u>	<u>Sponsor</u>	<u>Industry Segments Studied</u>	<u>Collection Method</u>	<u>Sample size (Year)</u>
Leo J. Shapiro	Automated Builder	Four:	Personal interview and past data	156 across segments (1987)
LSI Systems	Material, comp. and system suppliers	Seven	Survey and past data	801 across segments (1987)
Hallahan	Building Systems Councils	Two	Survey and past data	165 in panelized segment state data on modular segment (1988)

Table 3.2-1
Comparison of Data Collectors
 Sources: Manufactured Housing 1988, The Red Book of Housing Manufacturers,
 Factory Built Housing in the 1990's

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

Figure 3.2-1
Comparison of Total Industrialized Housing Production
by Collector - (1987)

Source: Manufactured Housing 1988; The Red Book; Factory Built Housing in the 1990's

Shapiro Assoc.

LSI Systems

Hallahan Assoc.

Figure 3.2-2
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

Assessment

These data collectors disagree about the size and production capability of the industrialized portion of housing industry. 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 substantial disagreement among all three data collectors as to which segments account for what proportion of that industrialized production. There is, for example, a 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)

Many statistical discrepancies are problems of definition that will never be resolved. Besides the clear definition of HUD code production, there are no industry wide categories that are consistently understood. Data are compiled from a wide variety of state and commercial sources that do not share common definitions. The problem is compounded by the fact that manufacturers produce a range of 'hybrid' houses that bridge or obscure definitional boundaries.

Since the housing industry is in a constant state of change, continually adapting production strategies to an ever changing housing market, definitions may be ephemeral, at best. Examples might be the wide adoption of panelization by production builders in the Northeast, and the very recent rise of systems builders who purchase components produced by more than one industry segment.

Other statistical discrepancies are methodological, consequences of the means of gathering and analyzing data. Again with the exception of HUD code houses, industrialized housing data are collected from hundreds of diverse sources, agencies and processes ranging from personal interviews to reviews of state building permits. No national agency consolidates or validates these numbers and the national overview is, by definition, the cumulative point of view obtained by adding and cross-referencing many small scale views to create industry wide estimates — a whole world view constructed from the findings of a 1000 microscopes.

To compound the problem, the data collectors are small market research companies commissioned by sponsors with specific interests, and limited resources to complete a large and comprehensive task. Analysts must focus on parts of the industry and disagree among themselves as to which parts are most representative as well as which methodologies are appropriate. Shapiro (George Rosenbaum) for example argues that Hallahan's panelized production numbers are based not on accepted comprehensive systematic survey methodology but rather on procedures more selective in scope. Hallahan's projection of past and future panelized production, for example, was based on a self-administered mail questionnaire with a 10% response rate.

In the absence of the comprehensive national analysis of industrialized housing, no single data collector's numbers can be deemed to be the 'right set' or datum to use here. Differences in definition and methodology, while substantial in some areas, reflect a range of themes, specificity, differentiation and reliability expectations. Their work has greater value in sum than individually. Both Shapiro and LSI Systems, for example, have been collecting and refining data for approximately 10 years and are deemed to be generally reliable about national trends that affect the industry as a whole. LSI Systems gathers data by state that can be used to regionalize the effect of national trends. Hallahan focuses with considerable detail and depth on panelized and modular segments seeking to forecast in the mid 1990's as well as record the past. Consequently, data utilized in this report will draw from all three sources and be noted accordingly.

3.2.1 Statistics and Trends Across Industry Segments

Differences notwithstanding, industry data collectors do agree that the degree and nature of industrialization in housing is increasing as well as changing. The level and intensity of factory building has been accelerating since the first modern industrialized housing companies emerged in

New England and the Midwest in the 1930's. On the one hand, houses are increasingly being produced, partly or wholly, in factories. Although such houses comprised only a very 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). In 1985, more than 1,000,000 units of the annual housing production were substantially factory-made. Of the 1,858,000 new homes (excluding 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)

'Site-Built' Industrialization

Increased industrialization can be measured in ways other than the number of houses being produced in factories. Houses built on site are also becoming increasingly affected by industrialization of construction processes and components. While many house builders would not readily describe their production as industrialized, industrialized components and processes are used on the vast majority of houses built. The average 'site built' house is now about 85% likely to have one or more major industrialized components of some kind. While few housing companies used industrialized components and techniques 20 years ago, by the late 1980's 2,000 companies were mass-producing components for houses such as floor, wall and roof sections, pre-hung doors and windows, prefabricated plumbing assemblies, and complete mechanical cores that consolidate the main heating, plumbing, and electric components of a house.

Fluctuations in Market Share by Segment

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. Since 1980, both have increased production by more than 80%. Production builders, on the other hand, 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 since that time has slowly declined.

Assessment

Turnover within the industry

A review of total national production is not necessarily a reliable indicator of growth and progress among industrialized housing producers. National statistics can give a false impression of a homogeneous, evenly distributed segment, obscuring significant -- sometimes contradictory -- regional growth and change. Housing production is very much a function of regional economy and segments that appear to be declining or stable nationally may in fact be growing and improving regionally. Moreover, growth and innovation in the expanding region establishes the level of industrialization and market sophistication possible in the segment as a whole. Modular

manufacturers, for example, appear to be growing slowly or holding a constant market share nationally while more than doubling market share in the competitive and demanding urban housing centers of the Northeast (Hallahan p. 23).

Figure 3.2-3
Industrialized Housing Production in Units and
Percent of Market Share: 1980-1988

Sources: U.S Department of Commerce; Manufactured Housing Institute;
 Shapiro Associates and Automated Builder

As industrialized housing production continues to evolve, it is increasingly less possible to maintain rigorous practical definitional differences between segments. While there are important differences between some segments, there is also considerable overlap and similarity among them. In some instances the same manufacturer may work in two segments from the same plant. This is the case with some HUD code and modular manufacturers for example. Moreover, the industry is in a constant state of change, and a technology that allows one segment today may not define it tomorrow. A manufacturer in one segment may adopt a design or production strategy from another. This is the case with panelized manufacturers and production builders for example.

For the purposes of energy conservation research, it may be more productive to simply define the

industry more loosely and by focusing on fewer fundamental design and production differences between segments. The most fundamental of these is whether the house is conceived and assembled from large volumes or from a more flexible matrix of interchangeable components. The former category characterizes HUD code and modular manufacturers which are later characterizes panelized manufacturers and productions procedures.

3.2.2 Statistical Trends within Industry Segments

Production

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 14% although share peaks and lows do not coincide with production peaks and lows. Market share increased sharply in 1981 to an all-time high of 18% when national housing production as a whole fell 13%. After that peak, production and market share have steadily declined to current levels of approximately 13%. 1986 was the lowest market share year at 12% and was also a relatively high production year.

FIGURE 3.2-4

HUD Code Housing Production in 000's
and as Percent of Total Housing Production

Source: U.S. Department of Commerce and Manufactured Housing Institute

Currently, the HUD code industry segment has been declining in production and market share since 1982. This downward trend appears even more dramatic in context of the single family house portion of national statistics. In 1983 32% 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 sf while the remainder were multisection units. By 1987, that distribution had shifted 13 percentage points to 60% single

wide units and 40% multisection units (Manufactured Housing Institute, 1988)

HUD code houses have historically been a low cost housing alternative and continue to offer significant cost advantages over other forms of construction. Table 3-6 shows that the average HUD code house of 1987 was 1,150 sf and sold for \$ 23,800, an average square foot cost of \$ 20.61. That same year, the average non-HUD code house was 1,910 sf and cost \$ 101,760, an average square foot cost of \$ 53.28 or two and one half times the cost of the HUD code home. With land, this average home sold for \$127,000.

	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1987</u>
HUD Code Houses						
All HUD code						
Average price	19,700	21,000	21,500	21,800	22,400	23,800
Average size	1,000	1,035	1,060	1,060	1,110	1,150
\$ / sf	19.70	20.29	20.48	20.57	20.18	20.61
Single wide units						
Average price	17,200	17,600	17,700	17,800	17,800	18,400
Average size	905	920	930	945	945	950
\$ / sf	19.01	19.13	19.03	18.84	18.84	19.37
Multi-section units						
Average price	28,400	30,500	30,450	30,100	30,800	32,400
Average size	1,320	1,350	1,364	1,370	1,395	1,450
\$ / sf	21.52	22.59	22.30	21.97	22.08	22.34
Other Single Family Houses						
Average price	83,900	89,800	97,600	100,800	111,900	127,000
Land	16,780	17,960	19,520	20,160	22,380	25,440
Structure	67,120	71,840	78,080	80,640	89,520	101,760
Average size	1,710	1,725	1,780	1,785	1,825	1,910
\$ structure / sf	39.25	41.65	43.87	45.18	49.05	53.28

Table 3.2-2
Cost and Size of HUD Code Versus Other Single Family Houses
Source: Manufactured Housing Institute, 1988

Geographic Concentration

Figure 3.2-5, Geographic Concentration HUD Code Manufacturers

Although HUD houses are produced across the country, they are distributed unevenly and comprise varying proportions of regional housing markets. While HUD code market share is nationally about 14%, regional market share comprises about 24% in the South; 15% in the Midwest; 10% in the West and 9% in the Northeast (LSI Systems, 1988). Within that distribution, the popularity of single and multisection units varies. 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).

Corporate Concentration

Figure 3.2-6, Corporate Concentration HUD Code Manufacturers (1987)

The 10 largest HUD code manufacturers shipped 56% of the segment's production in 1987 (Builder, February 1989, p. 60). The top producers, Fleetwood, Redman, Skyline, and Champion, also increased their market share at the expense of smaller producers (LSI Systems, 1988).

Assessment

This industry segment has not sold more than 300,000 homes for over 12 years and it would appear that it is in a mature market state with a stable annual demand of between 260,000 and 280,000 units. Only 20,000 or so are sold as real property on permanently installed foundations. Approximately 3.5 million HUD code homes have been purchased in the 14 years since the code was adopted in 1976. Most are located in cooling as opposed to heating climates, where good ventilation, overhangs and shading devices are required but not easily accommodated in the design and manufacturing process. The remanufacture and upgrading of those units, particularly with regard to energy performance, is a substantial renovation market opportunity.

Expandables and double wide units are increasing their market share. High volume, mass produced single wide units sold as personal property are more common in the East; double wides and expandables sold as real property more common in the West.

The declining market share of HUD code manufacturers will force changes in the product and the way it is sold. Non-HUD code home buyers will be targeted with comparable features, quality, appearance and design at a lower cost if panelized and modular home builders expand their low-end production or reach truly economical production levels, so that they narrow the price gap surrounding HUD code homes. Cost advantages will derive not from lower square foot construction costs, but rather from time and flexibility advantages. Plans and construction standards are pre-approved and can be quickly adapted to new site and market opportunities without lengthy design, regulatory or manufacturing delays (Automated Builder October 1989 p. 28).

HUD code units are increasingly marketed to housing developers, who develop and market a whole house package, rather than to end users. Developers who market the units 'with lot' installed in leased or owned subdivisions and will change the sophistication and character of the market to which HUD code manufacturers sell. Design flexibility and amenity level are critical to developers who want to custom refine the house and lot package to unique market niches and site conditions. The relatively recent appearance of porches, 5:12 roof pitches, drywall interiors, high finish quality and well daylighted plans with large openings onto adjacent terraces in the standard product line of many several manufacturers are examples. In other instances this process will result in a hybrid construction of factory and site built, and may add new components to the list of carports, sun porches, etc., presently offered to the HUD code owner. An increasingly wide variety of upgrades and custom features will likely become available.

3.1.3 Modular Housing Statistical Trends

Production

Modular housing is produced in a few areas of the country by approximately 130 manufacturers operating 159 plants. Shapiro records that modular production has grown steadily from 56,000 units in 1980 to 93,000 in 1987, increasing its 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. Hallahan has argued that the distinction between residential modular and commercial modular production is not precise since they are often manufactured by the same company marketing two applications of similar structures. Hallahan's closer examination of production in this segment reveals that over half of its production is commercial. Table 3.2-7 compares Shapiro Associates' unadjusted production and Hallahan's adjusted production figures (Hallahan, 1989, and Shapiro, 1988).

Figure 3.2-7

Modular Housing Production in 1980-1987

Sources: Shapiro Associates and Hallahan Associates

According to Hallahan, growth in the modular segment has been driven disproportionately by growth in commercial applications. For example, 1984 residential modular production reported in Factory Built Housing in the 1990's, was 28,291 (55%) versus approximately 20,000 commercial modular; 1987 residential modular was 37,379 (53%) versus approximately 40,000 commercial modular. Over that four year period, then, residential modular production would have grown 32% while commercial modular production would have grown approximately 100% (Hallahan, 1989, p.6 and 8).

Geographic Concentration

Figure 3.2-8, Geographic Concentration Modular Housing Production (1989)

More than other segments, 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. Modular markets in rural or economically declining regions are almost dead. Now favored are high growth urban areas where housing prices are rapidly increasing (Hallahan, 1989, p. 44). Growth is due almost entirely to increases in the Northeast and adjacent states. New England and the Mid-Atlantic market has more than doubled to more than 15,000 units per year. The South Atlantic and Midwest 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).

Corporate Concentration

Figure 3.2.-9, Corporate Concentration Modular Manufacturers (1988)

While production and market share have increased, the number of modular production plants has decreased 21% (LSI Systems, b, p.xiv). One manufacturer, Cardinal Industries, has dominated with 21% - 27% of production from 1984 to 1987, although that fell to 13% in 1988. The rest of the top

20 manufacturers account for between 47% and 56% of the total remaining production in that same period (Hallahan, 1989, p. 20).

While inclusion of Cardinal production increases informs the national market share of modular housing, it also obscures or overshadows important regional trends. Production statistics without Cardinal demonstrates greater market share growth and quite a different geographic and corporate concentration. The modular market share exclusive of Cardinal increased from 1.2% in 1984 to 1.9% in 1988, when Cardinal fell into decline. Without Cardinal, the Northeast (75%), Pennsylvania in particular, is the heart of that industry segment (Hallahan, 1989, p. 26).

Assessment

Presently, this segment is small, concentrated and unstable enough to be profoundly affected by economic and legislative forces. The Tax Reform Act of 1986, for example, had a devastating effect on modular producers. By late 1989, Cardinal Industries, the nation's largest modular manufacturer, is bankrupt largely because of tax law changes that severely depressed multi-family housing starts.

Increasing corporate concentration points to changing economies of scale in this segment. Design, construction and marketing of modular construction is a relatively sophisticated task subject to regulatory and market irregularities. Transportation and plant improvements are high cost propositions. Small volume modular manufacturers are going out of business while moderate to high volume manufacturers near high growth areas are expanding. Is it also reasonable to surmise that the ability to mix commercial and residential production adds flexibility critical to survival in this segment.

3.1.4 Panelized Housing Statistical Trends

Production

Panelized manufacturers exist at three production scales: high volume house builders with panel manufacturing capability within their companies (approximately 12 companies building panels for about 1800 units each for a total of 20,000 units in 1988); major panel manufacturers (approximately 35 companies building about 800 units each for a total of 29,000 units in 1988) and the remaining most productive segment, (approximately 620 companies) producing an average of about 125 units each for a total of 80,000 units in 1988 (Hallahan, 1989, p.30).

The last 10 years shows a slow but gradual increase in panelized production and market share that varies in magnitude with data collector. 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 flat decelerating 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 and decreased somewhat from 1984 to present (Hallahan, 1989, p. 38).

Figure 3.2-10

Panelized Housing Production, 1980-1987

Sources: U.S. Department of Commerce, Manufactured Housing Institute, Shapiro Associates, LSI Systems, Hallahan Associates

Geographic Concentration

Figure 3.2-11, 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 slight proportional shift from the Midwest to the East Coast, geographic concentration of

panelized manufacturing has remained relatively constant -- i.e., low, 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).

Hallahan describes a regional market share as high as 18 % where there is considerable production capability. Panelized production holds high market shares in Pennsylvania, Wisconsin, Maryland and Virginia, although these states also show a decrease in market share and difficulty keeping up with what is an otherwise expanding housing market. New Jersey is the only state to show an increase in market share coupled with an increase in the number of panelized units produced (Hallahan, p. 38). Texas, once the largest panel producing state, experienced a most dramatic drop of over 10,000 units annually between 1984 and 1988, and is now about tenth (Hallahan, 1989, p. 32).

Corporate Concentration

Figure 3.2-12, Corporate Concentration Panelized Manufacturers (1987)

The top 100 panelized housing manufacturers operate 130 plants and built 38,371 units, 54.7 % of the production attributable to this segment of the industry in 1988. Of those, three companies, NVRyan Homes, Ryland Homes and National Building Systems -- account for over 1/4 the panelized housing sold in 1987 (LSI Systems, b, 1988 p. xv).

Assessment

With some regional variation, the majority of panelized housing manufacturers are relatively small local market manufacturers, decentralized across the country, but represented in all active housing markets. The current slight decrease in absolute production and moderate increase in overall market share indicate that this segment may be in a period of stability or approaching stagnation (Hallahan, p. 39).

At the same time the industry appears to be shifting to more open panel construction to suit the need for design and construction flexibility, code accommodation, and regional and individual market needs. Closed panel production is decreasing -- from about 4,000 units in 1984 to under 1,000 units in 1988 (Hallahan, 1989, p. 30). Panelizers are beginning to work as turnkey subcontractors to developers who wish to contract the construction portion of projects.

3.1.5 Production Builder Statistical Trends

Production

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, using highly organized production line methods on site and heavy involvement of components. 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 primarily conventional site construction. These builders accounted for approximately 1/3 of 1987 housing production.

Figure 3.2-13

Production Builder Housing Production, 1980-1987

Source: U.S. Department of Commerce, Manufactured Housing Institute,
Shapiro Associates, LSI Systems

Assessment

The market share of production builders swings most erratically with the rise and fall of housing

starts. It is most likely to increase in a boom economy and recede in a bust. These builders, less impeded than more heavily industrialized builders are by large capital investments, can more readily collapse or expand their production in response to market conditions -- sometimes "going underground" by switching to remodel or commercial work in hard times.

3.3 FIELD OBSERVATIONS OF HUD CODE, MODULAR AND PANELIZED MANUFACTURERS L. Maxwell, S. Chandra

The findings are under the topic headings of Design Procedures, Energy Design Decisions, Energy Performance, Automation and Computerization, Manufacturing Methods, Quality Control, Raw Material and Inventory, and product marketing. The end of this section contains a few tables contrasting the differences in the three types of manufacturers.

3.3.1 Design Procedures

Three design scenarios were identified during the visits; designs brought in by the customer, standard designs with "customization", and advanced design scenarios.

Some manufacturers produce homes from plans brought to them by either a builder or home buyer. For these, design is usually limited to altering the plans to facilitate manufacturing within their operations set-up. Therefore, design is relatively non-existent. Further, any energy design decisions have been determined by the buyer prior to the plans being brought to the plant. This sort of manufacturing operation competes more with conventional house framing subcontractors as the builder who has brought the plans to the plant has usually solicited bids from framing sub-contractors also.

The greater portion of the manufacturers do perform product design within their company. The concept of design however varies greatly between manufacturers. To most, "design" constitutes altering a set of standard plans to a particular buyers desires. The method of revising will consist of a "cut and paste" alteration to the plan. In some instances this is literally the case, with "white-out" and corrections pasted over existing drawings, or in more "advanced" companies a CADD system (computer aided design/drafting) was utilized to alter the basic plan. This alteration, in many cases, is then considered a "custom home". The standard plans which are utilized have typically evolved over time from a very basic home which was updated as market desires changed. In many cases, these basic plans came from plan books, from similar product being built by a conventional site builder, or just evolved from a draftsman. The type of manufacturer utilizing this approach tends to be the HUD Code or modular manufacturer whose product line is directed more toward the low cost home market.

The companies that deal with the retail market in a more direct manner tend to be more design cognizant. They will usually maintain a design staff at either the corporate or plant level. The desire expressed by this type of company is to be "totally market driven". The design staff will work at redesigning existing product to meet market changes as well as the continuous development of new product. The decision for a new design is based either on perceived market desires or based on product being sold by the competition. The design process is similar to the methodologies incorporated in a typical design firm. These manufacturers will typically have one or more architects on the design staff.

3.3.2 Energy Design Decisions

There are three main levels of energy design decisions involved in the development of a home design. (1) The overall energy design stratagem for the design, (2) The quality of, or performance of, the components utilized in the construction, (3) The efficiency of the mechanical and electrical systems incorporated into the home. Not all the decisions are necessarily up to the manufacturer.

There exists a small number of manufacturers in all three industrialized housing types that make a very concerted effort to produce as energy efficient a product as possible. These companies have utilized the expertise of research organizations such as SERI, and outside architects and engineers, to develop home designs that apply passive and active solar strategies and advanced energy conservation measures to develop affordable energy efficient homes. These companies exhibit the greatest commitment to quality and energy conservation and are willing to seek out the expertise that can enable them to design, manufacture, and market a top quality energy efficient product. Another small group of manufacturers are trying to provide homes that provide energy efficiency through energy conservation strategies in their standard product line. These companies are typically producing lower cost affordable homes with commendable levels of energy efficiency. However, many of the energy decisions are based on a "more is better" principle (e.g. increasing levels of insulation) versus cost optimized conservation strategies. These companies could benefit greatly from a developed set of guidelines to incremental energy conservation strategies which could be incorporated into the construction of their product. The balance of the manufacturers, and unfortunately the largest segment of the industry, are producing homes without concerns for improving energy efficiency. They state almost unanimously that they cannot sell energy efficiency as the public does not care about it, but when the public begins to demand increased efficiency, they will provide it. Ironically, those manufacturers that are producing energy efficient housing, state that they are doing so because the public is demanding it.

The quality of, or the energy efficiency performance of the components that are selected are based on

either code minimum requirements, or inventory control decisions. The HUD Code manufacturer is basing his decision on which component (e.g. windows) is the least cost which will meet the requirements of the HUD Code. Cost and Code compliance are the criteria for selection. For the greater number of the other industrialized housing manufacturers, the criteria is energy code/life safety code compliance. It was noted however, that the modular home builders have been typically providing higher quality components which meets the requirements of the code and adds to the apparent quality of the finished product. This higher quality is partially achieved by maintaining one component type (e.g. windows) which allows for a decreased overall inventory, while increasing the number of identical units purchased, resulting in reduced per unit costs, and still maintaining code and quality requirements.

The selection of systems such as HVAC, hot water, heaters, etc., is rarely left up to the manufacturer of the home. The final builder/dealer makes the decision with the home buyer, therefore leaving the decision criteria up to the buyer.

3.3.3 Energy Performance

The energy efficiency performance of the homes produced by the industrialized housing industry falls into 3 major categories, (1) those meeting minimum code requirements, (2) those notably above code requirements, (3) those with very high standards. The largest number of manufacturers work toward the minimum code requirements of either the HUD Code or the prevailing energy code of the jurisdiction that the home will ultimately be sited in. However, about 20% of the manufacturers are producing and successfully marketing homes that exceed the codes requirements, and are finding that buyers are willing to pay for increased efficiency levels in the homes. A few manufacturers of homes are striving for high standards of energy efficiency and quality in their product, although they are very few in number. One manufacturer noted sells homes with a heat loss coefficient of 3 Btu/sq.ft./degree-day and also offers passive solar homes.

3.3.4 Automation and Computerization

The applications of computers in the industry to date is extremely limited. All companies visited utilized a computer in some manner, however, the use was rarely in the production end of the operation. Business affairs functions, e.g., word processing, and bookkeeping, are the primary applications of computers. In the design and drafting of plans, CADD is incorporated by less than 2/3 of the companies, yet few of these companies utilized CADD beyond its most basic applications. Design being the least used application while plan revisions or "customization" being the larger use. About 1/3 of the companies will also use the computer for truss design, and even fewer will use a computer for developing wall panel configurations. None of the companies used the computer

output to further control any machinery. Less than 10% of the companies utilized computers for material estimating. The use of computers for inventory tracking and purchasing was noticed in only about half of the facilities. Further, the use of computers for project management, work scheduling, or project tracking is limited.

The type of computer hardware used consists of PC's for the bulk of applications. Small PC's for typical office functions and some drafting functions. More of the drafting and design functions are performed on micro's in the IBM type 286 to 386 range. A small number of companies have networks established to interface all the computers, and a very small number of the manufacturers had mini-computers such as a VAX. The companies with the mini-computer systems tend to be the largest companies, and usually a company with several plants which are networked together.

The production of industrialized housing is virtually devoid of any automation. The industry as a whole remains conventional site built construction under a roof. All manufacturers utilize jigs for layout of walls and floors, but all observed jig applications required manual configuration and materials placement. At one plant, an automatic setup saw for truss member cutting was noted, and several plants utilized laser guided nailing bridges for attachment of exterior sub-sheathing. Beyond these devices, the most advanced equipment noted were pneumatic nailers. The reasons for the lack of automation appear to be related to the high cost of automated equipment for house manufacturing.

3.3.5 Manufacturing Methods

The industrialized housing industry remains a conventional site built construction technology under a roof. The manufacturing process lacks any major process innovation. Other than the conveniences associated with working in a plant, the virtues of assembly line manufacturing does not appear to be explored or exploited. However, many manufacturers mentioned that they kept the manufacturing process as close to the site process as possible because buyers would relate to it.

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. None the less, the industry remains very labor intensive, preferring to utilize labor instead of automation and process innovation for production. The overall practice is to use a large number of unskilled or low skilled workers who can be trained for specific repetitive tasks. Then in times of slowdowns, the company will layoff workers and not be burdened with large overhead. This is a very different approach than the Swedish example, wherein the Swedes prefer to hire fewer highly skilled craftsmen and provide the tools and automation to enable them to produce a higher quality product. One interesting deviation from the general trend is one manufacturer who utilizes all sub-contracted labor for production. The

trades represented are actual typical site work sub-contractors who bid for the work. However, instead of going to a different construction site for a each new job, they come to the plant to perform their sub-contracted work.

The major difference between present factory production and conventional site construction is that the work comes to the workers instead of the workers coming to the work. The work itself differs very little. The use of automated systems, quality enhancing tools or techniques, labor saving devices or technologies, or factory optimized construction practices is very limited. In the end, the reason given almost unanimously, is the desire of the company to be able to respond rapidly to changing economic conditions. When times are good, employees are hired, when things slow down, employees are let go. Whereas, with equipment, when things slow down, the equipment overhead remains to contend with. The typical factory size is 50,000 to 100,000 sq.ft. with about an equally large area for material storage. Capital costs for setting up a plant varies, but averages between \$1 and \$2 million.

3.3.6 Quality Control

Quality control can be addressed from two perspectives, the first being the quality control of materials that will be incorporated into the final product, and the second being the quality control of the product being produced. The quality of both varies widely across the industry, and in many ways is dependent on the market being served.

The levels of quality control strived for by the differing manufacturing factions is directly related to the amount of value added at the production facility, and the level of responsibility for the final product incurred on the part of the manufacturer. The modular builder, for example, provides a nearly finished product that compares most directly with a site built home. The construction quality related items that a buyer of a site built house would require a remedy for if unacceptable, would be the same type of items that a modular built home would be required to provide. A manufactured (HUD Code) home, on the other hand, does not appear to have the same quality requirements, in the eyes of the final buyer, that is required of a more "conventional home". Therefore, the level of quality control required of the producer of a manufactured home is just the amount necessary to meet the requirements of the HUD code, the code therefore sets the quality standard. The panelizer competes more directly with the site built framing sub-contractor. As such, he is not required by a code or an inspector to protect his building materials from the effects of the environment, nor does the need to provide tight tolerances or construction quality seem to be deemed to be as critical, as his work will be covered up by subsequent phases of construction. Therefore, the quality control of his materials or production process tends to be less than the other two manufacturing types. As a result of, or due to these factors, it was noted that modular home builders appeared to consistently maintain

the highest level of materials quality and control, as well as production quality control. Manufactured home producers would provide only the level of quality control as required by the code and the code enforcement inspector. Panelized wall producers, would typically exhibit the least level of quality control either with materials or production. The notable exception to this is the panelizer of quality homes who is striving to obtain increased construction quality through the use of a controlled factory setting.

3.3.7 Raw Material and Inventory

Throughout the industry, the levels of inventory maintained on an average is astounding. A typical manufacturing operation maintains between two week's to one month's worth of building materials at the plant. This can easily amount to over one million dollars in inventory on hand at any given time. This requires the added cost of the space to store the materials, insurance costs to protect the material, and the carrying costs incurred until such times as the additional value is added, product is delivered and payment received from the home buyer. The home manufacturers seem to feel that these additional costs are offset by the cost benefits of volume purchasing of the materials, and the vagaries of material delivery schedules.

One modular home builder visited utilizes Just In Time (JIT) inventory acquisition and control in their operation. Materials are ordered and received within no more than 2 days prior to use. This reduces all the costs mentioned above as well as the costs incurred from pilferage of, or damage to stored materials.

The quality of inventory storage and protection, as with the control of construction quality, appeared to have a direct correlation to the amount of end product quality responsibility a manufacturer was expected to provide. Most all manufacturers store their inventories in facilities to protect them from the weather. None however made any special provisions to maintain the moisture content of lumber products beyond keeping them away from direct contact with rain or snow, and several panelizers stored their dimensional lumber in open yards with no protection from the elements at all. HUD Code manufacturers were the only producers who faced the potential of having the moisture content of their wood products checked by inspectors. Therefore, they insured the materials would meet the minimum code requirements. Some modular home producers actually stored materials in the same building as the production line. This would allow all materials to stabilize to the same temperature and moisture levels prior to installation, which helped insure better quality control.

All dimensional lumber utilized by manufacturers is purchased in the "final use" dimensions, that is 2x4, 2x6, 2x8, etc. from the lumber supplier. This entails that the greatest level of value added has been applied at the lumber mill. Those materials that are destined to become waste have already had

the value added prior to becoming waste. In the Swedish example, the least value is added by the lumber mill, and then each piece is cut to final dimensions and the full value added at the point it is incorporated into the work. This affords cost savings in the Swedish example by allowing larger quantities of fewer sizes of lumber to be ordered by the manufacturing operation. It also allows for greater quality control and less waste generated by cutting only what is necessary, providing the added value at that time and then incorporating it into the work while dimension tolerances are still maintained.

3.3.8 Product Marketing

The marketing of homes by industrialized housing manufacturers varies by product and market type. HUD Code homes for example, are marketed through dealers that are independent of the manufacturers, and the dealers may retail units from several different manufacturers. The manufacturer will provide the homes as they are ordered from the dealer. The dealer will either maintain them in his inventory, or have a model unit and take orders for the actual sales. Modular manufacturers and some panelizers market their product through builder/dealers who actually sell the units by taking orders based on the standard plans the manufacturer has to offer. These homes offer some "customization" in that minor changes to the home is allowed of the buyer. The homes are marketed through brochures developed by the manufacturer and supplied to the builder/dealer. Retail modular and panelized manufacturers will market their homes through model homes, and will build homes on speculation and then market them through either their own or an outside real estate operation. Some of the larger retail home producers offer fully developed residential communities, marketed with their own sales forces, and can provide mortgage financing through their own mortgage companies or banking subsidiaries.

There is no known examples of manufacturers in the United States that markets homes through the use of computerized home design marketing tools and marketing strategies as used in Japan. The typical "customized" home design consists of the owner selection of finish materials and cabinetry, and in some cases minor modifications to the house plans. Some of the allowable plan modifications are restricted to plan change options listed by the manufacturer for that product, or in some cases, minor (non-structural) changes to the plan. These selections and revisions are accomplished by filling out an order form, which contains a list of options available, by the owner and dealer. The manufacturer will then provide the costs of the selections and revisions and the dealer will then contact the prospective buyer for his final approval.

3.3.9 Comparison of Manufacturers

The following table contrasts the three different types of Industrialized Housing Manufacturers.

COMPARISON CATEGORY	HOUSING TYPE		
	HUD CODE	MODULAR	PANELIZED
HISTORY	~1940	~1970	~1800
% FACTORY BUILT	80% - 100% *	80% - 100% *	~20%*
COST	LOW (as low as 18\$/SF to dealer)	MEDIUM (as much as \$120/SF)	MEDIUM
MARKETS	Starters, Retirees and Dealers	Investors, builders, dealers, high rise condos, luxury homes, prisons	Captive plants, builders, upscale markets
ENERGY EFFICIENCY		Minimal (low package) and upgrade	Minimal & Upgrade packages
DESIGN FLEXIBILITY	Very limited: a)shipping restraints b)factory inspection requirement	Same as for HUD code unless for luxury markets	No constraint (if closed panel, then factory inspection required)
EXPORTS	NO	NO (to Japan)	YES
EXTENT OF R&D	NONE (two have R&D units)	SOME (manufacturer)	LITTLE
INTERESTED IN PROJECT	YES	YES	YES

*Some manufacturers get carpets and drywall installed in the field.

TABLE 3.3-1
Industrialized Housing Characteristics

3.4 CASE STUDY: FLEETWOOD HOMES

Fleetwood consists of two manufacturing divisions, HUD code homes (\$0.5 billion sales) and recreational vehicles (\$1.0 billion sales). The HUD code home product line produces 35,000 units per year and distributes nationwide. There are 26 manufacturing plants in 5 divisions: Western, Central, Mid-Atlantic, Southeast, and Florida. Most sales fall within a 300-400 mile radius of the sales location. Fleetwood mobile homes are sold exclusively through dealers.

The Housing Group consists of three main branches in the area of product development: design, engineering, and manufacturing. Because Fleetwood's product is market driven, design and marketing functions are closely tied. It is the designer's role to anticipate future trends and respond to specific customer preferences. In order to accomplish this, the Design Manager meets with dealers, attends national conferences (e.g., NAHB), seminars (Color Marketing Group), and studies statistical surveys and trade publications.

The engineer's role is to make the in-house designer's concept buildable and to check for code compliance with these and other customer modified orders. Engineering together with the quality control (QC) supervisor has the responsibility to review for code compliance. Areas outside their jurisdiction are sent to RADCO, an independent testing agency.

Standard Fleetwood models are built from pre-approved floorplans, details, and schedules. Volumes of these engineering documents are kept as reference materials for coordinators who oversee working drawings. Similarly, a QC-inspector has access to approved specifications (Federal Standards for HUD-code Homes) for dealing with non-standard design/construction items in the plant. The purpose of these engineering documents is to establish Standard Assembly Methods for standard models with slight variations. These documents are vital to the plant operation because they contain the information necessary for manufacturing.

Product data sheets list all possible options within a product line. This sheet is completed by the designer and describes a model for manufacturing -- for example, interior finishes, roof, wall, and floor construction are specified on this form. The manufacturing section works from these product specifications or a similar form completed by a sales person in the dealer showroom. This written description, together with a floorplan, are the construction documents used to build a mobile home. Customer changes to a floorplan are simply noted on the plan. Plans are not redrawn for manufacturing.

In terms of the labor force, Fleetwood hires unskilled labor to do discrete factory tasks. Therefore, changes in the production configuration are costly due to the retraining of laborers and the disruption of the assembly line. Although labor only runs 15% of the cost of a HUD code home, it is a critical factor.

Fleetwood's headquarters organizes national advertising campaigns which they distribute to the divisions. The Design Manager plays a key contact in soliciting and receiving feedback on product performance from dealers, which he passes along to Marketing.

Due to the market-driven nature of Fleetwood designs, changes to the product are often a result of customer requests. Energy conservation provides a good example: in Oregon the Bonneville Power Administration's "Super Good Cents in Energy Program" stirred customer interest. Consequently, Fleetwood began offering mobile homes that met those standards.

Corporate computing needs are met on a DEC VAX. Fleetwood has been using DEC equipment for at least 13 years starting with PDP 8's, upgrading to DECMates, and then to the VAX. Corporate applications include payroll, accounting, sales analysis, spreadsheets, warranty claims history and analysis.

Fleetwood has centralized computing at its headquarters and networks with five satellite plants in California, Indiana, Virginia, and Oregon. The network used is Paradigm. The goal is to network to all plants (50 plus factories) with the VAX having 4-6 terminals and 2-3 printers per station.

Besides the VAX, employees initiated a Macintosh trend by bringing computers in from home. The company made the Macintosh the corporate standard because of the wide acceptance of this personal computer and because of the natural connectivity with the DEC.

3.4.2 Manufacturing Methods A. Elshennawy, W. Swart

This section documents a "typical" industrialized housing manufacturer for the purpose of providing base line data that can be used to develop a generic simulation model. Such a model will be the basis for detecting and classifying manufacturing bottlenecks and evaluating potential resolutions. The combined results of these studies will constitute the foundation for determining a manufacturing strategy for the industrialized housing industry.

Selecting a Manufacturer:

Fleetwood Homes Industries, the nation's largest manufacturer of mobile homes, has a plant in Haines City, Florida, which is within reasonable access from the University of Central Florida. Senior management of this company is represented on the steering committee of this research project and has been very supportive in this research. Their headquarters office in Riverdale, California collaborated closely with another phase of this project conducted by the University of Oregon. These factors contributed to the selection of the Fleetwood Haines City, Florida plant as the "typical" manufacturer. However, the primary reason for the selection was that the processes that take place in the manufacture of mobile homes have a great deal in common with processes that take place in both modular and panelized manufacturers. For example, the processes involved in the manufacture of wall systems at Fleetwood include the cutting of all raw materials to be used in the system,

building of wall framing, and attaching the wall board to the framing. A similar process would be observed if a panelized or modular plant were being investigated. Fleetwood's roof system consists of the cutting of all roofing materials, building roof trusses and attaching them to ceiling material, spraying a finish on the ceiling, and installing roof decking. Modular manufacturers build each component of the roof system precisely in the same manner. Fleetwood produces complete floor systems as well. This process includes the cutting of all raw materials to be used, assembling the steel chassis and floor framing, and installing the floor decking. Again the processes involved in the manufacture of this system are similar to those employed by other manufacturers.

The mobile home that Fleetwood manufactures can be viewed as a combination of modular and panelized housing types. All of the structural components are assembled within the factory environment. The process of prefabrication of the components is almost identical to the way in which panelized builders produce them. In addition, Fleetwood connects the three systems as well as all finishing components in the factory just as modular manufacturers do.

In spite of the above, certain differences must be acknowledged. Fleetwood does not generally mud and cure the interior walls of their units, a process which appears to create bottlenecks in certain modular home builders processes. The low roof pitches used in Fleetwood's units manufactured in Haines City, Florida are ideal for a transportation viewpoint. Manufacturers producing higher pitched roofs must include in their designs and processes manners in which to hinge and fold the roof during transportation. The impact of these, as well as some other differences between the various segments of the industrialized housing industry will be more fully evaluated during the generalization phase of the study where the findings at Fleetwood are welded into an industry process model.

Factory Overview

Fleetwood produces single and double wide mobile homes at the Haines City facility. These homes are typically complete with wiring, plumbing and all interior finishing items installed. Double wide homes are built as two separate modules (units), whereas single wide are just one module. These modules typically range in size according to the following specifications:

1. Length: 32 ft. - 60 ft.
2. Width: 24 ft. - 28 ft. (double wide)
12 ft. - 14 ft. (single)
3. Area: 752 sq. ft.- 1500 sq. ft.

Each module is produced entirely within the factory environment through a number of cutting, fabrication, and assembly processes performed at various workstations.

Each workstation is described in detail in subsequent chapters. Production runs are typically made in batches. That is, one day they will produce only double wide homes; another day only single wide homes will be produced. The batch types are determined by the specific production orders for that day. The production line typically contains an average of twelve modules at any one time. The daily production throughput averages about ten. It should be noted that this number can vary depending on the module size. Modules are transported from station to station lengthwise rather than the conventional widthwise orientation. The line is powered by a chain driven floor conveyor. A general overview of the factory is presented at this point.

The factory is approximately 60,000 square feet not including office space with 65 percent of that being production space and the rest storage and transport space. To understand the plant's operations and how they are interrelated to one another, a brief overview is provided. The fabrication of the chassis is the first operation. The finished chassis is then moved to the first station of the main production line where the floor system is assembled. The floor assembly is moved to the next station where interior and exterior walls, bath and kitchen cabinets are installed. The wall systems have been brought from the assembly workstations located on either side of the installation workstation. The walls are manufactured at these stations. The house assembly is moved to the next workstation where the roof system is installed. The roof system has been produced at the roof assembly workstation adjacent to the installation station. The trusses have been fabricated at a workstation located outside of the main plant and then transported to the assembly station. Once the roof has been fastened to the home the decking and covering is attached and the assembly is moved to the next workstation where all exterior finishing such as the installing of siding, soffits, doors, windows, etc. are performed. These materials were supplied from a storage area located outside of the plant. The assembly is next moved to the interior finishing workstation where appliances, interior trim and finishing, lighting, etc. are installed. The appliances are transported to the assembly from a storage area located adjacent to the finishing workstation. After completion of the module assembly, a final test and inspection is performed. Figure 3.4.2-1 shows the factory layout. This layout provides information about the location of the various workstations within the plant. For example, in the center of the plant and running from top to bottom is the main production line. All of the blocks on either side of the main line are subassembly workstations. The addition, the blocks outside of the plant represent storage locations for inventory stock. These warehouses contain all of the materials to be the used in the manufacture of the homes. As they are needed, these materials are brought to the appropriate workstations for use. The production process previously described is summarized in the process flow chart shown in Figure 3.4.2-2. This chart is briefly discussed in the next several paragraphs.

MAIN
STORAGE AREA

SECONDARY
STORAGE AREA

CHASSIS
PAINT AREA

STEEL
BEAMS
STOR.

Figure 3.4.2-1 Fleetwood Plant

Figure 3.4.2-2 Fleetwood Plant Process

A process flow chart is a device used to examine the flow of operations within a workstation or factory as well as the flow of items into and out of the stations. This flow chart is a useful tool for identifying problems with a layout resulting from inefficient material flow. A process flow chart can also provide an overall picture of what is actually taking place within the particular facility. The process flow chart can also serve as starting ground for restructuring a layout so as to optimize the sequence of operations as well as the flow of incoming and outgoing materials or assemblies. The flow chart should be superimposed onto the layout so that the exact location of each operation and storage area is correct for the analysis.

Each symbol has a specific meaning. Triangles represent storage locations. Circles represent operations, arrows represent transportation processes, a square signifies an inspection operation, and a D represents a delay in a process. The flow of materials follows the direction of the arrows. For example, S3 signifies the storage area for chassis raw materials, T7 is the transporting of these materials to a staging area S10. O8 is the first operation to be performed at the chassis workstation, O9 the second and so forth. T8 signifies the transporting of the finished assembly out of the workstation. This logic follows for all of the processes in this flow chart. Another example is TO which is the first transport in the layout. The chassis is being brought to the main production line to begin the first assembly operation O1. T1 is the transport to the assembly to the second operation O2 and so on. A complete listing defining all of the symbols is contained in the Appendix.

It is hoped that this factory overview will provide enough background to allow the reader to work through this document with a good understanding of the material contained in the Appendix which describe Fleetwood's manufacturing operations in detail.

Time Studies and Analysis

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. Table 3.4.2-1 summarizes the data. These data are preliminary and contain some gaps that can be filled later.

This type of data is quite useful. Figure 3.4.2-3 shows a graphical analysis of the data. Figure 3.4.2-3a shows the man hours required for one production unit (12'x60') and Figure 3.4.2-3b gives the available manpower per station. The process efficiency can then be determined by the ratio of man-hour requirements to manpower availability at each station. This data are shown in Figure 3.4.2-3c. This type of analysis pinpoints the work stations where productivity can be improved.

Fleetwood Plant Data: Manpower and Time requirements to produce
One Manufactured Unit (12'x60').

station name	description	#people	time(min)	sta#
Truss fab:	rip lumber	0.33	13	1
	cut chords & webs	0.33	14	1
	assemble trusses (30)	1.3	15	1
	move to store	0	0	1
Chassis:	assemble frame	3	45	2
	axle, wheels, hitch	2	20	2
	move to paint	0	5	2
	paint	1	20	2
	move to dry	0	5	2
	move to line	0	5	2
Floor:	assemble frame	3	45	3
	apply decking	2	30	3
	cut openings	2	20	3
	prep & floor covers	2	15	3
	inspect	0	0	3
Ext walls:	assemble side walls	4	50	4
	assemble end walls	2	25	4
	move to line	0	0	4
Int walls:	assemble frames (5.5)	3	44	5
	apply sheathing (5.5)	2	38.5	5
	move to line	0	0	5
Wall inst:	Ext walls	2	45	6
	Int walls	2	30	6
	elect wiring	2	30	6
	kitchen cabinets	2	20	6
Roof frame:	components to line	0	0	7
	assemble roof framing	4	30	7
	prep ceiling	1	30	7
	spray drywall	2	10	7
	move to line	0	0	7
Roof fin:	install decking	3	50	8
	move to next station	0	0	8
	install insulation	1	25	8
	install top & facia	2	45	8
	move to next station	0	0	8
	install felt paper	2	15	8
	install shingles	2	50	8
	inspection	1	5	8
Ext fin:	wall insulation	1	10	9
	end siding	1	50	9
	side siding	2	60	9
	windows/doors	5	25	9
	ext lighting	2	20	9
Int fin:	plastic cover	1	10	9
	counter tops	3	40	10
	closet/cabinets	3	45	10
	wall panel install	2	30	10
	wiring connections	2	35	10
	cleaning	2	20	10
	appliance & fixtures	4	30	10
	elec test & inspect	3	5	10

Table 3.4.2-1

STATISTICS:
 Total man-hr/unit = 44.5
 Total manpower = 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 3.4.2-3 Analysis of Haines City Fleetwood manufacturing plant requirements (a), resources (b) and efficiency (c) by station.

It has other uses too. We will later see that there are opportunities in the roof finish station (#8) to improve energy efficiency by more even application of the blown-in insulation if slightly more time is allowed. The analysis shows that station #8 is reasonably efficient already. So a little extra time spent in that station will not slow the line. Instead it will result in a higher quality and more energy efficient product.

3.4.3 Recommendations

3.4.3.1 Design M. McDonald, G.Z. Brown

Many of the tasks, especially in design and engineering of the mobile home, were prime candidates for computerization. Standard drawings, specifications, schedules, codes, could be electronically stored and manipulated. To go one step further, this information could also be viewed electronically on the factory floor. Increased direct communication in the form of data sharing may limit the non-approved custom model bottleneck currently experienced in the factory.

The same construction communication gap that exists between conventional site builders and designers, is found between HUD code home manufacturers and their designers. The manufacturer, whose primary concern is production efficiency, is faced with incorporating custom designs into the assembly line framework. The designer, on the other hand, is responding to customer demands which often stem from transporting conventional housing ideals to a manufactured home irrespective of the manufacturing process. One area of improved efficiency is the cross education of design about manufacturing. In this way, manufacturing efficiencies can be designed into a product from its inception.

Fleetwood is ready for more extensive computerization. Currently, four controllers in the corporate office use Macintosh SEs. The Drafting Supervisor is experimenting with Claris CAD and VersaCAD on the Mac II. The main accounting operations are carried out on a DEC/VAX mini computer. The hardware configuration is excellent for networking (Macs to DEC).

3.4.3.2 Energy Efficiency L. Maxwell, P. Fairey

The intent of this section is to discover and present opportunities for improving the energy efficiency of HUD Code (mobile homes) presently manufactured by Fleetwood Enterprises, Inc. The intent is to determine how the energy efficiency of the manufactured units can be easily enhanced, while adding no or very little increase in the cost of labor and/or materials to manufacture the unit.

Four areas of opportunities for improving energy efficiency have been discovered through the

studying of the different phases of the production process. These major areas are listed, in order of the greatest to the least beneficial increase in energy efficiency are the roof system, air distribution system, floor system, and wall system. Each of these areas will be described as they are presently performed, as well as suggestions for change along with potential cost ramifications.

Four areas involving the roof construction presented themselves as areas of low or no added cost energy improvements. These four areas are: (a) roof radiant energy control, (b) roof ventilation, (c) air circulation, and (d) roof thermal insulation.

Roof Radiant Energy Control:

Studies by the Florida Solar Energy Center (FSEC) and others have shown that significant energy savings can be achieved by the utilization of a "Radiant Barrier" in the roof of a structure. The studies indicate that under peak day conditions, total heat transfer down through attics can be reduced by more than 40% by utilizing a radiant barrier. Figure 3.4.3.2-1 illustrates the effects of a radiant barrier system on heat gains into an air conditioned space. The radiant barrier consists of a reflective material with low emittance properties which is utilized to reduce heat gains inside a structure by blocking radiant heat transfer from the roof to the conditioned space.

Figure 3.4.3.2-1
Effects of Radiant Barriers on Heat Gains
into Air-Conditioned Space

At the time of construction, if a radiant barrier is installed in the roof system, and is coupled with adequate roof ventilation, the homes peak cooling loads can be cut by 9%. This can be accomplished by installing the presently utilized type of roof decking, and installing it 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 would be installed so that the reflective face of the material would be 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.

Roof Ventilation

Increased roof space ventilation can aid in the increased energy efficiency of the manufactured homes, especially if utilized in conjunction with the radiant barrier system described above. This can easily be accomplished by several minor changes. 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.

Increasing the intake area can be accomplished by revising the perforated soffit vent used to increase the vent free area available, or to increase 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 necessitate any increases in labor or material cost to a unit being manufactured.

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, which should not necessitate any further labor in the plant, or in the field than is presently required. 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 very minimal.

Roof Air Circulation:

In the construction of some of the units, conditions that could prevent good circulation of air in the roof space were noted. This typically consisted of the insulation that was being blown into the roof space was also being blown around and over the HVAC ducts, as illustrated in Figure 3.4.3.2-2. When the roof decking was subsequently placed on the trusses, the insulation at the ducts was compressed up against the decking which would prevent circulation of air in those areas.

Figure 3.4.3.2-2, Attic Insulation Over HVAC Ducts

This can easily be remedied by ensuring that the air in the roof space is not blocked, or that circulation is not hindered. The remedy to this problem is such that understanding the problem and observing the construction process to ensure that it does not occur is all that is required, there should be no increase in either material or labor cost associated with it. This problem can also be aided by suggestions given under air distribution systems item below.

Roof Insulation:

Roof thermal insulation installed in the homes consists of blow-in mineral wool insulation. The application of roof thermal insulation is illustrated in Figure 3.4.3.2-3. 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. As the insulation is blown in from one side of the unit typically, any obstructions in the roof system (such as air distribution ducts), prevents proper placement of the insulation. This problem could be remedied by allowing a walk area around the entire unit for use by the installer.

Air Distribution Systems

Recent studies conducted in Florida by FSEC and by others around the country have shown that the potential for significant energy loss can be attributed to conditioned air distribution systems which are located outside the thermal envelope of the home. These losses can amount to over 50% of the total energy efficiency of a house. The loss of energy efficiency occurs 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. Example 3.4.3.1-4 illustrates the loss of energy

efficiency due to leakage of ducts outside the conditioned envelope of nine Florida homes tested. If the leak is in the supply ducts, conditioned air is lost to the non-conditioned area. Further, the home becomes under-pressurized in relation to the outside air pressure and air infiltration is increased to the home. If on the other hand, there is a leak in the return air duct, the air handler draws unconditioned

Figure 3.4.3.2-3, Application of Blown-in Attic Insulation

air into the system, increasing the cooling load, and at the same time increasing ex-filtration from the home due to over-pressurization. Whenever the air handler is located outside the conditioned space, the potential for either, or both, of the two problems mentioned above is increased.

Infiltration rates in nine Florida residences with air handler OFF and ON

Figure 3.4.3.2-4, Infiltration Rates of Homes with HVAC Duct Leakage

The design of the homes being manufactured at the plant is based on a package HVAC system which

would sit outside the home with supply and return air ducted into the home from under the floor. The supply air duct, once it enters under the floor, is routed up to the roof space and distributed to each room from above the ceiling. Figure 3.4.3.2-5 illustrates the air distribution system in the roof space of a typical unit. On a double wide home, the supply duct is split under the floor and each half of the home has a separate riser. In the same fashion, return air is ducted out of the home under the floor and back to the AC unit. If a leak occurs in the ducts to or from the home to the HVAC unit, one or both of the problems described above would occur. However, if discovered, the leaks can be repaired with relative ease. On the other hand, if a duct leak were to occur in the supply ducts located above the ceiling, (during construction or later), it would be impossible to repair since no

Figure 3.4.3.2-5, HVAC Ducts in Attic Space

accessibility to that space exists. Two areas of opportunity for increasing the potential energy efficiency of the homes in this area is relocating air distribution ducts within the conditioned envelope of the units and location of the air handler within the units is described below.

Air Distribution:

The design and placement of ducts within the conditioned space would eliminate the potential for the problems described. If a duct should leak within the conditioned space, no energy wastes would occur. 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 living and dining room and other such similar spaces where this amenity is especially desirable. This change would add minimal cost to the unit, most of which would be in the construction and installation of the soffits to conceal ducts.

Air Handlers:

Air handlers located within the conditioned space can greatly reduce the potential for energy waste, as can be seen by the graph in Figure 3.4.3.2-6 which shows a loss of efficiency from an air handler located outside of the thermal envelope. This can be accomplished by designing for split HVAC systems which will allow the air handler to be located inside the home. Due to the relatively compact size of air handlers available on the market, of the capacity required, this option should not affect the usable area or layout of the homes. Further, it would not be necessary for the manufacturer to install the air handler at the plant, but to merely provide 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 can be implemented with no additional or minimal additional cost to the production of a home.

FIGURE 3.4.3.2-6, Effects of Air Handler Outside of Conditioned Envelope

Floors

The floor construction of the typical units being constructed consist of the steel chassis, to which a black scrim cloth is draped and a 3/4" layer of unfaced fiberglass batt insulation is overlaid. Figure 3.4.3.2-7 illustrates the floor framing with the draped insulation batts. The floor joists are placed

over the insulation and cloth perpendicular to the chassis.

Figure 3.4.3.2-7, Floor Framing and Underfloor Insulation

Piping for hot and cold water is routed above the insulation but under the floor joists, as is illustrated in Figure 3.4.3.2-8. Water piping does not receive any pipe insulation. All underfloor wiring is routed on top on the insulation and under the joists similar to the water supply piping. A continuous rim joist is attached around the perimeter, and 3/4" plywood floor decking is attached with glue and nails to the floor joists. The floor joist system is bolted to the chassis. The edges of the black scrim

Figure 3.4.3.2-8, Water Supply Piping in Underfloor Insulation

cloth are pulled up around the bottom edge of the rim joists and attached with staples. Once these steps are completed, the balance of the construction of the home takes place on this platform. The loss of energy efficiency can occur by several means with the present construction. As there is no insulation on the side walls of the floor space, heat loss and gain can occur around the entire perimeter unimpeded. Further, if a tear occurs in the scrim cloth and insulation, heat gains and losses can occur throughout the entire floor area as the entire floor plenum is open to air transport. Any uninsulated hot water piping inside the plenum would lose heat to the surrounding space, and this loss would be increased if a breach in the insulation anywhere caused the underfloor area to be exposed to the ambient air temperatures.

Three areas of opportunities for improving the energy efficiency of the homes in the area of the floor plenum present themselves. The areas of opportunities are side wall insulation, floor plenum baffling or insulation improvement, and hot water supply piping insulating.

Side Wall Insulation:

Providing 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.

Floor Plenum Baffling:

If the scrim cloth and insulation is torn anywhere under the floor, due to its construction, air entering through the tear could circulate freely throughout the floor plenum. A simple way to eliminate this potential 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 from the next. Then if a air leak occurs in one area of the floor, it is contained in that area. This area of opportunity would not add any materials cost, and the labor required would only amount to several minutes time for the additional stapling, therefore the additional cost would be very minimal.

Another way to improve this area, would be to lay unfaced insulation batts between joists on top of the scrim and 3/4" batts. This would both increase floor insulation levels as well as reduce the potential for air migration under the floor. It would also have the added benefit of insulating the water piping. The added costs for this item would be based on the amount of additional insulation material installed, the additional labor cost is very minimal as just the placement of the insulation is necessary.

Hot Water Piping Insulation:

The energy to heat water for domestic use can be a significant portion of the energy used in a typical residence. Standby losses, (those losses attributed to heat loss while the hot water is standing in the

tank and in the supply piping) is the major area of energy waste. The addition of an insulating jacket for the hot water heater as well as installation of hot water supply piping insulation can significantly improve the energy efficiency of the system by reducing the standby losses. As the supply piping is located in the floor plenum, the only time it could be insulated is during construction. Since the insulation, like the piping, is flexible, it could be installed on the piping prior to installing the piping in the floor space of the unit, allowing the installation of the piping to remain the same. The insulation could be installed by the piping fabricators, adding little in the way of labor costs, and the costs of the insulation material is very small.

Walls

Several areas of opportunities exist to help improve the thermal performance of the walls. The opportunities are such that they do not necessarily occur in the wall construction only, but also occur in the floor and roof construction. The areas of opportunities are in air infiltration/exfiltration reduction strategies, and thermal insulation enhancements.

Air Infiltration/Exfiltration Reduction:

The infiltration/exfiltration of air into or out of the home can increase the use of energy by increasing cooling loads in the summer and increasing heating loads in the winter. Air infiltration and exfiltration can be reduced by utilizing several simple strategies in the construction of the manufactured homes. Sealing of wall, floor, and ceiling penetrations is one way of reducing infiltration. Wherever penetrations in the walls, floors, or ceilings are made for the passage of electrical wiring or plumbing, injecting foam or other sealant into the opening and around the wire or piping will eliminate air infiltration at these areas. Adding gaskets behind light switch plates and electrical outlets also helps reduce air infiltration. Avoiding the use of recessed ceiling mounted light fixtures whenever possible can greatly reduce infiltration/exfiltration through the ceiling. When recessed light fixtures are required, utilizing fixtures that are designed to reduce or eliminate infiltration or exfiltration from around or through them can help to significantly reduce energy losses. Another strategy to reduce infiltration/exfiltration is to seal the edges of the infiltration barrier that is presently utilized on the manufactured homes. This is simply accomplished by placing a bead of non-hardening caulk around the edge of door, window, and other openings, and around the perimeter of the wall at the edges of the barrier. The barrier is pressed into the caulking, sealing it from air movement. The cost of this strategy consists of the cost of the caulking and the several minutes labor of applying the caulk bead.

To achieve maximum benefit from thermal insulation, the careful placement of the insulation is imperative. Further, all areas of wall cavities need be properly insulated. Figure 3.4.3.2-9 illustrates cavities at angled walls where the application of insulation could alleviate potential thermal shorts.

Figure 3.4.3.2-9 Uninsulated Wall Cavities at Angled Walls

Careful placement of insulation can improve thermal performance by insuring that all areas have proper coverage of insulation. Figure 3.4.3.2-10 illustrates areas of potential loss of energy efficiency from carelessly installed batt insulation.

Figure 3.4.3.1-10, Carelessly Installed Batt Insulation

Conclusion

Construction of a home in the controlled conditions of a manufacturing plant offer opportunities to significantly increase the energy efficiency of the home. Many of the opportunities require little or no increase in the cost of the product to accomplish. The entire premise of this study was to

determine what could be accomplished to improve the energy efficiency of the product manufactured, within the existing framework of production, without adding significantly to the cost of the product. Any one strategy can be incorporated into the manufacturing process and will help improve the energy efficiency of the home. To realize the greatest impact on energy efficiency improvement, the strategies should be considered in the order they are presented. Control of radiant energy transfer as well as improving roof space ventilation can potentially decrease cooling loads by 9% or more through the reduction of heat loads on the structure. Incorporating the concepts concerning location of and distribution of conditioned air throughout the home can have significant potential for energy conservation through the prevention of energy losses that could amount to 50% or more. Utilizing the strategies for floor and wall construction can provide further benefits through the reduction of infiltration/exfiltration loads imposed on the home. All of the improvements to the energy efficiency of the homes with little or no costs to the home.

In the highly competitive home and manufactured home industries, strategies are constantly pursued to enable the builder to sell more of his product. The ability to produce and market a product that is more energy efficient than a competitors for the same price as the competitors product provides a great marketing tool. Further, the production of a more energy efficient product also implies a better quality product by its nature. Increased energy efficiency and improved quality at a competitive price, will always provide the extra edge required in the home building industry.

3.4.3.3 Recommendations to Improve Manufacturing A. Elshennawy, W.Swart

The complete Fleetwood report in the Appendix details specific recommendations for each of the workstations. To give readers a flavor, the recommendations for the truss fabrication and the overall recommendations are reproduced here.

Recommendation, for Truss Fabrication

It is recommended that the following suggestions be investigated:

1. Layout:
 - Exchange the finished truss stock with the truss cord stock area.
 - Expand workstation size to allow for more efficient flow of materials.
 - Relocate workstation near the roof assembly area to potentially reduce transport time that exists with current location. Production balance between trusses used and trusses sent to other Fleetwood plants should be considered.

2. Labor:

- Labor utilization should be examined. This operation might possibly be performed with a smaller crew if adequate materials handling and cutting equipment are utilized.
- Truss machines exist that are capable of substantially higher production rates than current machines.

3. Process:

- Reasonably efficient. Truss presses are adequate for required production volume.
- Cutting systems exist that are capable of straight and angular cuts on one machine, thus eliminating the need for two saws. An example of such systems is shown in Figure 3.4.3.3-1.
- Multi-head cutters are available that are capable of cutting multiple studs simultaneously. This production increase makes the possibility of using one man for cutting a feasible alternative. Other available cutting equipment are listed in the Appendix.

Double Cut-Off Saw

Figure 3.4.3.3-1

4. Materials Handling:

- Replace roller carts with automatic conveyors such as the one shown in Figure 3.4.3.3-2 in order to eliminate the need for manual transporting of components within the work-cell.
- Reduce loading and unloading efforts. Automatic truss stackers are available that can perform automatic stacking and palletizing of finished trusses, thus reducing labor time. An example of such truss stackers is shown in Figure 3.4.3.3-3. A list of available equipment is included in the Appendix.

CONVEYOR

TRUSS STACKER

Figure 3.4.3.3-2

Figure 3.4.3.2-3

OPPORTUNITIES FOR OTHER POTENTIAL IMPROVEMENT

The following recommendations should be investigated.

Centralize Cutting

- Centralize cutting for all structural components as well as gypsum board and plywood paneling. Every workstation has its own cutting section. Assemblers often have to perform their own cutting which slows down production time. The area created by the removal of chassis assembly could be utilized for this operation. The crew would consist of 3 to 4 workers supplied from those taken off other processes that are over supplied.
- The use of computerized sawing machinery capable of precision cutting at substantially higher cut rates could prove beneficial when considering production volume. Figure 3.4.3.3-4 shows an example of automated computer-controlled cutting systems. See the Appendix for additional listings of available cutting machinery.

Reduce Inventory

- Warehouse always contains substantial amounts of stock. The holding costs could be substantial for both materials and finished products. Inventory control procedures such as materials requirements planning, could be adopted to help optimize desired inventories.

- Developing a structured system will aid in improved planning and scheduling. If excess inventory does exist as suspected.
- Schedule and purchase materials only to fill customer orders. This change can only be considered after determining what the stock turnover rate is.

The Industry's Only Automated Computer-Controlled Cutting System

- Cutting lists are downloaded from your in-house computer directly to the saw's control console and stored until you are ready to produce the component
- The desired component appears on the IBM PC screen at your command
- A touch of a key sends the robotic saw arms into the setup mode
- 15 to 20 seconds later you are cutting lumber ... without running test pieces
- Industry leaders like Truswal, On-Line Data, Bemax and Hydro-Air can now provide software to download directly to the Auto Omni
- Join the growing number of companies on the leading edge of technology with Auto Omni

Figure 3.4.3.3-4

Improve Material Handling System

- Overhead cranes work very well for transport of heavy materials such as building components, but there is still a large amount of manual handling of heavy items, which increases likelihood of injury.
- The use of small conveyors, vertical roller carts, automatic lifts and conveyors, pallet tables, and automatic lumber stackers (see Figure 3.4.3.3-5 for example) should be considered for both production. In the Appendix, additional listing of available materials handling equipment is presented.

Provide More Inspection

- Very little inspection is performed other than inspection of finished products. More stringent criteria of selection should be used for raw material acceptance. Inspection of cuts, joints, processes can lead to a higher degree of quality for the overall product.

MAK-STACKER stacks lumber on the off-feed side of component cutters replacing off-bearers. SC Inc.

Figure 3.4.3.3-5

Jigs and Fixtures

- Currently the use of these tools is scarce. Only for truss fabrication are they employed extensively. For assemblies such as interior/exterior wall frames and floor frames, workers lay them out from memory and by sheer repetition have gotten very proficient at this operation. It is doubtful that jigs and fixtures could substantially improve the process over the current methods used.
- This is true as long as skilled workers are performing the operations, but when new people must be trained the operation is slowed considerably, making jigs a more attractive alternative. Additionally, the quality of the product would be improved.
- Adopting the use of jigs and fixtures (see Figure 3.4.3.3-6) would effectively eliminate the need for skilled workers to perform these operations and thus reduce labor costs. It is believed that these tools can offset the loss of production time caused by the use of less skilled people.
- They could also be used in cutting operations which would save time now used for measuring. Additionally, more consistent and precise cuts would be made improving quality.
- Layout tables with jigs are commercially available. See the Appendix for listings of available equipment.
- Only consideration would be the trade off between labor savings and the cost of building the jigs.
- Another alternative would be to develop templates for the various configurations that are used. This would be less expensive than making jigs and fixtures, as well as ease handling efforts.

**STEEL TABLE
JIGGING HARDWARE**

**WOOD TOP
JIGGING HARDWARE**

Figure 3.4.3.3-6

3.5 CURRENT STATUS OF ENERGY EFFICIENCY P. Fairey

There are at least six interrelated areas where industrial producers can make a significant difference in the energy efficiency of U.S. housing. These include but are not limited to: 1) joints, seals and tolerances, 2) envelope systems, 3) heating and cooling systems, 4) distribution systems, 5) quality assurance, and 6) building design.

Joints, Seals, and Tolerances

Joints, seals, and tolerances are very closely related to energy efficiency and quality assurance. In all climates, unwanted air leakage is a major source of building energy loss. In addition, the future will almost certainly require that indoor air quality be improved in out buildings. It will be extremely difficult to accomplish this without first controlling building leakage paths.

Major advances can be made in the tightness of buildings and their component parts if sufficient attention is given to this area of industrialization. Although very difficult to control in the field, the industrial environment offers a potential to make significant progress in this area in the future. new materials and building systems, perhaps like those being developed at GE's Advanced Plastics Division (1989), may yield advances that will significantly advance the state-of-the-art in this area.

Envelope

The design thermal integrity of residential building envelopes has been significantly improved over the last 15 years. In 1975 the majority of new homes had heat loss coefficients of 18-20 Btu/sf/degree-day. Today, the heat loss coefficient of the majority of new houses is in the range of 10-12 Btu/sf/degree-day and homes with loss coefficients of 3-5 Btu/sf/degree-day are readily achievable.

This substantial increase in design envelope efficiency has resulted primarily from a combination of government sponsored building energy research and mandated changes in building practice. Current research is aimed at even higher performance building materials and products (e.g. very high R-value windows with switchable, selective coatings; evacuated insulation systems; development of sophisticated thermal and moisture storage systems; etc.)

Field research, however, has consistently indicated that real buildings often fail to meet their predicted design efficiencies. Some of the discrepancy can be explained by the influence that occupants have on the ultimate energy consumption of buildings. Most of the remainder of these differences are the result of the fact that buildings are rarely, if ever, constructed exactly as intended. The reason for this is straightforward. The energy knowledge of the typical consumer, building contractor and building inspector is limited to well known energy efficiency concepts like R-value and EER.

Although these factors may play a significant role in the energy efficiency of a building, other factors that are not well known or understood by these individuals may have overriding building energy effects. To take an oversimplified example, if the R-value of the wall insulation material is rated R-13 but it is installed in such a manner that it is significantly compressed or if convective air currents or other major thermal bridges short circuit the insulation, then the in-situ resistance of the wall to heat flow will be far less than the product specification and building design stipulates.

Infrared observation of field wall and roof insulation systems by Nelson, et al (1986) showed many examples of insulation systems that were not performing as expected. Reasons for the observed performance degradation ranged from improperly fitted batt insulation in walls and ceilings leading to convective looping and thermal bridging to wet insulation resulting from air leakage pathways and moisture condensation within the wall or roof system. John Tooley (1989) of Natural Florida Retrofits, Inc. has also made infrared observations of over 300 houses in the Central Florida Area. He has found many degraded wall and roof insulation systems. By-and-large these performance degradations have resulted from installations that allowed convective loops to occur within the system.

Observations made by this research team during site visits to a Fleetwood manufacturing plant in Haines City, Florida uncovered a similar discrepancy whereby the ceiling insulation was being unevenly applied to the ceiling area. A blockage caused by ductwork located in the attic space caused the blown insulation to be applied predominantly to the ceiling area on the near side of the ductwork. A simple recommendation was made to allow blowing the attic from both sides of the transverse ductwork to obviate this problem. (See also section 3.4.3).

These data indicate that quality installation is often more important as quality design. They also point out the need for better quality assurance in building construction practice.

Heating and Cooling Systems

Many of the energy inefficiencies associated with contemporary U.S. housing from unanticipated interactions between the various components or systems comprising the building. For example, when we tighten the building envelope in order to reduce unwanted infiltration, we often unwittingly cause air quality problems and increase the potential for moisture condensation problems in many climates.

Heating and cooling systems are often a source of systems interaction inefficiencies in residences. From tracer gas measurements in 31 east Tennessee homes, Grammage et al. (1984) found that average air infiltration rates increased from 0.44 air changes per hour (ach) to 0.78 ach when the air handler units were operating.

Additional studies conducted by Nelson, et al. (1986) collected and analyzed energy consumption data from 112 houses in Minnesota. In contrast to expectations, the data showed very few correlations between energy performance and design features. One fact, however, stood out in the work: houses with forced air heating systems with duct work outside the conditioned space showed energy losses on the order of 5 to 10 million Btu/year that could be attributed to inefficiencies of the forced air heating system.

This finding has been substantiated and expanded upon by others. A study of 820 homes conducted by Northwest Power Planning Council in the Pacific Northwest and analyzed by Parker (1989) has shown homes with forced air heating systems to have measured air infiltration rates that are 70% higher than homes with other types of heating systems. This resulted in an average increase of 17% to 22% in energy use for forced air as compared to non-forced air electric resistance heating systems.

Research by Cummings (1989) and Cummings and Tooley (1989) has yielded similar results and has begun to uncover the nature and extent of some of the leak sources. In five particularly problematic homes in Florida, tracer gas measurements showed air change rates to be ten times greater when the air handler was running than when it was not (1.42 ach vs. 0.14 ach). Most of the leakage was found to be the result of leaks in the return air plenum. The problem was compounded by the fact that many of the return side leak pathways were found to lead directly to the attics of the homes. Calculations performed by the researchers indicated that return-side attic leaks of this magnitude would cause an air conditioning system with an EER rating of 10.0 to have an operating EER near 2.0, or a five-fold decrease in energy efficiency.

Development of integrated heating, cooling and ventilation systems that are capable of overcoming such problems should be a major focus of this research. Many industrialized housing manufacturers currently view these important energy systems as "add ons" to be accomplished by local contractors. This may be because no major mechanical system manufacturer has yet seen the system efficiency and economic benefits that could be associated with a factory-assembled, component-based, integrated system approach.

Distribution Systems

Homes are composed of numerous systems that must interact. Among them are the distribution systems of the home. These include the electrical, plumbing, heating, cooling, control and security systems. Each of these systems requires the design and implementation of a distribution system within the home. It has been previously mentioned that forced air heating and cooling systems have proven in the field to be severely lacking in energy efficiency in this regard.

Other residential distribution systems also have energy implications. For example, it is common practice to route wiring and plumbing systems through the insulated wall systems of the home. This often results in compressed insulation and convective air paths that can carry significant energy losses from one side of the envelope to the other.

The development of integrated and control systems for housing has already been begun by the NAHB Smart House Program and others. But what remains to be accomplished is a rethinking of the manner in which we systematize home distribution systems in the industrial process environment. The development of systematic distribution systems in houses can mean the difference between distribution systems that interfere with one another and distribution systems that function symbiotically.

Quality Assurance

Quality assurance is absolutely necessary for energy efficiency. As stated much earlier in the history of man, "the best laid plans of mice and men ...". Programs of quality assurance for energy efficiency, therefore, must be developed in the form of commissioning tests. Concepts like the NAHB and SERI (1989) short-term, whole-building experiments that are inexpensive to perform need much more research and development before reasonable confidence and costs can be assured. These must be integrated into the much broader quality assurance programs of health, safety and reliability.

Building Design

Last but certainly not least, the industrial process offers the opportunity to radically alter the manner in which buildings are designed. Development of integrated, expert systems that incorporate the knowledge bases of building energy management, industrial processes and aesthetic comfort are now a realistic technological possibility. They are a major objective of the research carried out in this program. This area represents the culmination of the work and is, in a manner of speaking, consequential of the other research.

Conclusion

In conclusion, industrialized housing techniques offer the potential to significantly enhance the energy quality of housing at realistic costs. The industrial environment offers the ability to closely control those elements of the building that make significant contributions to energy efficiency as well as cost without revamping the entire building industry. In light of the fact that industrialized housing is the most rapidly growing segment of the housing industry, improvements in industrialized housing technology are likely to have the most significant effect on the future U.S. housing energy use patterns.

3.6 UNITED STATES AND FOREIGN BUILDING CODES **J. Harrison, S. Chandra, J. Roland**

The most striking fact of the building codes and standards in the United States and those of select foreign nations is that builders in most foreign nations have only one or two national codes to deal with, while in the United States, the housing industry is assaulted by the sheer number and complexity of regional, state, and municipal codes and standards.

In the United States, there are currently three independent organizations that develop building codes and standards. The Council of American Building Officials (CABO) oversees and acts as the umbrella organization for the three regional agencies. These agencies, the codes they develop, and the region in which the codes are used are listed below.

<u>Agency</u>	<u>Code Development</u>	<u>Region</u>
Int'l. Conference of Building Code Officials (ICBO)	Uniform Building Code (UBC)	West of the Mississippi
Building Officials and Code Administrators Int'l., Inc. (BOCA)	BOCA Basic/National Building Code	Northeast and Midwest
Southern Building Code Congress Int'l., Inc. (SBCCI)	Standard Building Code	South

These codes are adopted by both public regulatory agencies and private sector parties. The complexity of code enforcement increases when state and local government officials develop area specific amendments and modifications to these codes.

Adherence to the codes and standards requirements established by the above referenced three independent national organizations (ICBO, BOCA, SBCCI) could conceivably be achieved by industrialized housing manufacturers. The overwhelming problem lies in determining local code and standard requirements. The magnitude of this problem becomes evident when one realizes that there are over 40,000 local jurisdictions in the United States. The immense size of the United States, weather variations, and geographically unique energy and safety problems lead to codes and standards that are instituted to address specific geographically conditions. In many instances this is unavoidable. For instance, in the southern Florida area the concern of potential hurricane force winds must be addressed. In the Northeast, excessive loads resulting from the weight accumulation of snow and ice pose problems for local construction techniques. A review of state requirements for industrialized/modular homes revealed that over twenty codes were referenced. These included the codes developed by the model code agencies as well as fire and electrical codes.

The term industrialized housing refers to many varieties of construction - manufactured, modular, panelized, etc. Of these, one type does have a standard that is accepted nationally in the United States. That standard is the National Home Construction and Safety Standards which applies solely to manufactured (mobile) homes. It is currently administered by the U.S. Department of Housing and Urban Development (HUD). In the near future, administration of this standard will be transferred to CABO. The importance of this standard is in providing standard requirements for

manufactured homes. It is noteworthy that some HUD-Code homes do not meet national codes (i.e., BOCA, etc.). This fact has been effectively used by local zoning boards to exclude HUD-Code homes from some subdivisions. It is also important in that it stands as an example of the possibility and viability of developing similar nationally preemptive and recognized codes for all sector of the industrialized housing industry. This has led to initiatives to simplify the wide variety of codes and standards requirements dilemma facing the industrialized housing industry.

Currently, thirty-five states have statewide regulatory programs for industrialized/modular construction. These codes are primarily a result of the Operation Breakthrough program of the early seventies. The structure of these programs vary widely between states. Due to this, some of these states have formed the Council of States on Industrialized Housing and Buildings to promote reciprocity on approvals between states. Covered under this are factory-built housing, including components. Currently, the states of Alabama, Florida, Georgia, Pennsylvania, and South Carolina have reciprocity programs.

Houses built to these standards cannot be excluded from a site by local officials. However, they do try and then the state's Attorney General's office needs to get involved to dissuade the local officials.

Inspection requirements of the state codes can be a bottleneck to production throughput in modular factories. Usually a sample of homes are inspected. Therefore a special inspection visit needs to be arranged to inspect a modular home which is one of a kind.

Several other avenues are being investigated by the National Institute of Building Sciences (NIBS) for implementing voluntary preemptive national codes for modular housing. In conjunction with NIBS, the National Association of Home Builders' Building System Council recently reviewed four options presented for the development of a national voluntary preemptive federal regulatory system for modular housing. Of these four, one was felt to be quite viable for implementation in the near future. This proposed option would use the existing CABO National Evaluation Service (NES) framework for labeling and monitoring industrialized housing products. Some of the highlights and positive aspects of this program would be:

- It would be a voluntary private sector program.
- Local and state officials are familiar with NES and usually accept NES judgments.
- Testing laboratories used to evaluate products would have to be approved by NES. BOCA, ICBO, SBCCI, and CABO 1&2 Family Dwelling Codes would apply for design and construction criteria.
- Congressional mandate would be required for implementation of this program. Implementation could proceed immediately after Congressional mandate is provided.

- Federal intervention in the program would be minimal. Congress would maintain oversight.
- Inspection of materials would be conducted at manufacturing facilities
- NES would evaluate inspectors who would both be employed full-time by NES and at times, part-time by state officials.

An alternative to this "Modular Construction Act" has been proposed by NCSBCS. This version leaves greater control to state officials.

The crux of the discussion to this point has been dealing with construction codes and standards. There also currently exists in the U.S. numerous model energy efficiency/conservation codes. The majority of these are usually developed with the technical groundwork established by one of the major conservation documents listed below:

1. Energy Conservation in New Building Design - ASHRAE Standard 90-75 and ASHRAE Standard 90A-1980 (Revision of 90-75).
2. Model Code for Energy Conservation in New Building Construction (1977) developed by the National Conference of States and Building Codes and Standards, Inc. (NCS/BCS).
3. Model Energy Code 1983 and 1986 developed by CABO with assistance from BOCA, ICBO, SBCCI, and NCS/BCS.
4. The BOCA Basic Energy Code/1981 developed by BOCA.

States will often add specific requirements to accommodate the energy characteristics for particular climatic zones. Some states in lieu of developing their own energy codes, will reference such model codes as the CABO or BOCA codes. Currently there are on-going efforts to improve the energy efficiency standards for the HUD- Code homes.

The multitude of codes and standards that impede the introduction of new industrialized housing materials and processes in the United States does not exist in such a great extent in many foreign nations. The Japanese industrialized housing industry has only one national building code which must be adhered to. The vast number of local and regional codes which frustrate the domestic United States construction industry do not exist in Japan. This is not to say that orthodox opinions of local officials may not somehow impede the introduction of new products on local levels, but overall, manufacturers have only to refer to one code in order to determine national compliance requirements. One must consider the geographic size and location of Japan in any discussion of their

building standards. Although Japan does have varied geographical and climatic conditions due to its numerous islands, overall it is quite small when compared to the vast expanses of the United States. This no doubt was an influence in developing one centralized national building code. Its location in a tectonically active geographic location has led to stringent national earthquake protection requirements.

Sweden currently has two national building codes, the SBN and the ELAK codes. This greatly facilitates the introduction of new industrialized products into the marketplace. As in Japan, geographical factors strongly influence the makeup of the codes. Due to its harsh northern climate, Sweden has very rigid standards on air tightness and insulation.

The industrialized housing industry will be greatly affected by the current work in the internationalization of building codes. The World Organization of Building Officials and the International Energy Agency, as well as, joint ventures by Japan, France, Sweden, and Canada are currently addressing this topic. It will undoubtedly be some time before concrete achievements are visible. The current widespread penetration of foreign markets by all nations will create impetus for the facility of codes and standards approval processes.

Europe is in a stage of economic transition due to the present activity in the European Common Market. Currently, being developed are building construction standards and codes for site-built and industrialized residential housing that will apply to all European Common Market member nations.

4.0 ASSESSMENT OF FOREIGN TECHNOLOGY

Introduction

The review presented here examines current industrialized housing construction in Europe with particular emphasis on Denmark and Sweden, while also reviewing industrialized housing in Japan. The goal of this work is to review the most recent industrialization trends and to identify those technologies that have the greatest chance of applicability to the U. S. energy efficient industrialized housing market. While many of the ideas presented here are technological breakthroughs, some represent ideas that have been developed to a high degree of utility within the framework of industrialized housing and energy efficiency.

The first part of this assessment deals with the Swedish Factory Crafted (SFC) Housing industry, which is among the most highly industrialized wood product housing production technology in the world -- both highly automated and extremely energy efficient. The basic production system is presented and a list of the key innovations reviewed. The second section examines industrialized housing construction technology from the rest of Europe. A more detailed review of Danish housing identifies projects, components, and industry segments worth further investigation. Last, the highly industrialized housing production technology of Japan is presented. The most important energy and industrialization innovations of these industries are reviewed and briefly discussed.

4.1 CURRENT STATUS OF DESIGN, MANUFACTURING, MARKETING AND INSTALLATION IN INDUSTRIALIZED HOUSING IN SWEDEN **J. Finrow**

4.1.1 Generic Methods of Design, Manufacturing, Marketing and Installation

Two systems of industrialized construction developed in Sweden are currently in use -- concrete slab and panel systems, and timber frame panel systems.

Prefabricated timber frame housing systems have developed out of a traditional wood house construction technology that has a considerable history in Sweden. The Swedish Factory Crafted (SFC) housing industry produces almost all single family housing built in Sweden today (Schipper et al, 1985) using two kinds of production systems -- panelized and modular. Modular systems, quite similar to U.S. modular housing, represent a small part of the Swedish housing market. Panelized systems, the larger segment, 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. While plastic conduit is placed in the panels in the factory, electrical wiring is done on the site in traditional fashion. Small panels are elements, small enough to manhandle, and which must be aggregated to build a wall. Large panels are entire walls, and require lifting machinery.

Panel production in SFC plants is devoted to two basic housing types, single family houses and multi-family housing, produced on separate production lines. According to the plant manager of Gullringshus, a large panel manufacturing company, small panel production facilities are giving way to large panel technology.

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 (see section 5.3 for more detailed discussion of this issue). That portion of the SFC house that is produced in a factory setting is highly automated.

Figure 4.1-1, Swedish Factory Crafted House

According to Jean Nico, President of Finnebo Hus, a housing export company, a typical SFC housing company is vertically integrated, and success of the SFC house depends on careful management of the whole company in all of its various parts. A single company produces, sells and arranges for installation of a complete house for an individual customer. Major companies have sales offices throughout Sweden where customers work with sales people in selecting a house and in making any changes needed to accommodate the unique needs of the purchaser. Various plant managers of SFC companies in Sweden commented that most customers have their own sites -- there are few "subdivisions" in Sweden.

Houses are produced from the factory for a specific customer and then sent to the construction site. According to plant managers, assembly on the site is usually contracted to a specialist company that does assembly and erection of the house. According to sales personnel of Borohus, each house carries a 10 - year guarantee period on the whole house and everything in it (including appliances) with 100% company responsibility for any call back repair work.

Some, though not all, companies also have their own sawmills which produce lumber used in the production process. In such plants raw logs enter one end of the plant and finished house panels leave the other end. Discussion with a Myresjo Hus plant engineer revealed that recent changes in the industry have seen a reduction in the use of on-site sawmill operations as the sole supplier of basic wood products to SFC plants. To be competitive, he said, each factory must purchase materials at the best price. On-site sawmills may not always be competitive with other companies.

4.1.2 Variations In Design, Production, Automation, Quality Control, Inventory,

Design

Each 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.

Sales offices are well stocked with brochures and sales materials for houses, appliances and furnishings; they also provides complete financing packages with all paper work completed by the sales staff. The sales manager of Hultsfreds Hus commented that computers are seldom used for housing design in the sales offices. Production drawings are completed in the factory using in-house, as opposed to point of sale, CAD systems.

Energy efficiency is somewhat neutralized as a sales issue because of the strong national energy building codes, according to a Boro Hus engineer. A review of financing costs for a Myrejsjo Hus model home pointed out a unique method for financing energy conservation elements in housing which provides an incentive for a customer to purchase the maximum energy efficiency at a discounted financing cost.

Figure 4.1-2 - Plan drawings from brochure

Production

In 1983 there were 100 housing plants in Sweden with production capability up to 44,000 housing units per year (Schipper et al, 1985). Production of SFC housing varies considerably based on the nature of the housing market in Sweden and on export potential. Housing production has declined in recent years from a high in 1977 of 44,000 housing units (Aho and Isacson, 1987) to current production of about 15,000 units. Even at its peak, SFC production is only 5% of the total U.S. housing production capacity. All plants visited were in the process of either updating equipment or installing a new production line.

SFC 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.

Figure 4.1-3 - Plant Site

Automation

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 are considerable incentives for increasing production through improving worker productivity (Aho and Isacson, 1987). Site visits revealed that factories vary greatly in their degree of industrialization.

Typically, a panel line begins with a framing machine which assembles a floor or exterior wall panel by automatically nailing frame members. Window and wall units (produced on a sub line) are placed into walls as they are framed. Wall segments then move to the insulation station where insulating material is usually cut and placed by hand into the frame. Moving on from the insulation station, interior sheathing is placed on the frame and automatically nailed. After leaving this area, the wall is flipped over and building paper, stripping then siding (prefinished solid board on board siding) is installed. Each panel is stamped with identification numbers to insure that panels for a particular job remain together at the plant. Floor cassettes follow a similar process. The most recent automation innovation involves automated installation of insulation and a sheathing machine that fully automates sheathing including placing material, nailing and routing of panel for openings.

Figure 4.1-4

Quality control

SFC houses are required to have a 10 year unconditional warranty, with manufacturers held responsible for all production defects over this period. SFC plant managers comment that liability problems with quality control are frequently caused by house assembly. Quality control begins with the raw materials. Wood products used in SFC housing must be dried to 10%-12% by law and building inspectors monitor the moisture content of the wood. Wood used in windows, doors, trim and casework must be of even higher quality (Schipper et al, 1985). Workers on the production line are encouraged to look for production errors and can stop the production line in order to correct

problems. Minor defects such as broken glass, missing nails, etc. are fixed immediately at the end of the panel line. Because finish work is done at the building site, any small imperfections can be adjusted on site. 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.

Inventory

According to a Gullrings Hus plant manager, 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. The development of the large panel format with great flexibility in location and nature of wall openings has also encouraged more individuated housing design. Such design strategies work counter to traditional panel inventory concepts, which may reduce the need for panel inventory.

Bottlenecks

Production attitudes coupled with Swedish labor laws have provided a particular environment that gives less emphasis to production power than might be the case in the U.S. There currently is a considerable production back log (up to 9 months in some cases) due to limited utilization of plants and equipment. Plants do not add shifts to provide more production. As orders exceed production capability, the bottleneck of plant capacity balloons order time. 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". According to the plant engineers of Myresjö Hus, plant expansion has sought to increase capacity by improving worker productivity, thus using the same number of employees to produce more houses. Labor is a serious problem in Sweden and finding workers is difficult.

4.1.3 Current Status of Energy Efficiency

A major factor in the success of the SFC House industry has been its extremely good energy performance. The current SFC house is the most energy efficient wood frame house available in the world today. Besides a strong market for energy efficiency, Swedish governmental policy has encouraged innovative housing construction technology that will also be energy efficient. Traditions of high levels of energy performance have been further reinforced by the policy to decommission all nuclear power plants in Sweden by the year 2000.

In order to achieve high levels of energy efficiency in single family detached houses, wall insulative values have gone from R-values of R-18 in 1973 to R-33 in 1984 and from R-24 to R-43 in ceilings. Research reported by Schipper in Coming In from the Cold demonstrates that energy conservation

strategies used in the ELAK SFC house could reduce energy consumption for a climate like Minneapolis by 80% or more from typical U.S. practice as of 1982. New housing energy consumption has also been reduced by 30% from pre 1941 housing (Schipper, 1985). Paul Kando, in a paper titled When the Best Costs Less, reports that an energy comparison of U. S. housing built to current (1988) standards with SFC housing also built to U.S. standards would yield energy savings of 28%, presumably just the result of higher construction quality. Building to Swedish standards would save even more. However, there are questions about the economics of these energy savings, as cited in section 5.3.

4.1.4 Assessment

Technologies To Be Investigated

From initial research it was determined that the most important technologies that need to be investigated include the SFC panel line machinery, and how the process of production is organized and what advances might have occurred since the last research on this subject. Of particular interest was the development of thermal break technology. This seemed to be the most important area of energy efficiency construction technology in SFC housing. Another concern was to review the actual degree of automation that is present in the SFC industry, as most research findings contain little information about the total degree of industrialization in SFC housing.

US Experts in the Field

An informal review group has helped gather basic information and identify innovative companies to further study. Experts in this group include Edward Dean, Lee Schipper, Arne Aho, and Paul Kando -- particularly Kando, who as an independent consultant and director of the Washington D. C. based consultancy titled The Center for the House assisted in planning field investigations.

Status of Current Knowledge

Substantial amounts of research materials were acquired documenting the SFC housing industry from both governmental research sources and from private companies. This data bank will continue to be expanded. In addition to the collection of published information, several SFC plants were visited including Boro Hus, Gullrings Hus, Myresjo Hus, and Hultfreds Hus. We also visited a window component factory owned by Myresjo Hus. All of these factories are located in the Smaland region of South Central Sweden. The field trips were undertaken in conjunction with a research team from the University of Minnesota and were organized by Paul Kando, who lead the tour.

Regulatory Environment

The most striking fact of the building codes and standards in the United States versus those of selected countries is that builders in most foreign nations have only one or two codes to deal with,

while in the U. S. the housing industry is assaulted by the sheer number and complexity of regional, state and municipal codes and standards. In Sweden there is one national building code. Having a single code for the whole country provides a more consistent means of evaluating new materials and construction practices for industrialized energy conservation housing construction technology. For a more detailed review of this subject in regard to SFC housing see Proceedings of the Swedish Housing Technology Colloquium.

Cultural and Historical Factors

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 using these early solid panel construction systems both before and after World War II. The housing of the Eskilstuna section of Stockholm is an example of this early industrialized building technology (Wallander, 1949). The houses produced by these systems were the traditional Scandinavian house which utilized steep roof pitches, double wooden window systems, board on board siding -- brightly painted with small gardens. The development of the housing export market of the early 1980's has lead SFC housing design to be adapted to many different building cultures around the world, including Japan, North Africa, and Central Europe.

Figure 4.1-5 - Bromma

Affordability and Energy Performance Balance

Swedish Factory Crafted houses are quite expensive, even by Swedish standards (see appendix for a detailed analysis of this subject). The cost of a typical SFC house in Sweden (excluding land cost) is about \$96 per sq. ft. Because the national building code used in Sweden mandates strict energy performance standards for all single family housing, first costs are high with the goal of decreasing life cycle energy costs. In order to achieve affordability, the Swedish government subsidizes financing costs in the first 5 years of a house loan by "buying down" interest charges to about half of

market rate financing. Housing consumers seeking a lower cost housing alternative will probably buy a multifamily housing unit.

Use of Computers

Computers are used extensively in the SFC industry, but mainly in the management activities of the housing factory (Aho and Isacson, 1987). Computers are used to generate cutting and milling instructions for numerically controlled machine tools and for human machine operators. According to a Hultsfreds Hus plant manager, a key element in the SFC factory is the integrated scheduling of all operations of the factory; especially critical are fork lift trucks. Computer controlled tools are extensively used in SFC plants, including "smart saws" that can be programmed to make panel cuts at any location in the surface of a panel.

Effects of Climate on Housing Design and Production

The winter climate in Sweden, while cold, is also frequently sunny which means that the opportunity for use of solar energy in the coldest part of the winter is good (Olsson, 1988). This fact has led to much experimentation and use of active solar heating, especially for hot water (Olsson, 1988). Demands for energy conservation in Swedish housing due to the severe climate means that housing consumers expect high levels of energy performance and considerable thermal comfort. While Swedish people like to keep their houses quite warm by US standards, they also use less energy (Olsson, 1988). Drafts are a problem in a cold climate such as Sweden and design details that eliminate drafts are very important. The development of highly sophisticated sealant technology has emerged from the desire for draft free environment, as has the most recent research to develop window technology that would reduce air movement around windows in exterior walls. Housing made in factories allows year around house production, an important consideration in Sweden.

Effects of Materials Availability on Housing Design and Production

Housing in Sweden has traditionally been built of wood. Wood is a significant natural resource in Sweden, where strict forest management practices on both public and private forest lands ensure an ongoing supply of wood. While sustained yield practices ensure a constant supply of wood, the cost of wood is quite high. This expense has supported materials efficient timber construction technology.

Conversations with a Boro Hus plant manager confirms the high degree of forest regulation in Sweden to insure that sustained yield practices are followed. National land planning, economic support for reforestation, and declining farming have begun to produce net increases in forest acreage with resultant increased supplies of commercial timber for industrial uses. The desire for materials efficiency is demonstrated in the development of the "truss" stud which uses less than half the previous amount of wood. Other examples of materials efficiency include the engineered truss, the use of wood trusses for headers over door and window openings, and the substitution of processed

forest products such as particle board in place of solid or plywood sheathing.

Effects of Standard of Living on Housing Design and Production

Sweden has one of the highest standards of living in the world. Swedes living in the country and in small towns have traditionally lived in single family detached houses. Mid-rise multi-family housing has been the predominant housing type in the larger cities. The size of single family houses has also increased and the number of "value added" elements (upgraded finishes, more and better appliances, etc) are actively marketed by sales staff. Variations from traditional house design are also beginning to appear, most notably the development of the single level house (traditional Swedish houses are of two stories). According to SFC sales persons, single story houses are easier to produce and assemble than two story houses. The increasing standard of living of the Swedes has encouraged housing companies to develop a broader range of housing choices -- both in basic house types and in finishes, materials and appliances.

Effects of Industrial Technology on Housing Design and Production

High levels of industrial sophistication have contributed to the development of industrialized housing. SFC houses are produced mainly in large panel format with each house designed and produced for a specific customer. The width of the production line is fixed to a national standard but the length and organization of openings in a wall are quite variable to suit a particular house type or customer choice (Aho and Isacson, 1987).

The development of the truss stud is an example of an innovative component that is best used within the context of the factory setting. Truss studs are a new kind of stud that reduces the amount of wood and increases the amount of insulation used in exterior wall framing. A truss stud uses small wood chords (approximately 1-1/2" x 1-1/2") and metal webs. Truss studs vary in depths, some are as deep as 12" or more. According to Housing Economics (Dec. 1988) 523 8' long studs are used in building a typical single family detached house in the U. S. Assuming that these are 2 x 6 studs and that only 250 are used in the exterior walls, the total wood savings from using truss studs would be over 625 board feet per house or a little under 100 studs. Such studs are very flimsy and cannot easily be nailed in a site built environment. The machinery that holds the studs and attaches them to the top and bottom plates allows these lightweight, flexible elements to be formed into whole assemblies whose structural integrity is only present in the full assembly.

Where SFC Housing Has Been Built in the U.S.

Several attempts to develop SFC plant technology have been made in the U.S. Most of these attempts have not been a financial success and all of the earliest attempts have failed. Factories have been tried in Minnesota, and in New England. The most notable housing project constructed in the U.S. using SFC construction technology is located in Laconia, New Hampshire. This is a condominium

development in an area of second (vacation) homes. Additional housing projects have been built and we are in the process of identifying those housing developments for future study

Figure 4.1-6 - Laconia housing

Most Successful Manufacturing Systems

SFC technology has been applied to a particular part of the house -- the exterior wall and floor panels. Manufacturing processes are directed toward the full automation of these building components. The most recent innovations in this technology are present in the Myresjo Hus production facility, where new equipment has recently been installed that fully automates the floor and wall panel production system -- including a machine that places insulation in the voids between studs.

With the adoption of this new technology, the only hand operation carried out in the wall panel line is the insertion of integrated wall and window/door elements into the panel line at the right location in a wall assembly. The floor cassette line is 100% fully automated, with human supervisory personal checking only for problems that might occur along the line due to technical "glitches". A Myresjo Hus plant engineer commented that while it was technically feasible to develop a 100% automated factory without any human operators, workers were needed to oversee quality control.

Most Important Aspects of SFC for Energy Conservation

The thermal performance of 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. The use of rubber gasketing around all wall openings and between floor-wall-roof systems greatly reduces infiltration. The use of 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.

Conversations with the sales manager of Myresjö Window revealed that new 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. A consortium of window and glass industry groups is currently sponsoring window technology research at Chalmers, a research university located near Gothenburg, Sweden.

Figure 4.1-7 - standing wall

The SFC Concept

Given the right circumstances it is entirely possible that the SFC housing system could be successfully transplanted to the USA. The process of industrialized panel construction technology is, in itself, a relatively simple process which could find wide use in this country, providing that the costs of such housing remain competitive with other housing construction types (Spitler, 1987).

Linking SFC plant production to a consumer based marketing concept could improve the potential for success of the SFC concept. For example, developing an SFC plant to provide panels to a U.S. HUD code manufactured housing production facility would use the strengths of both technologies. This would improve the energy performance and quality of U.S. HUD code housing. Another example would be for a developer to use the output of a U.S. SFC plant to supply houses for specific development projects within a housing region. The developer would be the "client" for plant products thus selling the SFC houses in conventional U. S. fashion in prebuilt subdivisions.

The most unique innovation that the SFC process brings to this method of building is in the

management of the system of house delivery to the customer. The technology of the plant and the design of the house that the plant produces is important, but the marketing strategies and vertical management of the house delivery process is the really crucial element of the economic success of the SFC housing concept. SFC companies combine production and sales into one company that markets on the basis of brand name. While this highly integrated system of marketing and production is not a technological innovation in itself, it is a key factor in the development of industrialized housing in Sweden.

The Thermal Break Wall

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. Wood frame housing in the U.S. uses solid wood studs, plates, headers and framing members which create significant amounts of thermal transmissency. SFC housing employees factory made wall framing members that virtually eliminate direct thermal contact between interior and exterior surfaces of the building wall. The development of the energy efficient truss stud is a truly significant improvement to the thermal performance of wood frame construction (Schipper, 1985). While a variety of hybrid studs are in use, the truss stud will probably become the dominant wall framing member in energy efficient industrialized housing as it is the most material efficient and can be "thickened" to accommodate increasing amounts of insulation.

Figure 4.1-8 - Truss stud

Automated Insulation Line

Designed and manufactured by Nordisk Karto in partnership with Myresjö Hus, the newest industrialized process in SFC plants permits automated insulation insertion into wall and floor panels. Insulation materials are produced in sizes that fit the wall cavity width. These batts of insulation are automatically inserted into the framing wall as panels move through the line. This system is very efficient and also removes workers from a potentially hazardous environment working with rock wool or fiberglass materials.

Window Technology and the Impact on Heating Plant Location

Advanced energy efficient window technology is currently being used in SFC housing. The ultimate goal of this window technology is to produce window systems whose thermal performance is about the same as SFC wall systems. Through triple and quadruple glazing coatings and electrically charged gases, Swedish window technology is quite sophisticated (Olsson, 1988). One of the primary goals of this research is to reduce the need to locate heating elements under windows in the exterior wall of the house. This change would eliminate the need for ducting or piping to the exterior wall of the house, which would save the cost of this equipment, eliminate line losses, reduced insulation compaction at the exterior wall, and improve overall heating efficiency.

Legal Barriers to Adopting These Technologies

The biggest legal barriers to using SFC technology in the U.S. are building codes. Local building codes work against any broader regional or national building industrialization. A preemptive national building code administered by HUD for the manufactured housing industry has allowed various kinds of "manufactured" housing to be utilized in widely divergent sites. This national code has created a baseline for construction quality which has allowed investments to be made for plants and equipment to supply houses to regional markets. If an SFC plant were to be established as a HUD code housing product, it might be possible for changes to be made to the HUD code that would encourage improved practices.

Building Science Research

Technical innovation in any industry is highly dependent on research and development. In the Swedish housing industry in general, and in the area of energy efficient factory crafted housing, research sponsored by both private industry and state building research stations has greatly aided the innovation process, including recent developments in improved energy performance of windows.

Multi-Source Financing of House and Energy Efficient Options

Swedish Factory Crafted houses are quite expensive. In order to make them more affordable, the government has developed ingenious ways to structure and organize financing to make such houses affordable. Depending on the house and the company, there can be as many as 4 or 5 different loans

each with different interest rates. Energy efficiency costs and expenses can be separately financed at a lower interest rate. In the U.S. this could be similar to financing a retrofit loan through a public utility. The unique part of this financing idea is that it is used to fund energy conservation technology as part of new home financing packages.

Market Acceptance of SFC Houses and Housing Products

The high cost of the SFC housing has slowed its entry into the U.S. housing market. In this sense, current market acceptance has been very low. However, SFC housing is an extremely high quality product whose market potential, given a more equal cost basis would probably meet with considerable success. Paul Kando maintains in When the Best Costs Less that given U.S. labor costs, an SFC housing plant would produce a cost competitive house for the U. S. market. This competitiveness would be fundamental to the success of any SFC venture. House designs, materials and products are generally very good and would be quite salable in the U.S.

While SFC homes are so far rare in the U.S., some Swedish building products have met with considerable success. For example, "breathable" building fabric has its origins in the Swedish construction industry. Some Swedish window manufacturers have begun to market their products in this country, but the extent of their use is still rather limited.

4.2 CURRENT STATUS OF DESIGN, MANUFACTURING, MARKETING AND INSTALLATION OF INDUSTRIALIZED HOUSING IN OTHER WESTERN AND NORTHERN EUROPEAN COUNTRIES J. Finrow

4.2.1 Generic Methods of Design Production, Marketing and Installation

WW II devastated the housing stock of all of Europe, leaving literally hundreds of thousands of people homeless. Prefabricated construction technology was the only realistic way to build enough housing units to meet the need. The resulting system, and most industrialized construction today in Europe, involves the use of precast concrete slabs and wall panels. Attempts to produce energy conscious prefabricated concrete construction, however, have only recently developed. This survey will focus mainly on this work by the Danish housing industry, and field research conducted in Denmark.

Energy Efficient Concrete Element Factory

The Mobeton Concrete element factory north of Copenhagen was visited in order to view a "state of the art" factory and how it deals with integration of insulation into its production system. The plant is partially owned by a construction company, A. Jespersen and Company, which is also a housing

developer. Most projects are presold on the basis of project prospectus. Housing produced through this process is exclusively multi-family; most are rowhouses of one or two floors. Designs are simple 2 and 3 bedroom units with brick exterior cladding and clay tile roofs.

The plant was quite typical of most concrete precasting plants with a central computer controlled concrete mixing facility that supplies suitable strength concrete to the various casting operations of the plant through a system of overhead pumping tubes. The Mobeton plant uses an innovative casting method called "vertical wall panel casting." Two sided forms are used which permit reinforcing and blocking for openings. After concrete has been poured, panels are cured twice, once in the form and once after the form has been removed. Panels go through a heated curing room which sets the panel and allows it to be removed from the form only a few hours after casting. Floor slabs are cast in long beds (over 100') and then cut to make elements of the desired length. Panels are trucked to the site for assembly.

Wooden Factory Crafted Housing Systems

A modest wood panel industrialized energy efficient housing industry exists in Denmark. In a way it is quite similar to that in Sweden, but on a much smaller scale. The leading company is Roslev Hus located in western Denmark in the town of Juelsminde. A second major company called Husby Hus has recently gone out of business. Housing produced in these plants is quite similar to SFC housing, with vertically integrated company management and highly automated production lines using floor, wall and roof trusses that are prefabricated and erected on the site.

Composite Construction Technology

Concrete elements are used today in Denmark, mainly in low rise moderate density multi-family housing projects. Concrete panels, however, have not proven to be as energy efficient as wood frame construction. Concrete element building systems are becoming less significant, as a new form of composite construction using wood frame exterior wall panels takes over an increasing share of the housing market in Denmark. Composite construction uses concrete elements for floor and party walls and wood panel elements for exterior infill panels. Concrete elements are used where they are most logical, and wood panels are used because of their enhanced energy performance characteristics.

According to Martin Rubow, a Danish architect who specializes in housing design, composite construction systems are less expensive, more energy efficient and produce a richer and more varied housing environment. Concrete is used in interior applications where it can perform a thermal storage role and at the same time reduce 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 Denmark, where wood is expensive, composite construction is also cost effective relative to complete wood frame construction.

4.2.2 Variations: Design, Components, Products and Energy Efficient Industrialized Housing Ideas

Southern Europe -- Greece, Turkey, Italy, Spain and Southern France

Precast concrete housing construction is common in these countries, along with in situ concrete and masonry infill systems of construction. A particularly significant housing component used in many of these countries does offer some potential for the U.S. housing market -- window/shutter technology. The dominant energy issue in much of this region is natural ventilation and cooling. The use of air conditioning is very limited. Consequently, very sophisticated shuttering has been developed especially in Italy for dealing with this problem.

Central Europe -- Austria, Switzerland, France, Germany, Holland and the Benelux Countries

Industrialized construction in these countries makes a significant contribution to overall housing production. The predominant technology for housing construction is precast concrete panel construction systems which are used for medium to high density multi-family construction. Steel is used in some cases, but generally is not economical for housing construction. In Holland and Germany, there are significant user based design projects for housing that are putting users directly into the process of design and, in some instances, construction of housing units (for example, the SAR system used in Holland). According to the plant manager at Gullrings Hus, Germany is the primary European export market for the Swedish Factory Crafted housing industry.

Eastern Europe and the Soviet Union

Modern housing production in these countries is almost entirely built with prefabricated large panel and slab concrete construction technology. According to conversations with international energy researchers at the Lawrence Berkeley Labs, here is little to learn from these systems regarding energy efficiency. One company in Yugoslavia claims to have produced energy efficient single family housing panelized systems that is much less expensive than comparable houses produced in Sweden with comparable levels of performance. This company is called Jelovica prefabricated housing company. This small paneled housing system is made of rigid insulation with gypsum on the interior surface and cement asbestos material on the exterior surface. High levels of energy performance are claimed by this system using variable thicknesses of insulation. Panels are likely to be quite heavy and the use of asbestos is highly questionable.

Northern Europe (except Sweden) -- the U.K., Norway, Denmark, Finland

The development of energy efficient industrialized housing in Norway and Finland parallels that of Sweden which is described in more detail elsewhere. The Danish approach to energy efficient industrialized housing construction is different from that of other Northern European countries and will be reviewed in more detail.

Denmark: Overview

Denmark has a significant international reputation in housing innovation and experimentation. Land is scarce, which has encouraged the development of multi-family housing. One of the most interesting and important of contemporary Danish housing programs is the retrofitting and improvement of concrete element multi-family housing projects of the 1950's and 60's.

A particularly successful project is north of Copenhagen. A typical retrofit begins with insulation installed over the existing older concrete wall panels (most with no insulation at all). New siding, usually of metal panels or "cement board" is installed over the insulation. Balconies are sometimes glazed to provide added insulative value and to extend their use over a longer season. In some instances, roof trusses are installed over previous flat roofs with insulation added in the "attic" space. In addition, Denmark also has pioneered the use of residential atria spaces, communal housing forms, energy efficient components such as the Velux "roof window" and has encouraged housing design experimentation.

Denmark: Atrium Spaces

Atrium space has emerged as a particularly popular and potentially quite significant idea in the design of energy efficient multi family housing. Typically, row housing units are organized along an interior street that is then fully glazed. The space is then used as a thermal buffer between the exterior wall of the housing unit and the outside climate. This buffer mediates heat loss between interior and exterior space along one wall of the housing unit and by so doing improves energy efficiency. Since it performs like a greenhouse, the atrium also provides a space that can be comfortably used throughout much of the year for children's play and for other common activities of the housing project.

Denmark: Components

Denmark also has developed many industrially produced building components that have important energy implications. Perhaps the most important is the VELUX skylight company, which has been exporting high quality and energy efficient skylights to the U.S. for 20 years.

Denmark: Communal Housing

Alternative forms of housing design, based on social goals of various kinds, have long been encouraged in Denmark. The most recent manifestation of this idea is in the co-housing movement.

Co-housing is a semi-communal form of housing where residents share common needs such as child care, food preparation, laundry, etc. Co-housing projects also have significant energy efficiency implications. Many projects such as that called Sun, Wind and Light utilize passive and active solar energy design, the use of wind power and other energy saving design strategies. The co-housing project called Jystrup Sawmill Collective makes use of planning and design concepts that minimize energy use. These ideas include the use of a common atrium that connects all of the housing units, small and very efficient housing unit design, and a common area for community wide such as cooking, laundry, etc.

Denmark: Other Housing Experiments

Lastly, Denmark has encouraged an active search for alternative housing forms and systems. This experimentation and the research that accompanies it has allowed advanced ideas in housing design to be built and tested. A recent example is the development in 1988 of the Byg and Bo housing exhibition in an area outside of Odense on the Island of Fenn. This project, developed to present the state of the art in Danish housing design, is a laboratory for a wide range of ideas about housing design. Included among its projects are several that offer interesting new ideas about energy efficient design including the use of atria and of sunspaces.

4.2.4 Assessment

Technologies To Be Investigated

Further study of European energy efficient industrialized technology is needed to identify additional technologies of interest to the U.S. market. The composite multi-family housing construction systems, in particular, have merit and should be more carefully explored and evaluated in the future -- especially as an affordable multi-family energy efficient system of construction. Atrium use in multi-family housing also presents some interesting possibilities as does multi-family housing as an energy conservation strategy. These ideas should be researched in more detail, especially from the point of view of developing industrialized housing systems that can produce "plexes" and row housing much more energy efficient than current single family detached housing. Experimental housing such as the Danish Co-housing projects offer an interesting and possibly important opportunity for energy conservation through alternative social organization. Finally, specific housing components such as the shuttered window should be explored more carefully.

U.S. Experts in the Field

Several experts in energy efficient industrialized housing outside of Sweden have been helpful to us in our investigation -- Jan Westra, a Professor of Architecture in Holland, Peter Sulzer of the University of Stuttgart, Erik Skoven of the Danish International Studies program of the University of Copenhagen and several architects including Martin Rubow of Denmark. There are few U.S.

experts in European, non-Scandinavian housing technology. Future research will seek contacts with additional experts in this subject.

What Are the Most Important Aspects of These Technologies That Support Energy Conservation

Of the examples cited to date, one of the most promising energy conservation technologies is the use of atrium space in multi-family housing. This idea, which is really a design concept, may have great benefits for both moderate and cold climate zones in the U.S. Window/shuttering components may benefit housing design in warm climates of the U.S. where humidity is not a major concern. Further detailed study of these ideas should be carried out to determine the potential. As we develop additional information about industrialized energy efficient housing of Europe, other technologies will likely emerge that warrant further attention.

Elements of Promise to the U.S. Market

Velux roof windows (skylights) have already had a major impact on the U.S. housing component market. Major window manufacturers in this country such as Pella and Anderson have responded with products of different design but of comparable quality. European designed cabinet hardware is another example of a technology developed in Germany that has taken over a major portion of the U.S. market. Given the right circumstances, the shutter/window may also have a future in the U.S. Composite concrete and wood panel construction systems could have wide applicability in the U. S. multi-family housing market.

Legal Barriers

Building codes could be a factor against the importation of whole systems; however, many components have already been successfully imported without significant problems. We can expect increasing competition from Europe as more basic building practices and materials are exported to the U.S.

Non-Technical Energy Conservation Ideas

The most important non-technical idea is that of encouraging multi-family housing applications of both current and evolving U.S. industrialized housing technology. The inherent energy conserving potential of multi-family housing, even in the "plex" and row house scale, offers energy savings with little additional cost in conservation design. Research that encourages the development of better approaches to multi-family development by the U.S. manufactured housing industry should be encouraged.

Likely Market Acceptance

Market acceptance for multi-family housing varies greatly through time. In times of economic

expansion, multi family housing sales usually decrease. In slower and tight economic times, industrially produced housing sales increase. If it provided a better range of choices and opportunities, manufactured multi-family housing would seem to have market potential. Atria provides appealing and useful space that would probably have wide customer appeal.

Current Penetration of These Housing Technologies in the U.S. Market

The Velux roof window company currently has a significant market share of the upscale skylight market in the U.S.. Other products have enjoyed great success and there is no sign that this trend will be changing. With the success of these products we can expect additional product entries into the US market.

4.3 CURRENT STATUS OF DESIGN, MANUFACTURING, MARKETING AND INSTALLATION IN JAPANESE INDUSTRIALIZED HOUSING **G.Z. Brown**

4.3.1 Generic Methods of Design, Production, Marketing and Installation

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.

A number of research efforts took place during this time to address the questions raised by these changes --- how to build houses rapidly, how to build them with materials that were suitable for urban areas, how to deal with domestic wood shortages (Kendall 1987). These new questions, combined with traditional questions related to earthquake and fire hazards, produced answers which supported Japan's movement towards industrialized housing. This building research was initially supported by the government and was frequently conducted in conjunction with universities and private companies. Construction companies and housing companies, as they became larger, have made considerable investments in research since the 1970's (Kendall, 1987, Coaldrake).

Japan developed as an industrial power during this period. The industrialization of Japanese housing components took place within the general industrialization of consumer products. There was considerable expertise shared from industry to industry. Toyota, for example, has been involved in producing houses and components. Some authorities feel that the general increase in mass produced products in Japan, especially those within housing, has preconditioned the Japanese consumer to accept the completely industrialized house (Coaldrake). There continues to be a high level of

housing research in government, universities and in industry sponsored by various combinations of private and public funding. Japanese industrialized housing has developed in a context which is unique to Japan -- an expanding economy, high levels of research and development, and cooperation between government and private industry.

Industrialized housing is defined differently in Japan than it is in the United States. While we concentrate on the means and place of production -- i.e., in the factory or on the site, or panelized or modular, the Japanese definition (Tatsumi, 1987) is characterized by its emphasis on company integration. Industrialized housing is defined as that housing that is produced by companies which market, finance, design, build and install a complete (frequently including furniture) house. While it is unclear whether this definition is maintained in the compilation of all statistics, this description does result in a much lower percent of the total market (15%) for industrialized housing than is true in the United States or Sweden.

Japanese housing construction was characterized 1983 by the Building Center of Japan as shown in Fig. 4.3-1.

NOTES:

1. 580,000 units in the "Builders" category were ordered for owner-occupation or rental.
2. Approximately 14,000 units of the "Builders" category (1/2%) were of 2 X 4 construction.
3. 130,000 units in the General Contractor (steel frame) category were ordered by private rental house owners.
- () is the number of units produced in that category.
- *1 are buildings which consists of two or more dwellings which have independant doors to the street (directly or via a garden).
- *2 are buildings of two or more dwellings which have passages, stairs & etc, which are used jointly.
- *3 private corporations which sell dwellings of condominium type.

Figure 4.3 - 1, Japan Housing Construction

It is worth noting that while a large percentage (60%) of the detached houses are built by builders comparable to small scale site builders in the United States who use industrially produced windows, doors, etc. as they do in the United States; they also use industrially produced heavy timber frames which are uncommon though available in the U.S. The frames produced by Sekisui House factory in Nogoya are completely made by computer controlled milling, routing and drilling machines, (Brown, 1989).

As can be seen from Figure 4.3-1, a little more than half were wooden construction and the rest were steel and reinforced concrete. Most of the industrialized housing construction is steel frame but that situation may change as companies like Mitsui and Sekisui Heim experiment with wood 2x4 and other forms of wood construction. About half of industrialized housing is single family and half apartments. The major home companies are shown in Figure 4.3-2 (adapted from Coaldrake, 8/86).

Company name	Residences produced 1982	Capital investment (in billion yen, 1983)	HD	Major Branches	Business offices & market outlets	Total Factories	Employees	Architects
Sekisui Prefab	23,000	181.5	Osaka	8	91	4	8,422	1,525
Daiwa House	12,145	194.4	Osaka	38	88	12	5,810	1,304
Asahi Hebel Haus	4,730	527.3	Osaka	-	16	5	1,113	114
Nat. House Ind.	11,920	33.4	Osaka	2	75	4	1,958	201
Toyota Automobile	930	1,209.5	Toyota City	2	1	2	221	24
Sekisui Heim	11,270	143.8	Osaka	17	145	7	1,077	304
Taisei Corporation	3,075	386.7	Tokyo	13	15	12	518	23
Dai'ei House	1,089	7.5	Nagoya	5	4	1	432	52
Misawa Homes	30,500	48.8	Tokyo	8	514	21	1,111	150
Koburi House	1,646	16.3	Osaka	11	28	2	588	153
Mitsui Home	5,138	13.7	Tokyo	12	24	6	1,010	185

Note: Factory figures include factories under contract and direct control of company.

Figure 4.3-2, Japanese Housing Companies

As can be seen from Fig. 4.3-2 Japanese industrialized builders are larger than most in the U.S. (NVR 8,500 units, N. American Housing 2,360 units and Fleetwood 36,700 units). The Japanese also use a variety of building systems and company organizations and offer a variety of product types. Almost all of the major housing companies produce Western style housing that has been adapted to Japanese living patterns.

Mitsui, Misawa, Sekisui Heim and Sekisui House (visited in August and September 1989) will serve as examples to describe the generic process of sales, design, manufacturing and installation. These companies, although different from each other, represent a cross section of industrialized home building companies. There are, as there are in the U.S., many hybrids and many subtleties within the

companies that are neglected in this description.

There seem to be two primary sales locations: 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 10-12 models to more than 50 models. The parks are developed by private companies who supply the land, the shared common customer building, and the park infrastructure. The housing companies lease lots within the park. The parks do not represent a typical street as they typically would in the U.S. where the model homes are eventually sold. The Japanese model homes are torn down after 2 or 3 years and the land is developed for other uses. Within housing parks each housing model is staffed by salespeople armed with extensive promotional literature and other sales aids.

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 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 and a few to developers who speculate by selling completed homes with land. A large percentage of the homes seem to go into individual plots or small subdivisions with less than 25 homes.

Once the 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. Frequently material ordering, inventory and shipping information are computerized and usually have some level of interconnection with the CAD system.

Production is highly automated (with the exception of Mitsui, a 2x4 builder) with each house being produced to 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 either done by hand in the field (Sekisui, Misawa) or by hand 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. The small size of Japanese roads and shipping restrictions related to them probably influence the size of both panels and modules, as it does in the U.S. Installation is performed by company crews or by independent contractors.

Design, engineering and research are largely outside the everyday sales-manufacturing-installation process. Once a customer orders a house it is put together from predesigned and engineered

components. Therefore, most architectural design, engineering and research is directed towards new product development. New products are introduced every two or three years and research is an ongoing corporate activity. Mitsui, again the exception, farms out most of its design to small contractors around the country. Mitsui also imports most of its materials and some completed homes from the U.S. or Canada.

4.3.2 Variations in Design and Production

This section is based on observations made at Mitsui, Sekisami House, Sekisui Heim and Misawa. These four companies manufacture houses using four different systems.

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 (the largest S.F. builder in Japan) and 10% apartments. Of the single family units, 90% are steel and 10% are wood modules.

The steel systems are produced in seven factories, and wood systems in six factories. The wood production facilities, when not combined with the steel, are smaller and serve a limited geographic area.

The steel module production takes place in the most automated factory observed: 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 90%+ complete when they leave the factory.

Sekisui House produces 60,000 units annually. 75% are apartments and 25% are single family. All the apartments and 90% of the single family are steel frame with infill panels, 5% of the remaining single family are 2x4 construction and 5% are conventional wood post and beam. 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, and it takes 90 days to assemble the house. The conventional posts and beams made for traditional homes are automatically cut, milled, routed, and drilled.

Figure 4.3-3, Sekisui Heim "Parfait"

Figure 4.3-4, Sekisui House, B Model

Misawa produces 40,000 units annually of which 26,000 are single family. Of these 26,000, 90% are stressed skin wood panels, and 10% are "ceramic" (lightweight autoclaved concrete). The stressed skin wood panel houses take about 40 days to assemble on site, where exterior finishes and roofing are applied.

Their newest product is the lightweight autoclaved panel (PALC) on a steel frame module (similar to Sekisui Heim). While production is still modest, the capital investment in the plant visited was substantial. The steel frame and the concrete panels are produced on separate lines and then brought together for interior finishing, wiring, and plumbing. The house is 90% complete when it leaves the factory.

Figure 4.3-5, Misawa Wood Panel

The concrete panel manufacturing process follows 10 steps:

1. Assemble steel reinforcing
2. Perform rust proofing dip of reinforcing
3. Insert reinforcing into mold
4. Pour concrete into mold
5. Set with temperature control
6. Demold and pallet
7. Pre-autoclave humidification
8. Autoclave
9. Drying
10. Painting and finishing

The concrete panels are taken to the module assembly line which employs the following basic steps:

1. Assemble floor module using steel frame and wood joists
2. Weld corner columns to the floor frame
3. Insert bath unit if bath module
4. Attach concrete wall panels
5. Attach exterior openings from subline
6. Attach ceiling panels from subline
7. Attach interior panels
8. Inspect
9. Move to stock

At any one time there is enough steel in the plant for 1/4 day's production.

The modules are produced just in time for delivery to the site. On the average there are 12 modules per house at about 100 SF. 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. The factory at Nogoya produces 200-250 houses per month, or approximately 1 house per hour.

Mitsui, producing 5,130 (1983) homes annually is a 2x4 builder using construction techniques based on those developed in North America. The firm imports all its house building products from the U.S or Canada. Currently it designs using a 3' (tatami) planning module but is changing to a 4' planning module in order to better accomodate North American materials. Mitsui is also experimenting with a U.S. designed stress skin panel with expanded polystyrene core.

These four housing companies have fairly different products and approaches to designing those products. All of the companies except Mitsui use computers in the design process. Computer use in these companies is described in detail in Section 6.1.

Figure 4.3-6, Misawa - PALC Module

Design

Misawa, Sekisui Home and Sekisui Heim all use centralized captive design groups. Sekisui Heim moved from houses that were "industrialized" in appearance to those with Western styling around 1980. Sekisui Heim designs one or two new models each year and there are currently 5 to 10 models being sold (depending how one counts). Sekisui Heim builds its houses from 10 sizes of steel modules and 3 sizes of wood modules. Sekisui Home designs one or more new models each year. In 1983 they had 6 basic models (Coaldrake, 8/86) with 36 plan variations. Misawa had 4 basic models with 26 plan variations in 1983 (Coaldrake 8/86). Mitsui contracts out most of its design work to a number of small architectural offices throughout Japan although it does have an internal design group as well. Mitsui has developed 150 models in the past three years.

4.3.3 Current Status of Energy Efficiency

Surprisingly, given Japan's dependence upon imported fuel, there are no mandatory residential energy

codes. There are energy performance standards required by government lending (or loan guaranty/approving) agencies. These standards translate into 2" to 3" of wall insulation. Academic, housing company, research and government personnel were all questioned about the low standards as compared to the U.S. One researcher speculated that Japan's lack of concern for energy conservation stemmed from their traditional very low energy use in their houses (no air conditioning and charcoal heaters). The traditional emphasis on designing the house for summer rather than winter has made insulation an unimportant consideration (Tatsumi). This tradition was felt to be continuing even in industrialized housing products where central heating units are used to maintain a minimum temperature and habachi are used for local heating. Air conditioning was said to be turned on only for guests.

These attitudes leading to frugal energy use are expected to change with the next generation of home buyers (Matsumura). Given the strict earthquake and fire codes, there certainly is a precedent for national energy codes. It remains unclear why the Japanese haven't adopted a national energy code. The result is that unlike Sweden, many of Japan's industrialized housing products are poor energy performers. The steel frame systems seem to have a number of thermal short circuits at panel joints and openings. These thermal leaks and the low levels of insulation due to panel thinness would make it difficult to substantially increase energy performance without extensive redesign.

Misawa's lightweight concrete wall panel system used no insulation. Nor was there any intentional use of the concrete as thermal mass, although in some cases it was exposed on the interior of the dwelling. The Misawa concrete/steel module system used a 2"-3" diameter flexible duct system to move heated and cooled air within the house. The joint between the modules was made with an internal sleeve and an exterior compression gasket. The mechanical systems were said to be heat pumps that we used for both heating and cooling.

Some manufacturers produce energy efficient homes and a number of housing manufacturers are conducting energy research. Mitsui, a 2x4 builder, promotes energy conservation and air tight construction. Mitsui is also experimenting with R-Control panels (an American product) which are stressed skin panels with an EPS core. Several 2x4 builders located in Hokkaido are experimenting with designs based on Canada's R-2000 specification.

Misawa currently varies its construction by climate zone. The firm intends to reduce the energy consumption of their homes by one third in the next 5 to 6 years. Their main research emphasis is how to achieve this reduction at an acceptable cost. Their approach to reducing energy use is threefold: (1) improving envelope performance through more insulation and better windows, (2) using more efficient heating and cooling systems, and (3) utilizing solar and ground water heating systems. Windows are a particular problem for them because of the Japanese preference for large windows.

High humidity is a significant comfort problem in air conditioning spaces and they are exploring dehumidification systems.

Sekisui House also has a number of test houses which it has used to monitor solar heating (Ishida) and is currently using to study air quality and dehumidification.

In summary, the situation of the companies I visited represents two extremes. The energy use of their average product is high compared to the U.S. due to low mandatory standards. On the other hand, their investment in energy research and their interest in the subject is higher than comparable companies in the U.S.

4.3.4 Assessment

There are a number of things that can be learned from the Japanese about energy efficiency and housing industrialization. First, the Japanese example confirms what we know from the U.S. HUD code experience. Industrialization does not automatically result in good energy performance. This confirms one of our initial suppositions about industrialization -- that even though the potential exists for industrialization to increase energy performance (as in Sweden), the fact that the U.S. housing is becoming increasingly industrialized means little about energy efficiency. Something has to be done in order to make sure U.S. housing becomes more energy efficient as it becomes more industrialized.

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

The Japanese companies' energy research is worth watching because it is driven by marketplace concerns. Products developed through these programs are likely to have a high level of consumer acceptance and may have value as imported products in the U.S. market.

The big Japanese housing companies are structured more like automotive companies than most housing companies in the U.S. They sell nationally, are capital intensive, have high labor costs, use sophisticated marketing techniques, have captive design groups, and sell a complete product complete with furniture. If U.S. companies evolve in this direction they may have greater incentive to, and be

able to, spend more on energy related product development as a way of reducing cost and improving performance. This scenario assumes a regulatory environment which requires or an incentive program which encourages high levels of energy performance -- meaning a higher level of interest in and support of Department of Energy research programs.

Most industrialized housing companies produce Western style houses and offer several product lines. These houses would probably sell in the U.S. and there is clear evidence that industrialization does not seriously inhibit design flexibility.

Most Japanese housing companies are more highly computerized than U.S. companies are. The computerization has been directed at making the design and especially the production more efficient. These systems are moving towards increased sophistication in engineering design and higher levels of integration of sales, design and production. The high level of computerization breaks down traditional barriers to computerized energy design tools. Computers are discussed in more detail in Section 6.0.

While there are many important differences between Japan and the U.S., there are also similarities related to housing. There are several aspects of the Japanese housing industry that make it worth monitoring on a continuing basis -- climates in Japan similar to major zones in the U.S., increased interest in energy efficiency, use of wood construction within a context of high industrialization, urban construction, and large housing companies which may become more of the norm in the U.S.

5. ASSESSMENT OF INDUSTRIALIZATION APPLICATIONS

INTRODUCTION

This chapter discusses the energy needs of U. S. industrialized housing in its climatic context (5.1, 5.2), compares the performance and costs of U. S. and foreign industrialized housing (5.3), relates the generic techniques of housing industrialization to typical climates and traditional houses shaped by those climates (5.4), examines a very non-traditional solution to energy efficient housing (the G. E. Plastic house, 5.5), and looks to the future of industrialized housing in its materials and components (5.6).

5.1 STATISTICAL ANALYSIS OF INDUSTRIALIZED HOUSING BY CLIMATE ZONE R. Berg

Introduction/Objectives

Industrialized housing production is distributed unevenly in the U.S., and of course regional climates and energy requirements vary widely as well. The goal of this part of the research is to identify and relate these variations in ways that will reveal energy-significant connections between production types and climates, and to suggest possible ways to make those types more responsive to the climates in which they occur -- thus more energy efficient.

The problems of scarce and inconsistent production statistics, already mentioned in Section 3.1 and elsewhere, become increasingly troublesome as the focus is sharpened to regional levels. Of the three major data sources discussed earlier, only LSI provides detailed state-by-state figures, and these neglect the "production builder" category. As it happens, the LSI view of overall industrialized production trends is less optimistic than that of either Shapiro or Hallahan (LSI, Where the Action Is, 1988, p. xi). For purposes of inter-climate study, however, the LSI figures provide us with sufficient (and only) information. New aggregations are made from these data in order to relate them internally, and to adjust them to the climate zones chosen as pertinent for energy study. The climate zones themselves are refined for simplicity and compatibility with existing production data.

5.1.1 Climate Regions and Energy Consumption

For the purposes of this study the climates of the U.S. are divided along state lines to form the map shown in Figure 5.1-1.

The basis for this map is W. Koppen's classification of climates according to vegetation (Solar Dwelling Design Concepts, 1977, p. 41), a system which establishes four climate zones: cool, temperate, hot-arid, and hot-humid. Of course these zones are not sharply differentiated in physical reality. They merge, and within each may occur a wide variety of climatic conditions. Still, the generally consistent pattern of insolation and weather within each region suggests a particular set of energy requirements. Total and per capita energy consumption figures are given in Table 5.1-1.

Figure 5.1-1, 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.

Climate Region	Total Residential Energy Consumption, BTU's x 10 ¹⁵ (quads)		Per Capita Residential Energy Consumption, BTU's x 10 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

Table 5.1-1, Climate Region Residential Energy Consumption -- 1987

source: EIA State Energy Data Report, 1987, p. 11

The cool region provides a wide temperature range, hot summers and cold winters, with persistent winds and relatively little solar radiation. In our map this region comprises a northern band from Montana to Maine, away from the moderating influence of the Pacific. Energy is used here primarily for space and water heating, and appliance usage. This zone was responsible for 6% of 1987 total U. S. residential energy consumption (State Energy Data Report, 1987).

The temperate zone offers roughly equal periods of over- and underheated weather, seasonal winds, sometimes high humidity and heavy precipitation, and both clear and overcast conditions. In our map this is by far the largest region, spreading across the central U.S. from the Pacific coast to the Mid- and North Atlantic. Energy here is used for heating, appliances, and cooling; it comprised 66% of U. S. residential energy use in 1987.

The hot-arid region features clear dry weather, long overheated periods, and large diurnal temperature and wind variations. In this Southwestern region, again isolated from the moderating ocean influence, a greater proportion of energy is used for cooling. Residential energy use in 1987 for this region was 9% of the national total.

The hot-humid climate provides high temperatures and humidity, and variable (sometimes very high) winds. From the lower Mississippi to the South Atlantic states this climate zone prevails, again with high energy requirements for cooling. In 1987 this region used 19% of the U. S. residential total.

Changing Climates, Populations, Energy Use

Whether it reflects a long-term trend or simply a short-term weather pattern, a clear shift in energy end use is evident in recent years. Between 1984 and 1987, for example, while overall household energy

use fell 3.7%, energy use for air conditioning rose 19%. The changes in household energy use are summarized in Table 5.1-2.

<u>Energy End Use</u>	<u>1984</u>	<u>1987</u>	<u>Percent Change</u>
Total	104.7	100.8	-3.7
Space Heating	59.4	54.6	-8.1
Water Heating	18.1	18.1	-3.7
Air Conditioning	4.2	5.0	+19.0
Appliance Usage	22.2	23.2	+4.5

Table 5.1-2, Changes in U.S. Household Average Energy Consumption by End Use, 1984 and 1987 (million Btu per household)

source: Household Energy Consumption and Expenditures 1987

Simultaneously there is a continuing pattern of migration to the "sun belt" states and corresponding reflection in housing starts. These trends are depicted in Figures 5.1-3 and 5.1-4.

Figure 5.1-2, Net Migration Rate per 1,000 population, by State -- 1987

source: Framework for the Future: 1989-1991

Figure 5.1-3, Housing Starts per 1,000 Population, by State -- 1987
 source: Framework for the Future: 1989-1991

The statistical "hole" in the middle of the sun belt, particularly involving Texas, Oklahoma, and Louisiana, reflects the recent collapse of the oil boom and overbuilding in the region in the early 80's. From a high of 55% of national housing starts in 1982, for example, the southern census region fell to 41% in 1986 (America's Changing Houses, 1988). Still, the general growth of warm climate regions is upheld in Arizona (and its neighbors California and Nevada) and Florida (and the Carolinas).

One feature of U.S. homes reflects these changes. From 1984 to 1987 the percentage of electrically air conditioned households increased 4%. Of these, the centrally air conditioned portion rose 4%. Among all air conditioned households, the percent operating their air conditioners "all summer" rose from 23% in 1984 to 32% in 1987 -- with a consequent doubling of their cooling energy consumption (EIA, Household Energy Consumption and Expenditures 1987, p.4). In every sense, home cooling became a more important end use of energy.

Unfortunately it is also true that houses are among the most climate-sensitive of all building types in their energy requirements. Figure 5.1-4 shows the distribution of building load (heating and cooling) factors for a variety of building types. Single family detached residences, and especially HUD-code homes, are particularly vulnerable.

Figure 5.1-4, 24 Hour Average Building Load Factors by Building Type

source: Loveland & Brown, Impacts of Climate Change on the Energy Performance of Buildings in the United States, p.33

What results, then, is a convergence of trends: migration to warm climate areas, concentration of housing starts in these areas, potential expansion in the extent of these areas as a result of climate change, and consequent increased energy use for cooling in particularly sensitive buildings. These trends will affect the kinds of housing -- industrialized housing -- that the U. S. requires.

5.1.2 Regional Production of Industrialized Housing

Overall

Tables 5.1-3 and 5.1-4 below show the overall distribution and prevalence of industrialized housing production among climate regions, and the number of industrialized housing producers in each climate region.

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

Table 5.1-3, Regional Industrialized Production -- 1987

[^]source data from America's Changing Houses (LSI), 1988 <B-32> data available from B-29 Shapiro

*taken here as all other starts

<u>Climate</u>	<u>No. of Producers</u>			
	<u>Prod. Built</u>	<u>HUD Code</u>	<u>Modular</u>	<u>Panelized</u>
Cool		41	18	93
Temperate		119	181	380
Hot-Arid		49	31	36
Hot-Humid		158	46	105
	<u>6500*</u>			

Table 5.1-4, Regional Industrialized Housing Producers -- 1987

source: data from Shapiro, Mfd. Housing, 1988, p. 19-12 <B-1>-- or B-29

*source: Don Carlson, Automated Builder publisher, phone conversation 11/15/89

Figures 5.1-5 through 5.1-12 show industrialized housing production and manufacturing plant trends for each climate region from 1980 to 1987.

Figure 5.1-5, Cool Climate Industrialized Production -- 1981-1987

Figure 5.1-6, Cool Climate Manufacturing Plants, 1981-1987

Figure 5.1-7, Temperate Climate Industrialized Production --1981-1987

Figure 5.1.8, Temperate Climate Manufacturing Plants, 1981-1987

Figure 5.1-9, Hot-Arid Climate Industrialized Production -- 1981-1987

Figure 5.1-10, Hot-Arid Climate Manufacturing Plants, 1981-1987

Figure 5.1-11, Hot-Humid Climate Industrialized Production -- 1981-1987

Figure 5.1-12, Hot-Humid Climate Manufacturing Plants, 1981-1987

These figures, drawn from LSI sources (Where the Action Is, 1988), include all one- to four- family dwelling units. Since single-family homes comprised roughly 80% of all 1987 residential production

(Standard and Poor's Industry Surveys, 1988), including large, multi-family buildings, we may assume that these numbers consist of perhaps 90% single-family dwellings. Multi-family units are concentrated chiefly in metropolitan areas, but how this fact skews the data regionally is open to speculation.

LSI Systems' data is gathered from an annual survey of "all producers of manufactured housing." The firm estimates that about 15% of its data is estimated, to compensate for incomplete reporting.

Figure 5.1-13, Industrialized Production by Climate Region --1987
 source: *America's Changing Houses*, 1988 (LSI)

Regional

It is clear from these figures that the temperate zone dominates production of all types except HUD code houses. Given the comparatively large size of that zone and the fact that it includes the two most populous states, California and New York, (Population Today, May 1988) this result is scarcely surprising. The small relative size of the other zones (only three states in the hot-arid zone; only seven in the cold zone) also exerts a strong impact on their totals.

5.1.3 Industry Locations within Regions -- Non-climate Considerations

Although our discussion of industrialized housing has stressed the climatic aspects -- *implications* -- of its location, the *reasons* for its whereabouts may have little to do with climate. One analysis of this issue is presented in Manufactured Housing, quoting University of Illinois Professor Gordon Bagby: "Industrialized building firms prosper in areas where unskilled labor rates are low relative to skilled labor rates. All other considerations, housing demand, ability to travel over highways, amount of wood available, etc., while significant, pall in comparison to this. . . ."

"You can predict where prefabrication will occur on the basis of the same phenomena -- where skilled labor rates are high, you get the panelized product. . . . The principal market for the modular product appears to be where relatively standard models can be. . . unfettered by building code restrictions. . . ."

The geographic implications of this argument are summarized in Figures 5.1-14, 5.1-15, 5.1-16, and 5.1-17. Here the distribution of industrialized housing is shown relative to city/country, skilled/unskilled labor, union/non-union labor, little/much product value added, and tight/loose code restrictions.

Figure 5.1-14, Labor Skill Distribution -- Urban vs. Rural
 source: Manufactured Housing, 1988 <pp 6-7 to 6-10>

Figure 5.1-15, Unionization/Value Added Distribution -- Urban vs. Rural
 source: Manufactured Housing, 1988

Figure 5.1-16, Regulation Level Distribution -- Urban vs. Rural
 source: Manufactured Housing, 1988

Figure 5.1-17, Industrialized Housing Distribution -- Urban vs. Rural
 source: Manufactured Housing, 1988

Manufactured Housing also stresses the dominating importance of supply, distribution, inventory extent, production volume and portability, and other factors in determining where industrialized Northeast, because they buy no furniture and use conventional distribution methods, and tend to locate in small cities; panelized producers who make log or pre-cut units are located in heavily timbered states; and HUD-code manufacturers are dependent on and located near furniture suppliers' warehouses in roughly a dozen U.S. locations. These industry centers are pictured in Figures 5.1-18, 5.1-19, and 5.1-20.

Figure 5.1-18, Panelized Production Centers
source: *Manufactured Housing*, 1988, p. 15-2

Figure 5.1-19, Modular Production Centers
 source: Manufactured Housing, 1988, p. 15-4

Figure 5.1-20, HUD-Code Production Centers
 source: Manufactured Housing, 1988, p. 15-5

5.1.4 Implications for Research

The consideration of climate's influence on energy use clarifies some important issues for industrialized housing. One, based on the universal need for houses to use less energy, comes

down to how -- through the "thermos bottle" approach, finding more efficient insulation, mechanical systems, windows, heat exchangers, etc., so that an efficient Minnesota house would need only a change of innards to work well in Arizona -- or through the "climate responsive" approach, tailoring a house to fit its climate via solar gain, thermal mass, cross and stack ventilation, etc.

Industry (the housing industry in general) has so far tended to use the first strategy, consciously or otherwise. Doing so permits the same design, allowing for local code-required changes, to be produced and sold anywhere. A new plant can open and its product line can be same as other plants in the same company hundreds or thousands of miles away. Given the naive state of industrialization prevalent, this has been a reasonable choice.

The second strategy requires more sophisticated design, more attention to the market area climate, and in some cases materials which effectively have not existed. Nonetheless this approach is tantalizing in its promise of cost effectiveness and return to the satisfactions of true regional architectural identity.

Research need not choose between these alternatives. Better insulation can improve any kind of house. A product or technique to add thermal mass, a common desert dwelling strategy, can allow a Minnesota home's heating system to operate chiefly during less critical, off-peak hours.

Climate related study also locates specific issues -- for example, the need for more research emphasis related to warm climate energy use, as a response to the changes described in Section 5.1.1. Here it is interesting to note that the U.S. might play a pioneering role, notwithstanding other nations' advances in housing research for cold climates.

5.1.5 Implications for Industrialized Housing

The effect of regional "climatization" of the industrialized housing industry might simply amplify the existing trends toward customization -- that is, using industrialized processes sophisticated enough to produce varied products with uniform speed, quality and economy. XYZ Corporation, for example, might produce from its Tuscon plant homes far different in energy character from those of its Detroit factory. Yet each home would match its own circumstances, and be produced from similar machinery directed by similar, or even the same, automated processes.

5.2 CLIMATE RESPONSE OF INDUSTRIALIZED HOUSING BY CLIMATE REGION R. Berg

Throughout the U.S. there are traditional house types associated with, and quite specifically adapted to, the climates of their home regions. Here we will explore the climatic implications for industrialized housing at several levels: *siting* and *orientation*, *configuration*, *enve'ope* (structure and materials), *openings* and *equipment* (HVAC, plumbing, and electrical).

Cool climates employ two general strategies to minimize residential energy use -- protection from cold ambient temperatures and capture of available solar heat. At the *site* level, these strategies imply use of existing site features such as hills or trees to protect against north winds. A south-sloping site is ideal for wind protection and solar exposure, for instance. Reflective surfaces such as paving to the south can increase solar radiation striking the building, particularly when the sun is low in winter. All industrialized systems can employ these kinds of techniques.

Orientation of a house should expose large surfaces to the sun, and concentrate openings on the south while minimizing north-facing windows and doors. All industrialized housing varieties -- panelized, modular, HUD-code, and production built -- can be oriented freely, but HUD-code buildings at least typically require a fairly flat site. HUD-code buildings are also unique in that the designer and manufacturer have little or no control over how they are oriented.

HUD-code and modular buildings, made as they are of somewhat linear volumes, suggest long walls which can be oriented southward for potential solar gain. The tall walls of two-story panelized, modular, or production built homes can serve the same purpose.

Panelized and production houses can provide extended shapes as well of course, but long forms are not inherent in these systems and in fact most modular homes sold today are compact volumes, particularly in their two-story versions.

These compact forms are in turn advantageous at the *configuration* level, providing as they do large volume-to-surface ratios with minimal skin heat losses. The extruded forms of HUD-code buildings are weaker in this regard.

The *envelope* of a cool climate house should be well insulated and impervious to cold air

infiltration. The thick surfaces thus implied by present forms of insulation shrink the already limited interior space in HUD-code buildings. The low roof pitches common to HUD-code and modular homes, however, can hold snow and benefit from its insulating qualities. Embedding the house in the soil of the site via berms or sod roof -- an effective way to hide it from low-temperature air -- is most feasible for production-built housing, though exploration of this idea might permit its use for other systems as well.

Structures such as double-wide HUD-code homes, and modular or closed-panel buildings with assembly joints which penetrate the entire envelope thickness, are vulnerable to infiltration at these points unless site assembly is carefully done -- a requirement perhaps inconsistent with the ethic of industrialized housing, and a potential weakness of these products. A HUD-sponsored 1985 survey of mobile home durability (RADCO, Final Report for Durability in Manufactured Homes, 1985, p. 13), for example, found 15% of the respondents noting problems in the section joints.

Openings into a cool climate house should encourage solar gain while resisting heat loss; generally in fact doors and windows for this climate are relatively high-tech, heavy and costly -- problem characteristics for virtually every industrialized system though least for production building.

The space and water heating *equipment* used in cool climate homes has a special need for efficiency because of its burden. The "tightness" desirable in cool climate houses makes indoor air quality an issue, and adds heat exchangers to the equipment list. The need to preserve the integrity of the thermal envelope bears on the way equipment is installed, to minimize thermal shorts and air leaks. These issues apply more or less equally to all industrialized systems.

Temperate climates impose both heating and cooling loads, and the complicating factor of conflicting seasonal needs. Thus solar gain, desirable in January, may be a problem in July. At the *site* level seasonal wind and shade variations become pertinent. Again, the HUD-code home permits perhaps the least flexibility in siting, but the fact that hillsides accommodate driveways and parking decks suggests that they could serve mobile homes as well.

Solar access is still an issue in this climate region. Northerly winter winds are to be avoided, while southwesterly summer breezes are desirable. Low winter sun is welcome; high summer sun is not. Deciduous trees on the south side of a house provide seasonal sun control of an automatic nature, shady in summer and open in winter. Site topography, plants, and adjacent buildings can screen or gather seasonal winds. These strategies are available to all production types.

Orientation of a temperate climate house should place its sun-gathering windows south-southeast. Outdoor living spaces should lie southwest for winter wind protection. These kinds of considerations require a kind of site-specific design or at least solar "handedness" which so far industrialized housing has generally lacked. The entire notion of integrated indoor/outdoor spaces, for that matter, is ignored in industrialized generic design schemes. There is no apparent reason, however, why any production system need ignore these issues.

The *envelope* of a house in this climate zone needs insulation as the cool climate house does, though less of it. It needs to be "switchable," however, to allow cooling summer breezes to flow through it.

Usually this task is handled by the *openings*. For thorough ventilation, these must include north-facing as well as south-facing windows. Here is an example of seasonal conflict: the openings needed for summer cooling make winter heating more difficult.

Hot-dry climates may impose both heating and cooling loads, sometimes in the same day. *Site* and *orientation* issues are largely like those of the temperate region, though summer shade becomes more important.

Large diurnal temperature swings invite the use of thermal mass in the *envelope* to level indoor temperatures, but thermal mass has so far been largely synonymous with gravitational mass, thus weight. Weight creates problems for HUD code and modular systems, and to some extent panelized ones, all of which require transportation of relatively large elements.

Openings in this region require shade, thus far something of a problem with HUD code buildings *per se*. The virtual universality of aftermarket awnings and carports attached to the mobile homes of sunbelt states demonstrates that there is a problem, and that it can be solved -- perhaps more elegantly. Modular houses are likewise subject to eave-width restrictions because they also travel on highways. Panelized and production houses permit more freedom to deal with this problem.

Equipment for houses in this climate is rapidly, as we noted in Section 5.1.1, coming to include an air conditioner as a necessity. It appears that substantial changes will be necessary in homes themselves (siting, envelope, etc.) to reverse this trend.

Hot-humid climates invite use of the *site* features (trees, fences, etc.) to enhance cooling breezes

through the house. *Orientation* should permit winter solar gain, and the appeal of a long, narrow house form to permit easy cross ventilation suggest an east-west house form, with a linear *envelope* (and one with little need for thermal mass) filled with *openings* -- like a skeletal HUD code building, except supplied with broad verandas. The usefulness of elevating the house for better ventilation likewise brings to mind a HUD code-style building, "up on blocks," as it were.

Equipment for a hot-humid climate building faces few novel demands if the need to ventilate the building is answered by the siting, orientation, envelope and openings of the building itself.

5.3 ANALYSIS OF DOMESTIC AND FOREIGN INDUSTRIALIZATION HOUSING COSTS AND ENERGY PERFORMANCE

J. Finrow

Research presented here will deal with comparisons of the Swedish Factory Crafted (SFC) housing industry and the U. S. housing industry.

HOUSING COSTS

An SFC house in Sweden is less affordable than a comparable average site built house in the USA. An analysis of housing affordability for single family detached housing between the U.S. and Sweden using a "typical" SFC house (a factory "Demo" house that was for sale) compared to the "average" new U.S. house confirms this conclusion. Land costs were factored out of the analysis. The true cost of housing (in U. S. dollars per 100 sq. ft. per month) is approximately \$96 for the SFC house and \$59 for the U. S. house.

Initial affordability of the SFC house is enhanced because the first year interest rate for the compared house has been "bought down" by the Swedish government to 5% with gradual increases over 5 years up to the full market rate (at the time of this analysis that was 11.75%). The first year SFC cost per 100 sq. ft. is actually \$51.30, which is somewhat below the cost of the U.S. house. If comparable interest rates were used for the U. S. house, it would cost less than the SFC house.

Further, if we examine these nations' standard of living as recorded in GNP terms, we find further evidence of the extreme difference in affordability between SFC and conventional U. S.

housing. As cited in the November 4 issue of The Economist, the average Swede has only 75% as much purchasing power as a U.S. counterpart. With 25% less income, Swedes have to pay a considerably higher percentage of their income for an SFC house than a U. S. housing consumer would for an average site built house.

A comparison of the SFC house and an average U. S. HUD code house shows even greater cost advantages to U. S. housing practice. According to Standard and Poor's October 27, 1988, Industry Surveys (for Building and Forest Products), a HUD code manufactured house is about 1/2 the cost of a comparable site built house. Given the analysis cited above, a HUD code house would be approximately 1/4 the cost of an SFC house. However, it should be noted that the quality of the SFC house is considerably higher than that of either the typical HUD code manufactured house or the conventional site built house. Energy performance is certainly much higher in the SFC house which suggests that as life cycle energy costs are factored into the analysis, the gap in housing affordability would be narrowed but probably not eliminated.

A significant factor in judging the cost and affordability of SFC housing is the cost of industrialization and plant facilities for factory produced houses. From conversations with plant personnel and from observation, it is clear that a substantial amount of the construction value of an SFC house is added on the site. This fact comes as a surprise, because it has been assumed that a more significant portion of the house was produced in a factory setting. From an analysis of data concerning the percentage of total housing values related to specific elements of housing construction it was determined that the probable percentage of on-site work done for SFC panelized housing is a little over 50%. Work that is completed on site for the typical SFC house is as follows:

- site work and concrete (in some cases, prefabricated footings)
- interior partition framing
- plumbing
- roofing
- heating system
- electrical system
- drywall finishing
- cabinetry installation
- interior finishes including wallcoverings
- painting
- finished flooring

According to statistics cited in the the Eugene (Oregon) Register Guard, this work would represent about 55% of a typical site built house value. Additional site costs including the assembly of the panels and the setting of the roof trusses. Total site-added value of the SFC house is likely to be about 60% of the total value of the house.

For comparable U. S. HUD code housing the percentage is probably much lower, quite possibly less than 10%. HUD code houses arrive at the site with most of the work listed above completed. Site work needed includes only grading and foundations, set up of the unit, systems hook-ups, skirting installation and interior patching as needed. In some cases decks and garages and carports are completely site built, a practice which is also true for SFC housing. SFC factory investments for panelized construction, therefore, produce a much smaller percentage of the total house value than does factory investments in U.S. HUD code manufactured housing.

In addition, U. S. manufactured housing is less highly industrialized than SFC housing plants and can operate on multiple shifts, thus improving investment amortization if markets will allow high productivity.

Three studies of the economics of SFC versus U. S. stick frame home building costs raise more questions than they answer (Kando, 1989; Aho and Issacson, 1987 and Spitler, 1987). All of these studies compare SFC and U.S. site built housing, but none of them compare SFC housing with HUD code or U. S. panelized housing costs. Most studies use person-hour data as a measure of construction economy. All studies suggest that SFC housing takes fewer person hours to construct and hence is potentially more economical. However, these studies do not seem to factor in the costs of plant and equipment to support the person hour costs. While the person-hours for industrialized house production are lower than for conventional house construction, the costs of plant and equipment needed to provide the added efficiency is quite substantial.

While requiring more person-hours to build, site built housing has very low plant and equipment costs. Plant and equipment utilization rates vary considerably as a function of productivity. Higher production means lower costs per house for plant and equipment. Person hours (labor) needed to produce a house of comparable size and finish is about 33% less for an SFC house than for an average site built U.S. house, according to Paul Kando. For the average house construction costs taken from NAHB data (Spitler, 1987), labor represents about 20% of the total value of a new house. Of that 20%, 33% may be saved due to SFC construction

technology, for a net savings per house of about 6% to 7% of total value of the house. Assuming the average house price in 1988 of about \$120,000, that portion represents \$7,200 of savings.

However, to achieve these labor savings, plant and equipment costs per house need to be factored in to arrive at the true costs for SFC production. Factoring in U. S. site built housing plant and equipment costs would reduce actual SFC savings to about \$6,000 per house. Paul Kando researched plant and equipment costs per house for three different plant types [Kando, 1989]. The plant and equipment costs for various plant types per housing units are:

Large capacity plant using large wall panels (1,500 housing units per year)

1 shift = \$12,000
2 shifts = \$6,400
3 shifts = \$4,200

Large capacity plant using small elements (1,000 housing units per year)

1 shift = \$9,800
2 shifts = \$4,900
3 shifts = \$3,300

Moderate capacity plant using large wall panels (500 units per year)

1 shift = \$11,200
2 shifts = \$5,600
3 shifts = \$3,700

These data show that capitalization per house for each plant operating on only one shift would exceeded the savings due to labor reductions which would mean that the cost of an SFC house would be up to 5% more expensive than that of comparable U. S. site built housing. As shifts are added the capitalization rate is reduced, making the cost of housing production lower. No significant cost savings would be realized for up to two shifts and for three shifts savings could be as much as 2%. The following chart illustrates cost savings or loss due to the plant and equipment costs for an SFC production facility compared to U. S. site built housing:

	<i>labor cost savings</i>	<i>plant & equip. costs</i>	<i>net savings or (loss)</i>	<i>percent</i>
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Large capacity / large element factory

1	\$6,000	(\$12,200)	(\$6,700)	(5.5%)
2	\$6,000	(\$6,400)	(\$400)	(.3%)
3	\$6,000	(\$4,200)	\$1,800	1.5%

Large capacity / small element factory

1	\$6,000	(\$9,800)	(\$3,800)	(3.1%)
2	\$6,000	(\$4,900)	\$1,110	.9%
3	\$6,000	(\$3,300)	\$2,700	2.25%

Moderate capacity / large element factory

1	\$6,000	(\$11,200)	(\$5,200)	(4.3%)
2	\$6,000	(\$5,600)	\$400	.3%
3	\$6,000	(\$3,200)	\$2,800	2.3%

The information presented by Kando, while making the case for the inherent economy of SFC production, also points out the critical importance of high levels of production to profitability. Plants that operate at less than full production capacity greatly increase the cost of housing with resultant loss of profitability and affordability.

Further comparisons of the cost of SFC technology and the U.S. HUD and panelized construction technology are needed. Based on previous cited information from Standard and Poor's Industry Surveys, HUD code housing is likely to cost considerably less than SFC housing. Based on personal observation and site visits, current HUD code manufacturing plants are not very highly industrialized (in comparison to SFC plants in Sweden). The costs of plant and equipment per housing unit are likely to be considerably lower for HUD code housing than that for SFC housing. An analysis of the cost implications of enabling a HUD code plant to produce housing of SFC quality, especially to SFC energy efficiency levels, would be useful to determine the feasibility of the cost effectiveness of the current HUD code housing industry.

In examining the issue of comparative affordability of Swedish Factory Crafted housing and conventional U.S. housing it is clear that there are many unanswered questions. What we know at this point is that SFC housing in Sweden is less affordable than either site built or HUD code housing in the USA. Further, given U.S. costs and production potential, SFC housing technology utilized in this country may be able to produce housing that could be more affordable than current site built

housing, but only at very high levels of plant productivity. In addition, SFC technology would not be cost competitive with HUD code manufactured housing production. The cost implications of building HUD code housing to SFC standards is not known at the present time.

Energy Performance

Sweden has been very effective at reducing energy consumption in its buildings. From 1977 to 1986, total energy consumption in Swedish buildings has been reduced about 8%, from 143 TWh (the quantity of energy supplied by a large nuclear power unit running at full output for a period of about six weeks) to 130 TWh (Olsson, 1988). In housing, space and domestic hot water heating energy use has fallen in the same period by a little over 20% from 250 kWh/sq. meter (kilowatt hours per square meter) to 190 kWh/sq. meter (Olsson, 1988). These are impressive results.

In terms of national energy usage for housing, Swedish households easily outperform their U.S. counterparts. The average Swedish house is 82% of the size of the average U. S. house and Swedish apartments are 85% of the size of comparable U. S. apartments [Schipper, 1985]. However, energy consumption per household in Sweden is only 65% of that used in the U.S. (Schipper, 1985). Assuming that 15% of this savings resides in the size of housing, the Swedes still use at least 20% less energy than do Americans. This difference may be explained in terms of three primary factors -- higher degree of urbanization, cooler Swedish climate, and stricter energy policy.

Sweden, like other European countries, is more urbanized than the U.S. The percentage of persons living in urban areas in Sweden is 83% while in the U.S. it is 73% or a 10% difference [United Nations, 1987]. Given the Swedish tradition of urban living in multi-family housing, it is safe to assume that the percentage of urban population living in multi-family housing is significantly higher than in the U. S. Multi-family housing is inherently more energy efficient than single family detached housing, which means that there is a factor of energy efficiency that is somewhat related to "building culture" that is contributing to the energy efficiency in Sweden. As their standard of living increases and more single family housing is built and occupied, this factor is likely to be reduced. However, implementing very high standards of single family detached housing energy efficiency would mitigate some of this decline.

The climate in Sweden is much cooler than in the U. S. Air conditioning to providing cooling in housing in Sweden is not necessary. In the U.S. cooling is critical in the summer months in large parts of the country, which increases energy costs. The following chart compares temperatures (in degrees fahrenheit) for various U.S. cities compared to Stockholm, which is located close to the

middle of Sweden:

<i>city</i>	<i>winter 97.5</i>	<i>summer dry bulb</i>	<i>summer wet bulb</i>
Stockholm	3	74	62
Minneapolis	-12	89	73
Philadelphia	14	90	74
Seattle	27	82	66
Kansas City	6	96	71
Houston	33	95	77
San Diego	44	80	69
Miami	47	90	77

Summer temperatures in Stockholm are quite comfortable while those in most of U.S. cities cited are too hot for comfort. The availability of relatively low cost cooling systems for single family detached housing, combined with changing standards of housing comfort contributes to the disparity in energy use in housing between Sweden and the U.S.

Building codes are much stricter in Sweden than in the U.S. regarding energy conservation. This difference is partly attributable to the national referendum that will lead to the elimination of nuclear power in Sweden by the year 2000 [Aho and Isacson, 1987]. Insulative R-values of codes doubled from 1976 to 1977. While codes have become more restrictive, the Swedish housing customer has always been interested in more rather than less energy efficiency. Data show that while the building codes have become more restrictive, they have only matched the level of consumer preference. Prior to 1976, builder and owner initiated new housing construction was already being built to R values comparable to the new R values in the 1977 code. Even after adoption of the code, consumer behavior continued to seek higher levels of insulation in housing as R values became, by 1983, 10% to 20% higher than the 1977 code requirements (Kando, 1989). This trend suggests that in Sweden, housing consumers are very sensitive to energy issues and will make investments to gain increased energy efficiency, even in the face of only slight economic justification.

If SFC housing production were adopted in the U. S., what would the energy savings be? According to Kando, there would definitely be energy savings. He predicts that energy savings due only to improved production quality resulting from the SFC process would be, for Minneapolis, about \$6.00 per month or \$72.00 per year at current rates (Kando, 1989). For an extra \$20,000,

SFC houses built to Swedish standards would save twice that amount or \$12.00 per month (Kando, 1989). As an investment decision, the cost of gaining this extra energy efficiency is not worthwhile: the cost per month for an additional \$20,000 of house is about \$190.

Of course not all of this cost is associated with only energy saving technology. A more detailed analysis of the costs associated with energy conserving technology in SFC housing and the impact on energy savings and affordability is clearly warranted. At the present time we could not find any comparative analysis of a typical U.S. HUD code manufactured house and and SFC house. Clearly, the costs for a HUD code manufactured house would be considerably less and energy performance would be comparably inferior.

5.4 TOWARDS 21st CENTURY MANUFACTURING:

**The GE Plastics Panelizing Plant for the Future A. Elshennawy,
W. Swart, S. Chandra**

Introduction

This chapter is a summary of the work performed which was partially funded by GE Plastics. Full details may be found in Elshennawy, Swart, et al. (1989).

General Electric Company's Plastics Division in Pittsfield, Massachusetts has developed prototype engineered plastic based foundation, floor, wall, and roof panels for a 21st century home. Conceptually, these large (40 ft. x 10 ft.) multifunction insulated panels made of recyclable plastics and other materials would be produced at a few centralized plants using different molding and forming technologies and shipped to panelized plants throughout the country. These panelizing plants would cut the large panels, install doors and windows, and ship them to the building site. Conceptual design of the manufacturing facility for producing such panels was developed by the Department of Industrial Engineering and Management Systems at the University of Central Florida. The facility provides a basic array of manufacturing systems and equipments. It includes several types of modern automated construction machines, such as numerical control cutting machines, automated material handling equipment, and a variety of industrial robots to tend the machines and to perform different operations. The entire facility is operated under computer control using advanced control and sensory systems.

Goals of developing such facility are:

1. to supply the American building industry with a new way of manufacturing homes with high

- quality and improved durability,
- 2. to encourage the modernization of the American building industry by providing the necessary technology and information based on a new generation of automation and manufacturing systems, and
- 3. to introduce new materials for the manufacture of industrialized housing.

The proposed factory layout satisfies GE's requirements within the boundary conditions imposed by:

1. The nature of material to be processed:
 - Physical configurations and chemical properties.
 - Size and corresponding weight.
2. The manufacturing processes required:
 - Sawing / Cutting
 - Drilling / Milling / Routing
 - Welding / joining / inserting
 - Assembly
3. Production Rates
4. Material Handling
5. Capital Equipment and Cost
6. Capabilities of the Raw Material Suppliers
7. Customer Needs
8. Existing as well as future advances in manufacturing technology

Production rates were the first requirement assessed in the design and development process for the factory. Given GE's specifications of 2600 houses per year as required output, along with other specifications for panel types, quantities, and sizes for each of four different house, it was determined that the factory would need to be capable of processing 1000 panels per day. This was a worst case estimate on exclusive production of 2500 sq. ft. houses.

The desire for a compact factory layout then triggered the assumption that the facility would operate for three shifts per day. Assuming two assembly lines; one assembly line is used for the production of exterior and interior wall panels while the second line is used for the production of roof, floor, and foundation panels, it was apparent that each line would require a capacity of 20 panels/line/hour.

Functional Tasks

Functional tasks associated with the operation of the facility are: information preparation and handling,

computer- aided manufacturing, and shop floor operations. As soon as customer requirements and specifications have been defined, the task of information preparation and handling starts. Computer- aided design generates architectural and structural drawings as well as a bill of materials. Such output is then translated into information that can be used by computer aided manufacturing equipment including NC (numerically controlled) machines and robots. Such information defines event sequence for the different operations, assign tasks to machines and robots, and directs the motion of tools for different operations in the shop floor.

The flow of information described above is depicted in Figure 5.4-1 which also shows that such tasks are executed in three different areas in the factory: sales and marketing, design and product engineering, and factory operations.

Information Preparation and Handling

Building an automated facility like this involves equally important tasks of information preparation and transforming the customer's requirements for a particular house into the production control data needed to manufacture that house.

Information and preparation tasks include designing the house, determining which materials and tools are necessary, developing the process plans that detail how the house is to be made, and generating the numerical control programs that instruct the robots and machines to actually make the house. Of equal importance is plans' verification to insure that design meets manufacturability and safety requirements.

Figure 5.4-1 Information Flow

Computer Aided Design

This is the actual start of the process. Once a house is designed, all of the information necessary to manufacture its components should be made in a standard, computer-readable format so that it can be used by other elements of the factory's control systems. Such information include architectural and structural drawings, material specifications and process/machine/tool selection.

Material Requirement Planning

Based on the output information from the computer-aid design phase, a computer-generated bill of materials is issued to suppliers that define material specification, quantity, building material (blanks) and industrial components (windows and doors). Building material for the factory are roof, wall, floor, and foundation "blanks", i.e. large segments which are structural in themselves. The quantity of material required is dependent on the customer specifications and requirements. The factory is capable of producing four different types of homes: A, B, C, and D which have different sizes and component parameters including the number and length range of panels for interior walls, exterior walls, roof, floor, and foundation panels, as shown in Table 5.4-1. Blanks are received in a 40 ft. x 10 ft. size with different thicknesses as also shown in Table 5.4-1.

Component Parameters for Different Homes

Home Type	Floor Size sq. ft.	Int. Wall # L.R.*	Ext. Wall # L.R.	Roof/Floor # L.R.	Foundation # L.R.
Type A	1000-1200	18 2-18'	6 2-40'	10 4-16'	6 2-40
B	1201-1600	24 2-24	12 2-40	14 4-18	12 2-40
C	1601-2000	28 2-24	16 2-40	18 4-20	12 2-40
D	2001-2500	30 2-30	18 2-40	20 4-20	12 2-40
Thickness		4"	5"	8"	7"

* L.R. = Length Range

TABLE 5.4-1

Process Plans

Such Plans detail the actual steps in a proper sequence that are required to produce a house (or component). In the factory, these plans - generated by computers - include: routing slips which are used to schedule the movement of materials into assigned workstations, operation sheets which detail the sequence of events for each workstation, and instruction forms which directs the tool through the motions required to perform the task/operation. The routing slips, operation sheets, and instruction forms are electronically transmitted to machine and robot controllers via computer terminals.

Computer-Aided Manufacturing

The concept for factory control assumes that it will be possible that both the hardware and software of automation are compatible and easily integrated with new and advanced products as they become available. This may not be true today, but continuous advances in technology will help make it possible tomorrow.

The control system receives orders from a computer terminal, defines the necessary resource, and then schedules, coordinates and monitors the activities of the workstations required to manufacture the components (panels).

The factory layout shown in Figure 5.4-2 has two production lines. Panels will move vertically using an overhead conveyor system to a position where machines and robots will perform required operations at different workstations.

Figure 5.4-2
Plan of Factory Layout

Figure 5.4-3
Handling Incoming Materials

The Production Process

Material Arrival and Unloading:

Building material (blanks) and other components (windows, doors) will be shipped to the factory in containers. Roofs, foundation, and floor panels will be manufactured in one production line, while exterior and interior walls will be manufactured in another production line. Containers will be unloaded from the trucks and placed on a rail system that moves towards the entrance of each production line. As the container is emptied, it will move into a position where a tractor will pull it to the shipping area to be loaded with finished panels and another container moves in for unloading. This scenario is depicted schematically in Figure 5.4-3.

Material Handling:

Individual blanks will be moved to the production line using the overhead conveyor system. The conveyor is composed of carriers (or engagers) that will move into matching slots inserted on top of the

blanks causing them to move along the different workstations as shown in Figure 5.4-4a. The overhead conveyor system consists of a structured beam track from which a powered conveyor chain is suspended and an unpowered trolley that contains the carriers (engagers) is attached (Figure 5.4-4b).

Recycle Material Disposal:

A conveyor is used for handling scrap for recycling. Two conveyor stations are used for this purpose. The conveyors are located near the detail cutting workstations (see Figure 5.4-2) for both production lines. Scrap from the detail cutting process (e.g. door and window openings) is loaded onto the conveyor using a robot. The scrap material goes from the conveyor to a recycling area.

Figure 5.4-4
Panel Handling and Movement

Workstation Scenario:

At each workstation, a robot or a machine controller receives information from a computer terminal that includes instruction sets, operation sheets, and routing slips. A signal is passed to the machine controller from the previous workstation after its operation will have been completed. The previous workstation also sends a signal to the overhead conveyor to move the panel to the next workstation. A sensor at the beginning of each workstation detects the panel arrival and passes such information to the robot/machine controller. The robot/machine will then to perform the operation. This scenario is shown in Figure 5.4-5.

Figure 5.4-5
Information Transformation for Work Stations

Panel Support:

At each workstation, three important events take place:

1. **Laser Bar-Code Scanners** -- The bar code scanners are located near the end of each workstation. They read labels on the panels as they move into the workstation as a check to make sure that the conveyor is carrying the proper panel.
2. As the panel moves into a workstation, a sensor is sending signals to the machines and robots in the workstation to get ready for operation. As soon as the panel stops, robots and machines start their tasks according to the set of instructions sent by the control system computers. After all tasks are complete, the panel starts moving again to the next workstation for other operations.
3. **Panel Support** -- When the panel stops at each workstation, a hydraulically-activated support system moves to support the panel during operations. The system consists of a number of hydraulic cylinders located at both sides of each production line.

Workstations Description:

The following is a brief description for each of the workstations in the factory.

Rough Cutting Workstation

Rough cutting is performed by a numerically controlled radial sawing machine. One machine would be employed for each production line where straight cuts as well as angular cuts may be performed as necessary. As shown in Figure 5.4-6, when the panel stops at the rough cutting workstation, the sawing machine moves to cut the panel as instructed by its controller.

(Top View)

Figure 5.4-6
Rough Cutting Work Station: Front view
(upper) and Top view (lower).

Detail Cutting Workstation

Water jet machining was selected as the means of achieving precise cuts (including drilling) in the panel. Although cutting rates for this process are relatively low, it is predicted that future advances in this area will make higher rates possible. The detail cutting is performed by a robot carrying a nozzle connected to the water jet machine with a hose. The robot is of cartesian configuration. Once the panel stops, the robot nozzle will start operation at a position defined in the instruction sheet sent to the robot controller. After the cut is complete, the panel advances to the next station. The robot moves on a track that is long enough to perform more than one cut in each panel, if required. Figure 5.4-7 show a schematic top view of the workstation layout.

**Figure 5.4-7 Detail Cutting Workstation
(top view)**

Welding Workstation

As the panel comes from the detailed cutting station, a joining strip is installed at its side to allow joining different panels when necessary. The strip will be inserted into and clamped to surrounding material with the use of a gantry (overhead) robot. The strip will be welded into the panel with an ultrasonic welding device that will accomplish either spot welds or seam welds as necessary. After the weld is complete both robot and machine release panel to move on. Figure 5.4-8 shows the strip being welded to the panel after its insertion.

Figure 5.4-8 Ultrasonic Welding

Window/Door Installation Workstation

Windows and doors are provided in halves and must be snapped in from both sides of the panel. The windows and doors are brought into the assembly station loaded in magazines. These magazines will be lowered down at which point a robot will take the window or door out of the magazine. The robot will then turn to the panel and insert the window or door into the opening made at the previous detailed cut station. This is schematically shown in Figure 5.4-9. These windows or doors will be snapped into holes in a clamshell fashion. Both halves will be installed simultaneously.

Figure 5.4-9 Window Installation

Staffing Analysis

Operation of the facility requires 10 workers whose responsibilities are mainly supervision, inspection, maintenance, and control. The primary location for each of these individuals is shown in the plant layout in Figure 5.4-2. Table II shows the different tasks or responsibilities and the number of workers or supervisors required.

<u>Task(s)</u>	<u>Location/Layout</u>	<u>#</u>
<ul style="list-style-type: none">• Supervise unloading of incoming material for each production line.• Visually inspect for defects in material.	A	1
<ul style="list-style-type: none">• Supervise recycle conveyor operation.• Supervise overhead conveyor branch for out-of-size panels.• Record any defects observed in rejected panels (if any).	B (one/line)	2
<ul style="list-style-type: none">• Supervise rough cutting workstations.• Supervise detail cutting workstations.• Observe any failures.	C	1
<ul style="list-style-type: none">• Supervise welding/inserting workstations	D	1
<ul style="list-style-type: none">• Supervise window/door installation workstation.	E	1
<ul style="list-style-type: none">• Final inspection before shipping.	F	1
<ul style="list-style-type: none">• Supervise shipping area.	G	1
<ul style="list-style-type: none">• Maintenance/Service.	H	1
<ul style="list-style-type: none">• Control room operations.• Observe any computer failures.• Observe any error messages.	I	1
Total Manpower Required		10

TABLE 5.4-2 Manpower Assignment

Conclusions

The report provides a brief description of the development effort of a concept for an automated facility building the 21st century homes using new materials which are to be introduced by General Electric Company in Pittsfield, Massachusetts.

The facility provides a new application of robots and automation in construction and industrialized housing manufacturing industry. It is fully automated and machines and robots as well as material handling systems are computer- controlled using an advanced control system. Employment of robots and machines for such operations as cutting, drilling, and welding is not new. What is new is the application of such technologies in an environment where the material size and characteristics as well as the nature of operations and working conditions are different from other manufacturing systems.

In summary, the report presented a procedure for developing a concept for an automated facility for the industrialized housing manufacturing industry.

5.5 EMERGING COMPONENTS AND SUBSYSTEMS

B. McGinn

5.5.1 Overview

A study of emerging components in energy efficient industrialized housing in the U.S. would generally need to address three distinct areas:

- existing foreign technology with potential innovation diffusion to the U.S. market
- U.S. and foreign innovative components on the market but in limited use that exhibit potential for a greater market share
- emerging component conceptual design and prototype development

The NAHB "Advanced Housing Technology Program" (NAHB, 1989) is focussing on the first two areas, so in an effort to avoid redundancy, this study will concentrate on the last area above.

5.5.2 Scope of Study

Four general areas of the construction process will be examined for innovative component research; the envelope, windows, mechanical systems and electrical systems. A list of components to be considered under these headings follows:

Windows

- development of high-R windows(6-10), windows with durable low emittance coatings to replace sputtered silver, and optical switching materials

Envelope

- glass fibre reinforced cement (grc) panels and products
- magnesium oxyphosphate cement-bonded wood products
- plastic envelope components

Mechanical Systems

- advanced heat pump
- integrated heat pump
- sterling engine heat pump
- residential gas turbine generator set
- heat recovery ventilators

Electrical Systems

- NAHB smart house
- grid-interface photovoltaic systems

5.5.3 Technology Diffusion

A study of emerging components requires a common basis for their fair comparison as well as deeper insight into what factors encourage and impede the adoption of innovative new industrialized components. Technology diffusion, a term used to describe how new innovations are absorbed into the market place, will provide the necessary comparative framework to assess the likelihood of successful adoption of various components by the residential construction industry.

5.5.4 Emerging Components

Windows

Lawrence Berkeley Laboratory's Windows and Daylighting Group, part of the Windows and Lighting Program, are developing the technical basis for the understanding and improving the energy related performance of windows. This goal is dispersed among the three major research areas; Optical Materials, Fenestration and Building Applications and Design Tools.

The thrust in the Optical Materials research area is to develop and introduce new glazing materials for energy performance. This directly translates to new and improved fenestration components for the industrialized housing industry. They made an significant contribution to the field in 1976 with the

development of low-E coatings for windows. They are searching for durable low emittance coatings to replace the existing sputtered silver coatings which tend to agglomerate with a loss of optical quality. Currently the most promising new coatings are titanium nitrate and diamond-like coatings.

An Optical switching material will allow a window to dynamically regulate the transmission of incident solar energy. In a simplified sense, it operates as a battery -- with an application of a low voltage, ions are deposited on an anodic coating through an electrolyte, which changes the transmittance of the substrate glass. They are presently working to improve the electrochromic nickel hydroxide coating through ion storage and a polymer electrolyte.

The group is continuing their work on a high-R window(6-10), (Arasteh, Selkowitz, Wolfe, 1989). It is modeled on a conventional triple pane window with two low-E coatings placed on surfaces facing each of two krypton-filled gaps. In collaboration with industry, several prototypes are being fabricated and will be tested in situ by the Mobile Window Thermal Test(MoWiTT) facility. The search continues for ways to minimize thermal bridging at the window edge. Vacuum sealed units with the glass itself bonded around the edge is one interesting possibility.

Envelope

Glass fibre reinforced cement (grc) is a fairly new composite building material that is lending itself to innovative new cladding, sheeting, and roofing systems. Special additives to the Silicate glassfibres, including up to 20wt% zirconium dioxide, has conferred a degree of alkali-resistance to withstand the highly alkaine environment of hydrated cements.

In the U.K. grc is not approved as structural material. There is a sophisticated treatment of fixings, edge treatments, and jointing of grc cladding panels to allow their free movement on the structural framework. The panels may be either single skin or sandwich construction with an insulated core. With the use of color additives and creative surface texturing, grc panels have been used to great effect in housing projects in the U.K. and Denmark. Flat and corrugated sheets of grc are being used as substitute for asbestos sheeting for roofing and special applications. Another interesting application is the use of grc for roofing 'slates' (BRE DIGEST, April, 1988).

A good deal of research interest is presently being directed at the production of mineral-bonded building products. A promising material for envelope components in this field is the magnesium oxyphosphate bonding of wood fibres and fibrous materials. The reaction of dead burned

magnesium oxide, a steel smelting waste, with ammonium polyphosphate results in a dense and hard refractory cementitious magnesium oxyphosphate solid. This cement has a high compressive strength, cures rapidly (10 minutes), and will tolerate a high quantity of wood particles as aggregate. (Fazner, 1989) In addition, the wood particles do not need to be pre-treated as in other mineral-bonded materials utilizing Portland cement. Products made from this new cement would enjoy high fire resistance, low thermal conductivity, water resistance, dimensional stability, and fungal and insect resistance.

The rapid curing time of this material would also allow spray applications for the fireproofing of flammable envelope components, such as the emerging plastic panel and block systems. This mixture could also be extruded for the manufacture of hollow building blocks of an interlocking design.

As alluded to above, a number of plastic component envelope systems have been developed and are in the prototype stage. One system is the Ener-G Block, a closed cell polyurethane interlocking block which provides an insulating value of 31. Through the use of specially formed lintel and header blocks, a reinforced concrete frame, acting as the structure, can be incorporated into the plastic block wall (Ener-G Corp., 1989). GE Plastics The Living Environments Program has initiated the design and prototype of an entirely plastic house. This innovative design includes plastic composite load-bearing sandwich panels with integral radiant heating devices, a plastic 'leave-behind' form system for basement walls, and plastic composite lightweight roof panels with a clip-on shingle system (GE Plastics, 1989).

A Willamette Valley, Oregon, grass seed farmer has developed a resin-bonded ryegrass-straw building panel called Meadowood. His manually operated prototype production equipment is capable of pressing 4'x8' straw panels whose mechanical properties appear to be superior to particle and wafer boards. The product's high formability into structural shapes or ribbed sheets increases its potential as a panelized industrialized housing component (Plant Visit, July, 1989).

Mechanical Systems

In 1981 the Electric Power Research Institute (EPRI) proposed a set of design goals for an advanced air source heat pump, which included a 30 percent increase in heating performance, demand limiting controls, and the incorporation of other energy-intensive household functions such as domestic water heating. (Petersen, 1989) This last goal shows great promise for the following reasons:

- hot water can be generated with little or no extra cost during space cooling periods, with a corresponding reduction in electricity demand
- the heat pumps heating capacity, underutilized most of the year, can be harnessed

-the advanced heat pump's higher coefficient of performance(COP) will provide higher heating capacity, making this option more attractive

Intelligent controls would be needed to generate household hot water requirements outside of utility peak demand periods to achieve optimal savings. This control system would also modulate a variable speed compressor to accurately follow the load as well as to anticipate load requirements in order to avoid bringing on auxiliary resistance heating.

The National Institute of Standards and Technology(NIST) has developed an economic analysis program for advanced heat pumps called HPEAK(HeatPump/Economic Analysis of Kilowatt-hours). Through a comparison to conventional heat pump systems in five U.S. locations, it was found that advanced heat pump systems had the potential to reduce kilowatt-hour consumption for space heating/cooling and water heating by 20 percent in northern areas and 40 percent in southern areas. On an estimated \$2000 premium for an advanced heat pump system, the life cycle cost analysis yielded a discounted payback period of seven to eight years.(Petersen, 1989)

The advanced heat pump system outlined above is an adaptive innovation that is similar enough to existing systems not to suffer significant trade resistance. Because the average homeowner keeps their home for an average of three years, there is little relative advantage to an investment whose payback is seven years. The cost of these units will have to decrease or utilities will have to offer incentives in order for these units to gain acceptance in the marketplace. Trane (Ener-G Corp., 1989) and Carrier are both developing prototypical advanced heat pump units.

A mechanical system integrating heating, cooling, ventilation, domestic hot water, and grey water heat recovery has been developed through the Advanced House Demonstration Project, funded in large part by Energy, Mines, and Resources Canada. The system is based on a liquid-to-liquid heat pump connected on the heating side to an integral domestic hot water tank and on the cooling side to a remote thermal storage tank. Also integral to the heat pump module is a house air fan coil unit and an exhaust air fan coil unit. Heat is delivered to the hot water storage tank by the exhaust air fan coil unit(recovering waste heat from the space) and the grey water heat exchanger. On a demand for heat, the heat pump operates, heating the hot water in the DHW tank and cooling the storage tank.(fig. 5.5-1)

Domestic hot water is supplied directly from the DHW tank, which is also circulated through the house fan coil unit for warm air distribution. Cold brine from the thermal storage tank is circulated through the cooling coil in the house fan coil for cooling. Air is supplied from registers located higher up on inside partitions in order to accommodate shorter duct runs as well as efficiently distribute

warm and cool air. It is expected that this system will use only 42 percent (7057 KWh) of the purchased energy of a conventional furnace/central air conditioner system(16,486 KWh). (Scott, 1989)

Figure 5.5-1, Integrator (source: Scott, 1989)

Figure 5.5-2 Heat Pump Compressor Assembly

(source: Ackerman, 1988)

Even though this is an adaptive innovation, it's perceived complicity is a market risk to the builder and a financial risk to the consumer. Fortunately in this case it is strongly supported by Energy, Mines and Resources Canada, Ontario Hydro and The Fram Building Group, who are the largest builder of R-2000 homes in Ontario.

The current intense competition between the electric and gas utilities for the heat pump market share has spawned numerous fundamental innovations. Two intriguing examples are a Stirling engine driven heat pump and the development of a residential gas turbine generator set with heat reclaim for heating and cooling applications. Engines based on the Sterling cycle have seen very little application to date, mainly because of the difficulties in approaching the cycle's isothermal (constant temperature) compression and expansion processes. Internal heat exchange between these processes is necessary but difficult on a residential scale. Oak Ridge National Laboratory, in concert with the Gas Research Institute and Lennox Industries, have successfully developed a Free-Piston Sterling Engine Heat Pump (Ackermann, 1988). The heat pump's natural gas combustor provides the necessary heat input for the free piston Sterling Engine, operating on a sterling cycle with helium as the working fluid, to displace the engine diaphragm (Figure 5.5-2). This diaphragm displacement sets up a pressure wave within the hydraulic transmission which, acting against the gas spring at the bottom of the machine, powers the standard Rankine refrigerant compressor (Figure 5.5-3).

Figure 5.5-3, Sterling Engine Hydraulic Transmission

source: Ackerman, 1988

A residential gas turbine power plant, engineered for a low number of components has been invented. The centrifugal compressor is driven by a centripetal turbine on a common shaft.. An AC generator is then driven by the shaft. The system also has the necessary engine exhaust heat reclaim apparatus to operate a boiler and/or an absorption cooler (Reynolds, 1989). Industry adoption of the above innovations is fraught with difficulty because of their complexity and unfamiliarity to builder and cosummer alike. If relative advantage over conventional systems can be established and prudent marketing strategy adopted, such as free trials and handling by a recognized distributor, both products could be successful.

Higher residential ventilation rates, to contend with demands for improved indoor air quality, has brought about a need for heat recovery ventilators. An interesting model is the Saskatchewan-made Van-E (Conservation Energy Systems, 1989) which comes complete with integral controls to activate a defrost cycle. The emphasis on increased ventilation in the popular R-2000 program in Canada has helped this product.

Electrical

The heart of the NAHB Smart House project is a revolutionary microprocessor based residential wiring system which facilitates communication with 'smart' appliances to achieve optimal energy use and comfort. With significant industry participation, several prototypical Smart Houses are presently being built.

A good deal of research is presently being directed at developing affordable electrical switchgear to interface residential photovoltaic system generated DC voltage to the AC voltage electrical grid. This would allow the PV system, operating as the primary source of residential power, to draw on the grid as an auxillary source. Some of the intriguing PV components emerging on the Japanese market are Sanyo's PV integrated windows and roof tiles.

These fundamental electrical innovations will likely suffer a slow pace of adoption because of their perceived complexity.

6.0 COMPUTERIZED DESIGN AND EVALUATION TOOLS

INTRODUCTION

This section has three parts: 6.1 - An evaluation of computerized tools used by industrialized housing manufacturers, 6.2 - An analysis of the energy decision making process in industrialized housing, and 6.3 - An explanation of a prototype design tool under development. The first section reviews the methodology we used to collect data, outlines a taxonomy for categorizing software, and discusses software use in the U.S. and Japan. Section 6.2 discusses who makes energy related decisions as a means of determining how software should be configured to meet these decision makers needs.

6.1 EVALUATION OF COOMPUTERIZED TOOLS USED BY INDUSTRIALIZED HOUSING MANUFACTURERS

G.Z. Brown, M. McDonald

"The recognized decline in the productivity of many U.S. companies over the past 15 years has been a strong stimulant for individual companies to search for ways to improve their operational efficiency and to become more competitive in the market place." (Flatau, p. 60). This phenomena is mirrored in the industrialized housing industry where computer usage is on the increase as manufacturers look for ways to give their product the competitive edge.

There is a multitude of software packages on the market for the general fields of architecture, building, construction, and manufacturing. Some of these software types have potential applications within the field of industrialized housing. Specifically, computer-aided design software is growing in popularity as housing manufacturers search for ways to sell customers on the flexibility, versatility, and efficiency of their products. Software that incorporates estimating, materials and resource planning, and material lists is also 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.

In the past, programs were written for a well-defined but limited purpose. This has resulted in a fairly large number of programs which solve individual problems without the ability to share data with other related programs. The focus of automation in manufacturing, and thus industrialized housing, is shifting to the problem of integration of computerized tasks, networking design, engineering, marketing, and manufacturing functions.

Methodology

Our methods involved examining the types of programs available to the general fields of architecture, construction, and manufacturing. Because little software has been developed specifically for industrialized housing, we considered what potential applications might carry over from these related fields. In examining specific software packages, input requirements, intended users of the software, output, and compatibility with other packages were considered in order to address the issue of software integration.

This information was collected from a variety of sources including software directories, industry and research publications, and product literature direct from the vendor.

Software Directories

Software directories provided an indicator of the wealth of software available for the industrialized housing and related fields. The National Association of Home Builders (NAHB) lists approximately one hundred pieces of software in eleven building related categories in their Software Catalogue for Home Builders (National Association of Home Builders, 1989). NAHB categories include: Accounting, Computer Graphics and Design, Engineering, Estimating, Financial Management, Home Control, Integrated Project and Construction Management, Miscellaneous Business Applications, Property Management, Sales and Marketing, and Scheduling.

The ASHRAE Computer Program Bibliography (Degelman, 1987) contains well over a hundred listings on available computer programs for Acoustics and vibrations; Building design; CAD/CAM; Duct design; Economic analysis; Energy analysis/simulation; Energy management and controls; Equipment sizing, selection and design; Fire protection; Heat transfer analysis; Heating/cooling load calculations; Lighting design and analysis; Piping design; Property calculations; Psychrometrics; Refrigeration; Solar systems; Specwriting; Weather data analysis; and other related applications. This information is available on floppy disk with on-line searching capabilities.

The International Energy Agency (IEA) in their Design Tool Survey (Rittleman and Ahmed, 1985) classifies energy related software according to machine or equipment required, building type applicability, phase of building design for which the tool is suitable, initial cost, operating costs, ease of use, range of building energy calculation application, calculation method used, type and number of inputs required, quality and quantity of output produced, and probable effect of the overall project cost. Over two hundred programs from twelve countries are given in this book.

The National Directory of Energy Software (Bureau of Governmental Research and Service, 1985)

lists 141 software packages under the headings of Thermal Performance/Solar Modeling, HVAC and Lighting System Analysis, Energy Accounting, and Miscellaneous.

A Software Guide for Architects and Designers (Bickford and Hillman, 1987) lists application software under numerous headings including CAD/CAM/CADD, database, drafting, engineering, numerical control/machine tool programming, and solid modeling/3D design.

The International Computer Graphics Directory (Collier, 1986) under the heading of Application Packages lists software in the following categories: architectural design, civil and structural design, computer aided design computer aided manufacturing, interior design, mechanical and engineering design, and numerical control.

Apple Computer, Inc., in their Apple Engineering/Scientific Solutions Guide (Apple Computer, 1988), lists fifty-six programs under the heading of Architecture, Engineering & Construction.

These directories were used to determine the extent of computerization in architecture, construction, and manufacturing fields. The directories also provided additional information on software identified during surveys and literature searches.

Literature Search

Books and articles were surveyed on computer-aided design (CAD), computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM), artificial intelligence, expert and ~~knowledge-based~~ systems. Subject headings in our literature search dealing with computers in building and architecture yielded additional information on software for specifications, cost estimating, structural, mechanical, and energy analysis, office management (accounting), material resource planning, project and facilities management. Finally, manufactured, prefabricated, and industrialized housing were joined as keywords with computers and several on-line computer databases were searched to determine current computer applications in the field but this provided no new information.

Interviews and Site Visits

The literature and software search provided baseline information which was used to survey industrialized housing manufacturers. Manufacturers and associations were contacted by telephone and interviewed regarding their experiences with and degree of automation. The preliminary survey was limited to the following:

Associations: California Institute of Manufactured Housing

Manufacturers: Shelter Systems Group, Skyline Homes, Poloron Homes, Wassau Homes, Ryland, Acorn Structures.

Trade Publications: Automated Builder Magazine (Don Carlson).

Site visits to manufacturing plants (Fleetwood and Western Insulfoam) supplemented this information and gave significant insights into the manufacturing process. Automation in these facilities is discussed later in this section.

A Software Taxonomy for the Building Industry

In the process of collecting this background data on computer usage in industrialized housing and related fields, a software taxonomy was developed to categorize a small number of distinct application types. The taxonomy gave us an overview of software development trends by indicating quantities of software in each of the categories.

Eight basic building/architectural software types were identified as being used in the building industry. These are: document preparation, data manipulation, reference data, graphic tools, analysis tools, manufacturing, integrated systems, and other systems.

Each category is further distinguished by a descriptor: generic or specific. "Generic" indicates general purpose software which is adaptable to a broad range of functions. "Specific" refers to a particular, limited application. (For example, "Specwriter" software may be used to create and edit specifications but not as a multi-purpose word processor.) Both types of software are in use for the industrialized housing industry.

A list of the categories and a brief description is given here.

1. **Document Preparation:** programs used for production of text documents (including text with illustrations) (e.g., word processors, specification writing programs);
2. **Data Manipulation:** programs used for input, computations, output display. (e.g., spreadsheets and database management);
3. **Reference Data:** data files containing graphic or alpha numeric technical information. (e.g., databases (climate data), symbol libraries (for CAD), subscriber networks);
4. **Graphic Tools:** programs for 2D/3D drawing-drafting-design-modeling;
5. **Analysis Tools:** programs used for structural, energy, finite element, and other forms of numerical analysis;
6. **Manufacturing:** programs used for CAM, numerical control;

7. **Integrated Systems:** programs which combine multiple uses (e.g., CAD/CAM/project management);
8. **Other Systems:** programs used for system overhead (e.g., modem software , terminal emulators, networking);

Software was inventoried in the quantities listed below.

	<u>Software Group</u>	<u># identified</u>
1)	Document Prep.	1
2)	Data Manipulation	6
3)	Reference Data	4
4)	Graphic Tools	30
5)	Analysis Tools	30
6)	Manufacturing	12
7)	Integrated Systems	3
8)	Other Systems	1

In addition to the eight basic building software types, an expanded taxonomy of energy software was also generated. This taxonomy includes the following categories:

1. **Algorithm Base** - steady state, thermal network, ASHRAE Degree Days, etc.
2. **Applications** - heating, cooling, lighting, thermal performance/solar modeling, HVAC, energy accounting, other;
3. **Loads, Energy Use** - component/zone/building, hour/day/month/season/year;
4. **Design Phase** - concept, schematic, development, post design, research;
5. **Output Report** - numeric graphic;
6. **Input Data** - location, building type and schedules, occupancy rates, building area, etc.;
7. **Output Data** - load determinants, type of load outputs, temperature;
8. **Documentation Format** - manual, Hypercard, video tape, cassette tape;
9. **Input Time** - days, hours, minutes;
10. **Typical Computer Response Time for Longest Operation** - days, hours, minutes, seconds;
11. **Intended Use** - architect, engineer, technician, research analyst, builder, home owner;
12. **Building Type to be Analyzed** - residential, commercial, large commercial;
13. **Form of Climate Data** - hourly data, average data, peak data;
14. **Hardware Required** - mainframe, minicomputer, microcomputer, hand calculator.

See Appendix for a complete a software bibliography by category.

Where Computerization Exists in Industrialized Housing in the U.S.

Computerization in industrialized housing began with engineering software tools. The first software penetrations into this industry were in 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. More recent developments include hot wire cutting of expanded polystyrene foam where an optical reader scans a (manual or computer drawn) template and simultaneously controls the movements of wire cutting instrument. In both of these examples, the computer is used as a number crunching, instruction processing tool accomplishing a specific task.

Manufacturers have begun to automate individual tasks in spite of the inability to data-share between them. A recent survey by Automated Builder magazine ("Top 100 Manufactured Home Dealers," June 1989) found that 61% of the top panelized producers had CAD capabilities with 24% of these also having CAM. Our survey of industry producers (including modular, mobile, and panelized) reached a similar conclusion; namely, that manufacturers are beginning to automate portions of their work especially in the areas of CAD/CAM. Most firms have some type of CAD package (or plan to implement CAD soon) and use the system for drafting not design. CAM capabilities is often just that-- a capability not yet implemented.

In our survey of software in use by the industrialized housing industry we identified the following:

THE PLAN: Ted Dasher and Associates, Birmingham, Alabama.

CAD/CAM software implemented for wall panel systems. This software allows the designer to input the building plan, perform some structural calculations (with the capability to import to a separate truss engineering package), generate fabrication drawings, cutting and batch lists, and sizing determinations. Data files can also be downloaded to **THE LIGHT** software which uses LED technology to determine exact locations of studs, cripples, headers, etc. in the wall panel framing. Light bars which appear on the wall panel machine replace manual methods of pattern marking.

ICG: Integrated Computer Graphics, Inc., Atlanta, Georgia.

CAD (including 3D renderings, color, and landscaping), estimating, engineering and costing, materials + resource planning, accounting, and job costing.

BorgCAD: Borgstrom Enterprises Ltd. and Structured Systems.
CAD/CAM system developed for industrialized housing industry based on Swedish software. In addition to drawing and engineering calculation capabilities, this software has bill of materials, materials + resource planning, and numeric control code generating features for computer driven manufacturing equipment.

TrusStar and TrusStar2, Trakstar: On-Line Data, Richardson, Texas.
TrusStar and TrusStar2 are integrated roof truss CAD/CAM software for micro-computers. This software performs automated splicing of truss chords, webbing of trusses, structural analysis, price quotations, and daily production reports. Data can be downloaded to other CAD programs and to Trakstar database management system.

Source, Layout System: Clary Corp., Grand Prairie, Texas.
Source is truss engineering software which also provides cutting, costing and pricing information. Source data shares with the Layout, a layout application program.

Trus-Calc: Alpine Engineered Products, Inc.
Truss design and analysis software.

Gang-Nail Systems: Gang-Nail Systems, Inc., Miami, Florida.
Truss design and analysis software which creates data ready for production.

Auto-Omni: Engineering Services Company, Rochester, MN.
Computer controlled saw that uses robotics to set up and move lumber through the cutting system. Auto-Omni accepts data from several truss design programs (Truswal, On-Line Data, Bernax, and Hydro Air).

Shortcut: Heuristics, Inc., Cos Cob, Connecticut.
Microcomputer program developed at Harwell Laboratory in the United Kingdom that uses mathematical methods to plan efficient production cuts for panel systems. Pricing information on sheets, set up, and cutting facilitate job costing.

Timberline, Housebuilder: Timberline Software Corp., Beaverton, Oregon. Integrated accounting, bid analysis, cost estimating, cut and fill, fixed assets, materials takeoff, and property management.

Profitbuilder: Construction Data Control, Inc.

Integrated accounting, building design and drafting, check writing, data management, estimating, job costing, materials takeoff, and spreadsheet interface.

We also identified a number of manufacturers who have been recognized for their automation efforts. These are:

Shelter Systems Group

Type: component producer

CAD: in-house software

CAM: in-house software

Energy software: n/a

Estimating: in-house software

Equipment: n/a

Other comments: Computers used for design and engineering, manufacturing, material + resource planning, and cost accounting. Time motion studies led SSG management to implement automation throughout company operations. This includes a manufacturing facility which employs the Auto-Omni computer controlled saw for automated panel production.

Source: telephone interview; article ("Component Industry's 'Idea Factory' Adds Growth and More Profitable Ideas," Automated Builder, June 1989, pp. 10-15).

Poloron Homes

Type: component producer

CAD: AutoCad AEC, in-house software

CAM: none

Energy software: none

Estimating: in-house software

Equipment: IBM System 36/Compaq 386 machines

Source: article ("Computers Key to Growth for Poloron Homes," Automated Builder, November 1988, pp.24-28)

Acorn Structures

Type: component producer

CAD: Palette, ADRA, VersaCAD

CAM: in conjunction w/VersaCAD

Energy software: Acorn Energy Analysis, CALPAS 3 & 4

Estimating: sales dept for pricing.

Equipment: DEC VAX, MicroVAX, NEC APC IV

Other comments: low level of automation

Source: telephone interview, site visit

Ryland

Type: component producer

CAD: AutoCad

CAM: none

Energy software: none

Estimating: MRP, Project Management Workbench.

Equipment: HP3000

Other comments: low level of automation

Source: telephone interview, site visit.

Wausau Homes

Type: component producer

CAD: ICG (Integrated Computer Graphics)

CAM: none

Energy software: none

Estimating: ICG

Equipment: IBM System 36

Other comments: none.

Source: telephone interview.

Fleetwood

Type: HUD code homes

CAD: Claris CAD (under consideration)

CAM: none

Energy software: none

Estimating: EXCEL spreadsheet program

Equipment: DEC, MacIntosh

Other comments: none.

Source: telephone interview, site visit.

Many of the manufacturers contacted had only recently begun to automate in the area of design and manufacturing due to the limited software available for their application and the cost of implementation (education and equipment).

Where Computerization Exists in Industrialized Housing in Japan

Of the four Japanese housing companies visited -- Sekisui Home, Sekisui Heim and Misawa were more completely computerized than any of the housing companies in the United States. All three companies claimed to be moving towards increasing levels of computerization.

Misawa has made three attempts at computerizing their sales, design and manufacturing operations. In 1974 they developed a CAD system on an IBM and Hitachi based on their free design (not one of their preplanned models) panel system. The system worked well but was very difficult to update as codes and specifications changed and fell into disuse. Their next attempt was based on the Japan/ARC CAD system and was for internal use to turn out drawings and specifications for their preplanned houses. It was unclear whether this system is still in use. The third system which is

currently in use and undergoing further development is based on a CAD system developed at Misawa. In its current form it operates on a PC with a hard drive. The sales person develops the plan on paper with the customer using sample plans and photographs. Once the design has been developed it is input, using a tablet and stylus, by the sales person (only one or two people are knowledgeable per office I suspect). The CAD system has a data base of Misawa products, therefore when a wall is created the computer knows the specs for the panels involved. The drawing sequence is 1) exterior walls, 2) interior walls, 3) openings, 4) built-in furnishings like kitchen cabinets and bathroom fixtures. The exterior walls are created just by clicking on the module (910 mm & 455 mm width) grid on the screen, using the stylus or the tablet (like a mouse) at each wall beginning and ending point. After that, interior rooms are created by clicking on the diagonal corners of the room and then the room type is selected from the tablet menu. Given a plan, the software will calculate the panel size (3'x6' or 8'x12' sizes) after the roof pitches and gable locations have been selected in roof plan. Once the drawing is complete the user then selects the finishes from three groups, using either the laser disk system, photographs, samples or a mix of these techniques. 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 the cost estimates for the customer. The dealer (privately owned) then mails invoices to Misawa. The system has been in use four years.

This system is being upgraded to the ZIP system which will transmit information directly from a 16 bit terminal at the dealer to a 32 bit terminal at the factory. The implication was that once the data was in the factory terminal it could be used directly in machine control. The system is being developed internally with consultants. The ZIP system is expected to be operational in one year.

Misawa used a laser disk system at its main dealerships to assist customers in selecting finishes and materials. They went to the laser disk after a hard connection to a main frame computer proved to be too slow. The main menu is 1) exterior, 2) interior, 3) products, 4) image video about Misawa life styles. There are submenus under each main menu item. For example, interior is divided into living room, Japanese room, children's room, kitchen, etc. Within each of these room categories there are images of interior spaces. The general system was developed by the Ministry of Construction with support from all manufacturers (8 disks). Misawa then went on and prepared two proprietary disks for its own use. The customers preferences are remembered and can be played back for final selection. If the dealer wants complete specifications on any product, a computer/fax combination queries the main frame at Misawa which returns the specs via fax to the dealer. The system has been in use for four years. Because it is expensive only the major dealers have the system. It wasn't clear how effective Misawa thought it was as a sales tool.

Sekisui House uses two different CAD systems -- one for use in the sales office and one for use in manufacturing. Currently, these systems don't transfer data to each other and the information they encode is similar but it isn't completely overlapping. For example, the sales system describes walls and their architectural location while the manufacturing system describes the components and panels which make up the wall and their location relative to each other but in an exploded view rather than architectural view. The computer operator in the sales office develops the CAD drawings from information developed during interviews with the customers. There is some manual checking of these drawings to be sure they conform to company component sizes and structural standards. The drawings are primarily a means of keeping track of customer decisions. They look like working drawings and aren't used to develop the design with the customer. Each sales office sends its drawings via floppy disk to the plant in their region. Not all sales offices are large enough to have their own CAD system. Those offices send conventional drawings to the manufacturing plant.

The manufacturing CAD group at the Osaka headquarters plant visited handled 16 sales offices and developed manufacturing drawings for 40-50 houses per day. The CAD system used at manufacturing was a UNISYS-CAD which was running on a UNIVAC 1180/70. The plotter was a D SCAN XP1000.

The drawings from the sales office are checked manually, additional design work performed, and prepared for the CAD operators. The CAD operators were not engineers or architects and were trained to operate the system in one to two months. The system had a special menu for Sekisui house components. As the operator develops the drawing, the screen displays the plan with information (size, material, etc.) off to the side about the component being worked on. The computer draws the foundation, perimeter, and slabs for porches based on the floor plan, and the operator adds secondary structural members. The computer also draws the elevations based on the plan. In order to change the window it must be done in plan. The computer also draws the roof, based on the plan, determining hips and calculating member lengths. It takes about one hour to input a house. The drawings are returned to the sales office for review. They are frequently changed as the customers refine their ideas about their house. Once the drawings are completed they are used to order materials and build the house. The data cannot be used directly for machine control.

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 in about a year. In the SEPIAS system, the 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, additional

engineering design performed and developed into manufacturing drawings. The step from architectural (sales) drawings to manufacturing drawings is expected to be highly automated. These drawings are used to order factory raw materials and components. 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 given to accounting and shipping. Some aspects of the SEPIAS system are currently operating.

Sekisui Heim, like Sekisui House, uses two CAD systems -- one for sales and one for manufacturing. The sales CAD system runs on a PC and is used to transfer data to the factory, and as a sales aid. At each sales office or model home there is only one person qualified to operate the CAD system. In the sales area, the CAD system was used to draw perspectives of the house from the floor plan that had been developed with the customer. The drawings are sent to the factory where they are redrawn in a form useful for manufacturing.

The manufacturing CAD system is McDonnell Douglas GDS 4.3 which runs on a DEC mainframe with Techtronix terminals. Sekisui Heim is also working on a system which integrates sales and manufacturing. The system is expected to be fairly intelligent in its ability to generate manufacturing information from sales drawings. This system is expected to be operational in one year.

Contrary to the literature and folklore, I didn't see any computer systems that developed manufacturing data at the sales office. I also didn't see any systems that integrated structural design or energy design with drawings produced by the CAD system. Energy analysis programs seem to be receiving minor use.

There is some academic work going on in computing systems for industrialized housing. Professor Watanabe at Waseda University is developing an AI-CAD system and demonstrated a prototype. The system as it currently stands will design a room based on a simple rectangle drawn by the user. The system produced the walls, windows and structural system. The user can query the program about any element in the system (wall, door, window, etc.) and receive a description. Walls or other elements can be added or subtracted. The program runs on the Apple Macintosh, is programmed in Small Talk and displays multiple windows. The system would work well for industrialized systems that have a limited universe of parts.

There is an energy analysis program being developed at the Building Research Institute under the direction of Yuichiro Kodama. Passwork V.2.0 runs on the Apple Macintosh. It has an interface

which enables the user to manipulate a three dimensional image of a room (wall, floor, roof, and window locations and sizes) and secure an energy evaluation.

How Energy Software Fits Into Manufacturing Design Process

Survey information and site visits reinforced the notion that energy conservation was addressed at the building code level. That is, manufacturers designed first to minimum code standards with the customer options at an added cost. Only increased insulation was a noted customer add on when it came to increased energy efficiency. This is attributed to general increased public awareness about the effects of greater insulation.

Heat loss calculations were performed manually in some cases or with the aid of a spreadsheet program usually by a mechanical engineer. In any case, these methods typically deal with U(overall) and do not reflect on building performance on a detailed level.

Use of energy software (CALPAS) to measure thermal performance was sited in one case.

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R-control (Western Insulfoam) panels are a good example of a product which is marketed in terms of its energy efficiency and savings. The manufacturers of this product joined with the regional utility (Bonneville Power Administration) to promote use of the R-control panels in "Super Good Cents" homes. (Houses with the "Super Good Cents" rating have exceeded building code requirements and met the utilities own energy performance criteria.) R-control currently does not use energy software in their design or marketing of the roof and wall panel systems.

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Use of energy software (CALPAS) to measure thermal performance was sited in one case.

Barriers to Computerization

Manufactured housing producers encounter the same barriers as other industries switching to computer-aided design and manufacturing. These include high initial investment in equipment and training plus the added cost of maintaining skilled computer personnel. Manufacturers are concerned about the return on investment in software and hardware with limited scope and potential. The following quote summarizes this phenomenon: "CAD/CAM technology is equal to the task of fully automating the factory, but is rarely applied to an entire manufacturing facility. Management has yet to be convinced of the validity of the productivity improvement promises of the automation vendors. Computers are employed only in situations in which the short term benefits are measurable and are likely to be realized. This has resulted in the appearance of 'islands of automation,' in which individual processes are automated without concern for compatibility with one another." (Orr, pp. 153-154).

Yet another issue is the ability to coordinate the manufacturer's process with available software tools. "In considering the manufacturing enterprise, one is immediately confronted with the inconsistencies between the data that describe the product, the technology, or the know-how involved in the manufacturing processes, and the data used to describe the management or the business operation. At least three types of data sets are frequently used in an industrial enterprise. One data set is used in the CAD environment, another for process planning, and a third for manufacturing." (Flatau, p.61). No single software company offers manufacturers an integrated package which combines the product, manufacturing, and management information. Thus, many smaller software units that network with the aid of custom programming is the alternative.

Conclusion

The transition to automated design, engineering, marketing, and manufacturing is slowly occurring in industrialized housing. Manufacturers recognize the need to automate as a means to increase productivity, improve quality control, and speed up communications between the various phases of production and management. As the number of software tools developed for their specific needs grows, so will the industries willingness to accept automation. The following quote summarizes this point: "The U.S. construction industry has had a net loss of productivity of almost 3% a year since 1972. To reverse this trend, the industry must automate. Automation is no longer an issue of labor/management acceptance. It is required for survival." (Slocum, p. 133).

6.2 ANALYSIS OF THE ENERGY DECISION MAKING PROCESS IN INDUSTRIALIZED HOUSING

G. Z. Brown

We are in the process of analyzing how energy decisions are made. By identifying the nature of energy decisions, we pinpoint when key decisions are made and how they vary according to design and production types. Once the key decision points are identified, we can determine what computerized design tools are available to support these decisions and how they should be improved.

We looked at energy decision making from two perspectives: what design characteristics effect energy use and how different industrialized housing types structure energy decision making. We developed a two dimensional matrix as a method of isolating the interaction of the two perspectives as shown in Figure 6.2-1.

		Design characteristics which effect energy use					
		Site	Morphological	Fabric	Equipment	Construction	Operator
Industrialized Housing Type	HUD Code	Who makes the key decisions?		How do the key decisions vary according to production type?			
	Modular	How do the key decisions vary according to design type?			When are the key decisions made?		
	Panel	What computerized tools are available to support those decisions?					
	Production Builders	How should those computerized tools be improved?					

Figure 6.2-1

Along the horizontal axis are arrayed all the building design decisions which effect energy use. They are: site decisions - orientation, microclimate variation, cluster shading, etc.; morphological decisions - building size and shape; fabric decisions - insulation level, window type, mass type, etc.; equipment decisions - type, fuel choice; construction decisions - how actually built versus how designed; and operator/occupant decisions - thermostat setting, occupant schedules, operable elements. Along the vertical axis are the various industrialized production categories. Each production category will be elaborated by business type in a manner which reveals who makes energy decisions. For example, some panel manufacturers also build houses ("panel builders") that use their panels. These companies have more control over the insulation specifications for the panels than do companies which supply panels to other builders who dictate panel insulation specifications. For each cell the following questions are asked; who makes the energy decisions, when in the design

process is it made, what tools are used to make the energy decisions, what criteria are used to make the decision, who checks the decision and how easy is it to change an energy decision once it is made. For example, comparing a large HUD code producer to a panelized 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 which is made by the purchaser possibly in conjunction with the dealer. In the case of orientation of the unit, the manufacturer doesn't know in advance how it will be sited and therefore can't take advantage of 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 those that are orientation dependent like solar heating or summer shading. The panelized builder comparatively speaking has more control of the siting decision. For example, in the case of a spec house the builder makes the orientation decision him/herself. The implications for design tools for the HUD manufacturer might be that they should be directed at the dealer/customer (at least for siting issues) rather than the manufacturer. While the tools for the panelized builder might be directed at the manufacturer/builder with output that could be used as part of the sales process.

6.3 PROTOTYPE DESIGN TOOL: R-CONTROL PANEL G.Z. Brown, T. Sekiguchi

Energy Scheming with R-Control is a prototype program that incorporates R control stressed skin panels and other energy considerations into the design process. An important aspect of **Energy Scheming with R-Control** is that it allows selection of building materials with focus on R-Control panels as a way of investigating the program's application for industrialized housing manufacturers. The following **Graphic Overview of Energy Scheming with R-Control** is a road map of some of the capabilities of this prototype. Following the overview is an enlargement of each miniature screen and description of it. The instructions which accompany the arrows on the graphic overview explain what action is necessary in order to get to the next screen.

The **Energy Scheming with R-Control** is a prototype that is built onto a program which evaluates energy loss and gain in buildings called **Energy Scheming 1.0** which was funded by the University of Oregon Department of Architecture, the Bonneville Power Administration, the U.S. Department of Education, and Apple Computer Inc. It is a program that incorporates energy considerations in the earliest phases of the design process. The user interface is a "sketch pad" environment that has been designed to foster design activities rather than analysis and allows users to input a building by drawing it at any level of detail. It provides a schematic evaluation of the building's energy performance and an energy loads analysis for four representative days. Calculation algorithms are simplified, both to speed up the computer's response time and to

minimize the amount of specification the user must be burdened with. By seeing evaluations of their work frequently and easily, users may make preliminary decisions about a design idea and develop a familiarity with, and an intuition for, the effect of energy considerations on their design process.

Energy Scheming with R-Control contains all of these features plus it puts special emphasis on R-Control panels.

Possibilities for its use include aiding panel sales representatives and their customers in incorporating energy considerations as a result of material selection in the customization and design of buildings. Its output affects production, engineering, and inventory by creating material lists, working drawings, cutting lists, and production information. This program is the customers interface with an integrated system of computers in the panel manufacturing process.

Energy Scheming with R-Control runs on an Apple Macintosh SE or Macintosh II.

Graphic Overview of Energy Scheming with R-Control

1. Desktop

When you turn on your computer and put in the *Energy Scheming* disk, you should see this. To start up the program, **double-click on the Energy Scheming w/R-Control icon.**

2. Title

Click anywhere on the screen to continue.

3. Opening Screen with "grayed" palette

When you first enter the program, the drawing palette is grayed, and most of the menu is disabled. *Select New from the File menu.* The following series of three screens will appear (note: Open Building File... allows the user to recall a previously created screen and the following three screens can be skipped):

4. Climate Location

A map is used so that you can see in which climate zone your location occurs. The dots on the map identify R-Control factory locations. *Click on the radio button on the right of the screen to select a climate.* This loads the climate file the program will use for calculations. The SOLMET climate files have typical clear and cloudy days for each of 12 months. Click on OK to finish.

5. Building Size

Because it is sometimes difficult to imagine how big a building is just based on its floor area, a graphic scale of buildings is provided to help you imagine the relative size of your building. In the future a bar at the bottom of buildings will allow you to set the scale without typing. The program generates a building form based on the floor area and uses it to set defaults for wall area, etc. In the text box at the bottom of the screen, *type in the building size in square feet.*

6. Building Type

The building type you select here will determine much of the data in the default building data base. *Click on the radio button that corresponds most closely to your building's type.* In the future more building types will be added. Click on OK to finish.

7. Drawing Environment for a New File

The palette is now un-grayed, and a few more features have been added to the menu bar. Most of the drawing tools behave like those in common Macintosh paint programs. Exceptions: the pencil and eraser react to changes in line weight, the normal cursor extends the full height and width of the screen, and the circles always draw from the center. For a new file the screen is blank. The interface allows the user to input a building design graphically and includes several features that are specific to architectural drawing habits. Building designs can also be input via scanner. In some cases, an R-Control sales representative may take a portable scanner into the field to input drawings. Drawings can also be imported from other applications.

8. Drawing Screen in Draw Mode After Drawing Is Made

This schematic sketch is typical of the amount of detail that you need in order to perform an energy analysis with *Energy Scheming with R-Control*. At the top is a rendering of one of the elevations. It is used for developing a "feel" for the building design. Notice that the drawings may be rendered to unequal levels of detail and that the forms shown need not match perfectly between drawings.

9. Drawing Screen in Takeoff Mode

At any point in the design process the user may begin the energy evaluation process. The first step in the process is to select the "takeoff" palette. The takeoffs allow the user to identify graphically, using an object-based system, parts of the bit-map drawing that are needed for R-Control panels and energy analysis. To get to this screen, *Click on the icon behind the T-square at the top of the drawing palette*. The T-square will be replaced by a measuring tape icon, and the drawing palette will be replaced by the takeoff palette.

10. The Flat File Cabinet Menu

Now you are ready to start inputting information about the building such as R-Control panel walls. *Click on the file cabinet.* A menu will drop down with two categories of drawings. *Click on Elevations.* This will open the Elevations drawer in the flat file cabinet.

11. New Elevation Drawer

A flat file drawer for a new elevation now appears at the top left of the screen. To open it, *double-click on the New Elev. icon.*

12. New Drawing Dialog Box

Two dialog boxes will appear, one on top of the other. In the top one you need to specify orientation and name for this first elevation. *Click on the circle on the compass, to correspond to due west.* You will be given a default elevation name which you may change if you like. To change the name, *drag the cursor through the text box and type in a new name.* Click on OK to finish.

13. Drawing Specification Screen

The second screen of the New Drawing dialog box contains information--name and orientation--from the last dialog screen. You must also *select a scale*. Click in the Close Box when you are finished with this screen.

14. WestElevation Drawer

Now there is a second flat file drawer icon on the screen, and it is labeled West Elevation. *Double-click on the West Elevation Drawer icon* to display the three folders. The takeoff information that you can provide on elevation drawings define windows, roofs, and walls. *Double-click on the Wall folder* to begin specifying information about the west walls. *Double-click on the New Wall Spec icon*.

15. Window Specification

The orientation and solar zone designation have already been selected. Select ventilation type (in this case, cross-ventilation) and area (here, 10. s.f.). The selected takeoff pattern is a dotted one, and the pictures near the bottom of the screen show the current defaults for exterior shades, glazing, and interior shades.

16. Roof Specification

The Roof Specification is similar to the Window Specification in the way information is input. All specifications follow a similar pattern to make the programs easy to learn.

17. Wall Specification

All information about walls can be input using this screen. This screen also allows input of walls by panel size and number for R-Control panels. Characteristics of the wall or R-control panel can be selected by using the Wall Components pop-up menu which brings up the Select Wall Components screen (screen #19 or #20.) The takeoff pattern is a stripped one and changing it can help to distinguish the takeoff on the drawing screen.

18. Wall Takeoff Detail

To input area for this wall specification, *Click* on the small measuring tape icon on the takeoff palette (not the one at the top left of the screen) to takeoff rectangular areas or the polygon shaped icon with measuring tape (the icon above it) to takeoff polygonal areas then trace over the walls on the drawing. *Click on a new pattern* if you like. The wall's area will show up after the word Area. This screen shows, in magnification mode, the portion of the drawing screen where the wall area has been taken off. Notice that the takeoff has been broken up into smaller takeoffs which are the size of R-Control panels.

19. R-Control Panel Components

To get to this screen click on the R Control Panel pop-up selection and release mouse over words R Control Panel. For each "layer" in the wall, there is a list of characteristics that you may choose from. Click on the cells to change R Control Panel characteristics. Below are optional selections for mass type, and external color of walls. When you click on OK to complete this screen, the wall specification pictures will reflect the changes you have made here. Technical data related to these changes have also been changed in the building data base.

Exterior Finish	Exterior Sheathing	Core EPS	Interior Sheathing	Interior Finish
None	None	7/16"	None	7/16"
None	None	1/2"	None	7/16"
None	None	9/16"	None	9/16"
None	None	5/8"	None	5/8"
None	None	3/4"	None	3/4"

Ent. Color:

Mass:

Detailed Wall Design

20. Conventional Wall Components

To get to this screen click on the Select Window Components pop-up selection and release the mouse over the words Conventional Wall. Select wall components for conventional wall is similar to the previous screen for input of R Control Panel components.

Exterior	Structure	Cavity	Interior
Plaster	Metal Stud	Rigid Ins	Plaster
Plaster	Brick 4"	Ar	Plaster
Concrete 1"	Block 8"	None	Concrete 6"
Brick 4"	Concrete 6"	None	Brick 4"
Block 8"	None	10"	Block 0"
None	None	12"	None

Ent. Color:

Mass:

Detailed Wall Design

21. User Define Input Screen

If you want to define walls numerically you can input this information in this screen. You can get to this screen using the Detailed Wall Design button.

Name: Wood Stud Wall Type

Total R-value: 12.6

Log in Hours: 2

Decrement Factor: 0.82

Absorbtivity/Conductance: 0.22

Wall Components: R-Control Panel

22. Format Options

There are several format options under the Format menu. **Alignment Snap** forces takeoffs to be drawn in increments of various element sizes such as panel sizes for R Control walls. **Grid Visible** gives guide lines (same size as in the Alignment Snap.) **Takeoffs Visible** brings up a screen that lets you select which takeoffs are visible so you will see only pertinent takeoffs. **Hide Takeoff File Icon** removes the system of file icons from the screen. **Turn Magnetic Takeoffs On** joins takeoff when they are moved close together. **Group Takeoffs** allows the user to select more than one takeoff at one time so various operations can be performed on them at the same time.

23. Rule of Thumb Sizing Aid

Select **Sizing Aid** from the **Rule of Thumb** Menu. This screen shows how different elements are performing on a number of measures. *Click on the check box at the upper left, to select Wall Insulation.* Clicking in any of the seven check boxes makes them available for viewing. The heavy black bar shows how close to optimum (100%) you have come toward having enough insulation in the walls to minimize heat loss.

24. Energy Report Format Screen

From the **Design** menu select **Energy Summary** to get this screen and the summary calculations. *Click on the hours that you want to show up in the report then click OK.*

25. Energy Summary Report

The report gives summary information on the performance of the building, climate information, and a breakdown of all components in the building.

File Edit Search Format Font Size Transfer

Energy Scheming Disk 1:Report.fil

ENERGY FLOWS FOR TWO ROOM HOUSE

ANNUAL SUM

Type: Residential Madison, WI Area: 1000 Sq. Dec.

Hour	Mar	Jun	Sep	Dec
Midnight - 1 am	(Btuh) 3714	(Btuh) 11392	(Btuh) 8004	(Btuh) 5972
1 - 2 am	3488	11843	7778	6198
2 - 3 am	-1512	809	-452	-808
3 - 4 am	-1485	865	-507	-908
4 - 5 am	-1485	865	-563	-842
5 - 6 am	-1401	721	-619	-808
6 - 7 am	-1401	888	-507	-842
7 - 8 am	-1401	1000	-61	-842
8 - 9 am	-2289	0	-782	-1898
9 - 10 am	-2121	0	-558	-1842
10 - 11 am	-8130	0	-1807	-7452
11 - Noon	-8130	225	-1355	-7001
Noon - 1 pm	-8130	452	-903	-6773
1 - 2 pm	-8130	1129	-677	-6323
2 - 3 pm	-7904	903	-677	-5972

26. Materials Report Format Screen

From the Design menu select Materials Summary to get this screen. It lists all of the R-Control elements that you have taken off. Click on the element for which you want a working drawing then click Create a Working Drawing button.

File Edit Design Format Rule-of-Thumb Define

Materials Summary

ITEM	UNIT SIZE	QUANTITY	UNIT PRICE	LIST PRICE
WALL PANEL	4'x8'x5 5/8"	20	\$ 70.00	\$ 1400.00
CABLES AND BEAM	4'x10'x3 5/8"	10	\$ 85.00	\$ 850.00
ROOF	8'x12'x6"	20	\$ 95.00	\$ 1900.00
FLOOR PANELS	4'x10'x8' 3/12	40	\$ 98.00	\$ 3920.00
SEALANT/CHAULK	4'x8'x8"	40	\$ 110.00	\$ 4400.00
JOIST PLUGS	30ea.	30	\$.58	\$ 17.04
RING SHANKS	2x10	110	\$ 1.00	\$ 110.00
SPLINES	10"	40	\$.48	\$ 19.02
OTHER INSULFOAM	8"	40	\$.40	\$ 16.00
	10"	100	\$ 1.10	\$ 110.00
	8"	120	\$ 1.00	\$ 120.00
			TOTAL PRICE	\$12862.06

Create a Working Drawing

27. Working Drawing

This screen brings up a working drawing of the element you have selected in the previous screen (in this case a R-Control panel.) It gives information on size, quantity, and accompanying accessories (such as screws, glue, etc.)

7.0 ASSESSMENT OF ENERGY PERFORMANCE OF BASELINE AND ADVANCED INDUSTRIALIZED HOUSING CONCEPTS

This section describes FY89 research on three activities:

1. Side-by-Side Houses (Section 7.1): To document the cooling energy performance of today's industrialized housing systems to that of conventional 2 x 4 construction.
2. Artificial Sky (Section 7.2): To characterize illumination performance of prototype industrialized house designs.
3. Wind Tunnel (Section 7.3): To characterize the natural ventilation performance of prototype industrialized house models and subdivisions.

About 80% of the effort on these tasks went into construction of three small (approximately 200 sq ft) side-by-side structures at FSEC. One is a conventional 2 x 4 structure with R-11 wall and R-19 attic insulation with attics ventilated by ridge and soffit vents. This is the baseline structure. The next structure is a Styrofoam (R) sandwich panel. In this construction scheme wall and roof panels are made in the factory and shipped to the site. These precut panels are quickly assembled at the site. The panels were donated by DOW Chemical Company. They are very 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 is 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. They were selected because of the potential energy efficiency and low cost of this housing system. The manufacturer, like DOW is very interested in working with the project and have cost shared in the construction. There is space for a fourth steel-frame construction. However, the manufacturer went out of business. We will be seeking another steel-frame manufacturer in 1990.

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

7.1 SIDE BY SIDE HOUSE COMPARISONS J. Roland

L. Maxwell, S. Chandra,

7.1.1 Description of the Houses

Three innovative construction materials and techniques have been selected for testing. To test the energy efficiency of these construction systems, small test structures of approximately 200 square

feet each will be constructed for each of the materials. Further a fourth structure of conventional wood framed construction will be built as a basecase house to provide a comparison of their energy efficiency performance.

The three selected materials or systems are: (1) steel stud wall framing and truss assemblies which can lend itself to innovative erection and assembly techniques and devices that can allow for decreased construction time and labor costs which would increase affordability of a home. (2) a "Styrofoam" insulated and OSB sheathed panel by "Dow Chemical Co." which can potentially improve energy efficiency and decrease construction time and labor costs, and (3) a pre-fabricated polystyrene and concrete panel system for constructing geodesic dome homes created by American Ingenuity, Inc. which holds the potential for very energy efficient affordable housing.

All four houses are constructed as similar to each other as their construction systems will allow. They are approximately 200 square feet each, constructed with a 4" concrete floor slab over 2" of extruded polystyrene rigid insulation, ("Styrofoam" brand insulation by Dow Chemical Co.). These slabs sit atop a 100 ft. by 49 ft. by 4" thick existing concrete slab as shown in Figure 7.1.1-1 The rigid insulation functions as a thermal break to eliminate any ground coupling effects between the house slab and the existing concrete slab or the ground. Figure 7.1.1-2 provides the basic floor plan layout of a typical unit. Each house has one door with an observation window in it. The door is located on the north elevation of each unit to eliminate any direct solar gains through the door or window. All 4 houses have a 6000 btu air conditioner, and electric resistance heater, and one incandescent light fixture in each. Additionally, each house has a stucco exterior wall finish, shingle roofing, (except for the geodesic dome which requires no roofing), gypsum wall board interior wall finish, and vinyl flooring. Figure 7.1.1-3 indicates the configuration of a typical test house. In order to achieve maximum impacts of insolation on the exterior walls for testing purposes, potential wall shading is minimized by eliminating roof overhangs except for the minimum amount necessary to provide the soffit vents needed for proper attic ventilation.

Figure 7.1.1-1 Test Structures Layout Plan

Figure 7.1.1-2 Typical Test House Floor Plan

Figure 7.1.1-3 Typical Test House

The following is a more detailed description of each of the houses:

(a) The Basecase House consists of conventional 2x4 wood frame wall construction with pre-engineered wood trusses for the ceiling/roof structure. Figure 7.1.1-4 is a building section indicating the construction of the structure. Thermal insulation consists of R-11 kraft faced fiberglass batt insulation in the walls, and R-19 kraft faced fiberglass batts in the ceiling. The exterior wall sub-sheathing is 1/2" plywood, with Typar house wrap, and expanded metal lath and stucco on the exterior walls. The roof is 1/2" plywood decking with 15# felt and fiberglass/asphalt shingles. The interior walls and ceiling are 1/2" gypsum board. The ceiling is at 8' above the floor. Screened soffit vents are provided and a continuous "Ridge Shingle Vent" by AirVent Inc. is provided along the entire roof ridge. Figure 7.1.1-5 illustrates the actual basecase house at 80% completion.

**Figure 7.1.1-4 Base Case Structure Buildings Section
(2 x 4 Wood Framed)**

7.1.1-5 Base Case Structure (80% complete)

(b) The Steel Stud Frame House is identical to the basecase house except that the walls are framed with cold rolled 3 1/2" galvanized steel studs rather than the 2x4 wood studs. Also, the roof is framed with pre-engineered cold rolled steel stud framed roof trusses in lieu of wood trusses. Figure 7.1.1-6 provides a building section which indicates the construction of this structure. Other than the wall and roof framing, everything else is as described for the basecase house.

**Figure 7.1.1-6 Test Structure #2 Building Section
(Steel Stud Framed)**

(c) The Insulated Stress Skin Panel House walls and roof house are constructed of panels manufactured by Dow Chemical Company and consist of "Styrofoam" insulation sandwiched between 2 sheets of 1/2" oriented strand board sheathing. A building section in Figure 7.1.1-7 shows the construction of this structure. The wall panels have 3 1/2" thick "Styrofoam" insulation, and the roof panels have 5 1/2" thick "Styrofoam" insulation. The ceiling is vaulted in the house since the ceiling is the underside of the roof panel. The interior walls and ceiling have 1/2" gypsum board attached directly to the panels. The roof and the exterior walls are finished in the same manner as the basecase house. Figure 7.1.1-8 shows the actual Insulated Stress Skin Panel house at 80% completion.

**Figure 7.1.1-7 Test Structure #3 Building Section
(Insulated Stress Skin Panels)**

**Figure 7.1.1-8 Insulated Stress Skin Panel House
(81% complete)**

(d) The Geodesic Dome House consists of premanufactured panels of 7" thick polystyrene insulation with a thin exterior shell of fiber and steel mesh reinforced concrete. Figure 7.1.1-9 indicates the floor plan of the geodesic dome, and Figure 7.1.1-10 indicates the elevation of the structure. The panels are placed in their respective positions with the wire mesh of adjacent panels tied together, and a pre-formed void between the panels is filled with fiber reinforced concrete, as indicated in Figure 7.1.1-11. When completed, the exterior will have a continuous stucco finish on the walls and roof. The interior walls are covered with a plaster finish directly over the polystyrene insulation. Figure 7.1.1-12 shows the Geodesic Dome House at about 70% completion.

Figure 7.1.1-9 Test Structure #4 Floor Plan (Geodesic Dome)

FRONT ELEVATION

Figure 7.1.1-10 Geodesic Dome Elevation

SECTION VIEW

Figure 7.1.1-11 Geodesic Dome Section and Detail

Figure 7.1.1-12 Geodesic Dome (70% completion)

7.1.2 Description of Data Collection and Instrumentation

To facilitate data collection, a 386 based personal computer based data acquisition system will be utilized. Providing information to the computer will be a Campbell Scientific CR21XL Datalogger, connected to the computer through an automatic dial up system utilizing conventional telephone lines from the test site to the computer. In order to track and record weather conditions at the test site, a weather station is constructed with the appropriate weather data collection equipment. The test facilities and their data collection points is listed in the following outline.

Weather Station Data Collection:

- Wind Speed
- Wind Direction
- Solar Radiation (horizontal)
- Ambient Temperature
- Ambient RH

Total data points: 5

Test Structure No. 1 (Base Case):

- AC/heater KWH (manual)
- AC/Heater KW
- Internal load KWH (manual)
- Internal load KW
- AC outlet thermocouple
- A/C Latent (tipping rain gage)
- West Wall main section thermocouple (1)
- fluxmeter (1)
- West Wall at stud

- thermocouple (1)
 - Ceiling main section
 - thermocouple (1)
 - fluxmeter (1)
 - Ceiling at truss member
 - thermocouple (1)
 - fluxmeter (1)
 - Roof
 - thermocouple south side (1)
 - thermocouple north side (1)
 - Infiltration airflow
- Total data points: 17

Test Structure No.2 (Steel Stud):
Same as test structure no. 1

- AC/Heater KWH (manual)
 - AC/Heater KW
 - Internal load KWH (manual)
 - Internal Load KW
 - AC outlet thermocouple
 - A/C Latent (tipping rain gage)
 - West Wall main section
 - thermocouple (1)
 - fluxmeter (1)
 - West Wall at panel joint
 - thermocouple (1)
 - fluxmeter (1)
 - Ceiling main section
 - thermocouple (1)
 - fluxmeter (1)
 - Ceiling at panel joint
 - thermocouple (1)
 - fluxmeter (1)
 - Roof
 - thermocouple south side (1)
 - Infiltration airflow
- Total data points: 17

Test Structure No. 4 (Geodesic Dome):

- AC/Heater KW
 - Internal load KWH (manual)
 - Internal Load KW
 - AC outlet thermocouple
 - A/C Latent (tipping rain gage)
 - Ceiling main section
 - thermocouple (1)
 - fluxmeter (1)
 - Ceiling panel joint
 - thermocouple (1)
 - fluxmeter (1)
 - Infiltration airflow
- Total data points: 11

Total data collection points (sum of all structures): 67

In addition to the data collection listed above, infrared scans of each test structure will be utilized to visualize thermal gradients.

7.2 ARTIFICIAL SKY P. Ryan, G.Z. Brown

7.2.1 Purpose

The purpose of this project was to set up, test and calibrate the artificial sky and its associated data logging equipment so that users can test the light distribution in architectural models without detailed knowledge of the equipment employed. User familiarity with MacIntosh computers and Microsoft Excel was assumed, however, as a spreadsheet format was to be used in communication with the logging equipment.

7.2.2 Permanent Equipment

There are three major components to the artificial sky project: the artificial sky room ("sky"), a set of sensors to place inside the model under test, and data logging hardware/software to receive and tabulate data from the sensors in a useful way.

Artificial Sky

The sky is a room 72" wide, 96" deep and 76" high. The upper 52" of the sides are sheeted with 1/8" plexiglass mirror; the bottom 24" is carpeted with a medium brown loop carpet as is the floor. The ceiling is one sheet of 1/4" thick translucent white plastic. The reflectivity of the walls is approximately 83%, the transmittance of the ceiling is approximately 28%. Two switches control power to the sixteen fluorescent fixtures above the ceiling, each controlling every other fixture, so that uniform half maximum illumination can be achieved. Entry is through a wall-wide door on one end.

Sensors

LI-COR model LI-210-SZ sensors are used. According to the manufacturer these sensors are accurate to within 5% of an absolute standard (National Bureau of Standards), with repeatability of better than 1%.

Data Logging Equipment

The data logging system consists of an IDAC Model 1000 data logger connected to an Apple MacIntosh computer, and software packages which are used for data logger instruction files and communication. Microsoft Excel is used to create the primary instruction files, and resulting data files are generated in Excel format. The IDAC program "Macontrol" is used to communicate with the data logger during initialization and data collection, and handles storage of the data on the MacIntosh hard disk.

7.2.3 Tests, Calibration Procedures and Modifications

General Approach

The general procedure is as follows: First, check for data stability; run initial tests of the data throughput and accuracy (electronics) and establish the data train and calibrate the sky against the CIE standard overcast sky. When a suitable match is achieved, begin to make model tests and improve data handling methods by making refinements to the input and analysis templates. Finally, run models of known light distribution and evaluate the accuracy of the sky/logger combination in order to determine the accuracy of subsequent test results.

Initial Tests and Modifications -- Data Logger and Sensors

First data were plotted using the Microsoft Excel plot utility. A data cycle frequency attributed to line frequency oscillations in the fluorescent tubes was solved by averaging data samples over samples a sufficiently long time period to average out the oscillations. This averaging method resulted in stable, repeatable data to within 5%, so the problem was considered solved. Later refinements further reduced the repeatability error and brought the data into line with the project needs. (See the section on model tests.)

Multisensor Tests for Stability and Consistency

The Macontrol program allows a level of automation to be brought into the data collection process through the use of input templates for control of the acquisition process, and analysis templates for post-processing. Our analysis template accepts and stores data from several sensors, then turns control over to an analysis template which averages and processes the data, storing the result in a Microsoft Excel spreadsheet in both foot-candles and "daylight factors". A daylight factor is the percent of full sky luminance that a given "control" sensor sees. For most applications it is desirable to display the data in daylight factors, which simplify the calibration process since no absolute calibration is necessary.

Open sky tests were run with all ten sensors in order to check them against each other -- a consistency important in providing accurate daylight factors. From these consistency tests the transfer values for each sensor was adjusted to effectively recalibrate the sensors to their average.

Calibration Tests on the Sky

Comparing our artificial sky to the CIE standard requires performing point calibrations over the hemisphere with an accurate photometer -- in this case, a Tektronics.

It was evident that at 30 degrees low intensities were a problem in the corners of the sky room (azimuths 45, 135, 225, and 315), while higher, at 45 degrees, low intensities were a problem on

the sides (azimuth 0 and 180 degrees). In addition the horizon was dim according to the CIE standard, which states that the horizon should be 1/3 the brightness of the zenith.

Adjustments and Corrections Made to the Sky

For simplicity, the horizon problem was addressed first by brightening the horizon directly; adding a white surface up to an altitude where the brightness of our sky matched the brightness of the CIE sky. Photometer tests were again run and the results plotted for the main compass points as before. The result was favorable for brightness near the horizon, at least for a small aperture.

It appeared that the major factor responsible for the mid-altitude dimness was a dim band extending across the ends of the ceiling, as a result of the unlighted ends of the fluorescent tube fixtures. Two 6 foot fluorescent fixtures were installed across and below the ends of the existing fixtures. Data was taken over the hemisphere once again. The results were encouraging.

Model Tests and Final Adjustments

The first model tested was a square black cardboard cube three inches on a side with one small window and a three by three grid of sensors inside. Several tests were run, at eight evenly spaced azimuthal rotations around the sky room, using our automated data collection system. It was apparent that a problem existed: the center row sensors, which should list decreasing luminance with increasing distance from the window, were instead consistently reporting higher values at the rear than in the center.

In time the problem was traced to radiated electrical noise, and treated by shielding the sensor wiring. With further modifications of the analysis template, a complete and consistent data collection process was now in place.

During early tests we observed that data could be grouped by orientation into two groups: from tests on the primary compass points, 0, 90, 180, and 270 degrees azimuth, and from points midway between the primary points (45, 135 degrees, etc.). Using this rationale, each model was tested at two azimuthal orientations -- 0 and 45 degrees -- with the assumption that tests made at these orientations would be representative of the entire sky.

7.2.4 Current Test Accuracy

It appears that most errors in the electronics (logger and sensors) have been removed. Through the previous tests systematic and repeatable errors have been detected and the system balanced by modifying calibration factors in the analysis template. The sky varies in illuminance from test to test; however, most of these fluctuations are removed when the data are converted into daylight factors.

Variations in illuminance with position appear to be small, rarely greater than 1 and usually less than 0.25 daylight factor. These variations can be averaged out to a large extent by testing models at different orientations and combining the result. Errors introduced by the model's proximity to the walls and ceiling are also possible -- particularly the absolute data change with elevation of about 0.4% per inch noted in the elevation tests.

All things considered, one can expect reasonably accurate, repeatable results from this sky. With careful test procedures the accuracy of the system should be accurate to within 0.2%, which is less than 3 foot-candles in our open sky.

7.3 WIND TUNNEL

R. Berg, G.Z. Brown

7.3.1. Physical Description

The wind tunnel used in this research is a low speed boundary layer tunnel of the flow-through (non-recirculating) type. The test section is approximately seven feet wide and five feet tall, over a working length of roughly 14 feet. Air is drawn through the tunnel by a five-foot-diameter axial fan driven by a five horsepower electric motor via a variable speed belt drive; as a result air speeds are infinitely adjustable over a range of 300 to 2,200 fpm.

A straightening section 44 feet long establishes uniform (laminar) air flows, and allows researchers to generate desired boundary layers by distributing turbulence generating "roughening elements" on the tunnel floor ahead of the test section. The boundary layer profile -- the vertical distribution of air speeds upward from ground level to that height where air speed is constant, unaffected by objects on the ground -- is carefully matched to a given set of full scale conditions. A turntable in the floor of the test section permits models under test to be rotated, simulating all wind directions.

The tunnel was designed and built under the direction of Edward Arens, now Professor of Architecture at U.C. Berkeley, and acquired through a grant from Environmental Impact Planning Corporation. Its architectural applications include the study of wind-induced structural loading, ventilation and site microclimates. More broadly it can be used for any study of low speed air movement through and around objects, from evapotranspiration studies to examination of pollutant dispersal.

7.3.2 Calibration

Initial steps in calibration of the tunnel are aimed at mapping the baseline air velocity distribution throughout the air flow at two or more stations along the test section. Similarities and differences in

the flow distribution from one plane to the next will indicate the degree of laminarity of the flow. Once an acceptably laminar flow is achieved and mapped, we will concentrate on learning how to generate specific boundary layer profiles through manipulation of roughening elements -- a process which may involve as much art as science.

Throughout this calibration phase software will be developed and tested, as well as probe mounting and location schemes to permit a wide variety of wind tunnel applications.

Housing is a nearly \$200 billion sector of the U.S. economy (Census, 1989). Housing is as large and important to the economy as the auto industry, yet the industries are vastly different in character. The auto industry is dominated by the big three U.S. manufacturers and is severely challenged by foreign competition. The housing industry is comprised of several thousand small builders, several hundred manufacturers of homes and building materials and is not severely threatened by foreign competition, at least not yet.

In this section, we will first look at the market conditions for the different sections of the U.S. industrialized housing industry. We will explore the reasons behind why the industry is where it is today and where it is likely to go from here. Next we will discuss the challenges facing the industry. Finally, we will recommend research tasks to ensure the availability of domestically produced quality, energy efficient, and affordable housing for the 21st century.

Several forces are likely to shape the U.S. housing market in the 21st century. Due to changing demographic patterns, the rates of new household formations and consequently the demand for housing is going to be reduced (Builder, 1989). The transformation from a manufacturing to a service oriented economy will continue to exacerbate the shortage of skilled labor in the field. Increased sophistication in the computer area will dramatically enhance the availability of computer integrated design and production technologies. The cost of robotics and flexible production machinery will be reduced by one, if not two, orders of magnitude. The availability of large amounts of existing housing stock, coupled with decreasing demand for new housing is probably going to slowly decrease the cost of modest housing to the point that new housing will be hard-pressed to compete with existing housing for the starter home market. Consequently, the action in new housing is likely to be in the high-end market (Builder, 1989). This is likely to be a highly competitive market with buyers who demand quality housing. Concern for a better environment will begin to pervade the general populace who will increasingly demand energy efficiency and a cleaner indoor environment. Increasing pressures on roads, sewers, etc. will lead to more intelligently designed new communities where wastes of all kinds (garbage, household, and transportation energy) is reduced. With this scenario, let's now look at the different industrialized housing segments.

Figure 8.0-1

Figure 8.0-1 shows the historical market share of the four segments of the U.S. housing industry. As noted in Section 3.2 there are data inconsistencies. However, it is quite clear that the market share of the panelized builders is steadily increasing, the HUD-code share is dropping and the modulares are holding ground or increasing slightly.

HUD Code

HUD-code homes typically depreciate and have a lower quality than non HUD-code homes. With the growing supply of existing conventional homes in the \$50,000 - \$70,000 price range, the aging of America, and buyers wanting property appreciation, the appeal of HUD-code homes is dwindling. This trend is likely to continue in the future.

The market share of HUD-code homes is likely to decline further if a National Modular Construction Act is passed which will allow modular manufacturers the same code advantages as the current HUD-code manufacturers. It is, however, important to note that HUD-code homes are affordable. A HUD-code manufacturer can sell to dealers for \$15- \$20/sq ft, which is about 30% lower than the conventional lowest-cost home. HUD-code homes are currently the least energy efficient yet the

energy efficiency can be easily increased. Thus, energy efficient HUD-code homes can be an affordable solution for those with limited monthly budgets, especially if the energy-efficiency benefits are included when calculating monthly payment to income ratios at loan approval time.

Modular

Modular homes have the smallest market share. Modular home producers are diligently trying to shed the "mobile home" image (Andrews, 1989). The bankruptcy of Cardinal Industries in 1989 is likely to revise the modular production statistics downward for 1989. Modulares make the most sense today when building homes of essentially identical designs. That was the reason for Cardinal's success when the tax climate was favorable. It was also one of the reasons for Cardinal's failure when the tax code changed and Cardinal had to sell, not to investors, but to owners who were interested in aesthetics and design (Nolan, 1989). Lack of design flexibility has led to failures in the past when modular manufacturers promised but could not deliver customized modular homes.

Different market forces tug at the modular industry. Labor shortages will tend to increase modular production, especially for the luxury market. The low-end modular market will probably suffer due to the same forces acting against HUD-code homes. If interest rates remain low, then that too would tend to work against modulares because the advantages of reduced construction time will not be so great. Modulares are made today with some innate disadvantages -- their structure is stronger (and thus, more expensive) so that during transportation there is less sagging and cracking, the marriage walls need to be carefully detailed to avoid the tell-tale manufactured look. Drywall finishing is a production bottleneck, high roof pitches need hinges so that they can travel highways in a low configuration and then be jacked up at site. These disadvantages will continue to slow the U.S. modular industry of today. However, computerized and automated design, production and inventory management can greatly enhance the productivity of this industry like it has in Japan.

Panelized

Panelized manufacturers are by far the largest segment of house manufacturers. The statistics of this segment is the least reliable. Panelized plants are commonplace with large builders. Operating in large metropolitan areas, these large builders build 5,000 or so homes per year. They typically integrate volume purchasing, manufacturing and site development activities. They conduct focus group interviews of buyers, have in-house designers design the homes, usually do not build on speculation, manufacture the wall and roof panels for a wide variety of house designs in a plant and are not held up by plant inspections (needed in modular and HUD-code homes). Thus, they do not suffer any of the aforementioned production bottlenecks and still enjoy the volume purchasing and low-wage labor benefits of manufacturing. It is also interesting to note that many closed panelizers

have transformed themselves into open panelizers so that they can offer flexible designs and not suffer from inspection bottlenecks.

The larger panelized manufacturers and the smaller manufacturers who cater to the move-up buyer, produce quality housing of good design and can produce energy-efficient housing. However, this comes at a significant cost. Since the design and material take-off process are still largely noncomputerized, it constitutes up to 20% of the final costs paid by the buyer of a high-end home (~\$100/sq ft). We believe that an integrated computerized design, marketing and production system can significantly lower this cost and consequently produce exciting custom energy-efficient homes at 10% - 15% lower cost than possible today.

Recommendations

The United States is the best housed nation on earth. The Japanese will gladly pay \$150/sq ft for a 2 x 4 American home in Japan. In Europe, including Sweden, home costs are significantly greater than that in the U.S. Yet, the U.S. home building industry is fragmented, does little R&D and seems to be least threatened by foreign competition. In the housing area, the greatest competition seems to be in the appliances and building materials areas, where large U.S. corporations are facing stiff competition from Europe and Asia.

We believe that the reason for this state of affairs is the localized nature of, and moderate skill requirements for homebuilding. There are several thousands of localities and personalities to deal with, lot of money is made in land development, one has to intimately know the local market. One can be a successful homebuilder operating from the back of a pick-up truck. No wonder, large U.S. businesses, not to mention foreign builders, have not gained a large share of the housing market.

This is not to suggest complacency. After all, one has only to look at the auto industry to see the effect of foreign competition. In our view, the housing industry can significantly increase the quality, energy efficiency and affordability through research and development. In addition, this R&D can help U.S. housing manufacturers gain a large share of the growing housing markets in east Europe and the newly industrializing countries of Asia. These R&D and technology utilization activities are covered in our multiyear plan (CHI/FSEC, 1989). The two major thrusts of our recommendations are:

1. Work with industry and perform cost shared R&D projects with government and industry funding
2. Concentrate on breakthrough technologies for the 21st century rather than on incremental improvements to today's technology.

Cost-shared R&D with Industry

This envisions an arrangement (proven successful in the DOE photovoltaic -PV program) where we develop request for proposals (RFP) from industry on a variety of R&D and demonstration areas. We (i.e., the project team of Oregon and Florida) will summarize the state of the art in a certain area that has significant energy conservation potential (i.e., air distribution systems, larger factory assembled systems, i.e. wall panels with a bathroom or kitchen core, energy and design software, radiant barrier, etc.) and invite industry to develop advanced prototypes for the area. Industry will pay 51% of the costs and government will pay 49% of the development costs and industry will retain patent rights. We will assist industry in all phases of development, test the prototypes and assist in technology transfer. Our preliminary conversations with industry indicates that they are quite interested in the concept. Of course, this is an expensive area and will require significant government funding (several \$ million per year) to make a significant contribution. The PV program has spent over \$150 million in the last ten years in this type of activity and has made remarkable progress (Sklar, 1989). The current U.S. technology base in PV is the result of \$1 billion in government and \$2 billion in private funds over the last 20 years (SERI, 1989).

Breakthrough technologies for the 21st century

Today's house is designed and built without significant attention to how different systems of the house are integrated, e.g., interior walls serve no more function than non load-bearing partitions. Separate trades (plumbers, electricians, HVAC, telephone, cable) run service plumbing, wiring and ducting. Dramatic increases in productivity appears to be possible if a house system can be developed where everything is integrated and each component performs more than one function, e.g., wall panels could have built in plumbing, wiring, ducting, interiors walls could have integrated thermal (and moisture) storage and possibly be load bearing. External walls, roofs can be made of modules which snap together in the field by unskilled workers or robots. The house components could be designed and manufactured with computer aided technologies which utilized the latest in expert system and industrial engineering techniques for material resource planning, just in time inventory and flexible automated manufacturing cells. The modules may be manufactured from advanced composite materials. In this scenario, energy efficiency will be integrated in all components and subsystems by design rather than as an afterthought.

We propose to begin a sustained long-term R&D and technology utilization effort, in cooperation with leading members of the homebuilding, materials software, and automation industries to develop the aforementioned breakthrough technologies.

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