

**ENERGY EFFICIENT
INDUSTRIALIZED HOUSING
RESEARCH PROGRAM**

**SUMMARY
FY 1990 RESEARCH ACTIVITIES**

**CENTER FOR HOUSING INNOVATION
UNIVERSITY OF OREGON**

AND

FLORIDA SOLAR ENERGY CENTER



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**CENTER FOR HOUSING INNOVATION
UNIVERSITY OF OREGON
EUGENE, OREGON 97403-1206**

**CONTACT:
G.Z. (CHARLIE) BROWN
(503) 346-5647**

AND

**FLORIDA SOLAR ENERGY CENTER
A RESEARCH INSTITUTE OF
THE UNIVERSITY OF CENTRAL FLORIDA
300 STATE ROUTE 401
CAPE CANAVERAL, FLORIDA 32920**

**CONTACT:
SUBRATO CHANDRA
(407) 783-0300**

U. S. Department of Energy Contract No. DE-FCO3-89SF17960

July 1991

AUTHORS

Center For Housing Innovation University of Oregon

Rudy Berg	Senior Research Assistant
G.Z. Brown	Project Director, Professor of Architecture
Ron Kellett	Principal Investigator, Associate Professor of Architecture
Margot McDonald	Research Assistant
Matt Meacham	Research Assistant
Artemio Paz	Research Assistant
Pat Ryan	Research Assistant
Tomoko Sekiguchi	Senior Research Assistant

AUTHORS

Florida Solar Energy Center

Bing Cai	Research Assistant, Department of Industrial Engineering, UCF
Subrato Chandra	Project Director, Director of Research & Development Division, FSEC
Ahmad K. Elshennawy	Assistant Professor, Department of Industrial Engineering, UCF
Philip Fairey	Principal Investigator, Deputy Director, FSEC
Elvis Gumbs	Research Engineer, FSEC
Peter Haas	Research Assistant, Department of Industrial Engineering, UCF
M. Emanuel Levy	The Levy Partnership, Inc.
Janet E.R. Mcilvaine	Research Assistant, FSEC
Lawrence Maxwell	Senior Research Architect, FSEC
Ingrid Melody	Director of Communications, FSEC
Sofien Moalla	Research Assistant, FSEC
Michael Mullens	Assistant Professor, Department of Industrial Engineering, UCF
Jim Roland	Director, Testing & Operation Division, FSEC
John Tooley	President, Natural Florida Retrofit
William Swart	Chairman & Professor, Department of Industrial Engineering, UCF
Lorenzo Young	Research Assistant, UCF

STEERING COMMITTEE

Robert Allan
Program Manager
Research and Development
Florida Power and Light
West Palm Beach, Florida

Wayne Beighle
Executive Vice President
The Charles Wayne Group
Daytona Beach, Florida

Jim Birdsong
Executive Director
NAHB Building Systems Council
National Housing Center
15th & M Streets, N.W.
Washington, D.C.

Don Carlson
Editor and Publisher
Automated Builder
Carpenteria, California

Michael Dickens
Director, ABACO Program
GE Plastics
Pittsburgh, Pennsylvania

John Elizalde
Chief, Residential Program Branch
Bonneville Power Administration
Portland, Oregon

Stan Floyd
Manager, Structural Materials
Corporate Research & Engineering
Weyerhaeuser Technology Center
Tacoma, Washington

United States Department of Energy

George James
Project Manager
U.S. Department of Energy
Washington, D.C.

Ken Franklin
Project Leader, Styrofoam Applications
Technical Services and Development
Dow Chemical U.S.A.
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Fisher Friedman Associates, Architects
San Francisco, California

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Selinsgrove, Pennsylvania

Art Milliken
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Acorn Structures
Concord, Massachusetts

Jon Nord
Senior Vice President
Fleetwood Enterprises
Riverside, California

Ed Sheets
Executive Director
Northwest Power Planning Council
Portland, Oregon

John Slater
Today's Building Systems
Newark, Ohio

Mike Lopez
Program Manager
U.S. Department of Energy
Oakland, California

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SUMMARY OF FY 1990 RESEARCH ACTIVITIES

ABSTRACT

This report summarizes research results from eight projects conducted from November, 1989 to March, 1991, the second year of the Energy Efficient Industrialized Housing research program. Detailed individual reports are available for each of the sections described in this report. The titles of these reports are: An Analysis of U.S. Industrialized Housing, A Review of Computer Use in Industrialized Housing, Design for Energy Efficiency, Energy Design Software, Manufacturing Process Innovation, Toward the Development of a Dimensional Coordinating Hierarchy for Housing Applications, Calibration of the Boundary Layer Wind Tunnel, and Cooling Season Tests for Industrialized Housing Systems.

An Analysis of U.S. Industrialized Housing includes a statistical and background analysis of the industrialized housing industry as it exists in the U.S. The report details trends outlining pertinent U.S. housing industry directions and energy use patterns. Research opportunities for improving energy efficiency are identified.

A Review of Computer Use in Industrialized Housing reports on the extent of computer software use and computerized energy tools in the marketing, design, engineering and manufacturing of industrialized housing. Comparison of U.S. to Japan and Western Europe state of the art applications and needs of the domestic industry are included. Report concludes with design criteria for new computerized energy tools unique to industrialized housing.

Design for Energy Efficiency examined four problem statements to define future housing demand scenarios inclusive of issues of energy efficiency, housing design and manufacturing. Future trends were identified in computing and design process; manufacturing process; construction materials, components and systems; energy and environment; demographic context; economic context; and

planning policy and regulatory context. From these trends, the report describes four detailed design studies for single family and multifamily housing systems.

Energy Design Software describes the development of a design tool for a stress skin insulated core panel manufacturer which uses an existing energy analysis program. The software is designed to integrate with the industrialized housing process from design to manufacturing. In the end, the software will increase the sophistication of energy design in the production of industrialized housing.

Manufacturing Process Innovation explores key operational and management questions critical to the restructuring and emergence of U.S. companies as new leaders of an industry that will furnish affordable, energy-efficient, industrialized housing to the U.S. and world markets. The report describes the Generic Industrialized Housing Manufacturing Simulator (GIHMS), a computer tool used to model complex manufacturing operations, which is in the software development stage.

Toward the Development of a Dimensional Coordinating Hierarchy for Housing Applications reviews the state-of-the-art of dimensional coordination systems in the U.S. and world housing industries and outlines a planned approach for development of a dimensional coordinating hierarchy for the U.S. A dimensional coordination hierarchy is a system of rules governing the dimensional characteristics and integration requirements of the various constituents that comprise a house.

Calibration of the Boundary Layer Wind Tunnel outlines the progress toward the calibration of this instrument for testing the energy performance of houses at several stages from design through occupancy.

Cooling Season Tests for Industrialized Housing Systems reports on the results from field testing of side-by-side industrialized and conventional house construction systems.

1.0 INTRODUCTION

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

This research program addresses the need to increase the energy efficiency of industrialized housing. Two research centers have responsibility for the program: the Center for Housing Innovation at the University of Oregon and the Florida Solar Energy Center, a research institute of the University of Central Florida. The two organizations provide complementary architectural, systems engineering, and industrial engineering capabilities.

The research program, under the guidance of a steering committee composed of industry and government representatives, focuses on three interdependent concerns -- (1) energy, (2) industrial process, and (3) housing design. Building homes in a factory offers the opportunity to increase energy efficiency through the use of new materials and processes, and to increase the value of these homes by improving the quality of their construction. Housing design strives to ensure that these technically advanced homes are marketable and will meet the needs of the people who will live in them.

Energy efficiency is the focus of the research, but it is viewed in the context of production and design. This approach will enable researchers to solve energy problems in such a way that they can assist industry to improve its product and compete with foreign companies, to alleviate the trade imbalance in construction products, to increase the productivity of the U.S. housing industry, and to decrease both the cost of housing and the use of fossil fuels that are expensive and damaging to the environment.

2.0 DEFINITIONS

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

- (1) **HUD Code** Houses (mobile homes)
- (2) **modular** houses
- (3) **panelized** houses (including domes, precuts, and log houses)
- (4) **production** houses (including builders that use only a few industrialized parts).

These four definitions were selected because they are the categories used to collect statistical data, and so are likely to persist. However, the categories are confusing because they are based on a mix of characteristics: unit of construction (modular, panelized), method of construction (production), material (panelized), and governing code (HUD Code).

There are other ways to define industrialized housing, each of which provides a different perspective on the energy use. Japan and Sweden, for example, define industrialized housing in terms of corporate structure. Industrialized housing is equated with home building companies. These companies vertically integrate all or most of the housing process, including raw material processing, component assembly, house construction, installation, financing, marketing, and land development. This definition is useful because it addresses the extent of control a given company has over the design, production, and marketing of the house, and therefore its energy use.

Other methods of defining or categorizing housing exist. These methods can shed light on important aspects of industrialization and enable us to predict the impact of innovations, establish priorities for research activities, and identify targets for information. For example, industrialized housing can be defined as utilizing open or closed systems. A closed system, which limits design alternatives, has the potential to benefit its supplier because it is exclusive. An open system, by contrast, is more tolerant of a wide range of designs and gives the home owner a range of component choices of and the opportunity to purchase these components in a more competitive market place.

Other important means of categorizing include: 1) level of technology employed -- high, intermediate, or low; 2) percentage of value that can be supplied by the home owner, using sweat equity; 3) physical size of the elements -- components, panels, cores, modules, or complete units.

HUD Code Houses

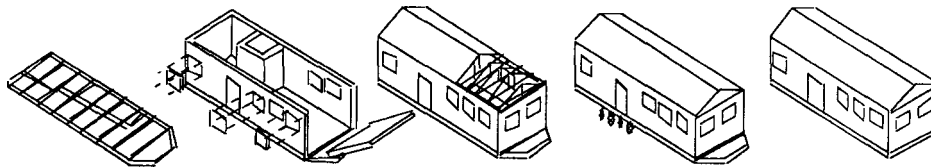


Figure 2.0-1
HUD Code House

A HUD code house is a movable or mobile dwelling constructed for year round living, manufactured to the preemptive Manufactured Housing Construction and Safety Standard of 1974. Each unit is manufactured and towed on its own chassis, then connected to a foundation and utilities on site. A HUD code house can consist of one, two, or more units, each of which is shipped separately but designed to be joined as one unit on site. Individual units and parts of units may be folded, collapsed or telescoped during shipment to the site.

Modular Houses

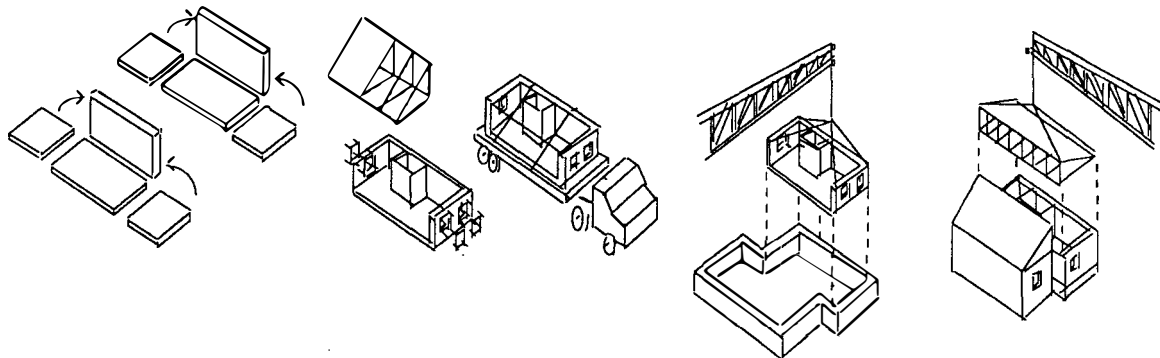


Figure 2.0-2

Modular House

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

Panelized Houses

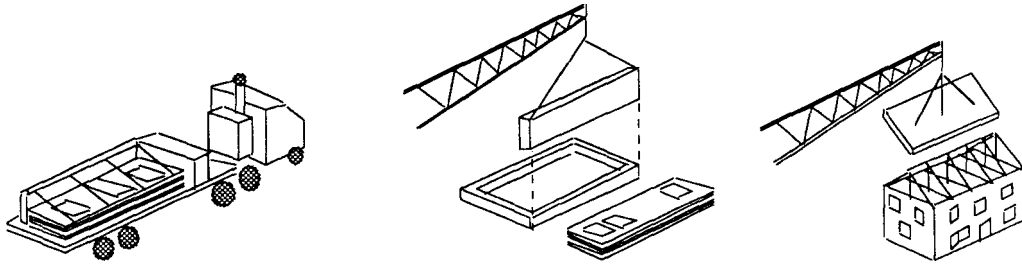


Figure 2.0-3
Panelized House

Panelized houses are whole houses built from manufactured roof, floor and wall panels designed for assembly after delivery to a site. Within this category several sub-categories exist. Framed panels are typically stick-framed, carrying structural loads through a frame as well as the sheathing. Open Framed Panels are sheathed on the exterior only and finished on site (interior finishes, electrical and mechanical systems). Closed framed panels are sheathed on both the exterior and interior and are often pre-wired, insulated and plumbed. Stress-skin panels are typically foam filled, carrying structural loads in the sheathing layers of the panel only.

Production Built Houses

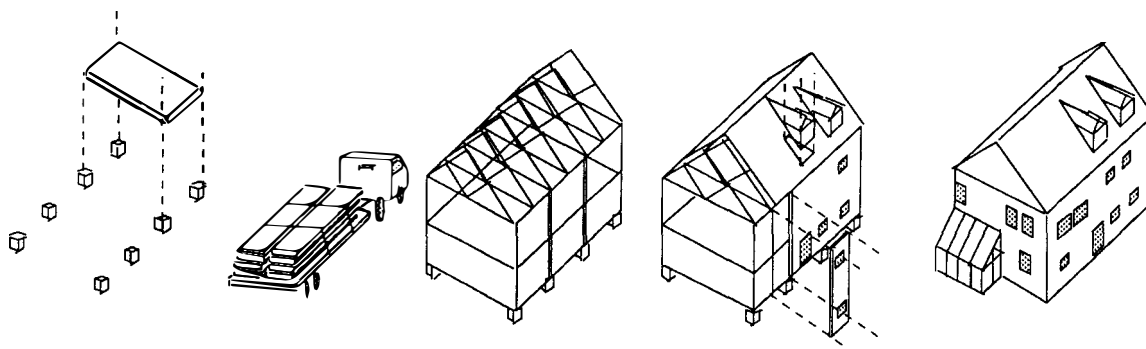


Figure 2.0-4
Production Built House

Production building refers to the mass production of whole houses 'in situ'. This large and influential industry segment is industrialized in the sense that it employs rationalized and integrated management, scheduling, and production processes as well as factory made components. In this instance, however, the factory is a building site which becomes an open air assembly line through which industrialized labor and materials rather than houses move.

3.0 U.S. INDUSTRIALIZED HOUSING

The purpose of this research activity was to conduct the statistical and background analysis of the industrialized housing industry. We have pursued several goals in this project including creating a nationwide 'snapshot' of industrialized housing, profiling trends characterizing the industry's form and direction and outlining pertinent U.S. housing trends and energy use patterns. From this analysis, we have identified research opportunities for improving energy efficiency and established an appropriate data base for this project.

Efforts to analyze U.S. industrialized housing, and particularly to grasp its quantitative dimensions, are impeded by scarce and inconsistent data. Consequently, cross referencing and triangulation between data sources are required to develop a clear statistical image. The resulting image reveals two characteristics. The first is a general increase in degree of industrialization throughout the home building industry -- increasing use of factory-made components and more sophisticated tooling, with one result that value added

per worker in the structural wood member industries has quadrupled since the early seventies. The second characteristic is an increasing market share claimed by the more highly industrialized segments of the industry; the modular and panelized producers. From 1980 to 1989 their combined fraction of the market has risen from 34% to 42%. These characteristics suggest that U.S. housing is particularly susceptible to energy conservation through innovations based on industrialized approaches.

The following chart profiles the growth of market share by various industry segments. This set of data derives from the most detailed currently updated statistical sources, and attempts to describe the entire universe of housing production.

<u>Year</u>	<u>Total Starts</u>	<u>Panelized</u>	<u>Modular</u>	<u>HUD Code</u>	<u>Production Builder</u>
1989	1,341*	487, 36	79, 5.9	202, 15*	573, 43
1988	1,358	548, 40	88, 6.5	233, 17	489, 36
1987	1,444	564, 39	83, 5.7	233, 16	564, 40
1986	1,507	573, 38	84, 5.6	244, 16	606, 40
1985	1,449	524, 36	75, 5.2	284, 20	566, 40
1984	1,500	476, 32	71, 4.7	295, 20	658, 44
1983	1,476	387, 26	60, 4.1	295, 20	734, 50
1982	982	264, 27	34, 4.6	239, 24	445, 45
1981	1,037	306, 30	50, 5.0	241, 23	440, 42
1980	1,184	341, 29	54, 4.6	222, 19	567, 48

Note: all production figures in thousands
percent of market
 *estimates

**Table 3-1, 1 to 4 Family Housing Starts and Market Share
 by Industry Segment 1980-1989**

Sources: U.S. Bureau of Commerce, Manufactured Housing 1988, Factory Built Housing in the 1990's, Red Book of Manufactured Housing, NAHB Framework for the Future: 1989-1991, and Manufactured Housing Institute

Several other housing trends with cumulative effects are evident -- for example, population migration to warm climate regions, concentration of housing starts in those regions, and increased use of energy for residential

cooling. When these trends are related to the characteristics of industrialized house types, promising energy conservation research goals become apparent: ways to optimize home sales/design/construction processes in order to match insulation levels and thermal mass to particular climates and even microclimates; ways to tune HUD code homes for better hot-humid climate performance -- particularly insulation and HVAC system upgrades -- and ways to maintain acoustic privacy in densely sited, naturally ventilated panelized or modular dwellings.

Industrialized housing techniques promise to enhance the energy efficiency of housing at realistic costs, by providing close control of the parts and processes of construction. Since the industrialization of U.S. home production is the most universal and economically viable characteristic of the industry, improvements in the energy performance of industrialized housing are likely to have the strongest effect on residential energy use. Most importantly, the difference between *economically* and *technically* feasible energy savings can be reduced by successful research efforts to bring theoretically possible conservation approaches into practice.

4.0 COMPUTER USE IN INDUSTRIALIZED HOUSING

The objectives of this research task was to review, assess and document the extent of computer use in marketing, design, engineering and manufacturing of industrialized housing. We compared and contrasted the state of the art in U.S. vs. that in Japan and Western Europe. Additionally, our research activity assessed and documented the needs of the domestic industry in this field. Our final goal was to establish design criteria for new computerized energy tools unique to industrialized housing.

We determined the extent of software use in industrialized housing by a combination of literature and vendor search, phone interviews and site visits. Computers' first penetrations into the housing industry were in component design and manufacture. This process began with computer generated engineering calculations for truss design and progressed to automatic lumber cutting procedures, jigging and truss plate attachment.

U.S. manufacturers continue to computerize an increasing number of discrete tasks such as drafting and material resource planning, but there remain substantial difficulties in sharing data between tasks. Japanese and Scandinavian companies are more sophisticated in their use of computers than U.S. companies. Sweden is more advanced in the control of production and links between production and design, while Japan is more advanced in the computerization of the sales process and its links to design. Given developments in computers and in foreign industrialized housing companies, we believe that U.S. industrialized housing companies are on the brink of extensive computerization.

The use of computerized energy tools by U.S. industrialized housing producers is low, with most manufacturers relying on rules of thumb and prescriptive code requirements. Our analysis of the activities required to make a house, the structure of companies that supply houses, and the nature of energy decisions revealed how critical it is to identify the correct audience for a computerized tool. For example, compare a large HUD code producers to a production builder on the basis of one decision -- siting: the HUD code producer has little control over 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 house, the manufacturer doesn't know in advance how it will be sited and therefore cannot 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 increasing insulation and reducing glazing area rather than those that are orientation dependent like solar heating or summer shading. The production builder, comparatively speaking, has more control of the siting decision. Thus HUD code design tools might be directed at the dealer/customer (at least for siting issues) rather than the manufacturer, while the tools for the production builder might be directed at the manufacturer/builder with output that could be used as part of the sales process.

Industry Trends

We identified several trends within the computer, manufacturing and construction industries which will form new energy tools. The computer industry is projected to continue development of systems with increased capacity at less cost in all size ranges. Increased capacity means that memory consuming graphic systems and user friendly interfaces will become more feasible relative to size, complexity, and speed, while decreased cost will make systems more prevalent in larger companies and within reach of limited budgets of smaller companies. On the human side, increased computer literacy in the workplace, coupled with continued development of user friendly interfaces, sets the stage for computerization of tasks not previously accomplished on a large scale.

Manufacturing enterprises are increasingly automated. Research in the field of industrial engineering is focusing on manufacturing process from business functions to design to inventory control. Because of the emphasis on the engineering function, many firms have already embraced computing in some aspect of their manufacturing process. Extensive research is being conducted at universities in the development of expert systems, computer modeling, and robotics with applications in manufacturing and construction.

The U.S. housing industry is becoming increasingly industrialized. In the process, housing production is becoming more standardized and rationalized. Both standardization and rationalization have the potential to make computerization of the production process easier.

These trends in computing and manufacturing will result in increased and more sophisticated computer use within the U.S. industrialized housing companies. If this occurs, several potential impacts on the design process and the house can be identified. Increased computerization within the industrialized housing industry is likely to occur based on one or more of the following scenarios.

Scenarios for Computerization

Suppliers of components (like truss or window manufacturers) will continue to supply software to engineers and designers that fits with existing CAD platforms. This software will become more prevalent and sophisticated, perhaps containing expert systems to assist the designer.

Existing integrated CAD/CAM software systems which already perform routine engineering calculations and material takeoffs will become more inclusive, forming a linkage from design to production and sales. Like existing CAD/CAM systems, they will be designed to accommodate a range of manufacturers, although they may be strongly linked to existing material systems and therefore will perpetuate their continued use.

Larger companies will develop in-house software with the express purpose of integrating two or more of the major functions of marketing, design, management, and production.

Criteria for Energy Design Tools

We developed general criteria for energy design tools. These criteria are intended to establish the scope and direction of new tools. More specific criteria, such as hardware and programming language, will be established later in the context of specific tool proposals. The general criteria are these:

- Energy tools, in order to be used, must be consistent with the trend towards computerization in industrialized housing. Energy tools developed should be integrated with software and hardware systems that will be used by industrialized housing companies.
- Energy tools should be an integral part of other computerized design and sales aids which are designed to be used with customers.

- Energy tools should be developed that support manufacturers of energy efficient products. These tools should link the manufacturers with the home owner.
- Energy tools should be design oriented rather than research oriented.
- Energy tools should help users make housing decisions that are interdependent with energy decisions.
- Energy tools should be a part of expert systems which assist non-professional personnel in housing design.

5.0

DESIGN FOR ENERGY EFFICIENCY

The long term objective of this research area is to develop advanced technology single family and multifamily housing systems that optimize projected and desired advances in computerized design processes, materials, components, and manufacturing automation and to achieve high levels of energy performance at reduced first cost. We will develop these systems in a way that allows housing designs to be compatible with future demographic, economic, environmental and regulatory changes.

In early FY 1990, four problem statements were developed to define future housing demand scenarios inclusive of issues of energy efficiency, housing design and manufacturing. Literature surveys were completed to assess seven areas of influence for industrialized housing and energy conservation in the future. Fifty-five future trends were identified in computing and design process; manufacturing process; construction materials, components and systems; energy and environment; demographic context; economic context; and planning policy and regulatory context. From these trends, four scenarios were created to investigate as design studies.

Computing and Design Process Trends

Computer literacy continues to increase throughout the work force. This creates the opportunity to customize industrialized housing design through computer aided sales, marketing and design, and to fully coordinate site installation with manufacturing and design processes using computerized design and production tools.

Manufacturers of computer hardware are producing equipment which offers increased computing capacity at less cost. Increased computing capability gives software developers the opportunity to create tools which are able to design, engineer, assess regulatory compliance, energy performance and cost concurrently, and evaluate energy conservation alternatives throughout design and manufacturing processes.

Manufacturing Process Trends

Manufacturers continue to develop products and options and to improve production flexibility. These changes allow for opportunities to define flexible manufacturing and dimensional systems accountable to energy performance standards.

Quality control standards continue to increase which establishes opportunities to improve and confirm compliance with energy performance specifications and assumptions throughout manufacturing.

Manufacturing innovation is evolutionary and provides opportunities to improve energy performance standards as a new manufacturing process is developed and adopted.

Materials, Components and Systems Trends

New technologies using composite and biomass-derived materials are being developed for construction which have the opportunity to enhance energy performance and manufacturing properties of engineered materials.

Increased thermal properties of lightweight materials will provide new opportunities to improve thermal resistance and storage in light, thin wall construction.

As energy systems miniaturize, opportunities increase to manufacture photovoltaics and space conditioning appliances to be integral with construction materials and components.

Greater integration of mechanical and electrical systems provides opportunities for rationalized service core and space planning.

Energy and the Environment Trends

Consumer demand for conservation efficiency increases and pressure is placed on manufacturers and builders to realize energy conservation opportunities across a full range of design and manufacturing processes including, for example, at neighborhood and site planning design scales.

Public demand for air quality continues to increase. This provides an opportunity for community and neighborhood planning strategies to include less automobile use and manufacturing strategies which will use materials and processes of low toxicity.

Worldwide concern for global warming increases and will create an urgency to develop non-fossil residential fuel sources, increase planting levels of oxygen-giving trees and plants, and decrease use of chlorofluorocarbon based materials in construction.

Utility load management strategies will seek to defer peak load demand and develop means of electricity generation in houses.

Demographic context

Changes in household composition increases as families and lifestyles undergo transformation. These changes establish demand for flexibility in house size and interior space organization.

As workplaces decentralize, it prompts a demand for mixed use neighborhoods and in-house workplaces.

Population migration and growth concentrates in southern and western regions of the United States. This shift of population establishes demand for new housing in predominately cooling climates.

Population growth concentrates in metropolitan suburbs which establishes need for energy conservation strategies appropriate to multi-family and densely sited single family houses.

Economic context

Land and infrastructure costs continue to rise which establishes need to develop energy conservation strategies appropriate to dense site planning and utility and energy distribution networks.

Entry level housing markets expand as first time buyers increase demand for low

first-cost houses that can be remodeled and upgraded.

Remodel and 'do it yourself' markets expand establishing need to develop energy conserving materials, components and systems for piecemeal, low skilled installation.

International markets and competition increase which establishes need for construction systems based on interchangeable components and international performance specifications.

Construction sector stratifies at national and local scales which establishes opportunity of two tiered construction and energy conservation strategy. Building parts manufactured and distributed at a national or international scale meet national standards, and parts manufactured and installed at a regional or local scale meet local market, climate and utility standards.

Mortgage alternatives increase which establishes opportunity to consider energy conservation as a life cycle cost and finance energy systems separately.

Planning policy and regulatory context

Utilities increase conservation and load management incentives which may include opportunities to economically upgrade space conditioning appliance quality, control devices, construction quality and the thermal properties of materials and components.

Housing affordability incentives increase and prompt a redefinition of planning, zoning and building regulations to mix land uses, reduce development and utility costs, and encourage community scale transportation and energy systems.

Land subdivision and ownership alternatives increase which establishes need to develop energy conservation strategies for a range of irregular house and site configurations such as cluster, zero lot line, Z- lots, and zipper lots.

Performance codes replace prescriptive codes which establishes opportunities for code compliance with innovative passive energy conservation design, engineering and manufacturing strategies.

5.1 Design Studies Integrating Future Trends

Many future housing demand scenarios could result from these and other trends acting on the diverse housing markets of the United States. We concentrated further research on four climate zones and housing types developed for elaboration as design studies — Starter House for a Hot-Arid Climate; Move-up House for a Hot-Humid Climate; Extended Family House for a Cool Climate; and Renewable House for a Temperate Climate. These were selected for their broad opportunity for innovation in energy conservation, housing design and manufacturing across a representative range of house types, markets, construction systems and climates.

The ‘Starter House for a Hot-Arid Climate (Phoenix, AZ)’ problem statement explores energy conservation opportunities compatible with trends anticipating strong demand for small, minimum cost multi-family houses in sun-belt suburbs, diversifying household composition, declining wood resources, advancing concrete technology, increasing site density, and increasing competition for cooling energy.

The ‘Extended Family House for a Cool Climate (Minneapolis, MN)’ problem statement explores energy conservation opportunities compatible with trends anticipating demand for median cost infill single family housing in northern metropolitan suburbs, improving performance of insulated panels, decreasing availability of dimensional lumber, increasing engineering capabilities of wood composite materials, and increasing computer coordination of design and engineering processes.

The ‘Move-up House for a Hot-Humid Climate (Miami, FL)’ problem statement explores energy conservation opportunities compatible with trends anticipating demand for above median cost single family houses in Florida, increasing demand for custom design flexibility and quality, increasing competition for peak period energy, miniaturization of variable air volume distribution systems and increasing utility participation in energy conserving construction programs.

The ‘Renewable House for a Temperate Climate (Seattle, WA)’ problem statement

explores energy conservation opportunities compatible with trends anticipating strong future demand for remodels, additions and upgrading of existing houses, increasing sophistication of 'do-it-yourself' building materials and components, increasing computerization of design, engineering and construction management processes, decreasing availability of dimensional lumber, increasing recycling and regulation of toxicity levels in building materials.

Each problem statement develops a set of goals, objectives and criteria that define the market, manufacturing and energy requirements from which a design study could be initiated. These include:

- A scenario of household characteristics and goals
- A delivery scenario of the whole process through which the house is conceived, designed, manufactured, assembled, marketed and financed.
- A design program of occupancy and design requirements. House size, room requirements, neighborhood context, occupancy and household income assumptions are defined.
- An energy conservation program of demand, utility and conservation requirements. Appropriate passive heating and cooling strategies are defined and design rules of thumb provided.
- A materials, components and systems program outlining the basic characteristics of a construction system. Foundation, envelope, structure, floors, roofs, mechanical and electrical systems to be used are defined.
- A manufacturing scenario of factory management and production characteristics.
- A summary of design, energy and economic goals and criteria against which design studies are evaluated. In all cases, designs must improve energy performance by 25% over current State of California Title XXIV standards with no net increase in total project cost.

Eight design studies were undertaken. Each study developed a schematic design for a house and site to meet requirements of the problem statement. Three

studies were completed of the starter house, three (and one variation) of the extended family house, one of the move-up house and one of the renewable house.

5.2 Design Study Evaluation

All eight design studies were evaluated against goals and criteria established in the problem statements. Energy Scheming computer simulations for four typical days in December, March, June and September were performed and compared. Conclusions were drawn and innovative energy improving design and manufacturing principles inventoried for further evaluation and refinement.

Studies of the 'Starter House' (Phoenix) problem revealed opportunities for passive heating and cooling innovations suited to the density, compactness and economy required of low cost multi-family houses. Low cost shading, ventilation and thermal mass can be achieved across a range of construction techniques and site planning strategies.

Space heating demand can be virtually eliminated and cooling demand deferred to off-peak periods. All studies eliminated heating and cooling loads on a typical December 21 day. Off-peak mechanical cooling was required to meet heat gains that ranged from 11,210 - 43,287 Btu on a March day, 112,478 - 128,005 Btu on a June day and 87,302 - 210,817 on a September day. HVAC, hot water and power systems of higher first cost but greater energy efficiency can be economically shared from common walls and cores.

Manufacturing efficiencies can be achieved through definition of a limited number of component parts that can be combined with variety and flexibility. Sweat equity, renovation and remodel opportunities must be accommodated within design, engineering and manufacturing processes in order to preserve life cycle energy performance of the whole house.

Studies of the 'Extended Family House' (Minneapolis) problem revealed opportunities for improvement in the thermal resistance of an envelope appropriate to the design variety and flexibility of light frame construction. Super insulating materials on very light wood frame construction strategies bring

significant opportunities to reduce structural material requirements by as much as one half and simplify site assembly by weeks.

The super insulating envelope substantially reduces space heating requirements and virtually eliminates need for cooling. Much of the heating demand can be met through recovery of waste heat. Three studies eliminated or virtually eliminated heating and cooling loads on typical June and September days. Mechanical heating was required to meet heat losses that ranged from 31,493 - 116,531 Btu on a March day, and 63,598 - 187,843 on a December day.

An 'open' manufacturing strategy based on components and materials from competing but complementary sources is vital to the design and site planning variety customary to this market.

Studies of the 'Move-Up House' (Miami) problem revealed opportunity to integrate water recycling systems with manufactured foundation systems. The cooling and heat storage capability presented can, in combination with a design that ventilates well, can significantly reduce demand for space cooling and hot water energy. This study eliminated heating and cooling loads on a typical December day and required mechanical cooling to meet heat gains of 37,531 Btu on a March day, 257,818 Btu on a June day and 296,378 Btu on a September day.

Studies of the 'Renewable House' (Seattle) problem revealed opportunities to upgrade energy performance in existing residential construction in conjunction with owner built additions and remodels. Among the effective strategies are upgraded insulation levels in walls and windows, improved plan zoning, windows and finishes for passive heating, and upgraded space conditioning appliances.

Energy simulations of the study submitted revealed that the renewed house (upgraded 1,274 square foot existing house plus 700 square foot addition) used less energy than the original house alone. This study eliminated heating and cooling loads on a typical June day and required mechanical cooling to meet a heat gain of 14,382 Btu on a September day, and mechanical heating to meet heat losses of 77,171 Btu on a March day and 123,520 Btu on a December day.

5.3 Future Design Study Areas

From the eight design studies conducted in four climate zones, the scope of design study areas narrowed to two housing types and climate areas. These are:

- A multi-family lightweight concrete panel house for a hot arid climate
- A single family wood composite frame and compact vacuum insulation (CVI) panel house for a cool climate

These design study areas were selected for their significance to national residential energy consumption and the future of industrialized housing demand. One is primarily a heating climate and the other a cooling climate. Both are regions projected to sustain new housing demand into the next century. Panelized construction systems are fundamental to the design and installation flexibility sought in future markets for industrialized housing. Engineered wood composites and lightweight concrete are projected to be common materials in future industrialized housing.

5.3.1 Multi-Family Lightweight Concrete Panel House for a Hot Arid Climate

The core principles from which design development, evaluation and refinement are summarized below.

Energy conservation and site design design considerations will include the following:

- Preserve opportunity to utilize site energy through ground to sky ownership and control of individual units.
- Establish site planning rules to protect access to sun, wind and light.
- Reduce surface area with attached house forms.
- Reduce area of roads, parking and utility systems.
- Increase site shading and humidification.
- Promote utilization of unconditioned outdoor living areas.

Energy conservation and house design considerations will include the following:

- Organize houses in two stories of reduced skin and floor area.
- Zone floor plan to keep living areas in contact and control of sun, wind and light.
- Temper micro-climate of outdoor spaces adjacent to living areas.
- Establish loadbearing structure parallel to direction of sun and wind.

Energy conservation and component design considerations will include the following:

- Increase thermal storage capability of materials and finishes.
- Optimize the design, engineering and manufacture of roof and floor systems.
- Provide lightweight, adjustable shading and ventilation accessories.

Energy conservation and service system design considerations will include the following:

- Combine and integrate energy consuming systems and services in a core wall.
- Supplement passive ventilation with evaporative cooling.
- Surface mount service distribution systems.
- Integrate solar collection surfaces with roofs, walls and windows.

Energy conservation and manufacturing strategies will include the following:

- Engineer and manufacture houses in two tiers — ‘structure’ and ‘infill’.
- Integrate manufactured, site-built and ‘do-it-yourself’ construction systems.
- Coordinate dimensions of sites, houses, rooms, components and energy systems.

Energy conservation and economic strategies will include the following:

- Design and manufacture energy systems to anticipate additions and remodels.
- Zone spaces for income generation apart from other spaces.

5.3.2. Single Family Wood Composite Frame and Compact Vacuum Insulation Panel House for a Cool Climate

Energy conservation and site design considerations will include the following:

- Apply passive heating and cooling strategies to constrained sites.

Energy conservation and house design considerations will include the following:

- Limit interior area and volume exposed directly to climate.
- Reduce heat loss and airflow at doors and windows.

Energy conservation and component design strategies will include the following:

- Differentiate structural frame from nonstructural insulating cladding.
- Increase the insulating and thermal storage capability of interior finishes
- Surface mount windows and doors.
- Improve the performance and convenience of movable insulation.
- Create thermal breaks at panel and frame connections.

Energy conservation and service system design strategies will include the following:

- Utilize concentrated mass passive heating strategies.
- Recover waste heat from appliances, exhaust air and water systems.
- Match electrical power source to end use.
- Surface mount service distribution systems.
- Optimize floor and roof cavities as chases and plenums.
- Improve flexibility of service distribution and connection systems.

Energy conservation and manufacturing strategies will include the following:

- Site assemble the house in a top-down continuous process.
- Coordinate performance standards among design, component and material options.
- Coordinate dimensions of sites, houses, rooms, components and energy systems.

6.0 ENERGY DESIGN SOFTWARE

The multi-year objective of this research activity is to develop software which increases the sophistication of energy design in the production of industrialized housing. The software should be integrated with the industrialized housing process (design, sales and manufacturing), taking advantage of characteristics unique to the automation opportunities of industrial processes and products.

We are currently working on three approaches to meeting this objective. The first, is the development of a design tool for a panel manufacturer using an existing energy analysis program, Energy Scheming. Future projects include developing an energy module that will be added to existing industrialized housing CAD tools and developing computerized sales tools so that energy decisions can be effectively brought to the home buyer.

This section describes the development of a prototype energy design tool for a stressed skin panel product called R-Control panel manufactured by AFM Corporation. The panel's structural loads are taken by the interior and exterior sheathing layers (skins) which are held apart by a steam expanded polystyrene core which provides the thermal insulation. R-Control panels, like many other similar stressed skin products, are inherently more energy efficient than conventional construction, which utilizes studs, joists or rafters to carry structural loads. These structural elements are thermal weak spots compared to the surrounding insulation.

The R-Control panel energy design tool prototype is built on top of the existing energy analysis program Energy Scheming 1.0, adding a number of features that are particularly useful to a panel manufacturer. For example, the prototype can display on the building drawing the number of panels, their location, specifications, finishes and fastening requirements. We are currently seeking the manufacturer's support to develop the proprietary non-energy aspects of the tool, and are using DOE support to develop the tool's energy features.

The R-Control prototype is conceived as a sales-through-manufacturing tool. The R-Control salesperson would scan a client's drawing into a portable Macintosh

computer, using a hand held scanner, at the client's office. When the drawing is displayed on the computer, the mouse can be used to graphically display the panels required to construct the building. The salesperson can immediately tell the client the cost of the panels and the energy performance of the house in comparison to conventional construction. On the spot changes can be made to the house design to optimize its architectural design, cost of construction, and energy performance. Back at the factory, the R-Control tool could produce material and cutting lists, inventory updates, and shop drawings. The software could also be linked to machine control software to produce panels automatically, as is currently done in Sweden.

The R-Control panel tool meets many of the criteria we established in our report, A Review of Computer Use in Industrialized Housing. It integrates the energy tool with other concerns the housing producer has, therefore, helping to ensure its use. The tool utilizes inexpensive personal computers consistent with trends within the industry. The tool spans from sales to production and recognizes the fact that during the sales transaction many important energy decisions are made. The tool is graphic and easy to understand so that energy decisions can be extended to the home owner who cares the most about energy use, allowing him or her to make tradeoffs between architectural amenity, cost and energy performance. The fact that the tool is being developed for a class of products that are inherently energy efficient, and whose manufacturers "sell" energy performance as one of their product features, helps ensure that the tool will be used to the benefit of the homeowner and the manufacturer.

7.0

MANUFACTURING PROCESS INNOVATION

The objective of this task was to provide a framework for conducting analyses that will allow industrial housing manufacturers and other interested parties to answer questions such as:

- What impact will changes in staffing, process technology, procedures, facility layout, or management technology have on the operation of an existing facility? This impact can be measured in throughput rate, dollars, labor hours, and other selected criteria.
- What are the existing bottlenecks in operations, and how can they best be resolved?
- As the market share for a facility increases, at what production (sales) volume do new bottlenecks arise, and how should they be resolved before they pose significant problems?
- What are the operational characteristics of new (proposed) facility designs and how can they be improved prior to actual construction?

The ability to address these questions can provide strategic and tactical support to organizations contemplating a proactive role in the restructuring of the U.S. residential home building industry. Such a restructuring is, according to some sources, inevitable due to its current fragmented nature. When restructuring occurs, it is hoped that U.S. companies will play a significant role and emerge as the new leaders of an industry that will furnish affordable, energy-efficient, industrialized housing to the U.S. and world markets. Of course, these same capabilities can also help a current manufacturer improve existing operations and hence, be more competitive.

Generic Industrialized Housing Manufacturing Simulator (GIHMS)

Computer simulation modeling is a tool which is commonly used to model complex manufacturing operations. As such, it can provide the framework for conducting the desired analysis and answering the critical questions. The tool is

called “Generic Industrialized Housing Manufacturing Simulator” or GIHMS.

To be effective, the tool must have certain key characteristics:

- It must inspire management confidence. It must be reliable, provide a believable level of detail, show animated system performance and provide output tailored to management needs.
- It must be practical. It must be cost-effective, allow rapid turn-around and not require a simulation expert.
- It must be generic to most industry users. It needs to have the capability to model a broad range of companies and have the capability to model a wide spectrum of improvements: new processes, equipment, layouts, methods, schedules, etc.

The development of GIHMS will be a multi-year effort and requires a number of tasks. GIHMS is being developed using a traditional software development approach including software specification, programming, testing and release. To enhance overall project objectives, two other tasks will be performed parallel to and in support of the specification task: prototype model development and process/equipment data base development.

Efforts to date have concentrated on the specification development task. These efforts focused on developing a better understanding of how simulation might be applied to accomplish project objectives. To accomplish this, we investigated several topical areas:

- How other industries are using simulation to facilitate manufacturing innovation.
- How the industrialized housing industry has used simulation.
- Approaches for developing generic manufacturing simulators tailored to a specific industry.

- The potential use of Quality Function Deployment (QFD) analysis techniques in software development.

The investigation yielded the following results:

- Simulation is widely used over a broad spectrum of industries to evaluate the impact of potential manufacturing innovations.
- Simulation has not been used in the industrialized housing industry. The primary reason is a general industry unwillingness to invest in manufacturing innovations.
- Alternative approaches for developing GIHMS include use of off-the-shelf, commercial manufacturing simulators or custom, research/proprietary simulators. Key tradeoffs include the relative ease of use, low cost, short development time and low risk typically associated with the commercial simulators versus a potential lack of modeling robustness (ability to accurately model a specific operation).

Prototype models will be developed in parallel to the specification development task. The prototypes will be used to provide insight into the relative benefits versus cost of various features, facilitate communication to industrialized housing manufacturers, and test performance of various software packages as platforms for simulator development. A screen from a preliminary prototype model is shown in Figure 7-1. Languages currently being used in prototype model development include SIMFACTORY, a representative manufacturing simulator; SIMAN/CINEMA, a representative general purpose simulation language; and MODSIM, a representative object oriented simulation language.

A concurrent effort is to build an equipment database using an extensive solicitation of equipment information from various vendors. We are using the equipment and processes from the Fleetwood Homes facility in Lakeland, Florida, to serve as a prototype of the database.

Technical guidance of the project task was initiated this period with the installation of a Technical Committee. The committee consisted of: Dennis Conlan of Integri Homes; Inyong Ham from Penn State University; William Nolan, a private consultant; Stephen Parsley of Litton UHS; and John Biegle from the University of Central Florida. Members of the Technical Committee offered valuable insight into the direction of the research task. Key comments included:

“The simulator will play an important role in introducing manufacturing innovations in the industrialized housing industry.”

“Others tasks including development of an improved building system (e.g. basic building blocks) are also critical to increasing the competitiveness of the industry and meeting long term project objectives.”

“Every effort should be made to minimize the “from scratch” software development effort. These efforts typically are costly, require long development times and are relatively risky. A preferred approach would be to build on a commercial simulator or an existing simulator research effort.”

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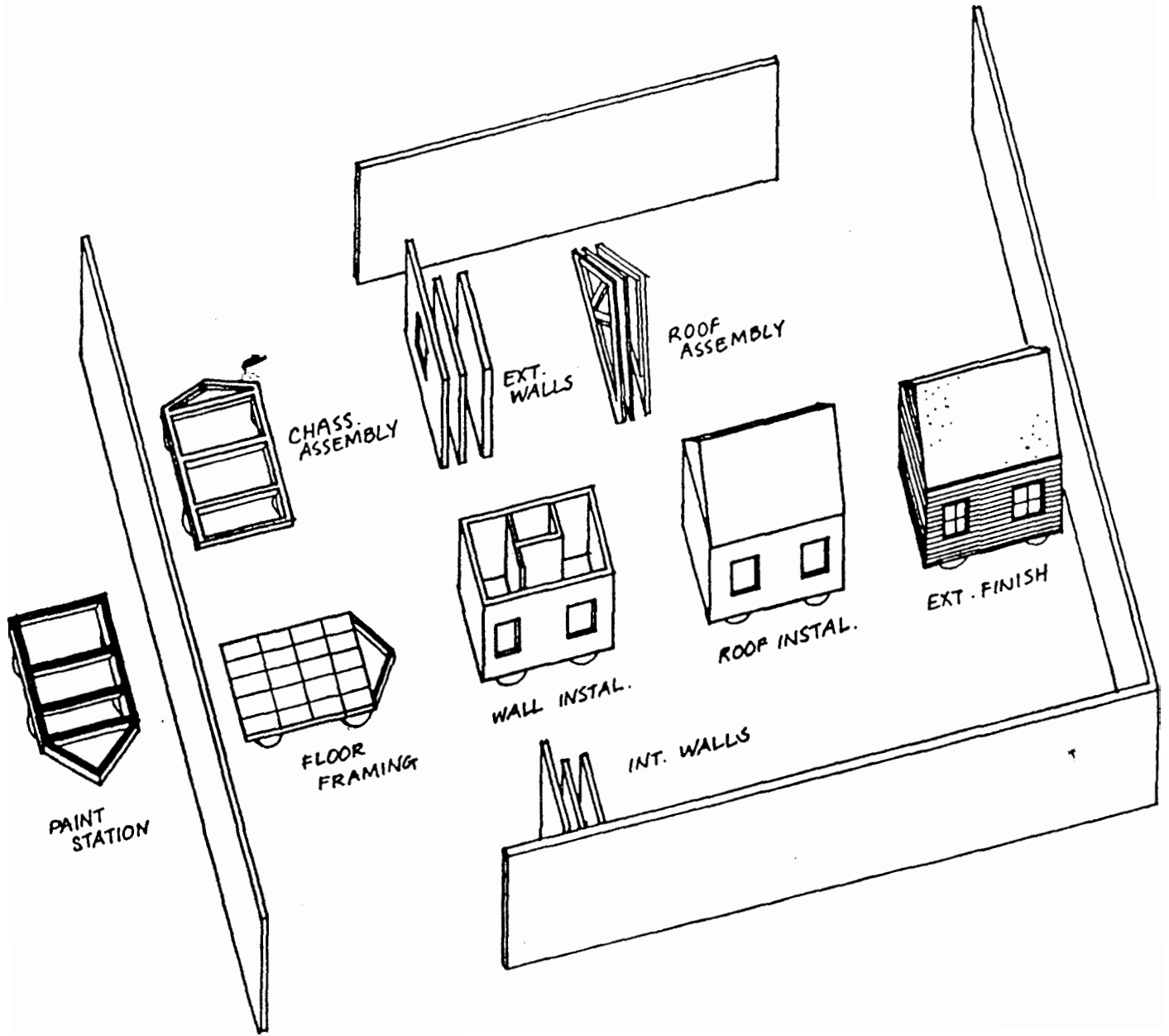


Figure 7-1
Screen from a Prototype Simulation Model
Generic Industrialized Housing Manufacturing Simulator

8.0 DEVELOPMENT OF A DIMENSIONAL COORDINATING HIERARCHY

This section reviews the state-of-the-art of dimensional coordination systems in the U.S. and world housing industries and examines the need for development of a Dimensional Coordination Hierarchy (DCH) for the U.S. housing industry.

A dimensional coordination hierarchy is a system of rules governing the dimensional characteristics and integration requirements of the various constituents that comprise a house. It is a means of coordinating and integrating the processes of designing, engineering, manufacturing and marketing affordable, energy efficient, quality housing in the 21st century.

Quality engineering and home design that respond to the needs of the homeowner implies individuality. In the U.S., this individuality is often assumed to imply a certain incompatibility with the industrial process because it lacks a prime component of efficient factory production -- repetition. The results of this study, however, indicate that it is entirely possible to have two goals of design flexibility and manufacturing efficiency in industrialized housing. Progress toward these goals within the international community, led primarily by the Scandinavians, is moving the European industry rapidly ahead. In addition, the Japanese have also committed their housing industry to the industrial process and are meeting with success.

There is ample reason to support the development of a Dimensional Coordination Hierarchy (DCH) for American housing. First, the timing is right. Although attempts in the past have been only partly successful, we now live in a different era with respect to computer and automation technology. Probably for the first time, we have the widely available technological capability to support the complex nature of this development effort. Second, the nature of what is proposed promotes the economic viability of an important U.S. industry by creating new opportunities. Among these is an increased opportunity to compete in the emerging housing export market.

It is not coincidental that many of the countries that have committed to industrialized housing as a proven technology for controlling costs and improving quality, have also committed to systems of dimensional coordination. The experience of the Scandinavian countries over the past 40 years indicate a number of distinct benefits of dimensional coordination systems, including the following:

- Improvements in design and engineering quality
- Improvements in process and systems integration
- Improvements in building energy efficiency
- Interchangeability of components and systems
- Reductions in manufacturing costs
- Reductions in material waste
- Increased demand for relatively unskilled labor
- Potential to benefit either vertically integrated companies or horizontally dispersed industries

Current trends strongly indicate that the U.S. housing industry is moving steadily toward increased industrialization of the home building process. However, it is occurring in a somewhat haphazard and disjointed fashion. The success of Scandinavian industrialized housing efforts suggest a three-tiered organizing format for coordinating the industrialization process:

- (1) Provide a framework of fundamental design principles and rules for the architectural planning and design process.
- (2) Provide a wide range of guidelines for the manufacture of standard housing materials and components.
- (3) Provide specific details and specifications to guide the design of interfaces between available products and materials.

Results of a world literature review, including European and Japanese research and development, have convinced the authors that dimensional coordination research has an excellent chance of success. Many prototypes have already been developed and used successfully by members of the Scandinavian community. A number of international standards on the practice and principles of dimensional coordination have also been developed.

Although the socioeconomic and cultural issues associated with the development of industrialized housing industries of Scandinavia and Japan differ from the American industrialized housing history, we recommend that the U.S. pursue a similar path of coordinating manufacturing, design, and marketing processes as pursued in those countries. By analyzing dimensional coordination systems developed in other countries and the unique industrialized housing industry in the U.S., the research team hopes to develop a dimensional coordination hierarchy suitable for adaptation in the U.S. housing market. We anticipate that adoption of a DCH will increase global market share of U.S. home builders. Individual companies pursuing and adopting dimensional coordination standards are likely to increase domestic market share by being able to provide custom design and engineering at production home prices.

DCH Concepts for American Manufacturing

Dimensional coordination in building is divided into two general areas: Coordination of Sizes and Coordination of Joints. From these two areas of coordination, standard building components are designed with standard methods of joining them together. Size and joint standards give manufacturers a definitive course to follow in developing new products and give designers a palette of building elements to combine as desired. Manufactured building products vary in degree of complexity from processes building materials to complete houses. In between, a general pattern of combining is apparent:

- Building materials are combined into building components.
- Building components are combined into modules
- Modules are combined into complete houses

The term hierarchy refers to the way simple elements are combined and fabricated into complex products. By focusing standardization and integration of sub-systems at the component level, the designer is given freedom at the module level. Standard wall panels, standard mechanical components, and standard jointing methods provide a menu of options for creating a variety of coordinated combinations of interior and exterior designs. Components of all the sub-systems of a house, including the structural, mechanical and spatial systems, must be coordinated to come together in a defined manner.

A suggestion for basic coordination of the placement of walls on the floor plane is delineated in Figure 8-1. It suggests that a system of priority be established for setting the dimensions of walls and for governing their placement within a module. Primary walls coordination with the horizontal planes would be given top priority, tertiary walls coordination being the lowest priority. The walls on the perimeter of each module are primary walls: loadbearing, continuous from one end of the module to the other. The interior spaces are divided by secondary walls, which tie directly into the primary walls and are continuous from one side of the module to the other, and tertiary walls which tie into secondary walls and are continuous only between secondary walls. By prioritizing which wall has “right of way” at an intersection (joint), the number of joint types is minimized without limiting the flexibility of interior spatial arrangements. If a DCH were in place, standard jointing methods and standard building components would relieve the designer or engineer from the laborious tasks of producing construction details beyond specifying the types of standard components and standard joints to be used. Many conceptual floor plans could be realized with one set of components, affording production repetition while preserving design flexibility.

Figure 8-1

Dimensional Coordination Hierarchy

Figure 8-1 One approach to coordination of wall joining might be to prioritize the placement of wall components within the module. This example shows junctions of primary, secondary, and tertiary walls.

One objective of our task is to develop prototypes which will simplify and integrate all the subsystems needed or desired in a house. One concept toward accomplishing this goal is the “Super Core”. The super core would serve as the central control and housing space for waste, water, power, and energy systems (see Figures 8-2a and 8-2b). But in order for the super core concept or the primary wall concept (Figure 8-1) to work, the sizes of components and their definitive placement in relationship to each other must be guided by a set of dimensional coordination standards.

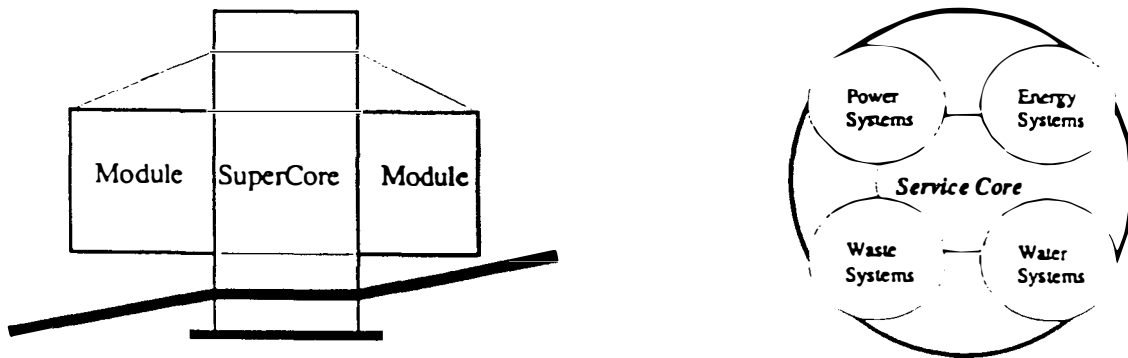


Figure 8-2a and 8-2b

Super Core Systems

Figures 8-2a and 8-2b “Super Core” houses control points for the waste, water, power, and energy systems.

The first step toward designing a dimensional coordination system requires an inventory of the dimensions common in materials and spatial arrangements. From this inventory, a set of dimensional guidelines may be established. These dimensions can be used to coordinate the various systems present in American homes: water supply system, electricity system, HVAC system, waste system, structural system, fenestration system, and spatial definition, among others. For example, closets come in 4 general varieties: linen, cloak, walk-in bedroom, and regular bedroom. These 4 types of closets could be used to divide spaces such as the set of closets dividing the living room and dining room in Figure 8-4. These dimensions can be used to design a simple wall panel set, the constituents of which can be combined to produce most any wall imaginable (see Figure 8-3.).

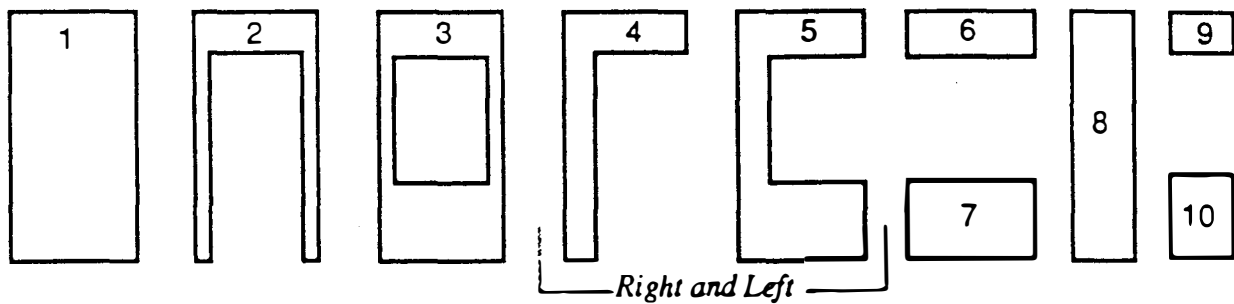


Figure 8-3
Dimensional Coordinated Wall Components

Figure 8-3 A simple set of dimensional coordinated wall components could be combined to form most any wall configuration.

As an exercise, the research team developed a schematic design for a house and began to convert the schematic into well defined modules using the set of above wall panels, the primary wall concept, and the “super core” concept. The result is a three bedroom house that can be built in several phases or all at once. From the “super core”, located between the master bathroom and the kitchen, the water lines, HVAC ducts, and electrical lines radiate to each room. It represents not only a concentration of mechanical control points but a concentration of the house’s major wet areas. Close proximity of kitchen, bath, and laundry limits wasted hot water and simplifies installation of plumbing while also reducing the amount of plumbing needed. The mechanical core, if placed between living and sleeping quarters, could be coupled with a zoned heating, ventilating, and cooling system to produce a more effective return and supply system. By physically dividing the living and sleeping areas of the dwelling, conditioned air could be channeled only to desired areas of the house, reducing the volume of air required by the residents at most times of the day. This measure could cut electricity use and reduce the loads on HVAC units. The extra space in the mechanical core could accommodate new mechanical systems as they develop, such as central vacuum systems, water treatment units, and waste handling systems. This type of use and placement of mechanical components within the building envelope will be an important aspect of improving overall energy efficiency in the coming years.

By using a simplified building process, standardized building components, and established guidelines for achieving quality assurance, the complex task of improving energy efficiency can also be simplified and guided. Once a DCH is in place, energy efficiency can be addressed component by component. This level of development suits the manufactured housing industry in America and can help manufacturers focus on improving energy efficiency in all aspects of home building while providing design flexibility at affordable rates.

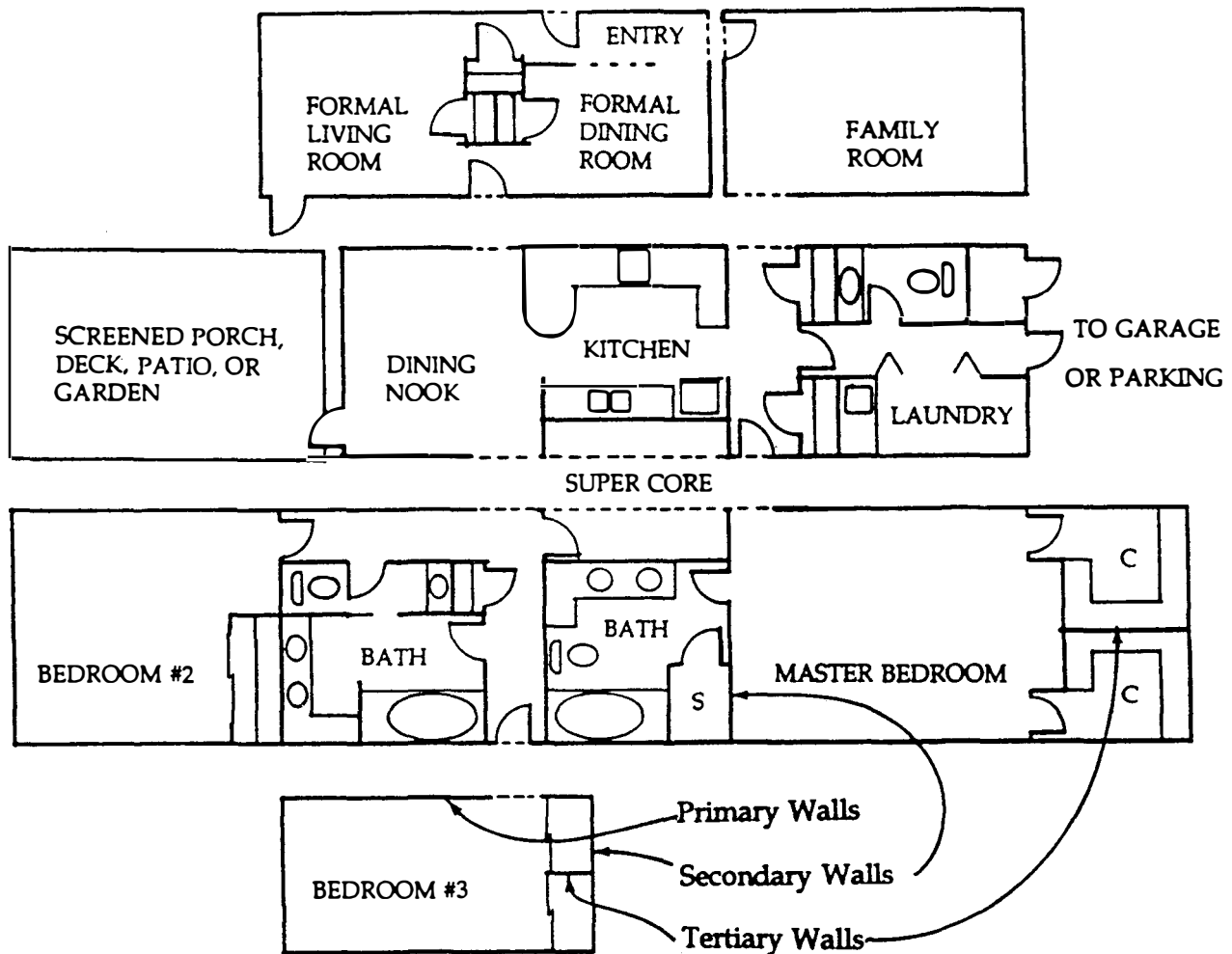


Figure 8-4
Five Module House Design

Figure 8-4 A five module house designed using the concepts illustrated in Figures 8-1 through 8-3 using a basic planning module of four feet.

From top to bottom:

- “add on” module of formal living areas (left)
- family living space (several optional sizes) (right)
- kitchen, laundry, powder room, and dining room all adjacent to the “super core”
- “add on” 2nd bedroom with second bath (left) and master suite with master bath (left);
- “add on” 3rd bedroom.

9.0 CALIBRATION OF THE BOUNDARY LAYER WIND TUNNEL

One aspect of the Energy Efficient Industrialized Housing research project is testing the energy performance of houses at several stages from design through occupancy. The activity described here comprises both field and laboratory studies. Toward this end the project will use the low speed boundary layer wind tunnel to study building ventilation and microclimates.

This section describes progress toward the calibration of this instrument. The tunnel itself is a duct roughly 60 feet long, coupled to a variable speed fan, and shaped to provide a smooth air flow with minimum background turbulence. During calibration this level of turbulence was examined using the tunnel’s three-part set of instruments: anemometry sensors (TSI Model 1066) and electronics, data acquisition system (IDAC-1000 plus custom communication program), and a controlling Macintosh computer.

Initial tests revealed two irregularities: a long (90 second) period air speed variation, and probe oscillations traced to fan vibration. This latter problem was effectively solved by decoupling the fan from the duct; the former, however, awaits further study with flow visualization techniques.

Finding a polynomial fit to the the TSI probe calibration data established that a third- rather than fourth-order solution is adequate for the present speed range, though extending the tunnel’s operating speed range may require editing the programs to include the higher order.

Initial speed measurements in the plane of the test section throat provided data weakened by two factors: possible inadvertent blocking of the air flow by test personnel involved in moving the data probe, and decay of agreement between the control and data sensors to 97% or less. In the absence of other probe calibration facilities, an attempt was made to employ the tunnel itself to recalibrate the sensors. Limited air speed range of the tunnel impeded this effort, but the low range was successfully extended. To date no attempt has been made to extend the upper speed range.

Setup and calibration activities typify the puzzles involved in the reconfiguration of a unique, complex and sensitive test instrument. They also indicate that its overall performance -- particularly the background turbulence level of the "clean" air flow -- is within acceptable limits. Completion of the calibration studies will permit work with the tunnel to proceed to generation and manipulation of boundary layers, and the instrument's incorporation into the EEIH energy testing program.

10.0 COOLING SEASON TESTS OF INDUSTRIALIZED HOUSING SYSTEMS

Industrialized housing manufacturers can utilize evaluation processes to quantify their products' energy efficiency and quality. The two subtasks discussed here present methods to accomplish that evaluation, specifically:

1. Field testing of side-by-side industrialized and conventional house construction systems.
2. In-plant use of high technology test methods (infrared camera) to detect and rectify energy leakage pathways during the home construction process.

10.1 Construction of Prototype Housing Structures

Three small (-200 sq ft) prototype housing structures were constructed at the Florida Solar Energy Center (see photo below). The Base prototype was built of typical 2x4 frame construction; the Dow prototype was constructed of Dow Styrofoam sandwiched between oriented strandboard; and the Dome prototype was built using expanded polystyrene sandwiched between gypsum wall board and a concrete outer shell. The Dow and Dome prototypes shown on the left of the photo are made of factory constructed panels that were assembled on site. All three prototypes were air conditioned with individual window air conditioners and operated such that their cooling energy use was representative of full-scale, occupied houses.

Major results of cooling season tests on the three prototypes are as follows:

- Both industrialized housing prototypes performed better than the Base, showing air conditioning energy savings of 11% to 16%. These results were as expected.
- The industrialized housing prototypes will reduce peak demand on electric utilities by 15% to 23% and will also shift demand to a time more beneficial to the utility. This finding could be of significant benefit to utility demand-side management programs.
- Roof color proved to have an effect on energy savings, with lighter colored finishes providing greater savings.

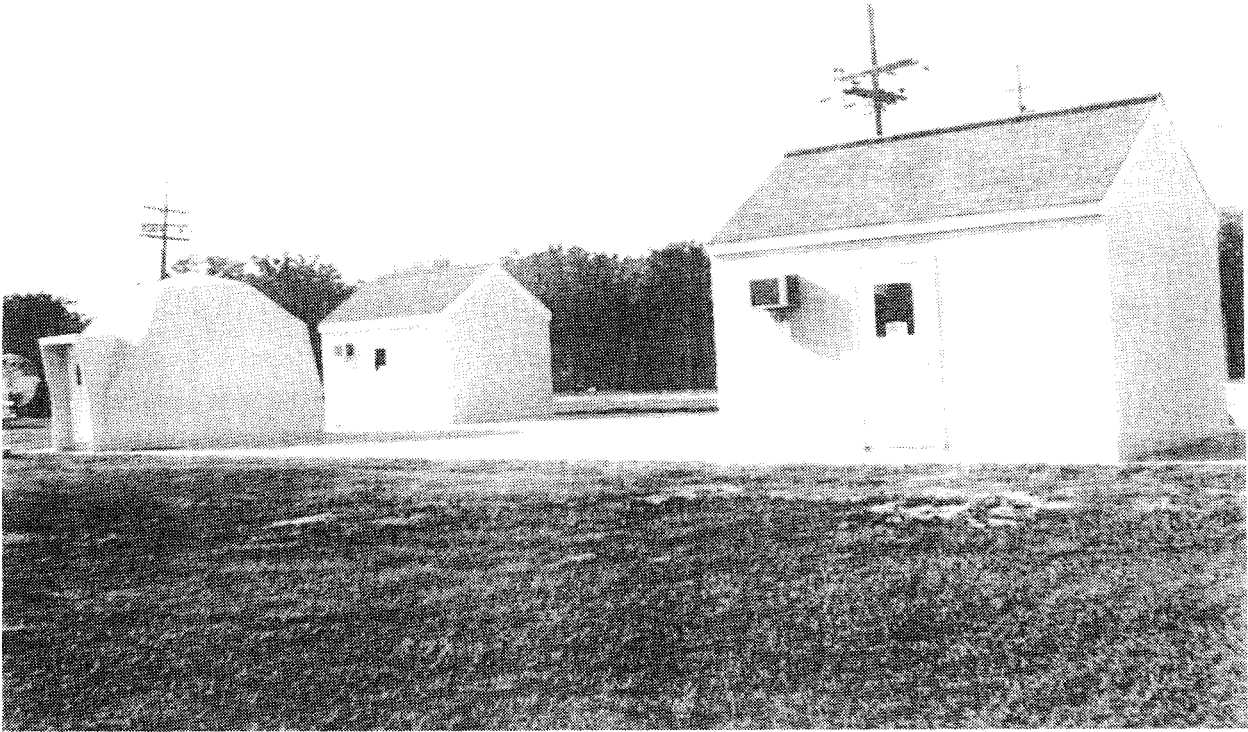


Figure 10-1
Industrialized and Conventional Prototype

10.2 Prototype Testing

Infrared cameras and blower doors were used to detect thermal anomalies in the field prototypes as well as housing modules produced in a manufacturing plant. In the plant, whole house sections were tested as they were air conditioned. For both the field and in-plant tests, the process as well as the infrared images were videotaped. The results of the tests were as follows:

- The industrialized prototypes exhibited air leakage only about half that of the Base. However, all three field structures proved to be very air-tight.
- Infrared tests indicated several minor construction problems for all three structures.

- In-plant testing showed some problems with insulation placement.
- Results of the in-plant testing are being used by the manufacturer to enhance product quality and inspection procedures.

Results of both subtasks have led to the following new projects:

- Development of radiant barrier-lined roofing tiles for placement on the Dow prototype to test for energy savings from innovative roofing materials.
- Refinement of infrared video camera and blower door energy testing through a program titled EQUIP, for Energy and Quality Unit Improvement Program. In 1991, plans are to quantify the cooling energy savings possible from the EQUIP protocol by applying it to production as well as factory-built housing.

11.0 ACKNOWLEDGEMENTS

This summary contains the results of eight projects conducted by numerous teams of researchers. Special thanks and credit is due to these teams who authored and conducted the research activity in the following reports:

An Analysis of U.S. Industrialized Housing

Authored by Rudy Berg, G.Z. Brown, and Ron Kellett. Research team members were Diane Fellows, Marian Fincher, Patrick Gay, Barry McGinn, Matt Meacham, Brook Muller, and Curt Wilson.

A Review of Computer Use in Industrialized Housing

Authored by G.Z. Brown, Margot McDonald, and Matt Meacham. Research assistance provided by Rudy Berg, Joyce Deters, K. Dietrich, Patrick Gay, H. Gebhard, and Brook Muller.

Design for Energy Efficiency

Authored by Ron Kellett, Rudy Berg, Artemio Paz and G.Z. Brown with Michael Mullens, from the University of Central Florida. Research team members were Mark DeKay, Diane Fellows, Patrick Gay, Kristin Harmon, Margot McDonald, Matt Meacham, Brook Muller, Gary Skalangya, Jeff Stern, Curtis Wilson. Design consultants included Virginia Cartwright and Peter Keyes, University of Oregon, Eugene, Oregon; Pliny Fisk III and Richard MacMath, Center for Maximum Potential Building Systems, Austin, Texas; Lance Lavine, Steven Weeks, and Charlie Huizenga, University of Minnesota; Joel Loveland and John Barnes, University of Washington; Michael Pyatok, William Pettus and Daniel Koch from Michael Pyatok Architects, Oakland, California; and Winslow Wedin of Winslow Elliot Wedin Architects Boca Raton, Florida.

Energy Design Software

Authored by G.Z. Brown and Tomoko Sekiguchi. Participation by Premier Building Systems which supplies R-Control panels in the Northwest is appreciated. University of South Florida deserves thanks for serving as a testing site for the software development.

Manufacturing Process Innovation

Authored by Bill Swart, Mike Mullens, Ahmad Elshennawy, Subrato Chandra, Lorenzo Young, Peter Haas and Bing Cai of the Department of Industrial Engineering and Management Systems, University of Central Florida.

Toward the Development of a Dimensional Coordinating Hierarchy for Housing Applications

Authored by Janet E.R. Mcilvaine, Philip Fairey, Subrato Chandra from the Florida Solar Energy Center with M. Emanuel Levy from The Levy Partnership, Inc., New York.

Calibration of the Boundary Layer Wind Tunnel

Authored by C.P. Ryan, Rudy Berg and G.Z. Brown.

Cooling Season Tests for Industrialized Housing Systems

The research could not have been completed without the interest, support and co-funding of the following: DOW Chemical (Mr. Kenneth Franklin, Project Leader) and American Ingenuity (Mr. Michael Busick, President) for the side-by-side tests; and Integri Homes (Mr. Roger Lyons, Owner, and Mr. Dennis Conlan, Engineering Manager) for the in-plant infrared testing. We sincerely appreciate their encouragement.

The infrared tests were conducted, under subcontract, by John Tooley and Neil Moyer of Natural Florida Retrofit. The prototype structures were built by Alan Garnett, Bob Abernethy, Mel Rosencratz, Jay Buckholdt, and Dough Matley of FSEC. American Ingenuity personnel built the dome prototype. We also appreciate the guidance of Philip Fairey in all aspects of this research and Danny Parker in data analysis. FSEC Graphics and Mable Flumm have, as usual, cheerfully provided document processing support. Patrick Robinson prepared documentation drawings.

This summary was edited by Karen J. Johnson and G.Z. Brown. The administrative specialist for the project is Joyce Deters.

