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PROGRESS REPORT

DESIGN FOR ENERGY EFFICIENCY

ENERGY EFFICIENT INDUSTRIALIZED HOUSING RESEARCH PROGRAM

**CENTER FOR HOUSING INNOVATION
UNIVERSITY OF OREGON**

March, 1991

MASTER

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PROGRESS REPORT

TASK 2.1

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**CENTER FOR HOUSING INNOVATION
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**U.S. Department of Energy
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AUTHORS

CENTER FOR HOUSING INNOVATION
University of Oregon

Ron Kellett
Rudy Berg
Artemio Paz
G. Z. Brown

with

Michael Mullens
Department of Industrial Engineering
University of Central Florida

RESEARCH TEAM

CENTER FOR HOUSING INNOVATION
University of Oregon

Mark DeKay
Diane Fellows
Patrick Gay
Kristin Harmon
Margot McDonald
Matt Meacham
Brook Muller
Gary Skalangya
Jeff Stern
Curtis Wilson

DESIGN CONSULTANTS

Virginia Cartwright
Peter Keyes
Department of Architecture
University of Oregon

Pliny Fisk III
Richard MacMath
Sustainable Design Associates
Center for Maximum Potential Building Systems
Austin, TX

Lance Lavine
Steven Weeks
Charlie Huizenga
Department of Architecture
University of Minnesota

Joel Loveland
John Barnes
Department of Architecture
University of Washington

Michael Pyatok
William Pettus
Daniel Koch
Michael Pyatok Architect
Oakland, CA

Winslow Wedin
Winslow Elliot Wedin Architect
Boca Raton, FL

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EXECUTIVE SUMMARY

Since 1989, the U.S. Department of Energy has sponsored the Energy Efficient Industrialized Housing research program (EEIH) to improve the energy efficiency of industrialized housing. 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. Additional funding is provided through the participation of private industry, state governments and utilities. The program is guided by a steering committee comprised of industry and government representatives.

This report summarizes Fiscal Year (FY) 1990 activities and progress, and proposed activities for FY 1991 in Task 2.1 Design for Energy Efficiency. This task establishes a vision of energy conservation opportunities in critical regions, market segments, climate zones and manufacturing strategies significant to industrialized housing in the 21st Century.

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. Findings influential in development of the four problem statements include the following:

Computing and design process

- Computer literacy increases throughout the workforce — establishes opportunities to customize industrialized housing design through computer aided sales, marketing and design, and fully coordinate site installation with manufacturing and design processes.
- Computing capacity increases at less cost — establishes opportunities to design, engineer, assess regulatory compliance, energy performance and cost concurrently, and evaluate energy conservation alternatives throughout design and manufacturing processes.

Manufacturing process

- Products, options and production flexibility increases — establishes opportunities to define flexible manufacturing and dimensional systems accountable to energy performance standards.
- Quality control standards increase — establishes opportunities to improve and confirm compliance with energy performance specifications and assumptions throughout manufacturing.
- Manufacturing innovation will be evolutionary — establishes opportunities to improve energy performance standards as a new manufacturing process is developed and adopted.

Materials, components and systems

- Composite and biomass derived materials develop for construction — establishes opportunities to define the energy performance and manufacturing properties of engineered materials.
- Thermal properties of lightweight materials increase — establishes opportunities to improve thermal resistance and storage in light, thin wall construction.
- Energy systems miniaturize — establishes opportunities to manufacture photovoltaics and space conditioning appliances integral with construction materials and components.
- Mechanical and electrical systems increase integration — establishes opportunities for rationalized service core and space planning.

Energy and the environment

- Demand for conservation efficiency increases — establishes need to realize energy conservation opportunities across a full range of design and manufacturing processes — at neighborhood and site planning design scales, for example.
- Demand for air quality increases — establishes need to develop community and neighborhood planning strategies for less automobile use, and manufacturing strategies for materials and processes of low toxicity.
- Concern for global warming increases — establishes need to develop non-fossil residential fuel sources, increase planting levels and decrease use of chlorofluorocarbon based materials in construction.
- Utility load management strategies increase — establishes need to defer peak load demand and develop means of electricity generation in houses.

Demographic context

- Diversity of household composition increases — establishes demand for flexibility in house size and interior space organization.
- Workplaces decentralize — establishes demand for mixed use neighborhoods and in-house workplaces.
- Migration and growth concentrates in south and west — establishes demand for new housing in predominately cooling climates.
- Population growth concentrates in metropolitan suburbs — establishes need for energy conservation strategies appropriate to multi-family and densely planned single family houses.

Economic context

- Land and infrastructure costs escalate — establishes need to develop energy conservation strategies appropriate to dense site planning, and simplify utility and energy distribution networks.

- Entry level markets expand — establishes demand for low first cost houses that can be remodeled and upgraded.
- Remodel and 'do it yourself' markets expand — establishes need to develop energy conserving materials, components and systems for piecemeal, low skilled installation.
- International markets and competition increase — establishes need for construction systems based on interchangeable components and international performance specifications.
- Construction sector stratifies at national and local scales — establishes opportunity of two tiered construction and energy conservation strategy, parts manufactured and distributed at a national or international scale meet national standards, parts manufactured and installed at a regional or local scale meet local market, climate and utility standards.
- Mortgage alternatives increase — establishes opportunities 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 — establishes opportunities to economically upgrade space conditioning appliance quality, control devices, construction quality and the thermal properties of materials and components.
- Housing affordability incentives increase — establishes opportunities to redefine 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 — 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, for example.
- Performance codes replace prescriptive codes — establishes opportunities for code compliance with innovative passive energy conservation design, engineering and manufacturing strategies.

Many future housing demand scenarios could result from these and other trends acting on the diverse housing markets of the United States. The four 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 — were among those with 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.

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. Superinsulating 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 superinsulating 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.

From the foregoing evaluation, the scope of design study areas narrowed to:

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

The core principles from which design development, evaluation and refinement will proceed in FY 1991 are summarized as follows:

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

Energy conservation and site design

- 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

- 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

- 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

- 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

- 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

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

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

Energy conservation and site design

- Apply passive heating and cooling strategies to constrained sites.

Energy conservation and house design

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

Energy conservation and component design

- 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

- 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

- 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.

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. Industrial processes offer the promise of houses with higher energy efficiencies, higher quality, and lower cost. To ensure that this promise can be met, the U.S. housing industry must begin to develop and use new technologies, new design strategies, and new industrial processes. Yet the fragmentation of the industry makes research by individual companies prohibitively expensive and retards innovation.

The goal of the Energy Efficient Industrialized Housing (EEIH) project is to develop techniques to produce marketable industrialized housing that is 25% more energy efficient than required by today's most stringent U.S. residential codes, at less first cost than present homes.

The multiyear project is funded by the United States Department of Energy, and co-funded by industry. It is conducted by a team from the Center for Housing Innovation of the University of Oregon, the Florida Solar Energy Center and the Department of Industrial Engineering at the University of Central Florida. Leading members of the housing industry serve on a project steering committee as well as several task technical committees.

The EEIH project focuses on the fact that a major impediment to improved energy efficiency in U.S. housing lies not in the components of the product — insulation, heat pumps, improved windows, etc. — but in the processes of design, construction and evaluation. These processes are the focus of work which will be performed in FY 1991-93:

1. Design Process

- Develop house designs for energy efficiency and manufacturability.
- Develop energy software integral with the design, sales and production software customarily used in housing design.
- Develop a dimensional coordinating hierarchy which will facilitate custom design and engineering at production prices.

2. Manufacturing Process

- Develop a manufacturing process simulation and data base to introduce manufacturing innovations to industry.
- Develop guidelines for concurrent engineering and design of energy efficient houses.

3. Evaluation Process

- Develop effective quality control methods (e.g., infrared cameras and blower doors) to find and rectify energy leaks in homes during manufacturing and construction processes.
- Use field tests and laboratory (wind tunnel and artificial sky) facilities to demonstrate the energy efficiency of components and subassemblies to ensure industry and consumer acceptance.

Results of these research tasks are transmitted to the marketplace through construction of prototypes, trade press articles, technical papers, and public presentations.

1.1 PROJECT CONTEXT

Related Research by Others

Research related to this project is currently underway in several areas of the U.S. The project team is familiar with the research goals and methods of the National Association of Home Builders/National Research Council (NAHB/NRC) efforts in technology transfer; GE Plastics' efforts in future materials and integrated subsystems; the efforts of Lawrence Berkeley Laboratory, the Solar Energy Research Institute and Oak Ridge Laboratory related to materials and component development; and Ball State University's collaboration with HUD code and modular manufacturers to improve the design of homes. Working relationships have been initiated and maintained with these and other groups with common research interests in energy efficiency and industrialized construction.

EEIH Research Areas

Through FY 1989-90 the Energy Efficient Industrialized Housing research project was structured around three key research areas, illustrated as circles in Figure 1.1 - 1:

- Area 1: Critical Review of Industrialized Housing, Products and Processes.
- Area 2: Design for Energy Efficiency in 21st Century Industrialized Houses.
- Area 3: Catalysts for Utilization.

Each area includes several tasks, illustrated as rectangles in Figure 1.1 - 1; these are described in detail in Summary FY 1989 Research Activities, February, 1990 and Multiyear Research Plan: Energy Efficient Industrialized Housing, June, 1989.

Figure 1.1 - 1
Research Areas and Tasks
Energy Efficient Industrialized Housing Research Project
 Source: Summary FY 1989 Research Activities

The 21st Century House

Research area 2, Design for Energy Efficiency in 21st Century Industrialized Houses, is directed toward the future — when the energy conservation issues, market demands and manufacturing technologies that will confront the next generation of industrialized housing have emerged and are at work in the marketplace. The assumptions implicit in this 'future' scenario establish both a practical beginning and a focal point for this research.

A common vision is fundamental to the coordination of any large, long term interdisciplinary research project. We are architects, engineers, energy specialists, and technicians working in several research areas on many separate tasks. Each investigates questions of housing and energy conservation from different points of view and at different scales. A common vision focuses the range of discrete but related investigations and methodologies we bring to the project.

The industry and problem we are studying is large, complex and in a transition of unknown duration and outcome. Although we are confident of the opportunity industrialization brings to the housing industry and energy conservation, the forms which that opportunity will assume are unclear. The future scenario provides a window through which we look beyond what we see clearly or understand as energy conservation or industrialized housing issues today, to the potential of what each might become. Once future potential can be glimpsed, opportunities can be defined, interim and short term goals can be established, questions posed, and research activities directed to achieve them.

The year 2030 is not that far away. Researchers must anticipate the time in which the products of their research will be commercially viable. New knowledge and technologies realized through research underway today may not have commercial impact for many years. The historical record of design and technological change in industry suggests that the diffusion of innovation is a long term process. An average of nine years has been estimated as the lag time between awareness or

knowledge of innovation to its recognition, passage through the decision making process and ultimate adoption (Rogers, 1986: 2:292). In mature industries such as housing and construction, that delay may be as long as 45 or 50 years (Ventre, 1980: 11:314).

Working toward the future can also be a way to achieve immediately useful ideas and products. As long range questions and ideas are developed and tested, short term "spin-off" ideas and products are discovered at the same time (Osborn, 1963: 95 - 97). There is also evidence that government sponsored research in particular consistently generates commercially viable innovation and significantly accelerates the diffusion of knowledge and technology. Government sponsored research in energy for application to residential construction is a particular case in point (Brown, Berry and Goel, 1989: 30-31, 55-56).

1.2 RESEARCH AREA CONTEXT

Figure 1.2 - 1 describes the relationship between Task 2.1 and other tasks in Research Area 2. In this diagram the top bar, Task 2.1, illustrates four annual cycles of design studies between 1990 and 1993. Each cycle includes a series of design studies and concludes with prototype house designs that can be evaluated against project goals. At the conclusion of each design and evaluation cycle, significant findings and questions can be inventoried and diverted to other research tasks in the area. Other findings that are immediately useful or realizable can be diverted to dissemination efforts in Research Area 3, Catalysts for Utilization.

Figure 1.2 - 1
Relationships Among Tasks of Area 2:
Design and Energy Efficiency in 21st Century Industrialized Houses

1.3 TASK CONTEXT

Research undertaken in Task 2.1, Design for Energy Efficiency, develops and applies industrialized housing concepts suited to the markets, materials, processes and designs with commercial potential in the 21st century. Prototypes for houses that integrate these concepts will be designed, built and tested in collaboration with industry. Through the prototype development process researchers will establish energy efficient designs and manufacturing and construction strategies that optimize the balance between marketability, site opportunity, design quality, energy efficiency and production cost.

The scope of this task is formidable. The U.S. housing industry and its markets are large and diverse. To streamline and focus this scope, we have concentrated our initial effort in this task on single and small scale multi-family houses in markets, climate zones, design contexts and construction types that suggest significant future energy conservation opportunities.

1.4 REPORT OBJECTIVES AND ORGANIZATION

In 1990, the first year of this task, we generated design problem statements for three single , one multi-family and family houses in four climate zones, three market levels, four manufacturing and construction strategies. Section 4., the core of this Progress Report, summarizes the eight design studies that were initiated to explore energy conservation and manufacturing opportunities within these problem statements. These eight studies were evaluated and two selected for further review and refinement. Section 5 presents an inventory of key energy conservation principles and innovations culled from all the design studies and applicable to the two selected.

It is also important to understand the future context to which these design studies respond. Section 3, Housing and the 21st Century, presents an overview of the forces that we anticipate will shape housing in the next century.

Other sections of this report place this work in context with other tasks and milestones of the project. Section 2, Methodology, describes the process through which the problem statements and design studies were derived. Section 6, FY 1991 Activities, describes the evaluation and refinement process that follows design studies.

2.0 METHODOLOGY

The research goal of this project is both comprehensive and open ended — 'Develop techniques to produce marketable housing that is 25% more energy efficient than required by today's most stringent building codes at less first cost'. The goal concerns the performance of whole houses, inclusive of the economic, technological and market forces that shape their demand and utilization of energy. This overall goal is understood, but more specific hypotheses related to it cannot, at the outset, be better defined or separated from one another. No amount of data, measurement or analysis will change this situation.

In response to this we have developed, for Task 2.1, a research methodology based on the iterative process of architectural design -- define what is known of the problem, propose alternative solutions, evaluate each, and redefine the problem from the knowledge gained. This methodology recognizes that specific research hypotheses cannot yet be stated with precision, comprehensiveness or priority. They must instead be identified and defined through an effective trial and error process.

Like the project research goal, design problems are typically broad missions of ambiguous scope and structure. Neither specific goals nor the means to achieve them are evident. Critical questions, parameters and criteria are not readily apparent and must be coaxed into view. Consequently, the initial phase of any design process is one of defining the limits of the problem, identifying the hypotheses to be tested, establishing their requirements and specifying the criteria for meeting them.

In this methodology, the process of designing houses — defining and resolving the many interacting variables that form a house — generates the hypotheses that can be researched, analyzed and evaluated quantitatively. Moreover, the research team can always visualize and

assess their effort and progress in context. As conclusions emerge and new energy conservation hypotheses formulated, they can be tried and tested 'in place' with other design, manufacturing and economic considerations. When and where appropriate, the effort can be redirected or redefined in response.

2.1 THE 21st CENTURY HOUSE DESIGN PROBLEM

A first stage in this process defined the range of issues and trends anticipated to motivate or significantly influence housing design, energy conservation and manufacturing in the year 2030. These were described as future trends in topical area reports. Based on these trends a second stage defined what impact these might hold for housing. Trends and impacts were linked with one another to create scenarios of future housing and energy demand. We then added additional criteria and detail to create problem statements. A third stage developed design studies that respond to the questions and specifications of each statement.

Figure 2.1 - 1 diagrams the process of deriving design studies in this task area. Future trends and impacts identified in seven topical area reports are combined with architectural variables and criteria to form four problem statements which, in turn, become design studies. Each process and its methods is described in detail below.

Figure 2.1 - 1
Stages in the Derivation of Design Studies for Task 2.1 in FY 1990

Topical Area Reports

What issues and trends might the coming decades bring to housing design, manufacturing and energy conservation? What, for example, will characterize the housing and energy priorities of people and communities? What kind of houses will they need? Where will they be needed? Of what materials will they be made? How will they be produced? How will they be marketed and purchased?

To inform these questions a comprehensive search and analysis of future oriented literature searches was initiated in the following seven topical areas:

- Industrial process
- Design process
- Materials, components and systems
- Demographics
- Economics
- Energy and environment
- Planning, policy and regulation.

Drafts of the topical area reports were circulated to experts in each area for review and comment. Section 3 of this report summarizes the findings of the topical area reports.

Problem Statements

Trends identified in literature searches and summarized in topical reports were not applicable to all segments of the housing market, all parts of the country or all components of the house. With an objective of systematically and rigorously determining trends that will likely occur concurrent with others, a study was undertaken to identify trends which might act cumulatively or in concert to significantly influence design, construction or energy demand in particular regions, market segments or design scales. In this study, trends identified in each topical area were considered across eight scales of housing design. At each scale we asked, "How might this trend affect energy conservation?"

Figure 2.1 - 2 illustrates a portion of the combinatorial matrix through which these considerations and evaluations were made. Across the horizontal axis were listed approximately 55 trends distilled from seven topical areas. Along the vertical axis were listed scales of housing design and energy conservation from neighborhood to component.

		Topical Area Trend 1	Topical Area Trend 2	Topical Area Trend 3	Topical Area Trend 4
GROUPS OF HOUSES	NEIGHBORHOODS				
	STREETS/ COMMON OPEN SPACES/ HOUSES		IMPLICATIONS FOR HOUSE DESIGN/ENERGY CONSERVATION/MANUFACTURING		
	HOUSES/SITE OPEN SPACES				
HOUSES	ROOMS				
	FOUNDATIONS				
	ENCLOSURES				
PARTS OF HOUSES	OPENINGS				
	MECH./ ELECTRICAL SYSTEMS				

Figure 2.1 - 2
Assessing Design and Energy Implications of Topical Area Trends

Working in group discussion sessions, we then diagramed the potential consequences of a particular trend intersecting a particular design scale and summarized the results. As this process was repeated, points where trends and design scales frequently converged or linked with one another were identified as potential topics of design studies.

While several potential housing scenarios could be identified in this process, four in particular represented market segments, construction innovations, energy demands or climate zones projected to be significant in the energy conserving industrialized housing future. These included:

1. A starter house for a hot-arid climate: a low-cost, entry level multifamily house for high growth western sun-belt states.
2. A move-up house for a hot-humid climate: a "state of the art" upper medium cost, single family house for high growth southeastern sun-belt states.
3. A renewable house for a temperate climate: a "do it yourself" remodel and addition kit for wood houses in the northwest.
4. An extended family house for a cool climate: an economical single family house for suburban infill sites in northern states.

These problem statements and the rationales for selecting these combinations are discussed in the introduction to the corresponding subsection of Section 4, Design Studies.

Design Studies

In the interests of exploring a diversity of ideas in a very short period of time, eight schematic design studies were initiated to respond to these problem statements. Two were undertaken by members of the Center for Housing Innovation. Six others were undertaken by outside design consultants (professional architects and engineers) selected for their expertise in energy conservation, housing design and industrialized construction and familiarity with regional climates and housing markets.

Evaluation and Refinement

Each design study has been reviewed against criteria specified in the problem statement. This design/evaluate process will be reiterated annually. With each evaluation, we will reconsider and refine the assumptions, scenarios and criteria defined in the problem statements. Research hypotheses and the studies they inspire will be added, expanded, dropped or combined with one another until the best ideas and questions can be identified and inventoried. Immediately achievable conclusions, innovations and ideas will be diverted to Research Area 3, Catalysts for Utilization. Ultimately promising multi-family and single family prototypes will be developed for construction and testing in greater detail.

3.0 TRENDS AFFECTING HOUSING IN THE 21ST CENTURY

Defining the design problem for the 21st Century House is, in part, a matter of predicting the future — an age-old activity with a decidedly mixed record of success. One of the safer assumptions of this phase of the project was this: much will change on the way to 2030. We could not assume that the housing needs, economic factors, building materials and systems, etc. of the future will be those of today. A major preliminary task in developing the design studies presented here was to develop valid descriptions of the housing needs to be met, pertinent circumstances and forces which would influence the designs, and promising methods and materials to explore.

The range of influences on design is considerable. Energy consumption in houses, for instance, is the consequence of many interacting variables — among them climate, siting, design, materials, production quality and occupancy — that establish energy demand and performance. Accordingly, we considered energy conservation as an important element of the *whole* house and its site, inclusive of the market, design and production variables that shape its energy characteristics.

This section of the report sketches some of the forces expected to shape housing demand and production into the 21st century. Discussion of these forces is presented by topic roughly in order of their degree of direct influence on the energy conservation, industrialized construction and design focus of the project. Included are discussions of future materials, systems and components; design processes; manufacturing processes; energy and environment; demographics; economics and planning, policy and regulation.

3.1 MATERIALS, SYSTEMS AND COMPONENTS

The materials, systems and components used to build houses profoundly influences their character and availability. This section includes a discussion of general trends in the industry, followed by more detailed examination of the chief residential building materials: concrete, wood, plastics and their derivatives. Next is a survey of significant energy conserving systems and components including insulation, windows and electrical and heating, ventilation and cooling (HVAC) systems.

As the construction industry adopts increasingly processed and engineered building materials, its products will become more reliable and will achieve broader levels of performance. These new products will be safer for the environment, incorporate more recycled ingredients, extend the effective quantity and quality of our natural renewable resources, and maintain a greater variety of engineered performance capabilities. Some new materials may be capable of changing in response to their environments (Amato, 1990).

In addition, the need to provide high quality, affordable housing will continue to drive the construction industry's reexamination of manufacturing processes, construction materials, and components. New products and houses themselves will reach the market under the guidance of "... international standards, directives, and product certification ... [and] use of metric units of measurement in the building industry as a means of wider industry participation in the international market place" (Building Sciences, November/December 1990).

3.1.1 Building Materials

Concrete

Concrete, traditionally a simple mixture of sand, stone, cement and water, is now becoming a complex and sophisticated product. The properties of concrete can be tailored to modify its density, thermal conductivity, strength, curing time, hardness, etc. Concrete supplements and admixtures, including industrial by-products such as fly ash and slag, can increase strength and reduce embodied energy and cost.. Cost effective lightweight concretes can be made with perlite and vermiculite to achieve thermal resistance properties of $R=.55$ to 1.4 per inch at 50 pcf, and compressive strengths of 880 - 1000 psi (Construction Specifier, 1989). Concrete's thermal storage ability will continue to influence its use, even in lightweight buildings.

Autoclaved Cellular Concrete

Autoclaved cellular concrete (ACC) is a lightweight building material developed in Europe. It differs from other types of concrete in that it contains millions of bubble-like microscopic cells generated during the manufacturing process. ACC is cured through an accelerated process (full strength in 24 hours, not 28 days) that produces lightweight rigid panels or blocks. Lightweight ACC can be cost effective in both reducing labor cost and conserving heating and cooling energy. It typically achieves thermal resistance properties of $R=1$ to 1.6 per inch for densities of 31 - 44 pcf, and strengths of approximately 600 - 1000 psi. The embodied energy of ACC is approximately 550 KWH/ton while that of materials with similar characteristics— clay brick, for example— is 1300 KWH/ton (Pytlík and Saxena, 1989).

Glass Fiber Reinforced Concrete

Glass fiber reinforced concrete (GFRC), a material used to produce thin panels and complex shapes, has several characteristics that make it amenable to industrialized construction. Dimensional stability, water and fire resistance, and elastomeric finishes create a building material

easily attached to steel or wood studs. GFRC has applications in shingles, corrugated roofing and wall panels (Prestressed Concrete Inst., 1987: 4).

Inorganic Bonded Wood Fiber Composites

Development and production of cement bonded wood composite materials, marketed as sheathing, siding, roofing, etc., has increased dramatically in the past two decades. In the future, recycled cellulose will contribute to the materials available for making cement composites (G. Davis, 1991). These products have good fire ratings and structural characteristics, and can offer reduced weight when combined as wood wool-perlite cement boards (Shigekura, 1988).

Composites of gypsum and cellulose fibers (in some cases from recycled newsprint) have emerged as drywall systems. In the U.S., Highland American manufactures a product developed by TORVALE—SASMOX, a Finnish producer of gypsum fiberboard, while Louisiana Pacific also offers a similar product. These gypsum fiber boards can also be modified with impregnated perlite for moisture resistance (Odom, 1990).

Wood Products

The timber industry has developed a variety of products derived from previously noncommercial species and from the low-density, fast growing trees that replace old growth timber (McDonald, 1990).

Sawn lumber as a structural commodity will be replaced by synthetic engineered wood products (Wilson, 1990). These new products spring from a technology that reconfigures wood flakes, splinters, veneer or fibers into structural "sticks" (e.g. Parallam, Arrowood, wood I beams, glulams, laminated veneer lumber, etc.) and sheets (oriented strand board, flakeboard and particle board are recent examples). "Manufacturers say . . . they have greater control over strength,

dryness, visible defects, and dimensional stability" (McDonald, 1990). These engineered/reconstituted wood products have profoundly influenced the construction industry. They are very strong and can be produced in long lengths, as well as in familiar forms and sizes compatible with the traditional 2 x 4 system, and permit use of existing carpentry techniques and tools.

Stressed skin panels manufactured from synthetic wood product sheets fused with plastic foam cores have created a promising system for house construction. These panels integrate structure and enclosure in the same element. They expedite site assembly in applications as foundation walls, floors, exterior walls and roofs.

Several U.S. manufacturers produce variations of wood sheathed stressed skin panels. Bellcomb Technologies markets a kraft paper honeycomb core panel. Fiber reinforced cement panels have been incorporated by Supradur Canada, Inc.. The Pyramod (California) system employs a panel of compressed straw sheathed with kraft paper and finished with vinyl stucco or elastomeric coatings.

Plastics

The high cost of plastic materials, compared to woods and metals, will be offset by their formability (Oak Ridge National Laboratory, 1988). The General Electric plastic home demonstrates plastic used as structure, siding, shingles, sinks, counters, door frames, light fixtures, plumbing pipes and windows, ". . . complex compounds . . . made to order for specific tasks." (Time, 1990). Materials such as acrylics, polyesters and polycarbonates, with improved flammability and aging characteristics in addition to higher structural strength, provide alternatives to glass glazing systems (CYRO, 1990).

3.1.2 Building Components and Systems

Insulation

Fiberglass continues to be the primary insulation material used in the housing industry, although that preference may change with health considerations. Hybrid foam insulations and other foam products which employ blowing agents without the ozone destroying properties of chlorofluorocarbons (CFCs) are approaching the performance of CFC blown insulations (Building Sciences, Nov/Dec 1990).

SERI's compact vacuum insulation (CVI)— a thin stainless steel envelope containing a vacuum, with thermal resistance properties of $R=52$ per inch (potentially $R=100$ per inch) — may have significant housing industry potential (SERI, 1989). Another vacuum based insulation (Vacuum Powder, with $R=50$ per inch) is being researched at Oak Ridge National Laboratories.

Several new systems feature concrete that has reduced thermal conductivity and added design flexibility. Thermal Wall System (Sioux City, Iowa) and the Ener G Block (Seattle, WA) typify products which integrate concrete with insulating foam panels or blocks. Steel reinforcement and exterior/interior finishes can be incorporated with the foam units for walls and foundations. Panel systems such as Amofam (Ames, Iowa), and Struc-Forms (Venezuela) create self-supporting walls and roofs from wire reinforced foam cores finished with field applied plaster or stucco surfaces. Recently, fiber composite connectors have been developed to replace steel connections in concrete and foam sandwich walls, substantially reducing thermal bridging (Wade, Porter and Jacobs, 1988).

Windows

The energy performance of windows is improving rapidly. Indeed, "... windows may soon provide as much insulation as the walls [in which] they're mounted" (Park, 1989). Among the

top performers are Ventilator Windows ($R=6$, triple glazed with ventilation air drawn from two outer panes), Switchable Glazing (an electrically charged film changing from clear to a silvery reflective surface), Aerogel Windows ($R=5-7$; a transparent insulating gel between layers of glass), Evacuated Glazing ($R=10$, a system with 2 panes of glass one centimeter apart, low emissivity film, and a partial vacuum in the interpane space) and Vacuum Gel ($R=20$ per inch). The Vacuum Gel window senses internal and environmental conditions and automatically adjusts to change -- a "smart" material that could have significant impact on the housing industry (IEA, 1989).

Electrical Systems

Electronic innovations continue to improve the quality of light fixtures and their power systems. The traditional 110v lighting system may be supplanted by a low voltage system (Lee, 1987: 90-91). Improved electronic ballast, dimming systems and occupancy sensors are producing greater energy efficiency (Dosch 1990: 2-4), while light fixture manufacturers are continuing to produce more energy-efficient lamps.

Heating, Ventilating and Air Conditioning (HVAC) Systems

HVAC units of the future will combine space conditioning functions similar to the Total Environment Control system used in the GE Plastics house: "The unit combines heating, air-conditioning, humidifying, water heating, and air filtration — with the potential to add on heat recovery and ventilation modules — in one fairly compact piece of equipment" (Binsacca, 1990).

Footings and Foundations

Several products and emerging technologies now make it possible to construct energy conserving lightweight footing and foundation components. Ener G wall (polyurethane), Econo-Forms (polystyrene), and RASTRA (recycled styrofoam and cement) are unitized block systems that integrate foundations with building walls that bear on poured concrete footings. Interlocking concrete masonry units such as IDR Footer Block and permanent wood foundations (PWF) offer

footing and foundation options by utilizing a compacted rock support base in lieu of a poured footing. All these systems can be insulated to higher levels than conventional concrete and concrete masonry foundation walls.

3.2 DESIGN PROCESSES

The process of designing industrialized housing encompasses a broad range of issues endemic to manufacturing, engineering, and architecture. The dominant trend in industrialized housing design, however, is that of computerization. The general trends of computerization are outlined here, followed by three possible scenarios for their impact on the design of U.S. industrialized housing.

Computerization

The computer industry is projected to continue development of systems with increased capacity at less cost in all size ranges (Bajarin: 5; Yoder and Schlesinger: B1). 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.

Distributed systems, wide area and local area networks (WANs and LANs) that connect microcomputers with mini and mainframe computers, greatly enhance the capability to share data and central processing units (CPUs) as well as increase the prevalence of electronic communication (Scientific American, 1990: 16-19, 100-101; Caswell: 20). Networking provides collective computing power that will facilitate efficient resource allocation and the ability to work on complex projects that involve business management, materials and resource planning, factory floor operations, design, engineering, inventory, sales and marketing (Kellso, 1989: 19-28).

These trends in computing and manufacturing will result in increased and more sophisticated computer use by U.S. industrialized housing companies. If this occurs, there will be several potential impacts on the design process and the house. Computerization is already occurring in many firms through engineering and design departments. The greatest impact is therefore likely to occur with the design process and its relationship to the product generated in this environment. Within industrialized housing this impact is likely to follow one or more of the following scenarios.

Scenarios for Increased Computerization: Supplier Model

There is growing dependence on manufactured products such as windows and trusses in the construction industry. Designers and builders incorporate standardized units into buildings because of cost, quality control, and scheduling benefits. Already some aspects of this industry have been computerized. In addition to using computer-aided design (CAD) for engineering calculations and product development, designers and engineers also select products from electronic catalogues often using CD-ROM or electronic networks. Product data, specifications, engineering calculations, material takeoffs and CAD interfactable files aid the designer and builder in integrating the product with the design process and production. This aspect of computerization has yet to reach full potential for use or integration (Heichler: 16).

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. Modular components which have existed at a small scale (e.g., cabinets) will be joined to create larger modular assemblies. Kitchens, bathrooms, entertainment centers, and mechanical rooms will become like pieces of furniture with integrated supporting walls. These "furniture-rooms" will provide their own acoustical and visual privacy.

Kitchen and bathroom equipment will take on a more component-like character. These systems would also offer a sales advantage, allowing customers to design their own kitchens or baths. Feedback on energy/water use of these systems could be a part of the software supplied for the consumer.

Modularization will increase integration between components used in house design and will play a key role in design process. Designers will be able to work from a finite palette that allows virtually infinite variations. As the available products attain modular dimensional stability around a standard, their use will simplify space planning.

With a palette of modular components, consumers will be able to design their own "furniture-rooms" which will allow great flexibility in house floor plans. Even after occupancy, remodeling can be simplified because overall building dimensions would also be based on a standard module.

In addition to the flexibility inherent in modular systems, computerization of more technical aspects of design could make it possible to evaluate consumers' house plans in terms of regulatory (i.e., life safety), mechanical/electrical, cost, and space planning efficiency issues. Inexpensive software for fire hazard already exists for microcomputers, allowing a consumer to evaluate the safety of a particular design (New Scientist, Sept. 1989: 36; High Technology Business, Nov. 1987: 68).

CAD/CAM Vendor Model

Existing integrated computer-aided design/computer-aided manufacturing (CAD/CAM) software systems which already perform routine engineering calculations and material takeoff will evolve to become more inclusive, forming a strong link between design, 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 the materials in common use. Integrated Computer Graphics is one vendor offering a CAD/CAM package.

Because these calculating software systems will evolve in a production/engineering environment, material and labor processes will be optimized instead of the architectural design of the product. While modular components dictate the dimensional aspects of the house in the supplier model, a more open ended dimensional approach will prevail in the CAD/CAM vendor model. Efficient material usage in design and production would result from software used in this application. In design, evaluation of skin areas, fenestration, and perimeter slab losses, based on climate and building loads/occupancy type could be performed at the design process stage (Huang, et al: 786-797). As computer systems are developed to optimize energy performance, there may be a parallel development which optimizes energy use through the adoption of new materials and other innovations.

The co-evolution of more sophisticated engineering design in conjunction with the progressive development of components may result in the creation of details which could contribute to developing new architectural designs. In the automotive industry for example, simultaneous development of the engineering methods and materials to produce frameless glazing directly influenced automotive styling.

Innovative materials that require intensive engineering calculations may become more accessible to the average producer/customer due to the availability of computing power, CAD/CAM, and expert systems. Examples of materials that may change the way buildings are detailed include industrial strength velcro (High Technology Business, Mar. 1987: 9) and super adhesives (Heppenheimer: 56-58).

A process called stereolithography can make plastic 3D models from computer models (CAD data files). "3D (company) is marketing stereolithography not directly to manufacturers but to CAD vendors -- who presumably, will offer the new capability as an option on their high-end systems." (Brody, July 1987: 63).

Japanese Model

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. This approach is currently being pursued by NV Ryan.

It will be easier to accommodate design variations requested by customers, through computerized changes to drawings. This may lead to "kits of parts" whose variants are known and materials requirements can be predicted. Expert systems will verify that proposed changes meet fire, structure and energy code requirements.

The consumer, working with a sales representative, will be able to trade off size vs. cost (and other performance criteria) of the house in an iterative process until an optimum mix is achieved. This may result in room sizes that are very different from "average homes" but which meet specific consumer needs.

Increased pressure to design within a limited set of component configurations may result in a body + chassis approach to house design in which many structural/mechanical/electrical components are the same for a given model, while the architectural styling varies.

Computer design processes allow more emphasis to be placed on design variation requested by customers. Extending this flexibility to multifamily housing would make possible individual units configured to meet specific customer demands -- perhaps a variation on the supports and infill approach (Habraken, 1972).

3.3 MANUFACTURING PROCESSES

This section identifies major trends in manufacturing and develops a number of potential scenarios for the future of industrialized housing based on these trends. Two types of trends are noted—general trends impacting all manufacturers globally, and trends specific to industrialized housing manufacturers.

3.3.1 General Trends in Manufacturing

Total Quality

A commitment to total quality is a necessary (but not sufficient) condition for survival in the 1990's (Crosby, 1979; Deming, 1982; Juran and Gryna, 1980; Fiegenbaum, 1983; Schoenberger, 1982). Fundamental elements of the total quality concept include:

- Commitment to making it right the first time.
- Each individual assumes responsibility for the quality of his/her own work.
- Each individual has one or more customers and recognizes that the quality of output is measured by the degree to which it satisfies customer needs.
- Management assumes responsibility to provide systems and training to enable each individual to perform at his highest capacity.
- The commitment to quality should be extended to vendors.
- Quality should be designed into all products and manufacturing processes.

Manufacturing Cost Reduction

Manufacturing costs must be cut dramatically and must continue to be cut (Seal, 1989; Tompkins, 1989). Cost cutting must focus on more than just direct labor. It must also address materials and overhead items such as facilities, equipment, supervision, inventory control, quality, downtime,

etc.. For example, Continuous Flow Manufacturing (CFM) and Just In Time (JIT) supply are similar concepts which focus on the elimination of waste (Schoenberger, 1982). Waste is defined as any element of the manufacturing process that does not add value, and includes excess materials (raw materials, work-in-process, finished goods), excess manufacturing cycle time (sitting in storage queues, set-ups, etc.) material handling, etc.. Fundamental elements of the CFM/JIT concepts include:

- Each individual assumes responsibility for eliminating the waste that he can control.
- Recognition that this is not a one-time process but a continuous improvement process.
- A production lot size goal of 1.
- A machine set-up time goal of 0.
- Elimination of uncertainties such as machine downtime, vendor quality problems, off-standard parts, etc.
- Product oriented "focused factory" lines or cells.
- Immediate identification of off-standard conditions and their correction.
- Flexible work-force and continual adjustment of line balance to meet production requirements.

Manufacturing cost reduction is supported by several tactics: eliminating excess overhead by consolidating operations, adding mechanization/automation to increase capacity, and closing redundant plants (Tompkins, 1989).

Market Sensitive Product Line

Another key trend is the continued evolution from a narrow, standard product line to a more market driven range of choice. To maintain customer acceptance manufacturers will need to offer more options, allowing customers a higher degree of flexibility and customization (Tompkins, 1989).

Manufacturing Flexibility

Associated with the need for a more market oriented product line is the need for increased flexibility in manufacturing (Seal, 1989; Tompkins, 1989) — flexibility to manufacture a family of products with high quality and cost efficiency, and flexibility to efficiently accommodate changes in production volume as product and markets change.

Flexibility must extend to operations/processes, facilities and labor. Note that the trend toward flexibility has implications for the level and type of automation to be considered. Manufacturers are no longer willing to let the economies of hard automation drive marketing because it means cutting back options. Alternatives to hard automation include limiting automation in general or providing softer automation, often in the form of flexible manufacturing systems (FMS). Flexible manufacturing commonly refers to systems of machine tools which allow parts to flow automatically from any machine to any other machine. This allows a high degree of manufacturing flexibility in comparison to a conventional transfer line where parts must move through a fixed sequence of machining operations.

Concurrent Engineering

Another key trend is the emergence of a more systematic, methodical and comprehensive product development process. Termed concurrent engineering (CED) or simultaneous engineering, the process is an approach to product development which integrates product and process design. Both functions are performed concurrently and are dependent on one another (Branson, 1990; Winner, 1988). The objectives of CED are to:

- Design products that the market demands.
- Design quality into all products and processes.
- Design products and processes which are as simple and flexible as possible.

- Design products which can be efficiently fabricated, assembled and tested.
- Design products with minimum lead time between initiation of product development and manufacturing start-up.

CED relies on multi-functional teams including representatives from marketing, engineering, manufacturing, support and purchasing. The team is asked to start with a clean slate with respect to materials and processes. If the existing manufacturing process is reasonably flexible, the product development may not require a major process redesign. If not, the manufacturing process may need to be reconfigured. CED will typically require significant increases in product development costs. However, product life-cycle cost savings will more than pay for the additional development costs (Tompkins, 1989).

Automated Manufacturing

A major long term trend is that manufacturing operations are becoming increasingly automated (Brody, 1987; Krouse, 1987). Automation ranges from full computer integrated manufacturing (CIM) systems to stand alone automated subsystems including processing equipment, material handling equipment, test equipment, production and inventory control systems, design systems, etc.. However, there is a growing recognition that automation, even integrated automation, does not necessarily improve manufacturing productivity. Automation often entails a high degree of risk (Nag, 1986). In response to these potential pitfalls, most companies have adopted a more pragmatic approach to automation. Termed modular automation, it focuses on automating in controlled, manageable phases (instead of the full blown automated factory). Using this strategy, most manufacturers are increasingly using a blend of automation, mechanization and manual techniques. Automation is used only where it makes the most sense, given the associated complexity, cost and risk factors involved (Cullinane, 1989).

Foreign Competition

A final trend, which appears to be driving many of the other trends, is the increasing penetration of non-U.S. manufacturers into the American market. European materials and components are increasingly common here — in cabinets, skylights, and building materials, for example. Although current Japanese housing costs are much higher than comparable domestic housing costs (measured in cost/square foot), the Japanese have shown a willingness to subsidize exports at the expense of their domestic customers.

3.3.2 Trends in Industrialized Housing Manufacturing

A number of major trends are already impacting manufacturing operations in the industrialized housing industry and may continue into the next century.

Shift to Industrialized Housing

Real cost savings and quality improvements continue to drive certain market segments toward industrialized housing. Although industrialized housing manufacturing employs some production methods similar to site-built construction, the controlled manufacturing environment, economies of scale and efficiencies of the assembly line can reduce construction costs and provide superior housing (Nutt-Powell, 1985).

Advanced Manufacturing Technologies in Construction

Major research efforts are underway to investigate and demonstrate the applicability of advanced manufacturing technologies in construction and industrialized housing. Technologies include:

- Computer technologies such as computer integrated database (Smeallie and Zitzman, 1987), integrated design workstations (Smith, 1987), CAD/information database integration (Smeallie, 1989), construction process simulation (Construction Division),

CAD/CAM prefabrication system (Warszawski, 1986), and computer integrated design (Mathur and D'Cruz, 1986).

- Robotics applications such as: robot control using graphics simulation (Bernold, 1986); interior finishing by robot (Warszawski and Navon, 1987); construction robotics (Verschuren and van der Eijk, 1987); construction applications (Bock 1987); large field robotics (Paulson, 1984); task-oriented robots (Blackman, 1987); on-site robotics (Cusack and Earl, 1988); smart construction machines (O'Brien and Compton, 1987); "Mark II" robot (Tanaka, et al, 1986); Wallbots (Slocum et al, 1987).
- Expert systems such as "The Brickwork Expert" and "The Metal Stud Partitioning Expert" (Cornick and Bull, 1987).

Implementation of these technologies may further advance cost and quality advantages of industrialized housing.

Acceptance of Technological Advances in Construction

Compared with other industries, manufactured housing makes only marginal use of technological advances. Volume is not high and production lines are not highly mechanized (Nutt-Powell, 1985). A variety of mechanized and automated equipment and systems have been identified for possible use in manufacturing industrialized housing; however, it does not appear to be widely used (Branson, 1990; Elshennawy and Swart, 1989). Furthermore, there does not appear to be widespread management acceptance of the basic principles of world-class manufacturing: total quality, continuous flow manufacturing, concurrent engineering, etc. A related point is that there is a serious lack of management concern for adopting new technology and for resolving customer complaints (Connors, 1988).

While technological innovation in housing manufacturing processes have lagged behind other sectors , innovation does occur. These innovations involve practical line extensions of existing processes, resulting from solutions to problems encountered in the field (Goldberg and Shephard, 1989). There has also been considerable innovation over the last three decades involving systems, subsystems components and assemblies. (NAHB-NRC, 1989). Housing component systems have been adopted by most industrialized housing manufacturers and are becoming increasingly popular with site builders as well (Branson, 1990). In general, innovation in industrialized housing manufacturing appears to be focussed on subsystems and components, such as trusses and wall panels, instead of on the house as a whole.

Obstacles to Manufacturing Improvement

Underlying the slow acceptance of technological advances is a set of obstacles which impede improvements in manufacturing. Government support of research and development programs which are needed to foster an environment conducive to technological innovation has lagged (OTA, 1986). Building codes vary from state to state, even county to county (Branson, 1990). The housing industry is composed primarily of a large number of small contractors. Most of the contractors do not operate with economies of scale sufficient to absorb significant R & D and capital costs.

3.3.3 Future Scenarios

The trends described above may lead the housing industry to a range of future manufacturing scenarios, three of which are described in this section. These scenarios are based upon two underlying assumptions. The first is that manufacturing processes for fundamentally different construction materials/techniques will not be integrated into the same manufacturing system. Examples of materials and techniques unlikely to be combined into a single construction system include wood panels, steel frames, ceramic panels, and plastic structural components. Second,

central final assembly lines supported by feeder sub-assembly lines will continue to be the most effective, cost efficient method to manufacture homes.

Scenario One: Evolutionary Change/Continuous Improvement

Manufacturers will continue to make evolutionary rather than revolutionary changes to their manufacturing systems. There will be no order-of-magnitude improvement in the form, quality or cost of industrialized housing. Evolutionary improvements will occur over a period of time. In this scenario several corollaries follow:

- There will be no major changes in material technology which will render existing manufacturing systems extinct. Change will continue to occur and will be integrated into existing systems without significant retooling — for example, improved insulating materials.
- Manufacturers will be reluctant to invest in high levels of automation in order to improve quality and productivity.
- Management will invest in proven, low cost automation whose cost effectiveness is clearly demonstrable. Installed automation will not be integrated with other systems, but will instead take the form of "islands of automation."

Scenario Two: Revolutionary Change/Automation

Manufacturers will upgrade their manufacturing systems, automating and integrating design, processing and material handling operations. This revolution in manufacturing strategy may be motivated by foreign competition or domestic investment incentives. The key impacts of this scenario will be higher quality, more energy efficient housing provided within short lead times at a lower unit cost. In addition, the manufacturing system will be more flexible enabling it to

efficiently accommodate design variations within a prescribed range. Negative aspects include high capitalization and a reduced capability to cut variable costs during market downturns and some loss in production flexibility associated with automation. Elements of this scenario include:

- Computer-aided design (CAD) systems will be driven by customer orders. The system might be integrated to the extent that it becomes a computer-aided-sales/design system, providing design options and costs directly to the potential customer. CAD features will include expert system support of the design process with respect to design feasibility, cost and energy efficiency, generation of architectural and structural drawings and development of a bill of materials which can be passed to a Manufacturing Resource Planning (MRP II) system.
- Computer-aided process planning (CAPP) systems will be driven by input from the CAD system. CAPP features will include the determination of material, process, machine, and tooling requirements and the development of process plans which detail how the house will be made. Process plans will include material routings and operations sheets detailing operations at each workstation.
- Manufacturing Resources Planning (MRP II) systems will be driven by input from the CAPP system. MRP II features will include development of material procurement and manufacturing schedules to meet order commitments and to fully utilize manufacturing resources.
- Operations control systems will be driven by CAPP and MRP II systems. Operations control will direct all operations on the manufacturing floor. This will include direct control of automated processing equipment, robots and automated material handling equipment. Where automation is not applied, the system will provide indirect

control to the operator through computer terminals (portable or stationary) or printed action documents. The system will also be responsible for maintaining real time location and status control for all materials and work orders on the manufacturing floor.

- Computer-aided manufacturing (CAM) systems will be driven by the operations control system. Modern computer numerical control (CNC) machines and robots will perform manufacturing operations where technologically feasible and cost effective. Potential applications include: cutting/sawing, drilling, assembly (nailing, fastening, gluing, welding), finishing, and machine loading/unloading (stacking/destacking).
- Automated material handling systems will be driven by the operations control system. The system will store, move and stage materials between manufacturing workstations.
- A Just-In-Time (JIT) based manufacturing strategy will minimize the materials on the manufacturing floor and will keep the materials that are on the floor moving. The manufacturing layout will support the JIT strategy and will minimize material movement.
- Material handling will be automated where technologically feasible and cost effective. Potential applications include automated electrified monorail, power and free, or automated guided vehicle (AGV) for panel handling and powered conveyor or AGV for small parts handling.

Scenario Three: Incremental Change/Outsourcing

Manufacturers will outsource more components at higher levels, thereby reducing their level of vertical integration. An example of this phenomenon is the auto industry, where major

manufacturers have outsourced 70% of the components of a typical product. Tighter industry standards will facilitate this process. Key housing components will be manufactured in "focused" factories, dedicated to manufacture of a narrow line of components. Small, focused factories will produce components of higher quality and lower cost than those of large, vertically integrated manufacturers.

The focused factory concept will encourage capital investment, since it can be amortized over higher production levels. Total capital investment for any manufacturer will be kept low, reducing vulnerability during market downturns. Large scale manufacturers can down-size their operations including facilities, labor, etc..

3.4 ENERGY AND ENVIRONMENT

To assess the impact of future energy and related environmental concerns for housing design and production in the 21st century, we explore several topics: U.S. energy trends, future energy use, environmental trends, economic influences, processing and information, and house and community design. In the context of each of these categories we look at the effect of amount, type, and timing of energy use.

U.S. Energy Trends

A recent study by the U.S. geological survey estimates that U.S. reserves of oil and natural gas will last only 16 and 35 years respectively. (Science, 1989: 1330). Despite present conservation efforts, foreseeable long range supply problems will increase U.S. dependency on foreign oil (which presently supplies roughly half of what we use — ASES, 1989:3), and draw attention to alternative energy sources.

The U.S. Department of Energy estimates that the annual influx of currently accessible renewable resources in the U.S. is 250 times the country's annual use of energy (Brown, L. R., et al., 1990, p.176). Renewable energy use is increasing, however, with hydropower accounting for about 40% of this segment. The non-hydro capacity, a result of the enactment of the 1978 Public Utility Regulatory Policies Act, provides over 9,500 MW of non-hydro renewable capacity (Radar, 1989: I-2).

Future Energy Use

By the year 2000, world energy consumption is expected to increase some 55% -- the equivalent of 3.8 billion tons of oil — despite a reduction in energy intensity of some 20%. The U.S. will still account for one-fifth of world energy demand in the face of conservation and more efficient use of energy in transportation and in industrial and residential markets (Hedley, 1986: 5, 58).

Natural gas will become the dominant world fuel in the 1990s, capturing over 60 percent of the world energy market by about 2030 (Carlsmith et al.:35). Coal production, consumption, and exports by the U.S. coal industry had a record breaking high in 1988, and current projections call for continued increases over the next few years (EIA, Nov. 1989:3). Hydropower will remain the chief source of renewable energy in the year 2000. A main advantage of hydro is its high energy conversion efficiency — up to 80%, compared with efficiency rates of 30% for other power sources (Hedley, 1986:164).

The most significant increase (52%, in projected end-use energy demand) consists primarily of solar and renewable energy, although it starts from a relatively small base (Office of Buildings and Community Systems, 1:4.5). Renewable technologies are likely to contribute at least 14 quads, or 15% to 19% of projected energy needs by the year 2000, and up to 80% of the national annual demand for energy in the year 2010 (Radar, 1989: II-1, I-3).

By 2010, the primary energy consumed in the U.S. in residential and commercial buildings is predicted to be 39 quads, as compared with current usage of 27 quads. 20-30% of this could be saved with the use of cost-effective, energy efficient technology (Office of Buildings and Community Systems, 1: 4.2). Well designed buildings can reduce energy consumption by up to 60% over buildings designed to standard practice, while reducing life-cycle and operating costs and often first costs as well (Pacific Northwest Laboratory: v).

Environmental Trends

Despite uncertainty over the magnitude of climate change from an increase in greenhouse gases, there is a scientific consensus that increased levels of greenhouse gases will cause a change in climate. Presently the buildings sector generates about 25% to 30% of global CO₂ emissions (Norberg-Bohm, 1990: iv,1).

Scientists anticipate that a buildup in the atmosphere of certain carbon, nitrogen, and chlorine compounds will change the earth's climate more over the next 50 to 75 years than it has changed over the last millennium and a half. The most worrisome compounds are released from coal, oil, and natural gas. NASA has projected a 10 percent depletion of the ozone layer by the middle of the next century. "According to the EPA, such a depletion could result in nearly 2 million additional skin cancer cases each year, damage to materials such as plastics and paints worth as much as \$2 billion annually, as well as incalculable damage to crops and aquatic life" (Postal, 1986: 5).

Future vehicles running on methanol will emit 80 percent less hydrocarbons than their gasoline powered contemporaries. On the other hand, these vehicles would emit much more formaldehyde - a smog-forming toxic air pollutant and animal carcinogen, and the fuel would cost more per gallon. (Lessen, 1990: 21). As a result methanol would yield no reduction in greenhouse emissions, but could substitute for gasoline as a fuel source.

Policy has been influential in cutting sulfur oxides emissions by 28% between 1970 and 1987 and particulates by 62 percent (French, 1990: 29). To continue to address air pollution, energy, transportation, and industrial questions, policy structures must be reoriented toward prevention (French, 1990: 28). "Improving energy efficiency is a clean air priority. Such measures as more efficient refrigerators and lighting can markedly and cost effectively reduce electricity consumption, which will in turn reduce emissions" (French, 1990: 31). Public policy in certain cities has made projections to reduce pollutants to the air. Toronto, for example, has committed itself to reducing emissions 20 percent by 2005. Los Angeles has plans to have 10,000 electric vehicles in operation by 1995 (Lessen, 1990: 22,23).

Environmental concerns — acid rain and the potential for global warming — have heightened public awareness about the importance of energy conservation in the economy. "A 1988 Gallup poll revealed that fully 54% of the American public favors emphasizing the development of solar energy before all other energy supplies to meet energy needs. Only 12% supported the development of nuclear power first. The poll also shows that half of the public would rather use energy more efficiently than produce more energy" (Radar, 1989: I-5). Awareness of environmental problems is causing changes in public policy towards energy, including energy use taxes, initial purchase taxes, utility least-cost planning, appliance standards, building codes, consumer information and marketing, and research and development (Norberg-Bohm, 1990: v).

Coupled with strict environmental requirements, pressure will increase to achieve efficient energy management and the development of low-pollution technology. Renewable technologies are far safer than nuclear power and pose less significant or no toxic waste disposal problems. (Radar, 1989: I-4). Nuclear proponents, however, are using the greenhouse effect and an increase in electricity demand from 28.8 percent to 36.3 percent (Balzhiser, 1990: 184) to make a pro-nuclear argument.

Economic Influences

"Future fuel prices are even more uncertain than implied by the volatility of past prices, because of the likelihood that environmental controls will increase" (Carlsmith: 26). Experts predict that a seller's market will return by the turn of the century, potentially reinvigorating OPEC and stimulating another round of geopolitical turmoil (Miller, 1986: 5). From 1988 to 2010, residential energy is predicted to increase from 10.83 (1988) dollars per million BTU to 16.45. During the same period, the Real GNP is predicted to increase from 4001 billion to 6871 billion, and the population to increase from 245.6 million to 287.8 million (Carlsmith: 53).

Processing and Transportation

Materials for buildings are major users of energy in their extraction, refining, processing, adaptation for usage, transportation, and installation. It has been estimated that 20% of a buildings' energy use over its lifetime is attributable to the energy embodied in its materials (Stein, 1977: 91 & 92). As the efficiency of building operation is increased, the percent of a building's total energy use that is attributable to its materials will probably increase.

An increase in energy cost would influence people to consider mass transit, the purchase of energy efficient cars, and possible moving closer to the work place, or moving the work place to home. If the price of oil stays low, the vehicle stock turnover will increase due to greater economic growth, placing more energy efficient cars on the road, decreasing the amount of energy consumed (DOE, 1989, p 29). As the years progress, the vehicles on the road will continue to be made up of those with a higher mpg, decreasing fuel consumption (EIA, 1989).

House and Community Design

A combination of the trends that have been discussed will result in decreased use of fossil fuels, especially those that contribute to global warming and pollution. Residential buildings as major

consumers of energy will probably increase the efficiency of their fossil fuel use and replace fossil fuels, especially in electricity production, with renewable fuels.

Peak electrical loads will be spread toward off peak hours. Two secondary effects may become important: building construction will impact energy use in the manufacturing sector and housing location will impact the transportation sector.

The effect of these energy strategies on house and community design is examined from three perspectives: What parts of the house will be affected, how will the size of the parts be affected, and how will the relationship between the parts of the house be affected?

Walls, floors, and roofs will help reduce energy use through increased thermal efficiency. They may incorporate thermal mass, to offset cooling peaks and store heating energy. They may use passive ventilation systems and materials, adhesives and fasteners made of materials that will reduce accumulation of indoor air pollutants. There will be increased emphasis on systems and assembly techniques which reduce infiltration. Chlorofluorocarbons (CFCs) will be eliminated in foamed insulation. The thickness of the building envelope is likely to increase to accommodate increased insulation levels unless higher performance insulations are commercially successful.

High R-value windows will be the norm. There will be improved thermal performance of the window frame and rough opening assembly. Shading will be more critical due to increased thermal integrity of the envelope and likelihood of overheating. Daylighting will be a more important strategy as internal loads will dominate residences' thermal performance. Windows are likely to increase in size, be higher in the wall and be oriented to the south in climates with a heating load.

Rooms may become smaller or rearranged to minimize house envelopes, increase the opportunity to collect solar energy or encourage ventilation. Passive heating and cooling strategies may dictate room arrangements. Zoning of the house for thermal considerations may become important.

Heating and cooling systems will decrease in size as a result of reduced envelope loads. Distribution systems may be reduced due to open planning and decreased heat loss and gain at the envelope. Heat recovery from ventilated air will continue to be important. Controls will be occupant and time of day sensitive. Cooling will become a more important consideration due to global warming. Operation on more than one fuel type may become important.

Non-incandescent sources will dominate residential lighting. Controls will be integrated with daylighting strategies to reduce peak loads. Photovoltaic generation and cogeneration may become viable residential strategies.

Water will likely be solar or heat pump heated. Reduced water use at fixtures will result in down sized heating systems and diminished heat loss. More careful attention may be paid to plumbing installation and vent penetrations through the envelope.

There may be major changes in the way neighborhoods are organized to accommodate work, shopping and living in the same area, reducing transportation needs. Mass transportation routes may become a more important determiners of city form.

3.5 DEMOGRAPHICS

This analysis of the demographic context of the 21st century house sets out to identify and assess those population trends and changes likely to influence its design and energy consumption. Of particular interest are those trends that influence the planning and density of communities and

neighborhoods, the size and character of residential sites and the houses on them, and organization and emphasis afforded various spaces, rooms, functions and equipment.

History is instructive on these questions. In the first two decades of this century, for example, houses were large and subdivided in order to accommodate an extended family. Sometimes as many as three or four generations would live in one spatially divided house. In the 1930's and 40's the next generation demanded houses that were quite different in design and density. Changing family structure and an economic depression brought smaller and increasingly standardized houses located in densely planned neighborhoods. As houses became smaller, previously well-defined rooms gave way to spatially efficient open zones of activity. Once a labor intensive service room at the physical and social perimeter of the house, the kitchen evolved into a room of energy consuming machines at the core of the house, an important social center for an increasingly active and mobile family. With post-war prosperity, houses again increase in size and move farther apart. Two car garages and the first family rooms appear adjacent to kitchens in the new houses of the late 1940's.

Making similar assessments about the future is, however, more difficult and predictions will be by definition imprecise. There are significant demographic trends that will provide context for the design tasks of the project. Recent research indicates ongoing change in the contemporary house for the remainder of the century. In addition to aforementioned change in the equipment, size and spatial enclosure of kitchens, demographic trends have also influenced the range of functions and sizes of rooms common in houses. Demand for large flexible bedroom / bath areas and work / study spaces, for example, has become increasingly common. Adult couple spaces in houses at the middle and upper end of market in particular have undergone profound change in size and appointment. Master bedroom areas have almost doubled in size, become more private, more equipped, more compartmentalized and more self-contained (Hasell, Peatross, 1990).

Outside the house proper, the zoning and physical differentiation of private house as separate and

distinct from public space has become more definite. Neighborhoods have become more frequently comprised of similar kinds of families leading similar kinds of lives (Rock, Torre and Wright, 1981). Lots have become smaller, garages have become bigger and the public realm of the house has moved from front to back yard.

Household Formation and Composition

At the close of the 1980's there were approximately 91.1 million households in the United States (U.S. Bureau of the Census, P-20 No. 432, 1988). While a majority continue to be the traditional married couple with children living in a single family house, there have been and will be important shifts. Since households of different compositions and ages choose different types of houses, demographic trends in the rate of household formation; average household size; household composition; and aging will shape the housing and energy demands.

Change in Rate of Household Formation

Housing demand is largely dependent on the propensity of the population to form households. The last fifty years has seen steady growth in both household formation rates and housing demand (Hughes and Sternlieb, 1989). Although population growth rates have steadily declined, the rate of household formation continues to exceed the rate of population growth, albeit to lesser degrees than has been the case in the past.

The rate of household formation increased about 2 1/2% in the 1970s, slowed to about 1 1/2% in the 1980's, is expected to decline to about 1% in the 1990's and further decline through the beginning of the 21st century (Holloway and Peach 1988). These periods saw the 'baby boom' generation (individuals born between 1945 and 1964) come of house buying age and create strong demand for new housing. The number of households in the 35-44 age group, for example, grew 38% to 19 million in the 1980's (Waldrop, 1989) largely as a consequence of the aging of the baby boom generation, changing attitudes toward marriage, and the increased frequency of divorce.

These and other trends precipitated a period of high rates of household formation during which housing starts regularly lagged behind demand.

Not far behind the baby boom, however, is a "baby bust" generation. This group will soon be of house buying age and the rate of household formation will decrease. Since 1982, housing starts have exceeded household growth. The two were approximately equal at 1.5 million each in 1987 after which housing starts surpassed the rate of household growth (Hughes and Sternlieb, 1989). Factors of pent up demand for low cost housing aside, there will be a demographically motivated decline in demand for entry level houses and some risk of over-building as this baby bust generation moves more fully into its household formation and house purchasing phase.

Change in Household Size

On average, households are getting smaller. Two parent families are declining both in number and as a proportion of all households. Families are having fewer children later in life and the number of persons living alone is increasing.

In 1987, the average number of people per family was 2.66 compared to 3.67 in 1940 (Cetron, Davies, 1989). While this increase in the number of small families has been significant, there has been an equally significant decline in large two-parent families. The number of families with three or more children was at a thirty year low of 11% in 1983 (Burns, Grebler 1986).

While the majority of persons continue to marry at some point in their lives, there is evidence to suggest that they will be doing so later and possibly at lower rates than they have in the past. The number of adults in their late twenties and early thirties who have not married has increased substantially. Households headed by 15-24 year olds, for example, have declined 20% in number while the marriage rate for these ages dropped 38% in the 1980's (Waldrop, 1989). Those who marry later tend to have fewer children (U.S. Bureau of the Census, P-25, No. 432, 1988).

Although some have simply postponed marriage to advance careers or education, others will be indifferent toward marriage through the rest of their lives. The longer marriage is delayed, the greater the likelihood that it may never occur. The percentage of adults who will never marry may eventually be higher than ever before.

Changes in Household Composition

The composition of both family and nonfamily households is diversifying and the proportional mix of family to nonfamily households is shifting. Over the period 1970 to 1985, more than half of all new households were nonfamily and only about one in four were the traditional husband / wife household. Married couple households declined from 70.5% of all households to 58.1%. Both the number of families with no spouse present and the number of births to unmarried women increased (Holloway and Peach, 1988).

There was a 90+% increase in the 1980's for non-family households in the 35-44 year old age group (Waldrop, 1989) and 25% of American family households are headed by single parents. The majority of these families are headed by women, half of whom have incomes below the poverty level (Anthony, 1990).

Toward the end of this century however, married couple households are anticipated to represent a greater proportion of new households than was the case in the 1970's and 1980's. Through the 1990's, for example, over half of the new households are projected to be family households with about one third projected to be married couple households (Holloway and Peach, 1988):

Changes in age distribution.

In addition to a steady trend of declining total population growth, the age structure of the population fluctuates dramatically. The pattern is one of a baby boom generation followed by a baby bust generation. Some analysts have estimated that as much as one third of the difference

between the growth rate of the population and the growth rate of household formation between 1960 and 1986 is attributable to shifts in the age structure of the population (Hendershott and Smith, 1985).

In the 1950's, the number of individuals under 16 years of age increased by about 35%, nearly double the growth rate of the population, prompting substantial suburban housing growth as well as demand for new primary and secondary schools. In the 1960's, the number of individuals aged 16 to 24 increased by nearly 50%, prompting substantial growth in college and university capacity. During the 1970's, the 25 to 34 age group experienced similar expansion as they formed independent households and stimulated demand for new housing (Holloway and Peach, 1988). Early into the 21st Century, middle aged and retirement age households are similarly going to increase. More than 13% of U.S. population in the year 2000 will be over age 65 — twice the percentage that was this age in 1940 (Scheel, 1986).

The generation following is much smaller in number. By the turn of the century, for example, the number of individuals in the 25-34 household formation rates will have returned to pre-baby boom levels, a decline of over 30% from the 1980's (Holloway and Peach, 1988) decreasing the number of young, prospective home buyers.

It is also likely that there will soon be 'two generation geriatric' families. The rise in life expectancy of the elderly implies that more of the 'young' elderly (persons in their 60's and early 70's) will have extremely elderly parents. These families may have both parents and children who either live together or nearby or require some form of care (Morrison, 1990).

Population Concentration

As changes in household growth and composition influence housing demand and design, shifts in the distribution and concentration of population influence the location and density of new housing.

While it is predictable that housing starts will tend to cluster within certain regions and metropolitan areas, specific regional population trends cannot be forecast with much reliability beyond eight or ten years (Morrison, 1990). Regional futures are determined or altered by the inherently unpredictable fluctuations of regional economies and employment demands. The rapid economic rise of energy producing Texas and Oklahoma, for example, precipitated unprecedented population growth in those states until world energy prices collapsed and the trend reversed almost as quickly. Uncertainties notwithstanding, there are discernible patterns of population migration and concentration strong enough to influence housing demand and energy use in the next century.

Regional Migration

More than 20% of U.S. households change residence each year. Most of these moves have resulted from employment or the changing needs of the household (Feldman 1990) and have created localized housing demand in a number of regions. Long-term regional economic projections by the Bureau of Economic Analysis of the U.S. Department of Commerce indicate that regions of the country that grew relatively quickly or slowly in recent history will continue to do so into the 21st Century (Garnick, 1983). The fastest growing regions will be the coastal states of the West and South, all of which are projected to grow approximately 2.5% per year. Of that regional growth, California will be the largest and fastest growing single jurisdiction in the West; Texas, Florida and Georgia will be the largest and fastest growing jurisdictions in the South (U.S. Bureau of the Census, P-25 No. 1039, 1989).

Housing demand will be most acute in the Sunbelt (states below 37° N. Latitude) of the South and West (Holloway, Peach 1988). These areas have experienced a full two-thirds of the nation's recent population growth at about four times the rate of the remainder of the country (U.S. Bureau of the Census, P-25 No. 1039, 1989). These states have also seen and will continue to see growth in manufacturing and other forms of employment (Garnick, 1983) well into the 21st century (Blackburn, Bloom, 1988).

Population growth will be faster in the South and West than North and Central regions of the U. S. Immigration continues to decline in areas of the Northeast where population will grow modestly or stabilize. This area leads the country in proportion of households with two earner couples at 42%. The proportion of households living below the poverty line is lower in the Northeast than in other regions, although these areas also have the highest housing costs (Blackburn, Bloom 1988).

Elderly retirees will continue to emigrate to the warmer, lower cost of living areas of South and West, while the numbers of young households will persist or grow in the Northeast. However, if housing costs influence future migration patterns as much as employment opportunities have, then younger households will likely migrate from the high cost Northeast to lower cost regions.

Metropolitan and Nonmetropolitan Area Growth

The U.S. is becoming increasingly urban. Since 1950, the percentage of the population living in metropolitan areas increased from 56% to 77% in 1987. Reversing a trend established in the 1970's, the metropolitan population grew twice as fast as the nonmetropolitan population. By the end of the 1980's, nearly one half of the population lived in 37 metropolitan areas of 1 million or more. The highest metropolitan population growth in the nation during the 1980's was the metropolitan West. California is now 96% metropolitan and Arizona 76%. In the South, Florida's population is now over 90% metropolitan, and Texas 81% (U.S. Bureau of the Census, P-25 No. 1039, 1989).

There were about 61 metropolitan areas experiencing growth at approximately twice the national rate over the last decade. All were in the South and West, most in the hot-arid, hot-humid climates of the Sunbelt. The fastest growing large city overall is Phoenix with an annual growth rate of 30%. Second is Dallas-Fort Worth. Of the remaining eight in the top ten, seven are in Florida and six of these are resort retirement communities. The fastest growing metropolitan area in a cool

climate is Minneapolis / St. Paul at 9.3% followed by Grand Rapids and Kansas City (U.S. Bureau of the Census, P-25 No. 1039, 1989).

Central City and Suburban Growth

Of the 70% of the population that resides in metropolitan areas in the late 1980's, nearly 60% of that metropolitan population lived outside the urban central city. The magnitude of this national suburban population, when considered in aggregation, is staggering. The suburban population of New York City (9.3 million) and Los Angeles (8 million) are each larger than the population of 42 states (U.S. Bureau of the Census, P-25 No. 1039, 1989).

Although central cities experienced some growth in the 1980's, the future rate of suburban population growth should be twice that of central cities. Of the growing central city areas, most are in the South and West where 80% of central cities have gained population while most north and central cities are growing slowly or remaining stable (U.S. Bureau of the Census, P-25 No. 1039, 1989).

The Existing Housing Stock

About a third of the housing stock is over 40 years old, much of it in the Northeast and central regions. Even though these regions are not anticipated to grow substantially over the next 50 years, 50 - 70 % of the housing stock will have to be replaced or substantially restored over that period. In the Mid-Atlantic states alone this will entail 8 to 12 million replacements or renovations. Less than 1 million new units will be needed to accommodate projected population increases through 2030.

Employment

Employment growth rates are often better indicators of the rate of new household growth than population growth. The rate of employment growth was, for example, roughly twice the population growth rate in the 1970's, which was a period of significant expansion in the rate of household formation. Through the end of this century however, employment growth is projected to decline, to about 50% above the rate of population growth, and decline again to approximately 50% lower than the rate of population growth by 2030 as the average age of the population increases (Garnick, 1983). Women are and will be increasingly active in the work force as working wives and mothers will come to outnumber full time homemakers and to expand their economic influence within the household (Cetron, Davies 1989).

While data on the subject is incomplete, few would argue against the proposition that changing technology has had a large impact on employment. Lighter weight materials, miniaturization and the substitution of microelectronics for mechanical processes have directly or indirectly changed the nature of work and production. Kinds and rates of employment, labor requirements, locations of employment and patterns of employment concentration and distribution have all been affected (Garnick, 1983).

Changes in Places of Work

Overall, economies based on dense market and labor concentration or proximity have been weakening. Advances in telecommunications, power transmission and to a lesser degree transportation, have increasingly overcome the impediments of distance in the provision of services, as well as in the production and distribution of goods. Dense multi-story plants are increasingly giving way to more distributed single story plants located where labor, market, and supply-source cost less overall (Garnick, 1983).

Self-employment in general and in information based segments of the economy in particular has been and will continue to increase, reversing a 25 year decline (Fain, 1980 and Garnick, 1983). It will bring a reconstitution of the house as a place of employment and occasionally production. More and more people will be leaving traditional jobs and starting up businesses at home. By the turn of the century 17% of the work force is projected to work at home (Cetron, Davies 1989).

The schedules of workers may become more diverse as alternatives to the once ubiquitous five day 40 hour workweek emerge. Skilled two worker families with children, single parent workers, semi-retired workers, part-time workers and others will influence employers to establish work schedules that accommodate varying family commitments.

Changes in Personal Income

Personal per capita income rose approximately 1.4% annually between the years 1973 to 1983 and is expected to continue to rise 1.8% annually through the year 2000 (Cetron, Davies 1989).

As the baby boom generation passes into the 35 - 54 age range, its economic strength and capacity to purchase housing will broaden relative to other generations. The two income families common to this generation will lead to more high-income households. Both the number and proportion of households with annual incomes above \$ 60,000 will be sharply higher by the year 2000 (Morrison, 1990).

At the same time, the proportion of middle class households in the nation is shrinking. Household incomes are diverging as some householders keep pace with inflation, while others fall behind. Numbers of affluent as well as poor households are growing (Blackburn, Bloom, 1988). Those that are poor are becoming poorer, particularly with respect to home ownership opportunities and many potential first time house buyers have deferred home ownership indefinitely.

Currently, the elderly are gaining faster in median income than any other population segment. At the same time, householders aged 75 and older overall have the lowest average incomes of all age groups (Waldrop 1989). The baby boom generation in particular will reach retirement age between 2010 and 2030 and will experience significant loss of projected retirement income. Private sector pension plans and Social Security benefits will be unable to keep pace with inflation or meet rapidly rising numbers of beneficiaries. Households may need to draw on personal savings to meet living costs (Vehitelle, 1990:1).

Changes in Housing Tenure

Also of interest are the tenure choices new households are expected to make over the remainder of this century. An individual's housing tenure choice is influenced by the cost of ownership relative to the cost of renting. Over the period 1980 to 1985, the proportion of new households which were owners declined to about 41% and precipitated a decline in the aggregate home ownership rate. Partly due to the projected increasing age of headship in new households and with it the increased likelihood of home ownership among older households, an estimated 70 - 80% of new households will seek home ownership through the end of the century (Holloway and Peach, 1988 p. 70-71).

Despite a generally declining rate of home ownership, the rate of increase in numbers of homeowners outpaced the increase in number of renters in the 1980's. Home ownership grew among those who could afford it yet increasingly became a privilege of a shrinking middle class. Rental dwellings in turn were increasingly occupied by the poor, the young and single headed family households (Sternlieb and Hughes, 1986).

Potential Energy and Design Implications of Change in Household Formation and Composition

Although it is difficult to draw firm conclusions, it is apparent that the characteristics and lifestyles of new households likely to form in the early 21st century are still evolving and will ultimately become more diverse. The type of housing they will demand will challenge conventional expressions of house and household. In any of several possible scenarios, houses will be less like those to which builders are accustomed. Greater design flexibility will be needed to meet the demands of increasingly diverse kinds of families and living arrangements.

Whether demand for single or multi-family housing will dominate is virtually impossible to discern. On the one hand, middle-age and retirement-age households, the population segments projected to increase the most into the next century, have in the past demonstrated preference for single family houses at low densities. On the other hand, nonfamily households and variations of family households have demonstrated less tendency (by necessity if not by preference) to seek out single family houses and may value the economic and social contact possible in multifamily housing. These are not conflicting but perhaps parallel interpretations of age distribution and household composition trends, the net effect of which depends on assumptions made about behavior within each category more than the category itself. Ultimately it may be the escalating cost of home ownership rather than demographically defined preference that favors an increase in demand for less costly multi-family houses at increased densities.

Changing rates of household formation, declining household size and other demographic changes such as fewer children per family and postponement of marriage will likely precipitate a further decline in the average number of persons residing in housing units (U.S. Bureau of the Census, P-25 No. 432, 1988). Assuming no significant increase in fertility rates, or extraordinary increase in the cost of housing and the resultant 'doubling up', trends toward smaller households and family sizes and preference for independent living arrangements are likely to persist.

It is possible, though not likely, that the number of houses required will increase while house size and per household energy consumption will decrease to reflect a larger market for smaller households. More likely, the sizes of houses may decline in terms of numbers of bedrooms, while the total number of square feet per person remains the same or increases as areas previously allocated to bedrooms etc., will be dispersed or allocated to other functions. Large single family houses will be in less widespread demand as single family housing costs continue to escalate and in greater niche market demand as multi-family housing for their ability to house multiple households sharing costs and maintenance.

Fewer households will be dominated by children and instead will be organized around the needs of individuals or employed couples with less time for maintenance and domestic chores. This implies low maintenance designs and materials as well as houses with more equipment that reduce labor demands on employed adults. Inside the single and single parent family house, layout may change to become more open and flexible. In houses occupied by multiple or nonfamily households there may be demand for greater compartmentalization in order to meet the privacy needs of unrelated persons or places of work. Yard size demands may shrink in response to fewer children.

Change in the age structure of the population and household composition will act in concert as long term care for an aging population may come to influence the design of the single family house. By early next century, people will have greater life expectancy but may find themselves without family support at home. Families may have the inclination to provide care to elderly parents but may lack practical ways to do so. Accessory apartments and secondary housing units in the single family suburb may provide a logical answer.

The anticipated increase in the number of middle-aged and retired households with considerable home ownership experience and greater discretionary income may indicate a knowledgeable housing market sensitive to value. Demand for quality, energy efficient new and remodel

construction could increase with an experienced generation familiar with the real cost of home ownership. The opportunity for industrialized housing producers to expand into remodel as well as new construction is significant. This market will likely specialize in 'do-it-yourself' parts rather than whole houses and seek to upgrade energy standards as the house is repaired, reserviced and perhaps redesigned.

A work force increasingly comprised of two worker and single parent family households will demand different kinds of houses and amenities than did "traditional" households. These might include: more open spaces with greater functional overlap (emphasizing shared space and thus gender integration), more private space for women outside of the kitchen (a study, library, or workroom for example), and/or flexible plans that accommodate shared domestic tasks.

Technology and the home office will potentially reduce commuting constraints on the location of new housing, although many forms of employment will continue to demand direct personal contact. On the one hand, acceptable commute time will likely increase and with it transportation energy consumption will proportionally increase. On the other, there may be a reversal of the assumption that housing demand follows employment opportunity. As the cost of urban housing and commuting increase, employers may relocate employment centers where there is affordable housing opportunity -- typically the suburbs and smaller metropolitan areas or towns near employment centers.

More people will work in their houses or partly out of their houses in order to commute during off-peak hours. Such work patterns and equipment will alter both the design and energy characteristics of housing. Houses will be utilized for more hours of the day. Housing design will need to accommodate office capabilities in the form of work areas, business equipment, etc..

The housing or energy impact of changing ethnicity in the population is yet to be experienced or

estimated. On the design side, there may be the opportunity to radically redefine residential house forms using the influences and diversity from these cultures. The energy conservation opportunity is considerable as many traditional non-western house forms embody passive energy strategies, usually in the area of cooling. The lightweight Asian courtyard house and the mass constructed Hispanic sala are examples of traditional energy conserving design, construction and material solutions to hot and warm climates.

Potential Energy and Design Implications of Change in Population Concentration and Migration

Historically, industrialized housing has advanced its technology, innovation and market share in periods of rapidly escalating housing demand. As new housing demands concentrate in particular regions and contexts, new industrialized housing plants and technologies will be attracted to those areas while existing plants will seek to stretch production and export capability to compete. As this occurs, the housing industry will need to effectively respond to regional markets, climates and energy availability. Adaptability to regional resources, housing typologies, materials and technologies will become issues in industrialized housing.

Population growth in the metropolitan, largely suburban Sunbelt will exacerbate the rapidly rising cooling portion of residential energy consumption. With the majority of new housing demand projected to concentrate in warmer climates, the resulting proportional increase in the share of national consumption attributable to cooling will support new opportunities for incorporation of mass and passive cooling systems in industrialized housing.

Assuming metropolitan areas will be discouraged from growing in physical size, rising land and development costs will lead to increased suburban densities and infilling of existing suburbs. To meet this market, industrialized housing will be designed to be compatible with older neighborhoods and construction strategies will be suited to physically constrained, scattered sites.

Multi-family houses and smaller sites will likely become more prevalent, typically in low rise high density patterns. Finding economical solutions to acoustic privacy and fire resistance will become a design and material research priority that must develop in tandem with energy related design and materials research.

3.6 ECONOMICS

This section sets out to identify and assess how trends in business, finance and marketing will influence housing design and energy performance.

The Construction Economy

Housing is a vital component of the U.S. gross national product. As of the late 1980's there were over 91 million dwellings with a market value in excess of \$ 3 trillion. Each year that housing stock is supplemented with an additional \$ 150 billion worth of new residential construction (Sternlieb and Hughes, 1986).

Like many businesses, the economic vitality of housing construction is cyclical. Unlike many businesses however, the degree of cyclical variation is extreme and housing construction involves unusual levels of risk and uncertainty. Housing starts in 1975, for example, were less than half the 2.36 million of 1972. Five years later in 1977 and 1978, starts had returned to the 2 million level, plunging again to nearly half in 1981 and 1982. The following year, 1983, starts jumped 70% to 1.7 million, a sudden increase not foreseen by economic forecasters (U. S. Bureau of the Census, Housing Starts Series C-20 and Sternlieb and Hughes, 1986).

Smaller volume builders have sought stability in this volatile and unpredictable market by cutting overhead and becoming more efficient in particular markets. Large volume producers have sought

stability through diversification and management flexibility in their businesses. Housing manufacturers have traditionally responded to market volatility by avoiding capital-intensive plants and production systems that need constant production rates in order to be economically viable.

Small Volume Builders

The U.S. housing industry continues to be comprised mainly of small volume builders (less than 25 homes annually) who make up 74% of U.S. housing construction firms. While the recession of 1982 forced many builders of all sizes out of business, the late 1980's were particularly hard on smaller builders. The 1986 tax reform and the decline of savings and loan institutions had a greater impact on smaller builders and their clients than on larger builders and corporations (Housing Economics 1990). By 1989, this group of builders accounted for only 13% of housing starts. Many survived by cutting overhead and improving productivity, focusing on markets and tasks where they were knowledgeable, efficient and profitable. By the end of the 1980's an increased share of total housing construction value was built by subcontract, evidence of an active economy of smaller independent and specialized entities (Housing Economics 1990).

Large Volume Builders

At the same time that small builders are becoming more specialized, the percentage of new starts being built by larger companies dependent on rationalized management systems and industrialized components is increasing.

In 1989, the 9% of the residential construction industry that are large volume builders (more than 100 units annually) constructed 67% of the total starts. Many of these builders are veterans of the 1980 - 82 housing recession and became increasingly diversified and flexible on the basis of that experience (NAHB, 1989: 19-20 and Housing Economics, 1990). Increasingly, their volume is maintained through project management expertise, often turnkey style management of competitive

independent subtrade and industrialized components rather than through maintenance of their own construction forces.

Industrialized Components

While widespread adoption of factory-building in the housing industry continues to fall short of predictions, the use of industrialized, factory-built components continues to expand. The resistance many builders once held for industrialization and industrialized components has eased now that they are becoming increasingly dependent on lower cost industrialized trusses, panels, floor cassettes, etc. Shortages of skilled labor in active housing markets certainly exacerbated this trend (Crowe, 1990:9).

As dependence on prefabricated components increases, the size and capability of building trades has declined. Once-common apprenticeship systems in housing construction have declined or disappeared, leaving large portions of the labor pool marginally skilled, which in turn creates new demand for construction components and systems that minimize site labor (NAHB, 1989: 19).

The economic and political influence of unionized labor will continue to decline with falling membership. Labor intensive and site-based specialties, such as the plumbing and electrical trades will increasingly shift to factory settings (NAHB, 1990) or be replaced by preserviced systems and components.

Capital Investment in Housing Manufacturing

The level of uncertainty and risk inherent in the construction economy has inhibited investment and modernization of housing manufacturing plants. Since housing demand is likely to continue being unpredictable, research, development and modernization will be difficult to realize.

Whether the investment levels characteristic of contemporary house manufacturing will persist into

the 21st century is unclear. Large builders that are well-managed and diversified may be better able to gain access to capital and markets in an increasingly competitive construction economy — a trend borne out by experience in other countries. In Sweden (Schipper 1985: 9) and Japan, builders are large, concentrated companies. Some consolidate or co-ordinate the multi-stage process of building and land development from raw material, to land acquisition, to design, to site assembly and sales.

Potential Design and Energy Implications of Trends in the Construction Economy

Housing construction may increasingly become a two tier industry. Capital intensive production functions will tend to consolidate at a few large, perhaps highly automated, centralized plants. Centralized plants will be supplemented by smaller, more flexible design, sales, distribution, and installation centers that may also produce region-specific and cumbersome, difficult to transport components. The international market may be similar. Joint ventures with foreign companies will develop processes and prototypes adaptable to regional and climate-specific issues. Sweden for example is entering U. S. markets. Swedish companies target quality custom builders familiar with a particular market to manufacture and market their products in the U.S..

Larger manufacturers will be able to be fully integrated while others will be forced to specialize in components that they supply to the larger companies. Builders with access to capital will offer all possible services to the buyer, from design to financing. Lower volume contractors will become suppliers of components or assemblers of custom houses ordered and built through manufacturers. Manufacturers will increasingly use fabrication systems that are 'open' and highly flexible allowing them to adjust to slow periods and to respond to diverse market groups. Housing systems will be 'open' based on an industry standard module, perhaps based on room sizes (12' x 12', 12' x 16', 16' x 16', etc.) instead of the unit dimension currently used which was determined by transportation dimensions. Advanced joinery systems must materialize to support this change.

Economic demand for efficient distribution and handling requirements will influence material and component properties. Lightweight materials, such as foams and plastics will be developed. These materials are conducive to extrusion and molding of long, irregular forms. A dwindling skilled labor pool will accelerate demand for complex and integrative components and systems that require little site coordination and assembly.

Affordability

In the 1980's national home ownership rates declined for the first time in three decades, as the real cost of housing outpaced income gain and created an "affordability gap." Housing is considered affordable when it can be bought or rented by households earning 80% of the median income in a region. Access to adequate affordable housing is not a problem confined to the poor. Middle income households, the traditional core of the housing market are now affected. A national priority will be returning affordability to housing into the 21st century (Mankiev, December 1988: 1).

Assessments of affordability will increasingly be measured beyond direct construction costs. Assessment will include the comprehensive range of direct and indirect costs that affect the ability of householders to acquire and maintain houses: land development costs such as service, commercial and social infrastructure; regulatory costs such as planning and building permit processes; construction costs such as material and labor standards; purchasing costs such as transaction and conveyance costs; financing costs such as interest rates and terms for construction as well as real property; and operating costs such as maintenance and utility costs (Maloney).

Between 1970 and 1980, the real cost of housing rose between 19% and 32% in various regions of the country. Much of the increased cost of housing stems primarily from the escalating cost of land and financing. During that period labor and materials cost have stayed relatively even, while the percentage cost of financing and land doubled (CHI, 1989: 8.5-2). Since 1950, the percentage of

housing costs allocated to land and financing have doubled, while the percentage cost of labor and materials have actually declined (CHI 1989: 8.5-2). If these financial burdens can be slightly reduced, the potential market for affordable housing is enormous.

The Harvard-MIT Joint Center for Housing Studies estimates there are 1.28 million households currently renting who could afford to buy a home costing about \$70,000 assuming a 20% down payment and a 9.8% interest rate. An additional 670,000 could also become homeowners of a \$70,000 home if the down payment is reduced to 10% with an interest rate of 8.3% (Inside Housing, Nov/Dec 1989: 2).

Mortgages

One area of considerable opportunity is that of mortgages. On average a contemporary mortgage at 10% interest has down payment requirements in the 10 - 20% range, beyond the savings and financial resources of many potential homeowners. Discount lending services through the Veteran's Administration and Federal Housing Administration are available to only 25% of the population (Schipper, 1985: 40). The problem is particularly acute for first time house buyers.

To mediate the rising cost of financing, new programs and tax incentives may emerge to encourage the construction and purchase of energy efficient homes. Congress, responding to public frustration with housing costs, has legislation pending that will reduce down payment requirements, modify tax laws and loosen credit requirements (Simonson, 1989: 11).

Financing based on higher construction quality and performance standards can reduce down payment requirements and/or interest rates to buyers and can lower the risk to lenders. An added return is lower energy consumption and other consumer infrastructure benefits. An Energy-Efficient Mortgage (EEM) is a mortgage alternative of this type (Binsacca, 1989: 28). Lenders, utilities, and government may collaborate to establish standards that ensure better energy

performance and less operating costs to the buyer, who will in turn be able to sustain higher mortgage payments. A model of this type already exists in Sweden (Schipper, 1985: 42).

Multiple mortgages which may finance various components of a house separately (Inside Housing, 1989: 3) reduces risk to lenders because more than one lender is financing a home purchase. Rates and terms of mortgages could vary with the risk and longevity associated with particular parts of the house. Mechanical equipment, for example, could be financed at different terms than land.

By virtue of their size and access to capital, manufacturers and larger volume builders may offer their own financing plans to buyers. Builders can substantially reduce finance costs and supplement their market viability at the same time by streamlining the number of participants in the financing process, and offering convenience and service to the buyer.

The Cost of Land and Infrastructure

One reason affordable housing markets were neglected through the 1980's was because low cost houses are not as profitable as expensive ones. Profit levels typically increase directly with sales price, since many of the soft development costs (land servicing, permits and approvals, etc.) are fixed and independent of the sales price. Strong middle to upper end markets like those of the 1980's eventually soften, and builders and manufacturers will turn their attention to realizing profit from reductions in these development costs.

Consequently, housing developers are beginning to consider land and infrastructure as integral with housing design and construction. As developer Jack Bloodgood put it, "I started out designing houses, now I design houses and land" (Adler, 1950: 73). In recent years the U.S. Department of Housing and Urban Development (HUD), the National Association of Home Builders (NAHB) and a growing number of communities have encouraged affordable housing by experimenting with the land development standards contained in their zoning and subdivision

ordinances. These standards govern density per acre, lot size, how houses can be sited on a lot, street widths, sidewalks, parking, and other development parameters that can influence the housing industry's ability to deliver an affordable, attractive house. As a result, smaller lots and varied configurations — e.g., wide and shallow lots, Z-lots and zero lot lines — are appearing. A parallel trend is for lawns and driveways to become smaller, while gardens take up a larger percentage of the yard. Future housing developments will require the supplementary open space of neighborhood parks and communal areas (Adler, 1990: 76).

Densities will increase. Multi-family housing will be chosen more frequently out of necessity. Single family residential areas will be rezoned, further subdivided and infilled, enabling homeowners to capitalize on appreciation while lowering the cost of a house and land in an already serviced neighborhood (Inside Housing, 1989: 6). Rezoning would encourage local governments to stimulate the supply of affordable housing. They could provide incentives to builders and assistance to buyers, and zone idle city-owned property, sell it as part of the incentive program and therefore receive property taxes on it instead of paying interest. An example of this process is the Home Expo in Rochester, New York (Coffey/Kleniewski, 1989: 20).

The Entry Level House Market

The economic forces which reshape land and infrastructure will also influence house designs, particularly at the entry level. Recent housing starts targeted to affluent buyers have in the process neglected a growing portion of the housing market — first-time buyers — for whom first cost, rather than style and amenities, is critical (Ahluwalia, 1989: 7).

New developments of affordable housing will be more concentrated on small, clustered lots with shared amenities. Commerce and transit stations will be within walking distance. Houses may be sited obliquely (angle Z lots) to give the appearance of spaciousness. Infilling and scattered sites will be more common. Production systems will be tailored to transportation systems and efficient

assembly in urban infill areas. Transportation vehicles may be smaller and/or contain booms or other equipment for on-site assembly.

The houses themselves will be more compact with more open plans and integrated indoor and outdoor spaces. Systems using perimeter bearing walls and long span floor and ceiling decks will accommodate this spatial requirement. Some spaces, such as dining rooms, will be eliminated and consumers will enlarge their houses later, as income and needs change (Ahluwalia, 1989: 6-9).

The Remodel and "Do it Yourself" Market

Remodeling is gaining market share as rising new construction costs discourage homeowners from house trading, and force first-time buyers to buy "fixer-upper" existing homes (NAHB 1989:22). Manufacturers will see a demand for off the shelf components used in remodel and retrofit projects. These component pieces can be at the low-tech end of the industrialization spectrum.

Marketing Energy and Conservation

Utility companies, both public and private, are in the business of marketing energy. Private utilities, on the one hand, are accountable to their stock holders who invest in the utility intending to realize a profit. Because an effective way to see a profit is to sell more energy, private utilities view conservation as necessary to ensure a long term supply as well as a means to compete with other utilities and secure new customers. Public utilities, on the other hand, are more politically as well as economically accountable to their customers, whose interests are more likely to embrace conservation of resources in the public as well as economic good. Public utilities are more likely to offer builders and homeowners incentives to build and purchase energy efficient homes and appliances (Maloney, 1990).

Conservation Incentive Programs

Public utilities offer a variety of programs to builders and homeowners in the form of cash and

marketing assistance to entice people to build energy efficient housing. An example of this is the Super Good Cents program offered by the Bonneville Power Administration (BPA), which provides design assistance and \$1000.00 upon inspection approval of energy conserving materials and construction practices in a new house. A branch of the program also offers cash incentives to buyers for purchasing an energy efficient manufactured house. Cash incentives, for example Eugene Water and Electric Board's solar water heater rebate, also exist to promote the installation of energy efficient appliances (Maloney, 1990).

Discourage-Use Programs

Utilities whose capacity to provide energy at certain peak times is constrained try to encourage energy consumption at off-peak times by increasing the peak hourly rate over the base charge. Some utilities, such as the Sacramento Municipal Utility District, increase rates by three times during peak loads. As resources become more limited and population centers increase, capacity constraint will be a common problem for many utilities.

"Smart" appliances are being developed that interact with the electrical system through computer chips; these operate only during off-peak times or provide a warning during high-peak times, as in the Smart House system. Residential construction with thermal mass can minimize demand for energy at high peak rates by reducing the magnitude of temperature swings. At the same time thermal mass is generally heavy and inefficient to transport, so a hybrid system of site-built foundations and thermal mass walls may emerge to combine mass with lightweight industrialized components.

3.7 PLANNING POLICY AND REGULATION

This section sets out to identify and assess the design and energy implications of trends in land use, zoning, building and residential energy regulation. Planning policy in this context refers to the broad agenda of public issues and goals that motivate regulation, which in turn establish the legislated regulations, rules and procedures needed to implement policy goals.

Virtually every decision about houses is regulated — where they are built, their relationship to land and other houses, their design, construction and thermal characteristics as well as the availability of energy to serve them. Regulations determine or directly influence housing decisions regarding size, material, and assembly from the scale of the smallest component up through scales of room, building, community, region, and state. Similarly, policy and regulations determine or directly influence the source, cost, availability and distribution of energy to houses.

Not surprisingly, both the agenda and character of the planning context for the 21st century house is exceedingly difficult to predict and assess. While future policy and regulatory agenda in and of itself is unclear, the politics and public opinion that determine the perceived importance and priority of individual issues are particularly unpredictable.

Long Term, Comprehensive View

Policymaking affecting housing, community development, land-use and related areas can be expected to take a long-term, comprehensive point of view. A comprehensive plan is an official document adopted by a local government as a guide to decision making over the next 20 to 30 years. It is intended to encompass all geographic parts of the community and all functional elements that bear on physical development, including consideration of factors such as private use of land, community facilities, transportation, utilities and civic design, as well as information on the population, economy, land use, assumptions and community goal (Starling, 1986: 166-68).

This trend is also acknowledged by the National Association of Homebuilders (NAHB: 1989) with respect to planning scenarios locally and regionally, and the United Nations concerning the importance of comprehensive, future-oriented community planning (UN, 1984: 37).

Limited Public Resources

According to the Organization for Economic Co-operation and Development (OECD, 1988: 16): "Modest rates of economic growth and concern over excessive public expenditure can be expected to continue to exert restraint on the growth of public expenditure programs...this suggests that high priority housing objectives will only be able to be met within the budget constraint if policies are designed with greater regard to selectivity and targeting than has been the case in the past."

In the West, governments will come under pressure to focus efforts upon the redevelopment of central cities, which have been in decline due to flights of capital and skilled labor. The most important implication of this is that emphasis will shift from supporting new construction in these geographical areas to improving existing housing stocks and enhancing neighborhood quality (OECD, 1988: 8-9, 20). Industrialized housing could play a role by supplying components for retrofitting existing units.

Standardization / Reciprocity

Pressure will continue for national standardization of U.S. building codes, as well as for international standards, by major organizations such as the Council of States on Industrialized Housing and Buildings. An exemplary model of this trend is the current development of "building construction standards and codes" in the European Economic Community (Harrison, 1989).

Several opportunities may be realized through such standardization. A persistent barrier to innovation in housing design and construction has been the complexity and inconsistency among the thousands of local building code jurisdictions. In the absence of consistency and reciprocity

across regulatory jurisdictions, the large markets necessary to sustain industry research, development and modernization cannot be realized. Domestic and foreign markets could establish the common standards that encourage productive competition.

Affordability

Low and middle-income American households are finding it increasingly difficult to afford a home or apartment. There is a widening gap between personal incomes and the costs of owning and operating a house, a situation exacerbated by Reagan administration tax reform, cutbacks in low-income housing aid and deregulation of the finance industry in the 1980's (Dreier & Atlas, 1989: 27-28).

There are now indications that political pressure for a concerted federal effort to reverse the situation is increasing, which could lead to a more equitable distribution of housing benefits across income groups (OECD, 1988: 9; Dreier & Atlas, 1989; Suchman, 19). There are numerous possible implications of this shift:

- Public subsidies will target those with modest incomes — e.g., rental vouchers (OECD, 1988: 71; Suchman, 1989).
- Organizational linkages will develop among various local interest groups in order to pool resources if federal assistance lags.
- Community-based, non-profit developers will emerge as recipients of federal assistance (Hutchinson and Murray, 1989; Dreier and Atlas, 1989: 34-5).
- Employer-assisted housing will be encouraged by corresponding changes in law and government regulations (Pierce, May 14, 1990).
- Tax breaks for home ownership will continue, although these may be approaching their limit due to national budgetary constraints and competing pressure by those wishing to channel resources toward helping poor renters (Yates, 1989).

Land Use

Land use policies specify the kinds of activities and processes which may take place on a given parcel of land. As such, they are political documents which change with the values systems of the culture which administers them (Robinson). These kinds of documents may also have the less explicitly understood function of preserving future opportunities. For instance, it is much easier for a society to preserve prime agricultural land than it is to recreate it; in a similar manner, it is easier to preserve solar access now, even if not necessary than it would be to obtain it after that access has been lost (UN 1984: 37; Boos 1986: 22).

The preservation of future land use options (UN 1984: 37) and ecological / environmental (habitat) protection will continue to raise questions about whether land development is a right or a privilege (NAHB, Jan.1989). Review processes regarding changes in land use status will become more important, but will also become more streamlined as our society realizes lengthy procedures can add substantial costs to development and construction. Resolution of these issues will depend in part on the continued trend toward more explicit and specific rules regarding land use.

More policies and regulations will be promulgated to preserve or reclaim land types which are community and environmental assets, such as prime agricultural land, open spaces near metropolitan areas, stream and river corridors, flood plains, wetlands and other parcels of land which actually retain or could support functioning ecosystems.

Policies and regulations will also become increasingly responsive to quality of life issues, since quality of life is highly dependent on local / regional constraints and opportunities, these issues are most appropriately resolved by creative, cooperative efforts of diverse local interest groups. The result will be a new blend of conservation and development. As a result, the allowable mixtures of urban functions (residential, commercial, etc.) will probably change from one of segregation to one of integration as a means of making the social and physical infrastructures more efficient and more

dense (Yaro 1988: 7,8). For instance, small shopping, office and commercial areas may be scattered throughout residential areas so as to be within walking distance of dwellings.

Explicit rule systems will also be developed for more specific issues such as how our cities and urban elements are formed, particularly those dealing with the distances between where people live and where they need or want to go (such as to work, or to shopping, or to recreation facilities) and how they can get there (Newsweek 1989: 75). These policies and regulations will also embody decisions regarding the infrastructure morphology and extent which are directly related to infrastructure efficiency and cost effectiveness (NAHB 1986: 80; Hare 1988: 4).

Zoning and Site Planning

Some land use policies are exclusive and some are inclusive in specifying how industrially produced houses are accepted into the community. Inclusive land use policies state that all housing must meet certain criteria regardless of their production origin (Sanders 1986: 2-6; Hare 1988: 3; NIBS 1988: 8; NAHB 1986: 78). In general, communities have greater acceptance of the industrially produced house now than in the recent past, and we expect this trend to continue as more jurisdictions continue to adopt this kind of policy.

The trend to more explicit policies and regulations will also continue in zoning and in site planning regulations. As density increases from 3 or 4 to about 12 dwellings/acre, the boundaries between neighbors become more critical and the conventions defining those boundaries more important (Richardson 1988: 16). The trend toward smaller plots of land for detached dwellings will continue, and the configuration of the lot will probably change as well.

Ownership of houses will become distinct from land ownership as real estate configurations become both sophisticated and complex, such as the angled "Z" lot and the Planned Unit Development (PUD) (Schnidman 1988: 4). These changes in real estate configuration can give

land owners and communities more opportunity to participate in the planning processes, decreasing the liability of the planning body while increasing the land available for development (and thereby also decreasing the cost of housing) (Schnidman 1988: 3).

Smaller lots mean that the size and configuration of the building footprint becomes more critical. The method of determining lot coverage (size) will probably change from an absolute maximum or minimum area prescription to a method using the building footprint expressed as a percentage of the lot area. The change in lot configuration and the subsequent change in building form in response mean that the building form may become increasingly constrained. This constraint in building envelope form / configuration can be an opportunity for manufactured housing, because the industrial process lends itself to the production of many parts of similarly complex form, while custom (site) built processes do not.

Zoning regulations will also become more sophisticated in accommodating change over time. An example of this is the idea of flexibility of lot coverage: neighborhoods may grow more dense over time as initial housing is supplemented by infill housing (Hare 1988: 10). These trends can place demands on the house producer by predetermining the structural envelope of an infill dwelling.

Another critical factor to consider in the site development process is the level to which the street is designed and finished: higher density residential development depends heavily upon landscaping for approval and acceptance. Consequently such projects are often a kind of "turnkey" process (Richardson 1988). This trend means residential developers may change the phasing or sequence of residential development in order to provide more public amenities; the tradeoff may be the form or finish of the dwelling which is not as visible.

New building types will emerge that challenge the way we think about land use and site planning. For instance, the utilization of an industrially produced "granny flat" or Elderly Cottage Housing

Opportunity (ECHO) dwelling as infill or transitional housing challenges the assumption that a certain kind of land use goes with the land. Instead, use may ride with the individual (Hare 1988: 4; NAHB 1990, May 21: 4,5). By implication, this kind of “temporary” housing also challenges traditional methods of foundation connection as well as utility distribution and connection.

Building Design and Construction

The attributes of a building design — where it is located, how it performs, how it looks, how it changes over time — affect more than the building itself or those who dwell within it. In a similar way, many outside factors affect the choices involved in a building design and performance. For instance, the so called “soft costs” of building development (such as debt service and land values) have increased in relation to the actual cost of construction and may be expected to continue to increase as land becomes relatively more scarce (NIBS 1989). This situation will probably result in higher density and a diversification of allowable activities within a community.

The initial and direct operating costs of a building are not the only factors in a building’s performance or efficiency. Many house design decisions create energy costs in sectors (i.e., transportation) other than the house itself. This complexity indicates a need for wise choices in the pre-design selection process: undesirable situations should be prevented rather than depending on mitigative processes and technologies to solve them in the future (Engstrom 1988: 157).

The design review process needs to be streamlined, according to some, because it causes long delays between design and construction. This might be feasible if certain construction processes were approved, providing compliance and quality could be verified (Sanders 1986: 3). Individual component performance may be more acceptable than ambient / aggregate standards because that will eliminate problems arising from interpreting ambient standards (Harloe 1988: 204; OECD 1989: 8,9; Sanders 1986: 13; Skinner 1983). Accepting standard processes instead of individual products may be a way to streamline as well.

4. DESIGN STUDIES

This section presents a summary and analysis of design studies undertaken by the Center for Housing Innovation and six design consultants in December 1990. These studies respond to the four future scenarios defined in 'Problem Statements for the 21st Century House'. Each problem statement included an introduction to an industrialized housing demand scenario; its background and context; design, energy and economic goals; architectural requirements; materials and construction systems.

Based on these statements, design teams were asked to develop a future house design that demonstrated innovative energy conservation opportunities afforded by industrialized construction processes. Each design team submitted a study that included an explanatory narrative; general perspective or axonometric view; site plan; floor plan; principal elevations; construction section; energy analysis; inventory of innovative economic and energy conservation principles; and recommendations for developmental studies and investigations. This work has been edited and summarized from design consultants' submissions.

These studies are presented in four major subsections — 4.1 Starter House for a Hot-Arid Climate; 4.2 Extended Family House for a Cool Climate; 4.3 Move-up House for a Hot-Humid Climate and 4.4 Renewable House for a Temperate Climate. An introduction to each subsection presents an overview of challenges, issues and assumptions unique to that problem statement. Following that introduction, one or more design studies are presented. At the conclusion of each study, an Energy Scheming computer analysis of the design is presented.

The projects presented are schematic and focused on integration of site planning, design, materials, economics, manufacturing innovations to create a marketable, energy conserving house. The ideas that result are experimental, speculative and untested. Some present excellent energy conservation opportunities that warrant further evaluation, refinement and development in 1991. These are inventoried in Section 5.

4.1 STARTER HOUSE FOR A HOT ARID CLIMATE

Scenario

The 'Affordable Building Company' of Phoenix AZ must balance the opportunity and uncertainty of an 'affordable housing enterprise zone'. The company has an option on a potentially profitable suburban land tract in Phoenix and a large pent-up market of first time house buyers. Other segments of the housing market are slower in this area, and the company has collaborated with the city and local utility in an affordable housing experiment. If this well capitalized and vertically integrated company can conceive, build and finance new houses for sale to below median income households now in rental housing, the city will relax site planning regulations and the utility will offer low interest 'energy' mortgages to offset the cost of energy conserving materials and mechanical systems.

Introduction

The market segment likely to seek out starter houses in 2030 will be one comprised of small households of diverse composition and needs. The average new household is getting smaller and the composition of both family and non-family households is diversifying. Two parent families are declining both in number and as a proportion of all households. Families are having children later in life and the number of persons living alone or with other unrelated persons is increasing.

Changing rates of household formation, declining household size and other demographic changes such as fewer children per family and postponement of marriage will likely precipitate a further decline in the average number of persons residing in housing units (U.S. Bureau of the Census, P-25 No. 432, 1988). Assuming no significant increase in fertility rates, or extraordinary increase in the cost of housing and the resultant 'doubling up', trends toward smaller households and family sizes and preference for independent living arrangements is likely to persist.

Of households most in need of low cost housing are single parent families which comprised 25% of all households in 1989. The majority are headed by women, approximately half of which earn incomes below the poverty level (Anthony, Chin and Weidemann, 1990). Other households will be less dominated by children and will instead be organized around the needs of individuals or employed couples with little time for maintenance and domestic chores.

In any of these scenarios, houses will be less like those to which builders are accustomed and will challenge conventional expressions of house and household. Non-family households and variations of family households may prefer multifamily housing for both economic and social reasons. More design flexibility will be necessary if new housing is to meet the increasingly diverse needs of families non-traditional living arrangements. Houses for single families and for single parents are likely to become more open and flexible. Houses occupied by multiple or non-family households may demand greater compartmentalization to meet the privacy needs of unrelated persons or places of work. Yard size may shrink in response to land costs and fewer children per household. There will be an increasing demand for low maintenance designs, materials and equipment that reduce time commitments by employed adults.

Goals

In this problem statement, a fully integrated housing company develops a tract of multi-family dwellings to meet market demand for small affordable houses at 12 - 16 units per acre density. This market segment includes a diversity of family and non-family households. Many have formed households based on economic rather than family ties, pooling resources and incomes to meet the cost of housing. Others have established a range of income generating business and accessory rentals for the same purpose. The house affordable to this market is small, has basic amenities and is sited on a small lot. Its design and construction must preserve the opportunity for owners to expand and improve its size and amenity as their needs change, or their household income rises.

This problem statement includes three potentially contradictory goals — energy conserving design and construction, single family site planning at multifamily density, and low first cost with design flexibility to meet a variety of owner requirements and remodel options.

Design goals

Site

- Orientation and siting to optimize passive solar heating and cooling.
- Minimal infrastructure requirements.
- Individual household identity, amenity and control at multi-family density.
- Private, climate-tempered outdoor spaces.

House

- Efficient plan suited to compact house and dense site planning.
- Flexibility to accommodate a range of household compositions, in-house work or rented bedroom if desired.
- Space planning for passive heating and cooling strategies.
- Opportunities to change and add to rooms and floors.

Construction

- Design variation with limited parts.
- Economical processes using concrete panels.
- Industrialized construction systems open to later 'do-it-yourself' remodeling.

Energy goals

A target household energy budget has been derived by projecting a 25% improvement over the most stringent contemporary standard, The State of California's Title 24 Energy Code. Phoenix is equivalent to California climate zone 15. Other energy goals include:

- Energy conserving design, materials and construction quality at low first cost.
- 75% - 95% passive cooling and heating strategies at high density site planning.
- Energy conserving materials and construction strategies sustainable over a range of design and remodel options.
- No demand at electrical utility peaks.

Economic goals

The house defined in this problem statement is intended to be affordable at 60 - 80% median income. In 1985, this median income was \$ 27,400 for homeowners, and the median value of owner occupied houses was approximately \$75,000 in the Phoenix metropolitan area (American Housing Survey: 1985). Assuming a 30 year mortgage at 9%, a \$55,000 house would have met 60-80% of this goal in 1985.

Housing delivery system assumptions

The housing developer assumed in this problem statement is a large and fully integrated housing company — a combination land developing, manufacturing, contracting, marketing and sales company. Although history has demonstrated that well capitalized companies with state of the art manufacturing technology are not by definition successful in low cost housing, a large vertically integrated company can be better positioned than others to succeed. By virtue of their size and access to capital, integrated housing companies, such as the Affordable Building Company (ABC), have the unique opportunity to reduce the number of independent participants in the housing delivery process, make volume purchases, concentrate expertise and streamline procedures.

ABC is building many units at the same time and controls virtually all of the design and development process. Design, engineering, financing, legal and other services can be integrated and coordinated to optimize levels of service and cost. Other economic benefits can be realized where and at whatever scale they may occur.

Occupancy assumptions

While there are several very different types of residents suited to a house of this kind, this design study will concentrate on three — an adult couple with 2 children; 1 adult and 2 children with a second unrelated adult tenant; 2 adults and an in-home clerical business.

Spatial requirements

Approximately 240 dwelling units at 800 sf. each. Each house must be able to expand by approximately one 300 sf. room. Room sizes and layout are to HUD / FHA minimum area requirements. In 1985, the following amenities were common to new owner-occupied houses in the Phoenix area: Fireplaces - 46%; Porches, decks, balconies or patios - 91%; Separate dining room - 35%; Garage or carport - 92%; Central air conditioning - 99% (American Housing Survey: 1985) Off-street parking is required.

Neighborhood, site and architectural context

The neighborhood is suburban, a mix of single and multi-family dwellings, recreation, commercial and public buildings. Adjacent buildings are 2 - 4 story structures in a mixed material palette of stucco, metal and concrete. Public recreation and open space are nearby. Public transit, and some commercial, recreational and public services are within walking distance.

The site is a 20 acre rectangular tract. There are no existing streets or site infrastructure. Zoning permits PUD type cluster planning and transportation system, and site scale solutions to waste, utilities and services. Allowable development density is up to 16 units per acre. Innovative, low

cost solutions to circulation and distribution of services are encouraged.

Construction System Assumptions

The construction system specified in this problem statement is a lightweight concrete panel system.

Foundation

Poured in place concrete slab on grade with integral perimeter footing, panel fasteners, reinforcement and insulation.

Envelope and structure

Narrow (approximately 4') lightweight concrete sandwich panels varying in height from 1 to 2 stories. Panels are two wythes of concrete with foam insulation core reinforced with thermally broken ties. The interior wythe is primarily structural while the exterior is primarily a weather proof finish. Panels are attached to the slab and one another with thermally broken fiber-reinforced concrete keys. Floor and roof cassettes act as diaphragms.

Floors and roofs

Floor and roofs are a cassette system of engineered wood composite lumbers and sheathings such as laminated veneer lumber (LVL) and stressed skin panels of oriented strand boards (OSB). Cassettes can be predrilled for service distribution. Roof cassettes can be manufactured with integral insulation and radiant barriers.

Mechanical system

A centralized heat pump appliance combines ventilation, cooling, heating and domestic hot water in a centrally located mechanical core. Air is circulated through rooms and construction systems without ducts.

Electrical system

Surface mounted raceways, lighting and electrical services on concrete panels. Floor and wall junction mounted multiple carrier plug-in strips of extruded temperature resistant plastic.

Phoenix climate

Hot, Dry, Clear Sky, Large Temperature Swings

Lat. 33 deg. N; Long. 112 deg.W; El. +1112'

The Phoenix region is characterized by large (30 °F.) diurnal temperature variations. Summer afternoon highs are very hot (90-106 °F.). Winter lows are cool (38-50 °F.). Sun intensity is very high. Skies are predominantly clear. Solar heating and night radiation potential are high.

Prevailing winds are mostly from southerly direction, shifting to westerly in afternoon. Speeds are moderate (5-7 mph average). Higher velocities occur on spring and fall afternoons. Night winds follow topography, with cool air draining from mountains.

Rainfall is about 5-8" per year; summer is the dry season. Water conservation is very important. Humidity is generally too low for comfort ranging from 10-40% in summer and only slightly higher in winter.

Primary passive cooling strategies are evaporative cooling and thermal mass; either strategy can provide over three fourths of the required cooling hours. Ventilation can achieve comfort in about two fifths of the required cooling hours. Combinations of passive strategies can achieve comfort conditions in all but about 8% of the required cooling hours.

Heating Degree Days Base 65 °F	1864
Cooling Degree Days Base 78 °F	1554
Winter Design DBT	34 °F
Summer Design DBT / Coincident WBT	107 °F / 71 °F
Too Cool for Comfort (mid Oct.- mid Apr.)	48%
Comfortable (mid Apr.- mid May; late Sept.- mid Oct.)	15%
Too Hot for Comfort (late May- late Sept.)	37%

Table 4.1 - 1

Phoenix Area Climate Summary

Source: AIA Research Corporation, Regional Guidelines for Building Passive Passive Energy Conserving Homes, 1978; Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Utility context

Passive cooling and heating; gas and electrical energy sources are available. The electric utility company in this problem statement operates close to its maximum generating capacity with little capital and political support to build additional generating plants. By necessity, this utility offers attractive incentives to minimize summer and afternoon peaking; and underwrites mortgages for durable energy conserving hardware and systems.

4.1.1 STARTER HOUSE FOR A HOT ARID CLIMATE: GARDEN HOMES

Pyatok Associates

Michael Pyatok, William Pettus, Daniel Koch

339 15th Street, Ste. 212

Oakland CA. 94612

1507 Western Ave.

Seattle, WA 98101

Design Summary

A settlement of Garden Homes is conceived as a community of starter families. While sound-proof garden walls separate the plots, the expanded outdoor living afforded by roof-top tents will increase neighborly contact, as well as distant views of the walled ground-floor "garden rooms". These homes utilize two traditional strategies for dwelling in hot, dry climates: a heavy-walled structure for passive cooling and warming when desired, and the light weight tent to provide shade with increased exposure to breezes. The two together permit a wide variety of living experiences within a compact environment.

Project Data:

<u>Site</u>		<u>House</u> (net usable)	
Density:	Approx. 15 units/acre?	Original House:	800 sf
Lot (48' x 48'):	2,304 sf	Expansion (one story)	560 sf
Building footprint (21' x 21'):	441 sf	Total Area:	1,360 sf
Outdoor rooms:	1,863 sf

Figure 4.1 - 1
Axonometric View
Pyatok Associates

Site

Each Garden Home is 48' x 48'. They aggregate within a grid layout that clusters the family transport vehicles into groupings of ten. This reduces the amount of road surface, not only compacting the settlement and reducing costs, but also helping to lower the ambient temperature in the neighborhood. One-way loop roads service four clusters of ten homes each. Shaded walkways connect the vehicular storage areas with entries to the Garden Homes. The furthest walk is approximately 75'. This planning produces a density of approximately 15 units/acre, including roads and parking lots. No portion of a home is more than 150' (as a fire hose lies) from the front end of a fire truck in a parking area.

GARDEN HOME
GARDEN ROOM

Figure 4.1 - 2
Site plan
Pyatok Associates

Unit Plan

The core of the Garden Home (21' x 21') is planned as a two-story, two bedroom 800 s.f. house (net usable). Outdoor "garden rooms" surround the interior portion of the home, adding another 1900 s.f. of livable space. Also, the south face is always available to receive solar gain when desired. Only one story additions are allowed to ensure privacy, solar access, and ventilation for neighbors, as well as control of density.

The core of the Garden Home is expandable by 520 s.f., in two one-story 260 s.f. increments (this is Type A. The Type B house is shifted to the east or west garden wall, allowing one large addition to one side only). The indoor portion of the dwelling is centered in the garden (Type A) to permit the expansions to the east and the west of the core house, maintaining the north and south gardens as permanent open space for light, air, ventilation, view, and use.

1. ENTRY
2. BENCH
3. LIVING PATIO
4. POOL
5. WORK AREA
6. RABBITS
7. MECHANICAL
8. STORAGE
9. FUTURE
EXPANSION AREA

2ND LEVEL PLAN

TYPE B: 1ST LEVEL PLAN

TYPE A: 1ST LEVEL EXPANSION PLAN

Figure 4.1 - 3
Unit Plans
Pyatok Associates

Construction

Most of the house components are constructed in factory conditions, shipped to the site, and erected by cranes. The Garden Home is built with 4' wide precast concrete sandwich wall panels, two stories in height. These provide the exterior skin, insulation, and structure to support the roof and the second floor. The roof and second floor are composed of stressed-skin panels. These are made of top and bottom plywood panels, glued and nailed to conventional lumber sections. These panels span only 10' from the outside vertical concrete panels to a gang lam beam, which spans 20' across the center of the house. Garden walls are precast wall-beams, spanning between pier caps which are approximately 6' to 7' on center. These are identical to the highway sound walls presently used by many state highway authorities. Additions by owners are expected to be of conventional, lighter weight materials, perhaps concrete masonry units or other lightweight panelized systems to facilitate self-help construction efforts.

SECTION A-A

SOUTH ELEVATION

Figure 4.1 - 4
Elevations and sections
 Pyatok Associates

Economic Strategy

Efforts to reduce costs in this solution included: compact site planning, compact house plan, energy efficient design, limited number of construction components. Future efforts to reduce costs should focus not only on the product, but on financing mechanisms, land acquisition methods, and infrastructure planning.

Energy Conservation Strategy

Exterior shading is provided for the roof, windows and walls. Windows are located on four sides for natural ventilation. In addition, precast concrete sandwich walls and a concrete slab permit passive cooling and heating when desired. These methods are supplemented by a heat pump. Water is heated by an active solar collector, with its pump powered by a dedicated photovoltaic panel and battery system. The utility core is located on the northeast corner with the kitchen and bath(s) in order to minimize plumbing lines and to allow only primary rooms on the south side. The south facing solar hot water collector is mounted above the second floor windows to ensure unobstructed exposure and to shade those windows. The main driveways would be shaded by such indigenous trees as Cottonwoods. The garden rooms may be shaded by smaller trees or shrubs such as Palo Verdes or Yuccas. Vines such as Bougainvillea may be used to cover a garden room and shade the ground floor windows.

Glazing Area (sf)

	1st	2nd	3rd
South	90	64	154
North	30	20	50
East	30	30	60
West	30	30	60
Totals	180	144	324

Mass Area (sf)

6" slab	400	---	400
4" int. face of ext. wall	450	492	942
Totals	850	492	1342

Energy Analysis
(computer simulation using Energy Scheming)

Figure 4.1 - 5
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: 11,210

Sep 21: 179,873

Jun 21: 118,953

Dec 21: 0

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>		<u>Max. Rad.</u> Btuh/s.f.
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>	
Mar.	84	51	48	15	13	3	294
Jun.	102	68	25	9	20	5	339
Sept.	102	77	44	20	23	0	294
Dec.	63	36	79	19	15	5	149

Assumptions and Program Inputs

R-values

Walls	17
Roof	13.71
Floor	2
Windows	1.67
Infiltration Rates: 15 Btuh/hr sf	

Energy Strategies Used:

Cooling:

External operable shades
Internal shades
Cross ventilation
Loss to mass
Night ventilation

Heating:

Gain from mass

Figure 4.1 - 6
Building Occupancy and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.

Lights: used 5PM-11PM.

Designers' Comments.

- Examine the possibilities for one-story houses combined with lower technology for concrete. This would eliminate dependence on cranes and skilled labor, but may employ more local people, unless the factory is nearby. Wood and steel structural components will always need to be imported.
- Examine alternative cluster layouts to provide easier access to homes by vehicles. This improves the range of possible at-home businesses, and eases the process of self-help additions.
- Examine shading devices made of inexpensive fabric products for durability under use, intense sunlight, and wind loads.
- Examine the possibility of a consumer home building center nearby, supplying both materials and advice on how to select and install these prefabricated systems. Any system using larger than hand-held parts, however, requires more dependence on machines, thus limiting the options for small contractors and homeowners.

4.1.2 STARTER HOUSE FOR A HOT ARID CLIMATE: ABC BUILDING SYSTEM

Center for Maximum Potential Building Systems

Sustainable Design Associates

Pliny Fisk, Richard MacMath

8604 F. M. 969

Austin, TX 78724

Design Summary

We propose a method by which design of the house is achieved through a complex group process involving clients, users, manufacturers, inhabitants, builders, and regional planners. Thus the process of design becomes, in a sense, "participatory regionalism." We also propose a different approach to the manufacture and use of industrialized components used in the construction of housing. We envision an open, changeable list of components made from regionally and locally available materials manufactured by area business and industry. These would be distributed by a separate "Building Mart" that provides design and construction services and building components.

This proposal presents a new set of rules to follow in the design of the proposed 21st century house. Some of these "rules" are completely new, some replace older regulations, and some are logical extensions of present day ordinances. These rules, when followed by the participatory design team, describe a "design game" in which the design "problem" is solved by participants in a cooperative manner. Although the rules are very specific and touch upon every phase of the project, there are an unlimited number of possible outcomes.

Project Data:

Site

Density:

800 sf

Lot: 60' x 125' or 40' x 95'

Building footprint: 10' x 30', 17' x 36', 40' x 40'

House (net usable)

16 units/acre

Original House:

Expansion: 300 sf - 1200 sf

Total Area: 1100 sf - 2000 sf

Figure 4.1 - 7
Building Mart Concept
Sustainable Design Associates

Site

In the year 2030, local ordinances will still specify density, minimum lot size, setback requirements, height limitations, and other standards similar to those used today. New zoning ordinances will create three dimensional zoning maps. These maps will describe solar access, daylighting, and air space restrictions. Solar access ordinances will deal with the sun not only as an energy source for heating water and space heating and for electric generation, but also as a daylighting source that will improve the overall quality of life. Assured access to the sun for all dwelling units may be implemented in a series of ordinances defined as the Solar Envelope. As stated in the program, allowable density is 16 units per acre.

For economy of construction, maintenance, and the preservation of site features, the units are arranged in typical "row house" fashion with long common walls. Six to twelve dwellings would be attached to form each cluster made up of a mix of one, two, and three-story units. The cluster may be arranged in straight or staggered rows depending on site vegetation, access roads, and pedestrian paths. Each cluster is built within its own solar envelope and has maximum potential solar access while not shading units to the north.

Figure 4.1 - 8
Cluster Model
Sustainable Design Associates

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2181/R91-2

Unit Plan

Building three different types of units of one, two, and three stories will help to eliminate the need to construct monolithic housing projects. Each dwelling unit can start out at 100 square feet and grow to 1,800 square feet or more within its own "footprint." One story units expand horizontally at ground level, three story units expand up, and two story units expand in both directions. Through a self-regulating pattern, density of units will vary within the site. Some units will be made very compact, while others will be left almost detached.

Homeowners purchase a specific dwelling site within a cluster. Each site in the cluster is assigned a type of dwelling unit, with three story units in the center, one story units at the perimeter, and two story units in between. The maximum buildable footprint of the three story house is 3 room unit, the two story, 6 room, and the one story, 9. The three story unit can be expanded to 9 room units, the two story expanded to 12, and the one story to 9. The cost of each dwelling site varies with size of allowable footprint and square footage of the house. Homeowners purchase their site based upon location, potential size, and budget criteria and follow one simple rule: they can develop all but one of their site room units, which is to be made flexible according to the choice of owner and adjacent neighbor. Some people need a home office, while others may want to connect to an adjacent room of a relative or neighbor or create a shared courtyard. These interchangeable rooms are to connect with the public parts of each dwelling, living room, hall, or courtyards.

When houses are built at typical multi-family densities, the upper floors of units receive greater access to the sun, especially when rows are close together. Three story units may have major living spaces located above minor ones. Living rooms for example may be on top floors with kitchen and dining rooms below. Home office spaces are located on the ground floor allowing potential business clients easy access without entering private spaces. A room rented out to another adult may also be located on the ground floor or separated in some other way from the private family spaces.

THREE-STORY UNIT

TWO-STORY UNIT

ONE-STORY UNIT

Figure 4.1 - 9
Unit Plans
Sustainable Design Associates

Construction

We have chosen a column, beam, and plank framing system, rather than a bearing wall system, for the structural building components of the industrialized house. It is borrowed with permission from Neal Mitchell, whose system has already proven successful in the U.S. and other countries. The column and beam system allows for greater flexibility in the design of the dwelling. Exterior and interior walls and partitions can be easily removed, replaced, and relocated without changing the building's structure. Even the perimeter walls can be allowed to be free from the roof and irregular in pattern. The walls, doors, and windows can be replaced by newer, more efficient units as they become available in the future.

If the walls are non-bearing, they are more likely to be lightweight and easily handled by one or two people. This system allows homeowners the option of contracting the framing work and completing the rest of the work themselves. It would also be possible for one firm equipped for large scale construction to complete the framework, while separate, smaller, firms or craftspersons could provide the enclosure and finishes. We believe that this system offers the greatest possible diversity in forms and individual expressiveness.

The origin of the grid arose out of the need to standardize the structural and "infill" building components. However, we did not want technical or structural criteria alone to govern the layouts of rooms and the dimensions of all these components. As we are concerned with a rather small structure - a single attached family residence -- we are certain that the structural problems can be easily solvable with a number of different materials. In order to determine the dimensions of the grid, we asked ourselves "What is the minimum volume we require for comfortable habitation?" rather than asking "What is the maximum span of a 2x10 joist or a laminated wood beam?"

TYPICAL SECTION

VARIABLE INSULATING ROOF
TOP RADIANT LAYER WITH PIPING
PLASTIC LINER
CLOSED CELL INSULATION
RADIANT FLOOR LAYER WHEN CONVERTED
TO FLOOR EXPANSION WITH PIPING
EMBEDDED
ICEILING SIDE FADIANT BARRIER

Figure 4.1 - 10
Construction Details
Sustainable Design Associates

Economic Strategy

Because of high labor costs, anyone wishing to purchase a residence for \$55,000 (in 1985 dollars) must be prepared to help build the dwelling. This may range from doing most all of the interior work, laying floors, installing cabinets, to simple finishing touches such as painting and wallpapering. Not only does the owner builder option reduce costs, it also allows interiors to be customized to fit the individual's choices. Different types of building packages will be offered such as the "resident built infill" (completing the project after the frame is erected), "resident built interiors" (partitions, cabinets, etc.), and "resident finishes" (painting, etc.).

Energy Conservation Strategy

Each dwelling unit is long and thin. Daylighting and solar access to many rooms is provided by courtyards, shared light wells, and skylights. Each unit is arranged so that either the kitchen-dining area or the major living area has a southern exposure. In most plans the master bedroom is also faces south. The area of the south exposure is equal to one third of the floor area of each dwelling. After framing, structure, railings, etc., this will allow for a south facing glazing area of 15%. Thermal mass is located in floors, walls, and optional mass walls. (The insulation is applied on the exterior side of the thermal mass.)

Roof terraces (for flat roofs) and gable or hipped roof, provide a surface area of 33% - 100% of the unit's floor area. These surfaces accommodate solar water heaters and photovoltaics. Flat roof designs can incorporate roof pond passive heating and cooling systems. Other units must rely on direct gain, mass wall, and sunspace solar systems.

Energy Analysis
(computer simulation using Energy Scheming)

Figure 4.1 - 11
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: 43,287

Sep 21: 87,302

Jun 21: 128,005

Dec 21: 0

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>		<u>Max. Rad.</u>
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>	<u>Btuh/s.f.</u>
Mar.	84	51	48	15	13	3	294
Jun.	102	68	25	9	20	5	339
Sept.	102	77	44	20	23	0	294
Dec.	63	36	79	19	15	5	149

Assumptions and Program Inputs

R-values

Walls	27/26
Roof	51
Floor	27
Windows	8

Infiltration Rates: 15 Btuh/hr sf

Energy Strategies Used:

Cooling:

External shades
Internal shades
Loss to mass

Cross ventilation

Heating:

Night insulation
Gain from mass

Figure 4.1 - 12
Building Occupancy and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.

Lights: used 5PM-11PM.

4.1.3 STARTER HOUSE FOR A HOT ARID CLIMATE: DESIGN STUDY

Center for Housing Innovation

Ron Kellett, Patrick Gay, Brook Muller

University of Oregon,

Eugene, OR 97403

Design Summary

This design study combines several solutions to issues of energy conservation and economy. The site plan is organized for access and southern orientation to all houses. Lots are very small yet planned to maximize opportunity for private unconditioned terrace and garden living areas that also preserve access to sun, light and wind for major indoor living areas. Houses are two story and attached in pairs to reduce surface area and share the cost of expensive heating, cooling and service systems. Interiors are organized for passive heating and ventilation, and expansion to private outdoor spaces. Construction systems, components and materials realize the economies of scale customary to industrialized building yet allow small scale remodel and addition by occupants.

Project Data:

<u>Site</u>		<u>House (net usable)</u>	
Density	15 dua	Ground floor	500 sf
Lot (64'x 25')	1600 sf	Second floor	500 sf
Building footprint (28'x21')	588 sf	Total area	1000 sf

Figure 4.1 - 13
Axonometric view
Center for Housing Innovation

Site

The site plan assumes the gridded plan of the Phoenix area has established the location and orientation of local collector streets. Assuming these will run north - south or east - west, this site plan further grids the site into a series of blocks based on 22' wide one way streets that connect two collectors. By 2030 public transportation will assume a greater role and the size of the streets are designed to encourage pedestrian traffic. Public parks recreation spaces are assumed to be nearby within walking or bicycling distance.

Blocks can be subdivided in a variety of efficient configurations including zipper lots, wide and shallow lots or clusters. The site plan illustrated is laid out to zero lot lines along east / west streets so that each house has equal access to sun, wind and light. In this version, every lot 'fronts' to a street on the south and 'backs' to a street on the north. Each house has a private street address with guest parking on one side of the street to the front and private service access with off-street parking to the rear. Also to the rear is a storage/workspace (garage optional). Access to off-street parking and entries is shared along property lines to minimize redundant circulation and maximize the size and privacy of gardens and outdoor spaces. Both front and rear outdoor spaces and the uses ascribed to them contribute to an active community streetlife where neighbors can meet if they choose in the course of everyday living and working.

Each lot is approximately 1600 sf and planned to utilize its limited area efficiently. The footprint of each two story house is small, leaving a private courtyard to the south that serves as both living area and climate buffer zone to the living spaces adjacent. These gardens can be shaded, given water features, and finished with light reflective surfaces to enhance passive heating, cooling and daylighting systems.

Figure 4.1 - 14
 Site Plan
 Center for Housing Innovation

Unit Plan

Two two-story units are attached along a core wall of services. Each unit has ownership and control over the function, appearance and maintenance of the site and house from foundation to roof line. Both units share a main entry walk located along the center line of the common wall. Sharing this path maximizes the size and privacy of the adjacent garden and promotes controlled regular contact between the owners of both units. Service access to the core wall is located at the shared entry porch.

The interior volume of each house is 20' clear in the shorter dimension. Major spaces are 14' wide and are located at the ends of the plan. These rooms can vary in length, have light on two sides and open to private outdoor courtyards at the front and / or rear. Between the two major rooms of this plan is a freestanding stair and storage unit that divides the ground floor into a public zone of living / dining room to the front and a private zone of bedroom, study or office to the rear. The entry between provides direct street access and permits these rooms to function independently if desired. On the second floor two bedrooms are created in similar manner. Along the core wall of both floors is a 6' wide service zone of kitchens, baths, utilities and storage.

Expansion of the house can take place in several ways. 'Saddlebag' additions can enlarge rooms through windows and doors on the bearing wall side and through nonloadbearing exterior walls to the front and rear. Another floor can be added through the roof. Zoning and covenants control the limits of these expansions.

FIRST LEVEL PLAN

SECOND LEVEL PLAN

Figure 4.1 - 15
Floor Plans and Expansion Strategy
Center for Housing Innovation

Construction

Construction is based on a system of parallel concrete panel bearing walls spanned with engineered floor and roof cassettes of wood composite materials. Concrete elements of this system combine loadbearing capability with thermal resistance, thermal storage, service distribution, fire protection and acoustic separation. Infill elements of this system are of wood frame or similar construction that maximizes design flexibility and affords the owner opportunity to add and remodel with basic hand or power tools.

Ground floor and foundation are site-poured concrete. Two parallel loadbearing walls of fiber-reinforced, insulated concrete composite panels are placed and anchored to the slab. These manufactured panels, continuous from foundation to roof, are 4' wide and vary in height. They are placed by truck-mounted crane and secured to one another with notched joints and fiberglass locking cams. The double common wall between the two units is a 'core' wall in which the space conditioning and service systems for both units are located. Courtyard walls and pavings are also factory fabricated concrete elements.

Floor and roof cassettes are clear spanning, bearing only on concrete panel walls. These are 4' wide stressed skin cassettes, predrilled for services and attached on or between concrete panels. Roof cassettes can be engineered and manufactured to a wide variety of shapes, pitches and depths.

Interior partitions, and exterior walls oriented to the street, sun and wind are nonloadbearing and can be of a variety of frame or masonry construction materials. These choices can be made late in the design process, independent of most engineering and code decisions. The opportunity is provided to maximize design flexibility in style, finish, opening size and shape as well as facilitate later owner built additions and remodels to the interior, front, rear or roof.

SOUTH ELEVATION

WEST ELEVATION

Figure 4.1 - 16
Wall Section and Elevations
Center for Housing Innovation

Economic Strategy

Economies are realized at several scales of design, construction and development. The site is densely developed, distributing land and infrastructure costs over many units. Roads and rights of way are minimized. Houses are small but can be enlarged and remodeled when household resources permit. Interior space planning supports small in-house income opportunities such as businesses or tenancies.

House and site components requiring significant design and engineering services are few and standardized. The manufactured concrete panels, for example, integrate structure with insulation and weather resistance as well as assume other important life, safety and service functions of the house. Other component choices, such as roofs and interior partitions, that vary significantly with the tastes and needs of occupants can be varied and modified without extensive redesign and engineering. Inexpensive, surface mounted, operable 'switches', such as shading devices and ventilation scoops can be manufactured of light metal or plastic and used in lieu of mechanized or built-in systems.

Some services and amenities can be shared. Sharing a service core, for example, achieves substantial savings in one of the costliest areas of a house and makes possible quality energy conserving equipment that could not otherwise fall within the construction budget. Similarly, shared walks and driveways conserve costly land and materials.

Energy Conservation Strategy

Heating load is met by passive direct gain solar energy supplemented by a mechanical heat pump reclaiming waste heat from utilities and appliances. The house is designed for a large south window with a courtyard in front to ensure unobstructed winter sun. Thermal mass is provided in the concrete construction of loadbearing walls and ground floor. Air is circulated by convection to bedrooms above. Conductive losses through concrete sandwich panels are reduced by fiber-

reinforced connector rods that all but eliminate thermal bridging. One roof cassette is fitted with a solar collection surface for a domestic hot water heater. Another has photovoltaic panels, to reduce with electricity demand from the utility.

South, west and east facing windows are fitted with operable shades that allow for great versatility in admitting or blocking heat, light, wind, etc. Adjacent private courtyards and terrace are shaded by tiles and fabrics. A two-stage evaporative cooler is built into the core wall. A pivoting wind scoop at the top and a vertical chase on the cooler tower draws in wind and enhances cooler performance. The roof slopes downward to the core supplying rainwater to the cooler. Thermally massive structure delays cooling loads to off-peak hours.

Energy Analysis

(computer simulation using Energy Scheming)

Figure 4.1 - 17
Summary of Heat Flow
 Center for Housing Innovation

Total Daily Heat Flow (Btu)

Mar 21: 15,534

Jun 21: 112,478

Sep 21: 210,817

Dec 21: 4744

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>		<u>Max. Rad.</u>
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>	
<u>Btuh/s.f.</u>							
Mar.	84	51	48	15	13	3	294
Jun.	102	68	25	9	20	5	339
Sept.	102	77	44	20	23	0	294
Dec.	63	36	79	19	15	5	149

Assumptions and Program Inputs

R-values:
 Walls 24/19
 Roof 48
 Floor 5
 Windows 8
 Infiltration: 15 (Btuh/hr sf)

Energy Strategies Used:

Cooling:
 External overhangs
 Internal shades
 Loss to mass
 Stack ventilation
 Cross ventilation

Heating:
 Night insulation
 Gain from mass

Figure 4.1 - 18
Building Occupancy and Allowable Indoor Temperatures
 Center for Housing Innovation

Equipment: Schedule follows occupancy.
 Lights used 5PM-11PM

Designers' comments

- Explore the manufacturing technology of low cost, lightweight concrete composite panels. Consider which materials and mixture variations lower energy costs in transportation and processing, are lightweight, structurally sound at residential loads and have sound, thermal insulation and storage properties.
- Define an efficient two unit core design which accommodates all major space conditioning appliances, water recycling, and service connections, yet supports a range of interior design variation.
- Define the technology of wood composite floor and roof cassette manufacturing. Refine the range of materials, shapes and depths possible. Explore factory integration of service distribution in floor cassettes and solar collectors and photovoltaics in roof cassettes.
- Define a range of convenient manually operated environmental controls and switches as well as those that are easily automated at low cost.
- Define the limits of energy conservation measures and design variation possible in orientation, space planning, massing, style, finish and fenestration at this density.

4.2 EXTENDED FAMILY HOUSE FOR A COOL CLIMATE

Scenario

"I don't want to spend my golden years cleaning three bathrooms". Mrs. E, an elderly widow with adult children wants to sell her house in suburban Minneapolis and move to a smaller, more efficient and economical 'apartment'. While she looks forward to the reduced commitment and privacy, she is at the same time disinterested in leaving a familiar neighborhood and friends.

In 2031, she puts her 40 year old house up for sale and subdivides its 5000 square foot lot into two parcels. She plans to retain one of the parcels and use the proceeds from the sale to build a new house for herself. With a family buyer committed to purchase the old house, she contracts with 'Suburban Systems', a design build company specializing in small scale construction and conversions.

Practical and economic concerns are primary forces shaping this house. It should be small, secure, easy to maintain and inexpensive to run. It also represents an important commitment to remain in a familiar area in order to maintain and enjoy the proximity of friends, children, grandchildren and business associates.

Introduction

Existing single family suburbs are a promising future housing opportunity. Space is available. Houses can be expanded or transformed with ease. Construction is lightweight and familiar to occupants. The space around each house offers sunlight, ventilation and access. Change can take place incrementally, within the confines of the lot, and without major disruption (Vernez-Moudon, Sprague, 1982: 55).

The economic incentive alone is compelling. Infill housing on a site one owns and controls is a relatively simple and economical undertaking for an individual resident house owner. Zoning and construction permits can be sought and secured as slowly or quickly as the owner wishes. General contracting and labor costs can be reduced or eliminated depending on the skill and enthusiasm of the owner. It is possible to save up to 40% in construction costs and significant percentages in other development costs.

There are several infilling strategies that will create small low cost secondary housing units in and adjacent to existing houses. One strategy is conversion and addition, through which a multi-family dwelling is created by remodeling or expanding a single family dwelling. Conversion of large underutilized single family houses can be a vital strategy in creating future affordable energy conserving housing stock. Properly sited and well-built existing housing, however worn and out of date, can often be refurbished. One need only look at the example of value and intense utilization of the housing stock in college towns and successful resort communities to understand the significance of this housing opportunity.

A second infilling strategy is to build a second, often separate, dwelling on a single family lot without changing the existing house. In this strategy, neighborhoods become increasingly dense over time. A third infilling strategy, a variation of the second, is to consolidate several lots to create adequate space for the added dwelling.

Several cities are beginning to support the small scale change over time suggested by all three infilling strategies. New programs and policies encourage innovative and economical site planning practices as ways to increase density or to introduce income-generating uses with housing. Codes and regulations that result in costly site infrastructure, services and networks are being re-evaluated. Zoning and planning regulations have and will evolve to permit subdivision and / or consolidation of houses and lots (Hare 1988, p10 and Vernez-Moudon and Sprague, 1982: 54-

55).

An important market consequence of infill housing is the significant increase in neighborhood density with a subsequent decrease in lot size and reduction of configuration options as new dwellings are added. Decreasing lot size and restricted access implies that the location, size and configuration of a house footprint establishes critical site planning, housing design and construction decisions. In extreme cases, these considerations will limit design and construction options to predetermined structural envelopes within which interior variation may afford the sole means to customize designs. Increasing density and lot coverage also exacerbates problems of fire safety as well as acoustic and visual privacy.

Goals

Infill housing presents opportunities to rejuvenate existing neighborhoods, create new housing stock without costly new infrastructure, and conserve energy in both transportation and residential use.

The 'Extended' Family House problem statement explores these energy conservation opportunities in an emerging market for new infill housing for existing low density single family neighborhoods. In this problem statement, a small second house is built on a lot with an existing single family house. The added house is a small detached dwelling with low operating and maintenance costs. It can be sited behind or between existing houses. Access and open space is shared with the adjacent dwellings, but otherwise each is an autonomous dwelling.

There are several potential resident scenarios. One is a retired person leaving a single family house for smaller more economical accommodation; a second is a senior or junior family member returning 'home'; a third is an income-generating secondary housing or commercial unit.

Design goals

Site

- Increase density yet remain compatible with the scale and openness of single family neighborhoods.
- Plan site infill to preserve household privacy, access and identity.
- Architectural integration of houses of differing scale and materials.
- Orientation and siting to optimize passive heating and cooling.

House

- Separation / integration of new house with existing houses.
- Efficient plan suited to compact house and site
- Passive heating and cooling strategies suited to a range of orientations and restricted site restrictions.
- Heating and cooling systems and strategies suited to elderly residents.

Construction

- Integrate fragile, high thermal performance materials with construction systems and components.
- Use lightweight components, systems and assembly processes suitable for small restricted sites.
- Dimensional and material compatibility between wood and metal systems.
- Realizing design and construction flexibility suited to small, one of a kind sites and clients.
- Service distribution systems for thin wall construction.

Energy goals

In this problem statement the goal is to demonstrate the potential for total energy conservation in existing neighborhoods using low maintenance systems that will be easy for elderly users to operate.

A target household energy budget has been derived by projecting a 25% improvement over the most stringent contemporary standard, The State of California's Title XXIV Energy Code. Minneapolis is equivalent to California climate zone 16. Other energy goals include:

- Demonstration of a residential energy conservation strategy in tandem with transportation energy conservation, reduction of sprawl and duplication of services and networks.
- Realizing passive ventilation and solar gain on constrained sites.
- Realizing thermal performance in lightweight construction materials.
- Maintaining indoor air quality with tight construction standards.

Economic goals

In 1985, the median income for homeowners in the Minneapolis metropolitan area was approximately \$ 30,900 (American Housing Survey: 1985). In this problem statement household income has been estimated at 80% median. Although the sale of the original house will generate a significant amount of capital, this resident's income is fixed and real buying power is projected to remain stable or decline with inflation. Land costs are assumed to be negligible. Cash available is assumed to be from equity in the existing house. Assuming a 30 year mortgage at 11%, a house valued at approximately \$ 75,000 (exclusive of land) would have met this goal in 1985.

Housing delivery system assumptions

The Suburban Conversion Company (SCC), the housing provider assumed in this problem statement, is a moderate volume design/build contracting company that specializes in remodels and accessory units for suburban neighborhoods. In much the same manner that contemporary kitchen remodelers work with a range of cabinet, finish and appliance manufacturers, this construction company collaborates with several manufacturers and sub-contractors, who represent a range of quality and market segments.

SCC's strength is individualized marketing and effective, flexible but guaranteed project management. Principal employees have expertise in business and project management. Installation and construction is primarily sub-contracted although the company maintains a small skilled construction labor staff for site co-ordination, minor installations and warranty claims.

The company works out of showroom / studios in neighborhood shopping centers. Most clients 'walk-in'. A typical initial contact includes working with a homeowner client to develop project goals, budget and schedule. From that contact, a proposal to deliver a house at a fixed price on a fixed schedule is developed.

Once a contract is executed, a design is developed by professional staff within the company usually based on a client's sketch supplemented with a library of representative designs and the example of recently completed projects. Designs are customized to meet client needs and budget.

From an accepted schematic design, SCC refines and its details and performance characteristics from a limited range of interchangeable components based on the capabilities and products of collaborating manufacturers. A roster of manufacturers and sub-contractors is derived for the whole project. A scope of work and schedule is defined for each sub-contractor. A field manager is appointed to oversee the project coordination and installation processes.

Financing can be arranged in several ways. Projects often depend on several financing sources. SCC has a finance consultant on staff and a working agreement with a local mortgage broker. Clients may elect to finance all or part of their projects with their own resources and financial institutions. The company also maintains a working relationship with the conservation offices of local utilities and is quick to incorporate conservation incentives and financing programs in their projects.

Occupancy assumptions

While there are several, very different alternative residencies, this design study will concentrate on the needs of an elderly single woman with an 'extended' social family of relatives, friends and associates.

Spatial requirements

One 700 - 800 sf single story studio house with two bedrooms, kitchen, bath(s) and a screened porch. One bedroom is primarily a guest room or work room. Guests are normally received in kitchen, living or dining areas. Room sizes and layout must meet the particular requirements of the first owner yet be amenable to resale.

In 1985, the following amenities were common to new owner-occupied houses in the Minneapolis area: Fireplaces - 42%; Porches, decks, balconies, or patios - 78%; Separate dining rooms - 45%; Garages or carports - 96%; and Central air conditioning - 50% (American Housing Survey: 1985).

The new house can be sited on the existing lot in any orientation or configuration deemed appropriate without re-configuring the lot given. However, this lot can be reorganized with walks, driveways, plantings and outdoor spaces as required. Address and entry must be fully visible and accessible from the street. Off-street sheltered parking for one car is required.

Neighborhood, site and architectural context:

There is a variety of types and styles of houses in this suburban Minneapolis neighborhood. Many versions of the single family 'rambler' and split-levels built after 1970 are prevalent. At the same time there are also a significant number of walk-up apartments and row houses near commercial centers and important intersections. The commercial, institutional and industrial infrastructure of the area is well-developed and many residents work in or near the neighborhood.

Construction System Assumptions

The construction system specified in this problem statement is a thin, high thermal performance non-bearing panel system attached to a structural frame of engineered wood composite components.

Foundation

Wood pier foundation and perimeter beams or insulated concrete footing with wood interior piers.

Envelope and structure:

Fiber reinforced concrete or metal weather skin over compact vacuum insulation (CVI) panels. Panels are attached to an engineered wood composite frame (LVL) using factory installed metal connectors and tensioning elements.

Floors and roofs

Laminated Veneer Lumber box beams with wood fiber sheathing. Stressed skin panels with foam insulated cores structurally integrated with frame.

Mechanical system

Centrally located, ductless integrated heating, ventilating and air conditioning (HVAC) and domestic hot water (DHW), recovery core heat pump mechanical system. The high thermal performance of the panel envelope does not require perimeter distribution and an 'open' spatial organization permits passive distribution and return from a central location. Water is distributed at the interior of the house using a centralized manifold and distribution tree system.

Electrical system

Services must not puncture CVI panels. Integrated wiring system incorporating all electrical energy-driven functions in a single plug-in carrier. Carrier can be architecturally integrated with a lighting system in a distribution tray / cove lighting element or a wainscot.

Minneapolis climate

Cold, Humid, Windy

Lat. 45 deg. N; Long. 93 deg.W; El. +834'

The Minneapolis region is predominantly underheated. Winters are severely cold. Temperatures are too cool for comfort most of the year, dropping to below freezing for months at a time. Diurnal temperature swings are 20-25 °F. most of the year.

Minneapolis is more sunny than not, but yearly distribution is poor. In winter it is cloudy much of the time.

Winds are generally high (average 9-11 mph) and cause significant heat loss in buildings most of the year. Prevailing direction is from the northwest and secondarily from the southeast, throughout the year.

Rainfall is about 27" per year, mostly in summer. Snowfall is about 41" per year. Humidity is generally high (60-90% RH) and tends to be higher in winter than summer. Morning humidity is uncomfortable all year.

Primary passive heating strategies are thermal mass and zoned plans, cooling strategies are ventilation and thermal mass.

Heating Degree Days Base 65 °F.	8118
Cooling Degree Days Base 78 °F.	160
Winter Design DBT	-12 °F.
Summer Design DBT / Coincident WBT	89 °F / 73 °F.
Too Cool for Comfort (Sep.- May)	79%
Comfortable (June-late June; early May- end of May)	11%
Too Hot for Comfort (late June- early Aug.)	10%

Table 4.2 - 1

Minneapolis Area Climate Summary

Source: AIA Research Corporation, Regional Guidelines for Building Passive Passive Energy Conserving Homes, 1978; Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Utility context

Hydro-generated electricity and natural gas sources are available. The electric utility company in this problem statement operates close to its maximum generating capacity with little capital and political support to build additional generating plants. By necessity, this utility offers attractive conservation incentives and underwrites the construction cost of conservation measures and mortgages for durable energy conserving hardware and systems.

4.2.1 EXTENDED FAMILY HOUSE FOR A COOL CLIMATE: DESIGN STUDY

Virginia Cartwright and Peter Keyes

Department of Architecture,

University of Oregon,

Eugene, OR 97403

Design Summary

The project includes a prototype house design that can be sited at the rear of the typical 50' x 125' parcel. Several configurations and orientations are possible, depending upon specific site conditions and constraints. The house is a handicapped-adaptable single story residence with a relatively open plan, and volume living spaces to counter the small floor area. In its technical design, the house makes extensive use of laminated veneer lumber framing, and compact vacuum insulated panels for envelope insulation.

Project Data:

Site

Density: Approx. 15 units/acre

Lot (50' x 125'): 6,250 sf

Building footprint: 1,260 sf
(approximately 45' x 32')

House (net usable)

Total Area: 872 sf

Figure 4.2 - 1
Axonometric View
Cartwright, Keyes

Site Design

Given the small lot size, and the typical front yard setback of 15' to 20'. The proposed house was located at the rear of the lot because it allowed maximum retention of open space. The house was also pushed to the rear lot line, with the garage acting as a buffer between the house and the public alley right-of-way.

Where the location of the existing front house allows, an attempt has been made to define two linked yet separated rear yard open areas – an 18' foot wide yard to the north or south of the back house, towards which the living spaces of the back house are oriented, and a yard between the two houses, which acts as a rear yard for the front house, and an entry or front yard for the back house. The two yard areas are generally separated by a new garage for the front house.

The back house can be built detached, or it may share a party wall with another back house across a side lot line. With the detached house configuration, each house can be situated along the northern lot line, and receive good solar access to the living space across its yard to the south. However, a house oriented to the north may be necessary in a case where the front house is too close to the southern lot line. The new front house garage would then be located on the north side, requiring that the back house be located along the southern lot line, where it would be the northern half of a duplex.

The relation between the back house and the street can be resolved in two different ways. In the first, as represented on **Site Plan 1**, the existing main street is the primary means of access for the back house. Each house has a front walk and entry that runs through the side yard of the front house to the street. The second approach, as represented on **Site Plan 2**, uses the alley as a secondary street for access to the back house. To achieve this reversed orientation, the back house plan has been flipped, so that the eating area is towards the alley, the living area is between the alley and the yard, and the bedrooms are along the lot line.

SITE PLAN 1

SITE PLAN 2

Figure 4.2 - 2
Site Plans
Cartwright, Keyes

Unit Plan

The proposed house design is for a single-story, four-room house, encompassing 872 square feet gross. There are four distinct rooms:

- 16' x 18' living room / entry
- 10' x 17' kitchen / eating area
- 12' x 12' den / guest bedroom.
- 10' x 12' bedroom

The three main rooms (kitchen, living, den), are articulated as rooms, in keeping with the more traditional tastes of older people, but are also related to each other along a diagonal, allowing each of these small rooms to borrow visual space from the adjoining ones. This openness is enhanced by the corner locations of the main rooms, while the bedroom is located off a back hallway, giving more privacy.

The living room and eating area face the front porch and walk, presenting the public side of the house. (The front porch area can be converted to a wheelchair ramp if necessary.) There is an open counter between the kitchen and living room, and the living room has a high volume, beneath the 5 in 12 roof. The den/guest bedroom opens to the living room through French doors. The back hallway provides access to the bedroom, handicapped accessible bathroom, and laundry closet.

Figure 4.2 - 3
Unit Plan and Elevations
 Cartwright, Keyes

House Construction

The house is constructed of a second-growth timber frame structure of laminated veneer lumber (LVL) supporting compact vacuum insulation (CVI) panels. The result is an open system of components – a kit of parts that will allow for modification, flexibility and incorporation of alternative components.

The frame structure is comprised of 3 1/2" square LVL posts, spaced on a four foot module. Support for the roof system at the eave end is along the north and south walls. Support for the ridge beam is in three columns located along the house centerline, by the front door, back hallway, and wall between the bathroom and garage.

The roof structure is composed of LVL I-beam joists acting as rafters, and spanning 14 feet. The joists consist of 2 x 3 LVL chords, joined by a 3/8" plywood web. The joists are supported at the ridge by hangers from an LVL beam, which spans 16 feet. If these joists can be spaced at 4' on center, they can be supported at the eave end by the LVL posts. If they are to be spaced 2' on center, an LVL header will span between the posts (as shown in the construction section).

The floor structure is also of I-beam joists, spaced 2' on center. However, it would certainly be possible to build this house as a slab on grade. The foundation system has many possibilities: Pier foundation spaced 8' on center with LVL summer beams picking up the floor joist system. Concrete foundation wall and continuous footings can be of poured concrete, concrete block, concrete panels or all-weather wood in either a crawlspace or basement application.

The building envelope makes use of CVI panels in the walls, roof and floor. Thermal breaks are minimized and joints gasketed against air infiltration. The wall panels are the most complex portion of the envelope. They are based on a 4' module, fitting in between and attaching to the LVL posts supporting the roof structure. A 1/2" thick CVI panel has been manufactured with a

thick steel plate on one side. This strong side will receive an enamel finish and form the exterior skin of the house. Backing up this CVI panel will be steel channel framing, which will attach to the LVL posts. The CVI panels will overlap these posts to eliminate the thermal break at the framing, and they will be gasketed where they butt, to provide an effective air infiltration barrier.

The windows will be installed at the exterior plane of the envelope, with no real recess. They are of double casement-type operation, with a fixed light above, chosen for their superior performance against infiltration, and their ability to make use of aerogel technology between the glazing layers. Their thermal performance will be greatly enhanced by the use of CVI shutters. These shutters will be track-mounted immediately behind the windows, electric motor-driven, and when not in use, will be stored below the level of the windows behind a wainscot.

The inner surface of the wall panel will be manufactured with a cementitious wainscot of encapsulated phase change material (PCM) for thermal storage. Its performance will be enhanced by the circulation of heated or ambient air in the cavity between the wainscoting and the CVI shutter. The low, baseboard portion of this wainscoting will be a removable/flexible mechanical systems conduit, allowing electric circuiting, and providing a location for air registers. This PCM panel will be in a plane beyond the interior face of the LVL posts, and wiring can be run past the post in that plane. The space between the panels across the posts will be covered with a trim piece, providing a chase for light and shutter-motor switches.

The roof and floor envelopes will be very similar – a fabricated-wood board (plywood, waferboard, oriented-strand board, etc.), supported by LVL I-beam joists. The roof deck will be covered with metal roofing material, while the floor board will be the subfloor. The lower chords of the joists will support CVI panels, which will be laid into place on a bedding / sealing material, providing a good air pressure seal. The only thermal break through this system will be the plywood web of the joist.

The floor / wall joint has been detailed such that the wall panel laps the end of the floor system, minimizing the thermal break at the band joist, and allowing the infill panel framing to sit upon the foundation / summer beam, for easy erection. The eave detail has the wall panel lapping the lower chord of the rafter, again to minimize the thermal break. The roof framing system stops at the rim joist. An overhang with integrated exterior window shade is built as a modular/ panelized unit and attached on the site.

SECTION @ ROOF

SECTION @ FLOOR

Figure 4.2 - 4
Sections.
Cartwright, Keyes

Economic Strategy

The wall panels as designed are costly. They take advantage of the thinness of the CVT panels, and use the space saved to incorporate other elements - shutters, PCM panels, mechanical system integration, etc. This additional cost would have to be balanced against large energy savings possible with such a wall system.

The separation of the building envelope from the structure represents an increase in material cost. Certain items are redundant, such as the metal framing in the wall panels. However, in this case, the use of CVI panels as interior finish would furnish some savings, and the higher cost could perhaps be balanced by the tighter structural loads and energy benefits of having the house so configured.

Savings would accrue primarily in two areas: construction time and site costs. The frame could be erected in a couple of days, and the house closed in in a few more. Interior finish of the exterior wall panels would require only installation of trim pieces. There would be a savings in on-site labor, but there could also be significant savings in construction financing costs, which often run to 10% of the total cost of construction. Uncertainty associated with small, dispersed-site stick-building due to the unreliability of small-scale residential subcontractors and the variability of the weather could be reduced or eliminated with this scheme. Losses from pilfering during construction would likely decrease because the building could be closed in very quickly.

The cost of acquiring the site would obviously be nothing if the present owner were to build the new house. However, even if the back house and / or site were to be sold off, there would still be significant savings due to reduced site-development costs. Utilities would be close at hand and relatively accessible. In addition to these basic savings, Site Plan 2 of this project would save the costs of driveways and sidewalks running from the main street to the middle of the site.

Energy Conservation Strategy

The primary focus in the incorporation of passive energy conservation strategies has been the appropriateness of the fit between the possible strategies and the lifestyle of the anticipated occupants. Extensive use of direct gain methods was decided against for a few reasons: difficulties in specific site conditions relative to a prototype design, possible disinclination of a large part of the targeted population for living in a very bright direct-gain space, and the likelihood that many occupants would decorate their houses in a way that would make the placement and utilization of direct gain thermal mass difficult.

Consequently, the focus has been upon creating a type of superinsulated house. The panels allow for very high levels of insulation, and care has been taken in the detailing to minimize potential thermal breaks. There is only a 2 % framing factor for the roof and floor, and no framing factor for the walls, as the CVI panels are lapped over the posts. The thermal mass, which will be affected more by ambient air conditions than direct solar gain, has been located in the lower section of the walls, where it won't be covered by carpets. Shading of the windows has been achieved through exterior shutters incorporated in a panelized eave assembly, controlled by motors from the interior. A passive solar domestic hot water system has been incorporated, with the collectors flush mounted between the roof rafters on the south-facing roof slope.

The house design allows for any kind of forced-air heating system. Our preference is for a small gas-fired furnace, perhaps of the high-efficiency, condensing type. The mechanical space has been placed in the crawlspace, so that the vibration can be isolated from the rest of the house structure, and so that the mechanical space can be thermally coupled to the living space, avoiding any waste of heat to unconditioned spaces. This location also allows for outdoor access, for exhaust, and fresh and combustion air intake.

Although the program called for unducted central heating, a supply air plenum has been provided in the floor framing. This will allow for much greater efficiency and comfort in distribution, without any additional cost or difficulty in constructing ducts, as the joist space is already available. The heating registers are at the bottom of the wall panels, where that space is open to the joist spaces. Additionally, this allows for warm air flow on the back side of the PCM wainscoting. A central return air register is located in the living room / attic wall, and is then ducted down to the mechanical crawlspace.

Energy Analysis
(computer simulation using Energy Scheming)

Figure 4.2 - 5
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: -31,493 Jun 21: 0
Sep 21: 0 Dec 21: -63,598

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>		<u>Max. Rad.</u>
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>	<u>Btuh/s.f.</u>
Mar.	37	20	77	63	16	6	91
Jun.	77	57	80	54	15	5	123
Sept.	71	49	87	62	15	5	119
Dec.	27	11	79	71	15	5	33

Assumptions and Program Inputs

R-values

Walls	50
Roof	50
Floor	50
Windows	10
Night Insul.	50

Infiltration Rates: 15 Btu/hr sf

Energy Strategies Used:

Cooling:

Cross ventilation
External shades
Night ventilation
Internal shades
Loss to mass

Heating:

Gain from mass

Figure 4.2 - 6
Building Occupancy and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.
Lights: used 5PM-11PM.

Designer's Comment

In general, we found the overall problem statement reasonable and insightful in its assessment of demographics, targeted age, regional markets, type of housing required vs. what is presently offered, type of site, energy and materials scenarios, construction process scenario, etc. Within that framework, this project has attempted to offer a non-radical solution on many levels – house and site design, construction technology and process. We believe that such an approach is more characteristic of the evolution of housing design and construction – offering a much greater chance of success than bold attempts to reconfigure housing all at once. It is important to design materials and components that can fit into the very flexible and open system of building that exists because innovative materials, products and techniques have historically invaded the building process slowly. This problem statement seemed to recognize the evolutionary nature of the industry, and allowed for the incorporation of high performance materials into that open system.

The following observations relate to details of the problem statement and ways in which further study might proceed:

- The site design was constrained by the need to house two cars. Scenarios could be envisioned where neighborhood redevelopment resulting in increased density would include a better mass transit system and local services – diminishing car-dependence.
- The desire to orient the back houses to the main street causes problems of entry, both symbolic (through someone else's backyard) and practical (disconnection of occupant from the street, snow to shovel). The alley as street scenario could be further developed.
- The target house plan floor area seemed unrealistic. This project had small rooms, very efficient circulation, and almost no wasted space, yet it was 72 square feet over the target. This was also after omitting the second bathroom (which was not necessary anyway).

- The degree of specificity and selection of mechanical systems seemed unwarranted. Perhaps mechanical systems should be developed independently as engineering research projects, and then fitted into house designs. From the house design perspective, thought should be given to lifestyle preference issues in mechanical systems.
- In many parts of the country, limited water resources will be a growing problem. The accommodation of and strategies for rainwater and greywater recycling should be investigated and incorporated into future problem statements.
- The current movement to require sprinklers in all buildings should be considered for its impact on any future building scenario.
- The initial specification of GFRC panels seemed unwarranted, due to uncertainties about their long-term viability, and certainty about their high cost. The solution we have proposed may be problematic also; investigation of CVI panels should focus not merely upon their thermal performance, but also upon their performance in the building environment. Their fragility and the need to protect them may rule out their use.
- The basic cost-effectiveness of CVI panels must be further studied. As stated in the paper from ASHRAE Transactions, they seem to make sense when the interior volume is worth over \$25 per cubic foot, well over what house space is worth. Perhaps they make sense in walls where this thinness allows for other components, or as high performance shutters, but it is less likely that they are cost-effective in floors and roofs, where there is often a large cavity that can be easily filled with low-cost fibrous insulation.
- Further study of zoning requirements should be considered, as this is the basic change underlying this problem statement.

4.2.2 EXTENDED FAMILY HOUSE FOR A COOL CLIMATE: DESIGN STUDY

Stephen Weeks, Lance LaVine, Charlie Huizenga

Department of Architecture,
University of Minnesota,
Minneapolis, MN 55455

Design Summary

Energy Self Sufficiency: One of the major objectives of the design process was to enable the house to be as energy self-sufficient as possible. Decreasing availability of fossil fuel resources and the increasing environmental strain of consuming them urges an energy strategy which utilizes as much site energy as possible.

Neighborhood Structure: If predictions concerning resource depletion and pollution generation prove to be true, it will become increasingly important to utilize existing resources thoughtfully. The new structure of neighborhood development creates a spatial organization that complements existing suburban spatial order.

Discrete and Overlapping Territories: Discrete territories are defined by fixed boundaries and are entered by passing through these boundaries. In overlapping territories, boundaries of space, light and climate are blurred.

Project Data

Density: +30% over existing suburban standard

Lot (45' x 50' of existing 50' x 125')

Building (25' x 29') 750 sf

House (net usable): approx. 1000 sf Outdoor rooms: 385 sf - 990 sf

Discrete and Overlapping
Territories

Figure 4.2 - 7
Design Strategies
Weeks, LaVine, Huizenga

Site

Increasing land use density in existing sparsely developed suburban areas may prove a potential strategy for more efficient use of existing urban infrastructure. This proposal would cede the rear 45' of existing 50' wide by 125' deep suburban lots to new development. The development plan that would emerge would turn the alley into a minor street. The result is a development pattern is capable of increasing existing suburban density by 30%.

Figure 4.2 - 8
 Site Plan
 Weeks, LaVine, Huizenga
 Page 4 - 83

Unit plan

Houses built from industrial components must prove their capability to create places of human significance. Our project develops two such kinds of places. The first is formed by discrete territories. Discrete territories are defined by fixed boundaries and are entered by passing through these boundaries. The bedrooms and the outside area adjacent to the kitchen represent discrete territories. The second kind of place is termed an overlapping territory. In overlapping territories, boundaries of space, light and climate are blurred. Adjacent areas overlap each other to form spatial, light, and climatic places that bleed one into the other. Thus the kitchen opens to the dining area, the dining area to the living area, the living area to the porch, and the porch to the neighbor's yard.

Figure 4.2 - 9
Unit Plan and Elevations
 Weeks, LaVine, Huizenga

Construction

Our project began with a door height (80") as a fixed dimension. We selected this dimension because a door is the height of opening required for human passage. The 80" height was broken into a 50" and a 30" component using the golden mean. We then used 50" as the base width of the manufactured panel. A 30" x 50" panel is added above the 80" datum line to bring light into the rooms at the ceiling.

The wall is comprised of two parts: a modified post and beam frame and an envelope panel. The modified post and beam frame is laterally tied by interior trim that is channeled to receive wiring. The thermal envelope panel is a lightweight (5 lbs / sq ft) concrete (silica, cement, cellulose, water and polymers) panel with a compact vacuum insulation core. The panel has factory-drilled anchor points which attach it vertically to the posts.

The structural frame is a precut and notched solid wood veneer post and frame system. The 3" x 3" posts are 50" on center and slipped into a notched laminated veneer lumber (LVL) plate. At heights of 30", 50", and at 110" (the top plate), there are lateral notches that receive 100" x 2" x 3" LVL ties. All the joints are predrilled for wooden dowels which are hammered into place. The edges of the panels are gasketed and overlapped to avoid thermal bridging. This wooden lattice/frame provides the datum for the exterior panel, which is set in from the outside between the posts. The frame also supports the LVL wood trusses as well as structural bracing. Since it is also exposed on the inside, it dictates the location of interior partitions.

The self-supporting 1/2" CVI panel is sandwiched with adhesives between two lightweight concrete surfaces of varying thickness. The exterior of the CVI is protected with a 3/8" finished veneer of either smooth or textured concrete, placed vertically or horizontally.

Figure 4.2 - 10
 Wall Section
 Weeks, LaVine, Huizenga

The interior has 2" of lightweight concrete with a smooth nearly polished appearance and finish that can either be painted or plastered. The panels are all 50" wide, and come in three heights: 30", 50" and 80". The largest panel (50" x 80") will weigh 85 pounds. The edge of the panel is formed with notches and holes for customer addition of more traditional sidings and for fastening trim pieces.

After the posts are in place, the exterior panels are set in from the outside. The panels are aligned by factory machined notches, and the panel has interlocking joints with preformed EPDM gaskets so that the insulating CVI panels are nearly continuous. A small adhesive strip covers the joints and overlaps the post providing a continuous exterior surface.

The roof is a hip roof of LVL I-Beams at a pitch of 8 in 12. There is an array of photovoltaic cells on the south face of the roof. The shingles are concrete, laid on horizontal LVL furring that spans 50". A preformed skylight sits at the top.

The floor systems consists of 50" x 50" panels which are laid onto the 100" x 100" grid of 3" x 6" box beams. The floor is framed as a two way grid of 3" x 6" LVL beams, each spanning 50". They are anchored to the piers, which are centered at 100", with metal brackets. They are notched to receive the floor panel which consists of a 3/8" weather skin, a 1/2" CVI core, and a lightweight concrete interior surface, which has an embedded PVC-radiant hydronic heating manifold. The joints are gasketed butt joints, which are sealed after the manifolds have been connected and covered with a plate.

The house sits on 6" round wooden piers, set on bearing blocks at frost line. They are leveled centered and capped with preformed metal brackets. The framing for the CVI floor panels is a two-way grid of 3" x 6" LVL box beams that span 100".

Figure 4.2 - 11
Sections
 Weeks, LaVine, Huizenga

Economic Strategy

The design of the house seeks to minimize on-site labor. Panels are easily assembled on-site with a minimum of equipment. The exterior panels are designed to provide a finished surface on both the exterior and interior. Provisions are made, however, for the addition of exterior and/or interior finishes. This provides a range of alternatives to the client in terms of design preference and cost.

The energy needs of the house are provided entirely by on-site sources. In conjunction with the low maintenance materials, this creates a very low operating budget for the owner. The pier foundation allows minimal site preparation expenditures.

Energy Conservation Strategy

The decreasing availability of fossil fuel resources and the increasing environmental strain of consuming them urges an energy strategy which utilizes as much site energy as possible. Of primary concern in the Minneapolis climate is the reduction of conductive losses through the building envelope. This has been achieved through the use of compact vacuum insulation (CVI) in the exterior building panels. The 1/2", R-50 CVI panel is fused to glass fiber reinforced lightweight concrete on either side. The thin layer (1/2") of concrete on the exterior forms the weather skin of the building, and the thick layer (1") forms the inside surface, providing thermal mass for the house. In addition to the CVI core, the exterior panels are gasketed to provide a very tight envelope to minimize uncontrolled infiltration.

The glazing system incorporated in the house consists of two panes of glass with two layers of low emissivity plastic film with a krypton/argon gas fill. The center of glass R-value is R-15, and the incorporation of the glazing in the exterior manufactured panel allows the use of a CVI frame with an R-value of R-20. Low solar transmittance glazing is used on the west side of the building and in the skylight to minimize unwanted solar gain during the cooling season. Higher solar transmittance glazing is used for the vertical south facing windows which provides desirable solar

gain but during the heating season, but shading is required in the cooling season. This method allows for a higher percentage of glazing.

The ventilation system makes use of a whole house fan which draws air in through diffusers located in the exterior edge of the slab. The diffusers are operated automatically, but can be manually overridden. In the heating season, the system maintains high air quality in the house by providing plenty of fresh air. In the cooling season, the system can take advantage of cool nights by drawing in cool outside air through the diffusers in the slab and thus minimizing the amount of cooling required.

The all electric system is powered by photovoltaic (PV) panels incorporated into the manufactured roof system. To meet the needs of the house, 150 sq ft of PV panel (with a peak capacity of 26 W/sf) is required. Electrical storage will utilize hydrogen fuel cells, which store electrical energy by generating hydrogen through electrolysis. This system requires one cubic meter of storage.

The mechanical system is based on a liquid-to-liquid electric heat pump. The floor panels are pre-plumbed to provide a radiant floor heating delivery system. The radiant floor system works well to distribute solar gains and night ventilation cooling from one part of the house to another. The heat pump is connected to both a cold water tank and a hot water tank. A heat recovery coil is used to extract waste heat from both the exhaust air and greywater.

The heating system could also be adapted to a forced air system by using a fan coil unit located in the mechanical closet. This might be a lower cost alternative to the radiant floor system.

Ventilation is provided by a whole house fan and ventilation supply points in each room. The main exhaust from the house is ganged with the exhaust from the bathrooms and kitchen before passing through the heat recovery coil. A filter/grease trap in the kitchen helps keep the coil clean.

Energy Analysis
(computer simulation using Energy Scheming)

Figure 4.2 - 12
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: 61,032 Jun 21: 0
Sep 21: 0 Dec 21: 117,659

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>			<u>Max. Rad.</u>
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>		<u>Btuh/s.f.</u>
Mar.	37	20		77	63	16	6	91
Jun.	77	57		80	54	15	5	123
Sept.	71	49		87	62	15	5	119
Dec.	27	11		79	71	15	5	33

Assumptions and Program Inputs

R-values

Walls	52
Roof	52
Floor	52
Windows	15(inc. insul.)

Infiltration Rates: 15 Btu/hr sf

Energy Strategies Used:

Cooling:

Cross ventilation
External shades
Internal shades
Loss to mass

Heating:

Gain from mass
Night insulation

Figure 4.2 - 13
Building Occupancy and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.
Lights: used 5PM-11PM.

Designer's Comment

- The site given in the problem statement does not take into account that most suburban lots in Minneapolis have a curb cut rather than an alley, which provides access from the street. We examined how our design could be implemented given a number of different site scenarios.
- Another issue which warrants further research is the life expectancy of materials, particularly the CVI panels. We designed the system such that the panels could be replaced if necessary, but it was assumed that the panels would have a fairly long life span.

4.2.3 EXTENDED FAMILY HOUSE FOR A COOL CLIMATE: DESIGN STUDY

Center for Housing Innovation

Rudy Berg, Mark DeKay, G. Z. Brown

University of Oregon,

Eugene, OR 97403

Design Summary

Site goals include separation and integration of the new house with existing houses, and orientation and siting of the new house to achieve passive heating and cooling. Our approach to site design was to identify basic options and generic strategies common to most sites analogous to ours. Each can be adapted to a variety of specific site conditions.

In house design, goals include plan efficiency, resolution of public and private spaces, utilization of passive design strategies, and stylistic variation using a limited number of interchangeable parts.

Project Data

Site

Density: 16 units/acre

Lot (50' x 125'): 6250 sf -rear half 3000 sf

Building footprint: A (32' x 25'): 800 sf
B (30' x 25'): 750 sf

Outdoor rooms A: 1,500 sf
B: 1,200 sf

House (net usable)

House (net usable) A: 756 sf

B: 694 sf

Figure 4.2 - 14
Axonometrics
Center for Housing Innovation

Site

We identified two basic strategies for locating the new structure and addressing the need for a visible entry from the street. One required the new house to be sited on the edge of the property so that its main entrance could be visible from the street. The other called for a site farther from the property line and the construction of an entrance gate, portal or other visible entrance path near the street, leading to an entry into the side of the house perpendicular to the street.

Siting the new house on the north edge of the lot, in either zoning option, maximizes its public visibility, its solar exposure, and the opportunity for usable shared south facing outdoor space. A variety of outdoor spaces with different degrees of privacy and transitions between them can address the needs for privacy of individual households and the community.

Figure 4.2 - 15
Site Plan
Center for Housing Innovation

Unit Plan

Unit plans are compact and volumetrically efficient, while providing varied ceiling heights, supportive space/subspace relationships, and integrated outdoor spaces. Heat-saving air lock entries become screened porches in summer, and the combination of ample south windows and sun control devices (overhangs and arbors) aims to provide daylight, solar gain in winter and shaded entry for summer breezes. Both plans are fully accessible.

We identified two generic plan options, a single volume plan and a multi-zone plan.

We realized that this choice of plan zoning had implications for the location of the mechanical core.

A multi-zoned plan would need a more centrally located core in order to reduce distribution runs, whereas a single zone plan could employ a perimeter core to reduce the spatial impact of placing the core within the single volume.

HOUSE 'B'

HOUSE 'A'

Figure 4.2 - 16
Unit Plans/Elevations
Center for Housing Innovation

Construction

The design presented is based closely on the existing open system of construction patterns and element sizes, codified in a system like the NAHB UNICOM Method. This system is a good example of a thoughtfully derived modular construction system based on U.S. construction practices and materials. The construction system employed in this design is an 8' modular frame and panel system. The frame is founded on an 8'x12'± grid of piers which can also support outside structures such as decks, walkways and walls. The pier-based system minimizes construction impact on the site, effects of frost heave, and difficulties of concrete work in cold weather. The 8' basic unit derives from the problems of carrying two- and three-dimensional components to constricted sites, as well as the prevalence of that size in U.S. building products.

To begin the construction process, the pier system is laid out and drilled with a small power auger. Concrete punch pads are poured and piers installed. The piers themselves are treated wood, concrete or composites. Screw-type earth anchors might serve as piers, requiring no drilling or backfill. Another option is to impact drive hollow pier elements and inject soil stabilizing compounds through them. A moisture barrier is then laid on the area to be covered by the floor, its perimeter tucked into a trench which will receive the no-fines concrete apron panels that permit passage of air. Floor panels (8'x24') are bolted to the piers, using fittings built into the LVL-type perimeter of the panels. A special panel connects to the rough utility module and carries the connections through the floor, maintaining the integrity of the building envelope.

Construction of the walls and roof can take several courses. If project density, site conditions, etc., permit use of a crane, the builder constructs the roof directly on the floor deck, including gypsum ceiling panels and soffits which employ preinstalled stiffening ribs on their upper surfaces.

Figure 4.2 - 17
Wall Section
 Center for Housing Innovation

Trusses (or alternatively TJI-type framing members if a closed ceiling, or Parallam members if exposed framing) are positioned over fittings in the floor deck which will later anchor wall frames. Self-spacing braces are snapped into place, then Thermo-Ply type structural sheathing with attached purlins is pneumatically fastened. Corrugated wood-based roofing sheets (Onduline) complete the weather surface, and provide a self-venting "cold roof." When the roof is complete, it is lifted to a spot adjacent to the deck until the walls have been erected, then set onto them. As soon as the roof is clear of the deck, the kitchen/bath/utility module is installed. In cases where the roof is built last, the core module is usually installed as soon as the deck is complete.

Wall construction employs a variety of vertical structures on 8' centers: columns of Parallam or Scrimber type material, holding to the basic 3-1/2" x 3-1/2" modular column dimension and engineered to varying capacities; appearance grades wrapped with veneers or otherwise prefinished; and "offsets", usually shear/compression panels, used as closet walls, sides of window bays, etc. These elements carry the vertical and wind loads of the building, their capacity determined by the builder's structural design program.

Once the wall structure is bolted in place, CVI insulation panels and glazing, then wood-cement composite siding panels are clipped into position with thermally broken clips or through ties. In many cases the builder brings completed wall panels to the site. Siding panels are available in a variety of textures and colors, but the current penchant for authenticity has made "Realcrete"TM the best seller.

Figure 4.2 - 18
Components/Systems
Center for Housing Innovation

Economic Strategy

A compact plan minimizes construction and operating expense. Energy conservation measures minimize operating costs. Durable materials (cement composite siding, etc.) minimize maintenance costs. Integrated design processes minimize construction costs, according to priorities selected in optimization program. Pier foundation reduces labor, material and site work expense. Lightweight framing system minimizes material used and foundation required. Re-use of existing garage avoids replacement expense.

Energy Conservation Strategy

Energy performance is integrated into the design process from the outset, through sophisticated computer programs. Siting the house on the northern edge of the lot maximizes solar access, improved by the zero lot line site option. Compact building forms minimize skin losses. The pier foundation system reduces excavation, transportation and embodied energy needs. A multi-fuel gas water/space heating system provides reliable performance at low temperatures. The mechanical/electrical/plumbing core recovers waste water heat and minimizes distribution heat losses, and the air/air heat exchanger ensures air quality with minimum heat loss. High performance glazing permits increased daylight levels, reducing lighting energy requirements. Eutectic phase-change panels permit heat storage.

Shading and ventilation is provided for summer cooling. The 12/12 roof optimizes the solar collector angle for the Minneapolis site. Wing walls provide shelter from prevailing northwest winter winds, improving the microclimate. Air lock entries reduce the thermal impact of open doors. Passive solar heating strategies (sunspace and direct gain) are employed. The engineered, lightweight frame reduces material requirements and embodied energy. The panelized construction system permits recycling of building elements.

“Energy Scheming” analysis- House A
Annual Energy Use

Figure 4.2 - 19
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: -116,531 Jun 21: 2,375
Sep 21: -1,015 Dec 21: -187,843

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>		<u>Max. Rad.</u> <u>Btuh/s.f.</u>
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>	
Mar.	37	20	77	63	16	6	91
Jun.	77	57	80	54	15	5	123
Sept.	71	49	87	62	15	5	119
Dec.	27	11	79	71	15	5	33

Assumptions and Program Inputs

R-values

Walls	40
Roof	60
Floor	30
Windows	10

Infiltration Rates: 15 Btu/hr sf

Energy Strategies Used:

Cooling:

External operable shades
Internal shades
Cross ventilation
Night ventilation

Heating:

Gain from mass

Figure 4.2 - 20

Building Occupancy and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.

Lights: used 5PM-11PM

“Energy Scheming” analysis House B
Annual Energy Use

Figure 4.2 - 21
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: -74,750	Jun 21: 44,626
Sep 21: -9,636	Dec 21: -107,932

Climate Data Input

	Ave. Temp. F.		Ave. %R.H.		Wind m.p.h.			Max. Rad. Btuh/s.f.
	High	Low	High	Low	Max.	Min.		
Mar.	37	20	77	63	16	6		91
Jun.	77	57	80	54	15	5		123
Sept.	71	49	87	62	15	5		119
Dec.	27	11	79	71	15	5		33

Assumptions and Program Inputs

R-values

Walls	40
Roof	60
Floor	30
Windows	10

Infiltration Rates: 15 Btu/hr sf

Energy Strategies Used:

Cooling:

External operable shades
Internal shades
Cross ventilation
Night ventilation

Heating:

Gain from mass

Figure 4.2 - 22
Building Occupancy Assumptions and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.
Lights: used 5PM-11PM.

4.3 MOVE-UP HOUSE FOR A HOT HUMID CLIMATE

Scenario

"We plan this to be the last move we'll make!" . The finances and wealth (total assets minus total debts) of the S family have steadily improved with 20 years of career advancement and prudent investment. Both spouses work and their two children, now of college age, work part-time as well.

Reaching peak earning years, debt retirement and the children's decreasing dependence have contributed to a steady increase in the S's discretionary income. This circumstance has enabled them to more carefully consider and ultimately emphasize questions of character, quality and convenience in the goods and services they acquire.

The recent decision to move to suburban Miami is a case in point. Like their previous house purchases this one is not a hurried or serendipitous decision but one borne of need and careful planning. The children are about to move out of the family house and partial retirement of the elder parent is now within the 10 year plan. These are the end of the peak earning years that offer the opportunity to find a desirable house and neighborhood for a transition to a period of reduced mobility, stress and income.

While questions of quality and convenience will continue to be paramount there is at the same time recognition that this house will likely be a long term commitment made less for resale value and more for quality of life. Its ownership and operating costs will extend through a period of declining income and maintenance capability.

Introduction

As the baby boom generation passes through the 35-54 age range at the turn of the century, its economic strength and capacity to purchase housing will broaden relative to other generations. The 40's and 50's are already peak earning years for most households and two income households are common to this generation. Many have owned one or more houses that have appreciated significantly in value. This group will define a housing market with proportionally greater income and capital to allocate to housing (Morrison, 1990).

Although these higher income households will by no means dominate the housing market of 2030 they will occupy a significant and profitable niche, particularly in desirable high growth regions. This affluent and experienced market segment will likely continue to concentrate wealth in their houses and periodically 'move-up' to larger, better equipped, single family houses which in turn will consume greater energy without matching sophistication in energy conserving components, design standards and construction quality.

Long term regional economic projections by the Bureau of Economic Analysis of the U.S. Department of Commerce indicate that the fastest growing regions of the country in the 21st Century will be the coastal states of the West and South. These areas will grow approximately 2.5% per year — four times the rate of the remainder of the country — a trend accelerated by high rates of migration to the South and West (Feldman, 1990).

The situation is particularly acute in Florida, one of three fastest growing jurisdictions in the South. (U.S. Bureau of the Census, P-25 No. 1039, 1989). An important consequence is the dramatic increase in energy consumption and projected demand for cooling in the Sunbelt. Faced with long term management of a difficult power planning future and short term management of peak loads, some Sunbelt utilities have aggressively pursued incentive programs.

Goals

This problem statement is focused on four interacting issues and future trends that will influence industrialized housing design and energy conservation in the southeast; high migration rates to the smaller cities and suburban areas of the sun-belt; the economic strength, market experience and quality expectations of middle-aged homeowners; interest on the part of sunbelt utilities to invest directly in conservation measures, particularly those that control peak cooling loads; and opportunity to design, engineer, and integrate components to achieve the quality possible with a 'state of the art' housing design and manufacturing factory.

Design goals

Site

- Orientation and siting to realize passive cooling.
- Siting and organization to reduce infrastructure requirements.

House

- Spatial organization to realize effective cooling conservation zones.
- Low maintenance, low operating cost energy conservation features with a 'custom' designed house.
- Reconciling thermal zoning and energy conserving envelope with occupancy requirements.

Construction

- Integration of miniature electronic, mechanical and air distribution systems in envelope.
- Industrialization of high quality construction and finish standards.

Energy Goals:

A target household energy budget has been derived by projecting a 25% improvement over the most stringent contemporary standard, The State of California's Title XXIV Energy Code. Miami is equivalent to California climate zone 14. Other energy goals include:

- Zero net electrical energy demand.
- No peak demand on electrical utility.

Economic goal

The house defined in this problem statement is intended to be affordable at 200% median income. In 1986, this median income was \$ 26,000 for homeowners and the median value of homeowner occupied homes was approximately \$ 71,000 in the Miami region (American Housing Survey: 1986). Assuming a 30 year mortgage at 11%, a house valued at approximately \$ 110,000 would have met this goal in 1986. Cash requirements are assumed to be met through savings and equity built up in previous houses. In the occupant scenario, household income will decline within ten years with retirement as will household expenditures in support of college age children.

Housing delivery system assumptions

Custom Housing Industries (CHI), the housing developer in this problem statement is a medium volume custom house building company in which marketing and sales are oriented to the unique needs of individual upper middle income customers. CHI is a regional company that does not manufacture 'whole' houses. It is a subsidiary of a large private utility, and has been very successful manufacturing a high quality modular shell that can be customized with a variety of options. Most options are installed at the factory; some are installed on site.

CHI pursues two markets. About half of its sales derive from preserviced modular shells marketed to other builders. The remaining sales derive from a design and build market made from storefronts in high growth areas of the region.

Rather than stretch themselves too thin as a full service company, CHI concentrates on what it does best and collaborates with sub-contractors and suppliers who possess the expertise and experience in specific markets. In Miami they have been most successful as a developer of relatively small projects, marketing design and construction flexibility to a knowledgeable move-up market. They have acquired a reputation for design quality, high standards of project management and well-constructed, convenient and easy to maintain houses that can be cooled effectively.

In this market, they have recently initiated several joint venture projects with the utility parent company in efforts to reduce rapidly growing peak demand in the area. In the project defined in this problem statement, the utility is a partner that will design, own and maintain a 'state of the art' network of site service systems and space conditioning appliances. These systems are designed not only to reduce demand but also to generate energy, returning electricity and 'cool' to the utility for redistribution.

Occupancy assumptions

While there are several very different alternative residencies suited to a house of this kind, this design study will concentrate on a family of four (two middle aged adults and two young adult children) about to become an empty-nester family of two adults. This is the third house owned by a family moving down in size but up in quality and convenience.

Spatial requirements

Approximately 2,000 sf two story house with four bedrooms, three baths. One bedroom is primarily an office or work space. Two other bedrooms are occupied by adult children and scheduled to become guest rooms. Spatial organization must be 'closed' to work with conservation strategy and zoned mechanical system.

In 1986, the following amenities were common to new owner occupied houses in the Miami area: Fireplaces - 4%; Porches, deck, balconies or patios - 92%; separate dining rooms - 35%; Separate garages and carports - 37%; and Central air conditioning - 100% (American Housing Survey, 1986).

Neighborhood, site and architectural context

The neighborhood is a recently developed suburb of single family dwellings and related services. Adjacent architectural context consists of well landscaped open spaces and a similar 2 - 3 story residential and commercial buildings. Public transit, commercial, recreational and some institutional services are within walking distance.

The site is a small but desirable lot and will accommodate approximately 20 houses. Zoning permits PUD type cluster planning and circulation system, as well as site scale solutions to waste, utilities and services.

Construction System Assumptions

The construction system specified in this problem statement uses large modules of wood and wood composite frames and stressed skin panels.

Foundation

Manufactured wood panels or concrete or concrete masonry foundation walls on poured in place concrete footings.

Envelope and structure:

Modules are constructed of stressed skin wood composite panels reinforced with a laminated veneer lumber (LVL) frame. Modules are sheathed with extruded wood-fiber / concrete composite material on the exterior and wood-fiber / gypsum material on the

interior. Machine cut insulation is set in between framing members. A metal connector system expedites alignment and tightening of modules on site.

Floors and roofs

LVL box beams support wood composite stressed skin floor and roof panels with foam insulation cores.

Mechanical system

The mechanical service system is a central mechanical core using a concealed small diameter pipe distribution system with variable air volume control dampers. Core integrated heat pump service systems with distribution through small diameter plastic pipe. Miniature variable air volume (VAV) dampers reduce the velocity of supply air from a high pressure fan source to end use pressures. A system of this nature is zoned to vary room temperature and ventilation rates in response to heating and cooling loads or occupant demand. Distribution pipe, VAV dampers and grilles are partially recessed into an extruded or molded wainscots. Return air is collected in a central hall or vestibule.

Electrical system:

Power and lighting services are distributed through walls. Power is distributed through partially recessed thin electrical carrier strip with surface mounted receptacles. Miniature high power electronic ballast electrodeless HID lighting is mounted on walls and reflected.

Miami climate

Hot, Humid, Breezy, Rainy, Partly Cloudy

Lat. 25 °; Long. 80 °; El. +8'

The Miami region is characterized by temperature distribution in the 60-85 °F. range with small diurnal temperature swings (6 °F. in summer, 10 °F. in winter) year round. Winter temperatures never fall below freezing. Summer temperatures are rarely above 90 °F. .

Partly cloudy and cloudy conditions predominate, with a few clear days each month. Radiation is intense and largely diffuse. Cloudiness increases with temperature.

Wind velocities average about 10 mph. Prevailing winds are consistently from the east during the summer and from the west and east in winter. Sea winds of 20-30 mph are not uncommon on summer afternoons. Wind velocity tends to increase with temperature.

Rain falls principally in the summer, about 60 " per year, and can be torrential at times. Humidity is consistently high , 50-90 % RH most of the year. Miami is considered extremely uncomfortable one quarter of the time and uncomfortable due to humidity alone about half of the time.

Shading is required most of the year. Primary passive cooling strategies are ventilation, dehumidification, and where air conditioning is used, a 'closed' plan to maximize conservation of mechanical cooling. Dehumidification alone can accomplish comfort levels during about one fourth of cooling hours.

Heating Degree Days Base 65 °F.	285
Cooling Degree Days Base 78 °F.	1045
Winter Design DBT	47 °F.
Summer Design DBT / Coincident WBT	90 °F. / 77 °F
Too Cool for Comfort(Jan- mid Feb.)	11%
Comfortable (mid Feb.- late Mar; late Nov.- end of Dec.)	20%
Too Hot for Comfort (late Mar-late Nov.)	69%

Table 4.3 - 1

Miami Area Climate Summary

Source: AIA Research Corporation, Regional Guidelines for Building Passive Passive Energy Conserving Homes, 1978; Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Utility context:

Passive cooling and heating; gas and electricity available. The utility company in this design problem operates close to its maximum generating capacity with little capital and political support to build additional generating plants. By necessity, this utility offers attractive incentives to minimize summer and afternoon peaking. In this problem statement, the utility company has developed a lease program of high efficiency heating and cooling cores for new developments and cluster or site scale systems of electricity 'buy-back'.

4.3.1 MOVE-UP HOUSE FOR A HOT HUMID CLIMATE: ROMIS 2030

Winslow Elliot Wedin Architect

141 NW 20th Street,

Boca Raton, FL 33631

Design Summary

The year is 2030: our children and grandchildren are living in a world vastly different from the 1950's. Water conservation is a must; 100% recycled water is a goal incorporating xeriscaping, graywater systems, R.O. purification systems and maximum collection/storage potential. Solar radiation provides all forms of energy, with electrical/optical as the energy delivery system. The dwelling unit as we envision it may not have any resemblance to the single family house.

Cohousing, dwell-cruise, extended families and a highly flexible lifestyle will radically change the components of the habitat. Work, education and information exchange will be personal, local and lifelong. Technology will eliminate the need to "travel to-" except for social need.

Project Data:

Site

Density: Approx. 8 units/acre

Lot (40' x 100'): 4,000 sf

Building footprint (20' x 50'): 1,000 sf

House (net usable)

Total Area: 1,750 sf

Figure 4.3 - 1
Perspective View
Winslow Elliot Wedin Architects

Site

The given program suggests a density of 6 to 10 dwelling units per acre. This project utilizes a density of 8 dwelling units per acre. The site is 40' x 100' with the long axis east and west. The house is placed tight to the north edge - zero lot line. This placement allows a full 20' of south facing yard and excellent solar access. The master bedroom is located on the east to accept morning light and has a large balcony available. Entry and optional carport occupy the least desirable orientation for Florida - west.

Figure 4.3 - 2
Land Use Plan/Site Plan Move-up House
Winslow Elliot Wedin Architects

Unit Plan

The two story scheme was selected considering land utilization and construction cost. Our design has a home office just off the entry. A slide-into-the-wall panel closes off the public entry/office from the more private parts of the dwelling. A small toilet facility is provided, as the area may double as a guest facility. Mitered glass corners expand interior spaces spaciouly to the exterior.

Figure 4.3 - 3
Unit Plan
Winslow Elliot Wedin Architects
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2181/R91-2

Construction

The cistern/foundation is a composite of styrofoam cast with reinforced concrete on two sides capable of being fitted with water bars, etc. to provide an insulated watertight box. Doors and windows are custom sized to fit the modular openings but are site fitted. The modular wall assembly system is hollow, allowing us to incorporate factory installed wiring and plumbing harnesses. Roof panels are 8" thick modular metal clad foam (ESP). This project will incorporate factory acrylic finishes and a new roof batten system.

The construction process proceeds as follows: The site is prepared, foundations excavated and components assembled. The cistern is prefabricated poured concrete wall sections assembled on site. From verified field dimensions, the modular wall and roof panels are assembled from stockpiles of windows, doors, structural frames, panels, plumbing and electrical harnesses to this project configuration. Exterior and interior finish work is executed as required and equipment is installed, attached and tested.

Economic Strategy

The cost saving economies employed are in the fabrication of major components off site in a "factory" situation. Site work is limited to preparation, foundations, component assembly, minor exterior finishing, interiors, some equipment installation, hookup and testing, and landscaping.

Figure 4.3 - 4
Isometric View and Sections
 Winslow Elliot Wedin Architects

Energy Conservation Strategy

A portion of the south facing roof shall be assigned to solar collection surfaces for space heating. A water cooled heat pump from a fully recycled deep well can run at an EER of 15.0. Another portion of the south facing roof shall be assigned to hot water collection. Several flat plate collectors with their own PV circulation pump provide hot water to small tanks for the three bathrooms, laundry and kitchen. The tanks are stainless steel encased with urethane foam within the cavity wall space near each fixture requiring hot water. No auxiliary back-up is required.

A major consideration in hot humid climates is cross ventilation. Each habitable space in this project has north/south ventilation. The prevailing summer breezes in our area are from the southeast. A small opening on the south (the screen vents under the windows) coupled with the high north vents (both upper and lower levels) will induce a venturi effect providing a cooling draft that and move humid air up and out.

In addition to standard doors and windows (almost exclusively south facing) there are three systems of natural daylighting. First, a north facing clerestory lighting band running continuously east to west provides daylight to all habitable rooms on the upper level. Second, a north facing series of high windows on the lower level provides light to the foyer, living and dining areas, and third, an insulated (4" of low density foam bonded to two layers of UV inhibited fiberglass) north sloping roof illuminates the hall/closet portion of the upper floor.

Energy Analysis
(computer simulation using Energy Scheming)

Figure 4.3 - 5
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: 37,531 Jun 21: 257,818
Sep 21: 296,378 Dec 21: 0

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>		<u>Max. Rad.</u>
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>	<u>Btuh/s.f.</u>
Mar.	80	63	82	56	16	5	121
Jun.	88	74	87	67	12	4	64
Sept.	88	75	89	67	12	4	75
Dec.	77	60	83	58	14	4	88

Assumptions and Program Inputs

R-values

Walls	13
Roof	50
Floor	0
Windows	0.9

Energy Strategies Used:

Cooling:

Cross ventilation
External shades
Loss to mass
Internal shades
Night ventilation

Heating:

Gain from mass

Infiltration Rates: 15 Btu/hr sf

Figure 4.3 - 6
Building Occupancy and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.
Lights: used 5PM-11PM.

4.4 RENEWABLE HOUSE FOR A TEMPERATE CLIMATE

Scenario

"This house is simply too valuable to tear down" is a familiar sentiment among the owners of well constructed wood-frame houses in mature urban neighborhoods of the Pacific Northwest. The land on which they are built is extraordinarily valuable due to its prime location. Surrounding neighborhoods are well developed with urban amenities and services.

This house and site, for example, have undergone several periods of change that reflect the increasing intensity and value of housing stock in the neighborhood. Interior finishes, non-bearing partitions, bath and kitchen have been remodeled twice. Insulation and storm windows were added in 1990. The original 5,000 sf lot was subdivided for a second house in 2010.

In 2020, the house is for sale at a price that requires a partnership of three working adults to raise the necessary capital and maintain the mortgage. Before the new owners, a married working couple and a single colleague, can move in the house must be enlarged and renovated. All three residents have modest construction and considerable management experience and plan to reduce the cost of the project by acting as their own general contractor. In this capacity they will hire sub-contractors for the complex and heavy equipment portions of the project and provide their own labor for most other tasks. The project will be undertaken in phases over approximately 4 months.

Introduction

With rapidly rising land and financing costs, renovation and remodel of existing houses will more frequently become a preferred alternative for households that previously might have relocated and moved-up to a bigger or different house. The economic incentive is compelling. Compared to a contracted project, an owner-built remodel can be a relatively economical undertaking for a resident owner. Zoning and construction permits can be sought and secured as slowly or quickly as the owner wishes. General contracting and labor costs can be reduced or eliminated, depending upon the skill and enthusiasm of the owner to realize a potential savings of up to 40% in direct construction cost and significant savings in other 'soft' cost areas.

Already, the residential remodeling market has more than doubled in the past decade. The annual value residential alterations and repairs increased from \$45 billion in 1980 to over \$100 billion in 1989 (Ahlwalid, 1990: 8-9). As this market continues to grow it will likely evolve from contracted assembly of unfinished raw building materials to manufactured 'do-it-yourself' pre- or partly finished parts and sub-assemblies adaptable to various applications and consumer skill levels. To meet this opportunity, raw building material suppliers may increasingly add value to their products in the form of customization, engineering and construction simplicity. Modular kitchen cabinets and flexible, quick connect plumbing components are cases in point.

The rate of housing stock replacement suggests that over the short and medium term, improvement of existing houses will give greater energy conservation returns than new housing. At current new housing construction rates of roughly 1.3 million starts per year, new production will replace the existing stock at a rate of about 1% per year assuming some loss of existing units. At this rate, by the year 2000, 10% of the housing stock will be units constructed after 1990 (40% by 2030).

Assuming an aggressive program of research, development and technology transfer, it may be possible to significantly influence the energy efficiency of approximately one-quarter of these

units, or 2.5% of the total housing stock in the year 2000. Were these houses built to Model Conservation Standards (MCS) they would realize an energy savings of about 20% versus conventional codes and construction practices and result in a net conservation of roughly 0.5% of residential energy use at the year 2000 (20% energy savings in 2.5% of all houses).

The energy conservation opportunities presented by the remodel and repair of existing housing are different from those of new construction. Many remodels are built slowly and incrementally, sometimes by owners and sometimes in collaboration with contractors and/or manufacturers. Energy conservation measures can be incorporated if products and materials are developed to upgrade energy standards in conjunction with repair and refinishing.

The 'Renewable House' problem statement explores opportunities to improve the energy conservation standards of older houses as they are remodeled and expanded. In this statement, the house is a 90 year old single family dwelling in a mature urban residential neighborhood.

The residents are three working adults who have pooled their capital and income resources to acquire a well-located house close to the central city. The existing house is a wood frame bungalow constructed in 1950. This remodel will be extensive, increasing the house by a third, replacing original services, partitions and finishes.

Goals

This problem statement studies the consequences of several future trends — the high percentage of residential energy consumption attributable to existing houses; a relatively low rate of replacement of existing housing stock; the increasing frequency of owner initiated and executed repair and remodeling; an expanding market for industrialized materials, components and systems in 'do-it-yourself' remodel, replacement and repair applications; and increasing demand for healthy, low environmental impact building products.

Design goals

Site

- Separation / integration of addition with existing house and site.
- Orientation and siting to realize passive heating and cooling.

House

- An 'open' easily understood system of parts coordinated in modular dimensions yet manufactured by several sources.
- Utilization of passive design strategies
- Integration of energy conserving materials and components with existing construction and finishes.

Construction

- Design and construction integration of industrialized construction components and systems with wood frame components of dissimilar form and construction technology.
- Processes that are 'transparent', their sequences of steps and decisions easily understood by persons without specialized knowledge or experience.
- Adaptation of 'do-it-yourself' capability and 'after market' energy conserving products and materials to industrialized construction.
- Closed panel fabrication of renewable, low toxicity wood materials.
- Construction technology accessible to the skills and physical capability of one or two persons with basic tools and skills.
- Joining and installation procedures that are 'reversible' so that installers can attempt any step, confirm that it is desirable and correct and then change or complete it.

Energy goals

A target household energy budget has been derived by projecting a 25% improvement over the most stringent contemporary standard, The State of California's Title XXIV Energy Code. Seattle is equivalent to California climate zone 2. Other energy goals include:

- Strategies to improve the energy performance of existing houses by 'adding' conservation value to the materials and components (finishes, openings and appliances) that are frequently part of a renovation and addition project.

Economic goal

The house defined in this problem statement is intended to be affordable at median income. In 1987, this median income was \$ 47,250 for homeowners and the median purchase price of new owner occupied houses was approximately \$ 93,200 in the Seattle metropolitan area (American Housing Survey: 1987). Assuming a 30 year mortgage at 11% a house sold at approximately \$120,000 would have met this goal in 1987. Cash requirements are assumed to be met through savings among the members of the partnership.

Housing delivery system assumption

The housing delivery scenario developed for this problem statement is based on a chain of retail building materials outlets that carries a wide range of 'do-it-yourself' products and specializes in environmentally safe, low toxicity, renewable systems and materials.

The Green House Store is similar in concept to a contemporary high volume building materials and supply outlet. Although the store continues to stock a wide variety of 'off-the-shelf' products and components, by 2030 the concept has been refined and developed so that all materials and systems stocked in the store are compatible with one another.

Products available range in scale from integrated packages such as whole house panel systems, to kits such as kitchens and service distribution systems, to components such as windows to finish materials, small parts and accessories.

The store has also greatly expanded the level and range of expertise available at their information desk. In addition to product and technical expertise, the store now offers design, estimating, energy evaluations and project scheduling. The order desk computer system refines a customer's rough sketch; provides a dimensioned plan, section, elevation, isometric or perspective summary; thematic drawings by task — foundation, framing, openings, finishing etc.; a schedule of materials; catalog cuts of potential 'off the shelf' manufactured components or sub-assemblies; instructions, probable schedule and tool list.

Occupancy assumptions

While there are several alternative residencies suited to a house of this kind, this design study will concentrate on three working adults, a married couple and peer age colleague, in their thirties. While all three share ownership and maintenance, it is not equally divided. The married couple have assumed ownership and control over most of the existing house and their colleague has ownership and control over a studio.

Spatial requirements

500 - 600 sf studio with bath addition to existing one and a half-story bungalow organized in three zones. Required: Two bedrooms; three private work areas; kitchen; dining; two baths; laundry, utility and storage areas.

Room sizes and layout will meet the particular requirements of the first owner yet be amenable for resale. The new studio and bedroom/private work areas of the existing house are separate and

private. Kitchen, dining, storage and utilities are common spaces. Spatial organization must be 'closed' to work with zoned heating system.

In 1987, the following amenities were common to new owner-occupied houses in the Seattle area: Fireplaces - 74%; Porches, decks, balconies or patios - 96%; Separate dining room - 51%; and Garage or carport - 90% (American Housing Survey: 1987)

The addition can be sited on the existing lot in any orientation or configuration without re-configuring the lot given. However, the lot can be reorganized with walks, driveways and landscape as required. Address and entry to both units must be fully visible and accessible from the street. Off-street parking for two cars.

Neighborhood, site and architectural context

There is a variety of types and styles of houses in this suburban Seattle neighborhood. Many and diverse versions of the single family 'rambler' and split-levels built after 1970 are prevalent. At the same time there are also a significant number of walk-up apartments and row houses near commercial centers and important intersections. The commercial, institutional and industrial infrastructure of the area is well-developed and many residents work in or near the neighborhood.

Construction System Assumptions

The construction system specified in this problem statement is a closed panel system of renewable wood products. Some tasks are assumed to be contracted to professionals, others are assumed to be completed by owners.

Contracted tasks include foundations, services and roofing. Do-it-yourself tasks include panel installation, roof and floor cassette installation, interior partitions, finishes.

Foundation

Manufactured wood panels or concrete or concrete masonry foundation walls on poured in place concrete footings.

Envelope and structure:

Manufactured closed panel of low toxicity, renewable wood and wood by-products including pressed and formed wood fiber cladding and sheathing board; composite I-section stud framing and interior sheathing of wood fiber gypsum board.

Mechanical system

Zoned heat pump system of several dispersed units installed in window openings. Each element can function as an independent 'stand alone' unit or be networked with an auxiliary boiler and evaporative cooler.

Electrical system:

Integrated wiring channel, multi-carrier strip and linear plug-in faceplate integral with interior wall surface and I-section stud. At key locations, vertical trunk strips penetrate upper and lower framing plates and connect with a floor perimeter channel.

Seattle climate

Lat. 47 °N; Long. 122 °W; El. +19'

Cool, Moderate, Humid, Breezy.

The Seattle area climate is generally underheated with sub comfort conditions every month. Puget Sound moderates temperatures which are not often below freezing or too hot. Summers are mild and generally comfortable. Winter temperatures are in the 30-45 °F range. Prevailing winds are from the south and southwest in winter and from northwest in summer. Velocity is moderate (8-10 mph) throughout the year.

Rainfall is about 35" per year; snowfall, about 10-20", melting quickly. Summer is a dry season. Humidity is relatively high (60-80 % RH) most of the year. Sky condition is predominantly cloudy, with several partly cloudy and clear days each month.

Heating Degree Days Base 65 °F	5690
Cooling Degree Days Base 78 °F.	19
Winter Design DBT	26 °F
Summer Design DBT / Coincident WBT	80 °F / 64 °F
Too Cool for Comfort	93%
Comfortable (July)	6%
Too Hot for Comfort	1%

Table 4.4 - 1:

Seattle Area Climate Summary

Source: AIA Research Corporation, Regional Guidelines for Building Passive Passive Energy Conserving Homes, 1978; Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Utility context

Hydro generated electricity and natural gas are readily available. Local utility is winter peaking utility although global warming studies indicate potential forthcoming increase in cooling loads (Loveland and Brown, 1990)

4.4.1 RENEWABLE HOUSE FOR A TEMPERATE CLIMATE: DESIGN STUDY

John Barnes and Joel Loveland

Department of Architecture,

University of Washington,

Seattle, WN 98105

Design Summary

Three working adults in the year 2030 buy a bungalow in the Ballard neighborhood of Seattle, Washington. Their objective is to extensively renovate the existing house and increase the square footage by a third. Two of the adults are married and expect to take control of the larger portion of the house including the kitchen/dining area and utility area. The third adult will move into the addition and have access privileges to the kitchen/dining and utility areas. The house is a vintage 1917 style bungalow was extensively remodeling in 1990. The three wish to keep the historical flavor of the house in the revered craftsmen style. The original site has been subdivided, and Seattle zoning code prohibits further building in the rear area of the house. The three also wish to reduce the cost of the project by doing the general contracting and providing as much on-site labor as possible.

Project Data:

<u>Site</u>		<u>House (net usable)</u>	
Density:	no net increase	Expansion (one story):	700 sf
Lot (40' x 80'):	3,200 sf	Total Area:	2,018 sf
Building footprint (30' x 46'):	1,380 sf		
Expansion (one story):	700 sf		
House (net usable)	2,018 sf

Figure 4.4 - 1
Axonometric View
Loveland-Barnes

Unit Plan

The renewed portion of the house has 1274 square feet of floor area. Total exterior walls are 1203 square feet. The addition is 35' x 20' or 700 square feet of floor area. Total wall area of the addition is 629 square feet. The windows are 13% of the gross wall area. The basement was untouched by the renovation and suitable for storage purposes. South glazing for the total house is 120 square feet which is 6.08 percent of the total floor area.

Figure 4.4 - 2
Floor Plans and Elevations
 Loveland-Barnes

Construction

The proposed rigid panel system incorporates two families of products. A wall system that includes the use of thermally broken studs (commonly found in the Swedish premanufactured housing industry), and a floor and roof system that uses an I-section framing member. The exterior skin is composed of a sheathing board and cladding of wood by-products that incorporates formed, oriented, low toxicity wood strands. Both panel families are constructed on a module of 30 inches. A multiple of modules will fit in a shipping container with interior dimensions of 2330 cm with the greatest economy of space. These panels then can be "flat packed" to any location in the world. The demand for American housing in Japan is an example of the market potential of the shippable premanufactured component system. The panels come with utility cores or with plain cores. Layout of both the wall system and the floor/roof system can be done off-site by trained technicians and the panels can be marked (either on the deck of the floor system or the pre-cut top and bottom plates of the wall system), then shipped to the site with instructions on panel location, preprinted on the deck or plates. Window openings can be pre-cut or premarked and cut on site. Corners are formed on the outside walls by removing the exterior stud of a utility core panel. Both the floor system and the roof system are simple post and beam assemblies. The ridge beam and interior bearing partitions form one post of the assembly and simplify the roof framing. The construction sequence involves the owners completing the demolition of the roof and the original house. One site manager/master carpenter would prepare the existing structure for the panelized addition. The owners then can assemble the addition. The roofing is done by sub contractors as is the electrical and plumbing rough-in. The owners install the wood-fiber gypsum wall board. A finish crew of skilled carpenters can complete the job.

Economic Strategy

The cost saving methods employed includes the addition's design, which eliminates the need for footings, and the use of the owners' demolition work and assembly of the addition.

Figure 4.4 - 3
Construction Details
Loveland-Barnes

Energy Conservation Strategy

A Calpas 3 energy analysis was performed on both the existing house and the renewed house with the addition. Simulations indicate that the added square footage of the addition with the renewed house below uses less energy than the existing house. The wall panels with rigid insulation incorporate a thermally broken stud design that is used regularly in the Swedish premanufactured housing industry. Roof and floor panels with a composite I-section framing member were modeled with rigid insulation cores. Window U-values were assumed to be .5. In the simulations the basement was assumed to be insulated from the rest of the structure. The mechanical system incorporated in the renewed house includes an air to air heat exchanger. Interior mass in direct contact with southern sun is provided by a masonry floor in the south bedrooms and downstairs study.

Energy Analysis
(computer simulation using Energy Scheming)

Figure 4.4 - 4
Summary of Heat Flow

Total Daily Heat Flow (Btu)

Mar 21: -77,171 Jun 21: 0
Sep 21: 14,382 Dec 21: -123,520

Climate Data Input

	<u>Ave. Temp. F.</u>		<u>Ave. %R.H.</u>		<u>Wind m.p.h.</u>		<u>Max. Rad.</u>
	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>Max.</u>	<u>Min.</u>	<u>Btuh/s.f.</u>
Mar.	52	37	82	63	15	5	27
Jun.	69	51	82	53	13	4	63
Sept.	69	50	86	58	12	4	72
Dec.	45	36	82	77	15	5	5

Assumptions and Program Inputs

R-values old/new
 Walls 11/25
 Roof 25/3
 Windows 2
 Floor 11
 Infiltration Rates: 15 Btu/hr sf

Energy Strategies Used:

Cooling: Cross ventilation
 External shades
 Loss to mass
 Heating: Gain from mass

Figure 4.4 - 5
Building Occupancy and Allowable Indoor Temperatures

Equipment: Schedule follows occupancy.
 Lights: used 5PM-11PM.

Designers' Comments

- Explore the potential for the addition of mass to an existing south facing glazing assemblage. The addition uses a 2-inch masonry floor but more mass could be added elsewhere. This particular problem relates to a number questions concerning cost economies in this particular climate. Will added mass ever pay itself back?
- Examine the potential for manufactured interior partitions. Perhaps a system could be developed that is not unlike the office partition systems that are flexible yet semi-permanent.
- Examine the potential for utility core cassettes with plumbing or electrical utilities that pop into the utility cores of the panels.

5.0 DESIGN STUDY EVALUATION

Section 4 presented eight schematic design studies as submitted by the design teams. Section 5 is a review and inventory of energy conserving principles and innovations culled from these studies as they pertain to the two design studies that will be developed, further evaluated and refined in FY 1991. These are presented in subsections:

- 5.1 A Multi-Family Lightweight Concrete Panel House for a Hot-Arid Climate
- 5.2 A Single Family Wood Composite Frame and CVI Panel House for a Cool Climate

Within each subsection, energy conserving principles and innovations are summarized in parallel with the design, manufacturing or financing strategies with which they overlap. Included are discussions of

- Energy conservation and site design
- Energy conservation and house design
- Energy conservation and component design
- Energy conservation and service system design
- Energy conservation and manufacturing strategies
- Energy conservation and economic strategies

Each discussion area presents the core principles and innovations that conclude this FY 1990 cycle of design studies and will form the basis of FY 1991 work in the Design for Energy Efficiency task. More and different principles will be added through this and subsequent cycles.

Project resources dictate that the scope of design studies be narrowed from four study areas to two. The two most promising are a Multi-Family Lightweight Concrete Panel House for a Hot-Arid Climate and a Single Family Wood Composite Frame and Compact Vacuum Insulation (CVI) Panel House for a Cool Climate. The reasons for these selections are several.

- The multi-family and single family house types represented are important, but not equivalent, constituencies in housing markets of the future. They differ significantly with respect to market characteristics, energy demand, conservation strategy and construction method.

In 1990, the U.S. market for new housing was comprised of approximately 75 % single family units and 25 % multi-family units. Increasing land, development, and construction costs will likely result in an increased demand for more economical multi-family units into the 21st century.

- The cool and hot-arid climate zones represented are significant and growing national energy consumers — one primarily in space heating and the other primarily in space cooling. These climates represent the extremes of U.S. residential energy loads. Knowledge gained can be adapted to temperate zones.

Space heating and cooling end uses accounted for 48% of residential energy consumption in 1988. By 2010, energy consumption attributed to space cooling is projected to increase 82% to 2.0 quads, a rate of increase greater than that of any other residential end use. By 2010, energy consumption attributed to space heating is projected to increase 20% to 7.5 quads. (U.S. DOE Energy Conservation Multi-Year Plan FY 1990 - 94: 4 - 9)

Although a relatively small percentage (approximately 4%, of new housing starts in 1987) are constructed in cool climate zones, these houses are the largest consumers of energy in the U.S. at approximately 69.4 million Btu's per capita (EIA State Energy Data Report, 1987: 11). Space heating energy use is projected to be the most significant opportunity for economically achievable conservation in 2010. (U.S. DOE Energy Conservation Multi-Year Plan FY 1990 - 94: 4 - 9)

Housing demand in hot-arid climates, on the other hand, while only slightly stronger today, is growing and projected to be a significant contributor to the increasing demand for space cooling energy. Approximately 7 % of new housing starts in 1987 were in hot-arid regions. Several hot-arid climate cities however, are among the fastest growing metropolitan areas in the U.S. Phoenix, AZ, for example, is the fastest growing large metropolitan area at approximately 30% annually in the 1980's. Cool climate areas are growing as well, but at lower rates. Minneapolis / St. Paul, for example, grew at approximately 10% annually in the 1980's. (Census P-25 No.1039 - 1989: 10)

- The industrialization strategies represented will be in the mainstream of future industrialized housing. Panelized construction technologies dominate the highly industrialized housing construction of Sweden and are fundamental to the design and installation flexibility sought in the future markets of U.S. industry. Panelized housing manufacturers are already a growing sector of U.S. industrialized housing and have increased market share approximately 8% in the past decade.
- The construction systems represented are proven, widely adopted, and well suited to the climates in which they are common. Wood frame structures are well suited to an energy conservation strategy of 'light and tight' construction common to cool climates.

This climate is characterized by winters of cold temperatures and low insolation, summers are hot with a small diurnal temperature swing. Energy is effectively conserved by reducing heat gains and losses through the walls and roofs of houses in this climate.

Concrete structures are well suited to an energy conservation strategy of 'mass and glass' construction which is common in a hot-arid climate. This climate is characterized by winters of high insolation and summers of hot days and cool nights. Energy is effectively conserved in buildings when high thermal mass utilizes passive energy sources.

- The construction materials represented are also anticipated to be commonly in future industrialized housing. These materials and components offer better performance at less cost and will be particularly attractive to high volume industrialized builders where the effect of material economies and innovations are magnified many times over.

Wood composite materials (particleboards, hardboards, fiberboards, waferboards, oriented strandboards, laminated veneer lumber, and gluelams, for example) are a rapidly expanding area of building materials research and product development. 'Reconstituted wood' in structurally efficient shapes continue to supplant studs, joists and trusses in residential construction. Recently, oriented strand boards (OSB) have displaced plywood as a roof and floor sheathing material; laminated veneer lumber (LVL) I-sections have displaced structural lumber and prefabricated trusses have displaced rafters in many housing markets of the U.S. Houses constructed of lightweight, long span wood frames will not have to compensate for the inherent weaknesses and imperfections of sawn lumber. They will be easier to engineer, more economical to manufacture, and can be plumbed, wired and insulated to greater

performance standards than conventional wood framed buildings.

Recent material research and development indicates that concrete is a material with considerable future opportunity for energy conservation and manufacturing. Advances in concrete technology continue to lower its weight and increase its insulating, thermal storage and fire resistance properties. While conventional concrete has unit weights in the range of 140 to 150 pcf (pounds per cubic foot), synthetic and manufactured aggregates reduce that weight to as little as 20 pcf. Reduced weight overcomes the prime disadvantage of concrete in manufacturing and distribution, and also reduces construction costs related to foundations and handling.

Lightweight concretes also offer an economical source of thermal mass, and make a range of effective passive heating and cooling strategies available to industrialized construction. Energy research at Oak Ridge National Laboratory, for example, has tested lightweight aggregates that improve thermal storage capabilities and thermal lag to reduce peak heating and cooling loads and defer them as much as 4.5 hours (VanGeem 1989: 1 - 3).

5.1 A MULTI-FAMILY LIGHTWEIGHT CONCRETE PANEL HOUSE FOR A HOT-ARID CLIMATE

Energy conservation opportunities appropriate to entry level multi-family housing are difficult to achieve within the site densities and construction budgets customary to this market. No single strategy is adequate in performance, economy or convenience to meet the combined challenge of cooling and heating in this climate.

The economic resources of households typically in multi-family housing markets are significantly constrained. First cost is a prime consideration so construction budgets are often too low to allow for energy conserving designs, equipment, components and materials because they increase the first cost.

The increasing density of development sites has been an effective means to lower the first cost of a house and site, reduce site infrastructure, conserve transportation energy and slow the environmental impact of urban growth. It has also, at times, compromised the opportunity for each house to have unrestricted access to passive energy sources of sun and ventilating breezes.

Attached multi family houses typically reduce energy loads from the gain and loss of heat through walls and roofs. Additional conservation opportunities can be realized if other energy consuming systems, such as space conditioning appliances, hot water systems and plumbing, can be attached or combined as well.

The combined loadbearing, fire resistance, acoustic and thermal storage properties of concrete and concrete panels also present a unique energy conservation opportunity to multi-family housing. Precast concrete panels are becoming stronger, lighter, better insulated, more easily manufactured and less expensive. They present an extraordinary opportunity for economical manufacturing and

energy conservation.

Concrete panels challenge the way designers and builders consider the structure and interior of the house. There are many restrictions on the size and locations of openings. It is also difficult to install panels or remodel without specialized equipment and skills.

5.1.1 Energy Conservation and Site Design

Preserve opportunity to utilize site energy – ground to sky ownership and control.

Although the site is developed at multi-family density (approximately 15 dwellings per acre), these houses are privately owned and controlled units on privately owned and controlled plots of land. This principle of ground to sky ownership and control is fundamental to energy conservation opportunities at subsequent design scales. Access to sun, daylight, ventilating breezes, and private outdoor space must be permanently preserved around and on top of all houses. South faces in particular must preserve access to solar gain through privately controlled yards.

Figure 5.1 - 1
Axonometric of Passive Energy Systems
Pyatok Associates

Establish site planning rules to preserve access to sun, wind and light

Regulatory support is necessary to realize the foregoing site planning principle. These houses must be close together and tall. Expansion will be either vertical, to a third floor, or horizontal to unbuilt portions of the site. The size and shape of such additions must be regulated to define the unit within which no sun, wind or daylight is lost to neighboring site. To preserve access to sun, daylight, and ventilating breezes, the locations, sizes and heights of buildings and landscape elements must be controlled after the initial planning, design and construction period.

Figure 5.1 - 2
Model Study of Site Massing
Sustainable Design Associates

Reduce surface area with attached house forms

Attached housing forms are inherently energy conserving. Total heat loss and gain through exterior walls is significantly less than that of detached houses. This house design is attached along the longest dimension of the plan. As a consequence, approximately 20% of its potential exterior surface area is not subject to heat gain or loss.

Figure 5.1 - 3
Site Plan Detail of Attached Houses
Center for Housing Innovation

Reduce area of roads, parking and utility systems

A prime opportunity of multi-family densities and construction systems is that of sharing the capital cost and operation of expensive and site consuming services. Throughout this site plan, the amount of paved road surface is reduced and distribution networks efficiently planned to compact the settlement, reduce site development costs and help lower the ambient temperature of the neighborhood. Site utility services are efficiently and economically distributed to groups of houses and then to individual households. One-way access roads serve houses gathered in clusters. Resident cars park in small sheltered shared lots. Visitor parking is accommodated on the street. Entry walks and other paved circulations are shared as well.

Figure 5.1 - 4
Site Plan Detail of Shared Road and Parking
Pyatok Associates

Increase site shading and humidification

Roads and driveways are shaded by indigenous trees such as cottonwoods. Private spaces can be shaded by smaller cultivated species such as Palo Verdes or Yuccas. Owners may also grow vines such as bougainvillea over garden structures or on exterior walls over windows. This landscape provides shade and humidity, extending the human comfort of living spaces indoors and out.

SOUTH ELEVATION

Figure 5.1 - 5
Elevation Study of Shading
Pyatok Associates

Promote utilization of unconditioned outdoor living areas

The minimal floor and surface areas of these houses reduce the potential space conditioning energy demand of each household. An important corollary to this principle is to provide adequate private outdoor space to permit indoor living areas to open to the outdoors for additional space.

The site is planned to make possible a variety of private gardens immediately adjacent to primary indoor living areas. The small house appears larger. Opaque soundproof garden walls create a privacy buffer to permit the larger openings necessary for passive heating and cooling.

Figure 5.1 - 6
House Plan Detail of Garden Adjacent to Living Area
Pyatok Associates

5.1.2 Energy Conservation and House Design

Organize houses in two stories of reduced skin and floor area.

Two story houses consume less site area, and realize better privacy zoning, ventilation, and access to light and sun. The ratio of surface (exterior walls and roofs) to floor area is more economical and energy efficient than that of one story houses. Interiors, while compact, can be zoned on different floors for different uses and degrees of enclosure— home offices and rental rooms apart from bedrooms are cases in point. Additional unconditioned living spaces can be created on roof terraces. Two story houses also afford a wider variety of window heights and placements and can be more easily daylit, convection heated, and stack and cross ventilated.

Figure 5.1 - 7
Elevation Study of Two Story House
Center for Housing Innovation

Zone floor plan for contact and control of sun, light and wind

The plans of these houses are organized to locate living areas in direct contact with (and control of) their own daylight, heating and cooling. Larger, primary living spaces are oriented to sun and light. Services and secondary rooms are oriented to the north or poorly daylight portions of the plan. Utilities and service chases are located to the north and along party walls. The temperature and comfort of each of these zones can be adjusted individually.

Figure 5.1 - 8
Plan Study of Interior Zoning
Center for Housing Innovation

Temper micro-climate of outdoor spaces adjacent to living areas

The surfaces, wall and paving materials of private outdoor spaces offer an opportunity to temper micro-climates immediately adjacent to the house. Carefully selected materials and design features can improve shading, light reflection, air flow, and humidification to make outdoor spaces more comfortable as well as enhance the performance of passive energy systems.

Figure 5.1 - 13
Axonometric Study of Climate Tempered Outdoor Space
Center for Housing Innovation

Establish loadbearing structure parallel to direction of sun and wind

Loadbearing walls are parallel to side lot lines to ensure fire safety and acoustic privacy. All other interior and exterior walls are nonloadbearing. Nonloadbearing walls oriented to sun and ventilating breezes can be designed to create opening sizes and patterns of considerable design variation, unencumbered by the engineering limitations of structure. Windows and doors can sized and located to maximize view, access to sun or daylight and promote even distribution and continuous flow of ventilating air.

Figure 5.1 - 9
Axonometric Study of Structural System
Center for Housing Innovation

5.1.3 Energy Conservation and Component Design

Increase thermal storage capability of materials and finishes

Loadbearing walls and the ground floor slabs of these houses are thermally massive and supportive of passive heating and cooling. Although the concrete ground floor surface will be obscured by furniture and floor coverings, this mass will, however, postpone the effects of overheating and defer the resulting demand for cooling energy to off-peak periods. Phase changing interior finishes further supplement the thermal storage capability of the house. Walls, for example, can be exposed concrete above 42", the approximate furniture height of each room, with phase changing board below.

Figure 5.1 - 10
Section Study of Thermal Storage Materials
Pyatok Associates

Optimize design, engineer and manufacture roof and floor systems

As houses become smaller, it is increasingly important to optimize interior volumes for living spaces, and to improve the efficiency of its plan and section, specifically the ratio of gross to net area and volume. One means to achieve such efficiency is to reduce the amount of interior space given to space consuming construction elements and systems. Trusses, for example, while simple to install occupy considerable volume and render a significant portion of a roof unusable as living space.

Figure 5.1 - 11
Section Study of Roof and Floor System and Connections
Center for Housing Innovation

The roof and floor structure systems of this house use manufactured cassettes. Cassettes are stressed skin panels that combine joists, sheathing, insulation and finishes in one engineered component. Stressed skin construction is thinner, more structurally efficient than traditional framing, and can span greater distances with less depth.

The roof in particular is one of the most important combined design / energy conservation / industrialization opportunities in housing. It is a major element of construction cost, subject to extraordinary engineering and design variation. In place, it is a primary source of heat loss, heat gain and solar collection. Its construction complexity is well suited to the precision and economies of industrial processes.

Figure 5.1 - 21
Axonometric Study of Roof Cassette
 Center for Housing Innovation

Roof cassettes in particular can be manufactured to a wide range of design and engineering properties. They can be precisely fabricated to high standards of engineering and energy conservation. Sophisticated materials can be safely stored and handled in the factory. Quantities and properties can be optimized to achieve high strength to weight ratios. Insulation can be precisely fit between thermally broken structural elements. Because they are fabricated of layers of

material, cassettes can be customized to particular regions and climates. Material specifications can be modified without necessarily modifying other design or engineering properties. Radiant barriers, for example, can be factory integrated with sheathing and insulation in hot climate applications.

Provide lightweight, adjustable shading and ventilation accessories .

Lightweight and owner adjustable shading devices permit and encourage occupants to fine-tune the amount of sun, light and air available to living spaces. With little knowledge of passive heating or cooling principles, owners of these houses can learn to extend the number of hours these houses can be naturally heated and cooled. Fabric shades and wind scoops, for example, can be extended, shortened or reoriented to improve the thermal comfort of the house and its outdoor spaces. All openings, outdoor spaces and roofs can be shaded and / or ventilated in this manner.

Figure 5.1 - 12
Axonometric Study of Shading and Ventilating Accessories
Pyatok Associates

5.1.4 Energy Conservation and Service System Design

Combine and integrate energy consuming systems and services in a core wall

An economical energy conservation strategy unique to multi-family housing is the opportunity to share space conditioning appliances and services in common walls. This house design utilizes a core wall within which is a heat pump, hot water, evaporative cooler, plumbing, electrical and communications systems. Adjacent are located the rooms that directly utilize those systems.

Figure 5.1 - 14
Plan Study of Core Wall
Center for Housing Innovation

The energy conservation performance and economic advantages are significant. The efficiency and quality of systems and appliances is higher if cost is shared between households. The system as a whole can be readily designed to integrate functions and recover heat and cooling from exhaust air, plumbing and appliances where appropriate. Since distribution distances are minimized, so are

energy losses.

Supplement passive ventilation with evaporative cooling

Small houses on densely planned sites will overheat when access to cross-ventilating breezes are restricted, humidity is high, or ambient temperatures are unsuitably warm. This house design supplements cross ventilation cooling with mechanically assisted stack ventilation and a two stage evaporative cooler in the shared mechanical core.

A stairwell in the center of the plan provides stack ventilation. An evaporative cooler located in the core wall. This portion of the core wall can be filled with rock or similar thermally massive material. When ambient air temperatures are too high, this mass is evaporatively cooled at night, during off-peak hours and then used to cool circulated air from the house the following day. The system also provides direct evaporative cooling when ambient air temperatures are appropriate.

Surface mount service distribution systems

One of the onerous construction and energy conservation problems of panelized construction is the wide range of electrical, plumbing and communication services that are customarily routed and accessed through walls. A construction problem concerns the alignment and integrity of these systems as they pass through hard material (concrete), vapor barriers and other continuous membranes, as well as panel joints and corners. An energy conservation problem arises when the conduits, junction boxes and access hardware for these systems displace structural and insulating material in the wall. Similarly, as efficient construction components such as floor and roof cassettes (manufactured panels that combine joists, sheathing, insulation and finishes) are increasingly used, roofs and floors are lost or greatly diminished as service chases and plenums. The challenge is to distribute services in other ways.

Plumbing services in this house design are gathered to the common wall between houses where service distribution is less of a construction and energy conservation problem. Electrical and communications systems are concealed and protected in a surface mounted chase that doubles as an interior wall finish. Installation is simple, access is convenient. Change and extension to services is easily accomplished.

Integrate solar collection surfaces with roofs, walls and windows

Houses at this site planning density will not often enjoy unobstructed exposure to solar radiation. The quantity and location of solar energy will vary significantly from site to site, and house to house. In order to capture solar radiation when and where available, a variety of roof, wall and window integrated collection surfaces must be available to designers and customers.

Figure 5.1 - 16
Axonometric Study of Solar Collection Alternatives
Center for Housing Innovation

Roof collection surfaces can be integrated with roof cassette construction in the factory. Wall mounted surfaces are not likely to be factory integrated with concrete panels since these walls are the most shaded on the site plan. Wall collection surfaces must be site mounted where they can also be used to shade window openings or integrated with shading / reflector systems.

5.1.5 Energy Conservation and Manufacturing Strategies

Engineer and manufacture systems in two tiers — 'structure' and 'infill'

Elements that 'structure' the house (such as loadbearing walls, roof and floor systems for example) establish critical parameters of design, engineering and energy performance for the house. They are typically sized early in the design process and installed early in the construction process. Elements that 'infill' (such as nonloadbearing partitions and openings for example) can be designed or remodeled to owner preference. These elements are lightweight, variable in design and quality, typically secured to previously installed structure elements.

Figure 5.1 - 17
Axonometric Study of Structure and Infill Elements
Center for Housing Innovation

The more complex energy systems of this house are manufactured as part of the structure and can be designed and engineered with precision. These include the thermal storage and insulating capabilities of floors, walls and roofs and the capacity and efficiency of space heating and cooling systems and appliances. Energy systems manufactured as 'infill' are those that vary by site and owner preference. These include the size and location of windows, shading and insulating devices that influence the operation and efficiency of passive energy systems.

Integrate manufactured, site-built and 'do it yourself' construction system

The financial resources of a starter house market demand construction systems that are fundamentally low cost yet support a range of design variety and remodel opportunity. Lowest first cost overall will be achieved through a combination of factory manufacturing, site fabrication and an owner's sweat equity.

Complex components such as concrete panels and roof cassettes, for example, are well suited to the precision and mass production economy of a factory. Simpler tasks, such as preparation of the site, foundations and utility services are, by comparison, labor intensive, highly variable, and more economically completed in the field. Other elements that vary with owner preference, such as interior partitions and exterior finishes are similarly best completed in the field.

Still other elements may not be installed in initial construction phases or may be expanded and changed later as household needs or resources change. The size, amenity and finish level of these basic houses suggest that owner initiated changes will inevitably happen. The original house must be designed, manufactured and built to allow owners to enlarge an opening, change a finish, enlarge a room, add a room, etc. if materials and construction systems that may vary from those of the initial house.

Questions of value and performance remain paramount across all these. Low cost must not also result in undesirable houses of poor design, poor quality, high operating or maintenance costs, and poor energy performance. Engineering and manufacturing processes must support this construction hybrid and be particularly supportive of owner initiated changes without compromise to the safety, integrity or energy performance of the house as a whole.

Figure 5.1 - 19 .
Axonometric Study of a Remodel Construction Strategy
John Barnes and Joel Loveland

Coordinate dimensions of sites, houses, components and energy systems

An important means to realize low first cost, energy efficient houses is development of a limited set of dimensional rules. The coordination of building components (windows matched to wall sections and room sizes, for example) and the possibility of system integration (air distribution systems matched to structural components, for example) will contribute significantly to the economy, precision and quality necessary to construct a marketable, energy efficient house.

These rules must be flexible enough to permit diversity and variation in design and component choice, and at the same time adequately limited to, improve and simplify coordination of design, engineering and manufacturing. The design parameters of this dimensional system are particularly critical in small houses where the spaces are few and small, and must be adapted to multiple functions and uses.

Technical, manufacturing or energy criteria alone do not establish these standards. They are instead founded on the sizes of efficient and flexible spaces in which people can comfortably live. The spaces generated must be both large and small. Each must accommodate alternate arrangements of furnishings, activities and services without becoming overcrowded or poorly zoned. Rooms must combine with adjacent rooms to appear spacious yet minimize organizational, operational and visual conflicts.

Energy conservation strategies and standards must be a part of this dimensional strategy as well. Components must be sized to permit adequate insulation and thermal storage levels; rooms and their openings must be sized and proportioned to heat and cool; groups of rooms must be organized to ventilate and distribute heat.

The modular system illustrated below is an example of a dimensional coordination system that supports energy efficient design, construction and service distribution. The double grid

differentiates two kinds of spaces and dimensional needs — larger living areas and smaller service spaces. The major living spaces created by this system are unobstructed, variable in proportion and flexible in arrangement. Minor spaces for circulation, stairs, storage, space heating appliances, service chases and so on are typically adjacent. Heating and cooling systems can be installed and zoned. Duct and distribution runs are short and straight.

Figure 5.1 - 20
Plan Study of Modular Dimensional Grid
Sustainable Design Associates

5.1.6 Energy Conservation and Economic Strategies

Design and manufacture energy systems to anticipate additions and remodels

The purchase price of these houses is reduced by building use area and amenity often a larger or different house is needed. Over time, household needs, lifestyles and resources change. Land development and construction costs may increase dramatically in value making the cost of acquiring another house prohibitive. Or, cost of energy may increase dramatically and construction standards economical at the time of construction may be a poor economic choice a few years later. In either case, residents must be able to expand or improve their houses accordingly.

Figure 5.1 - 22
Axonometric Study of Expansion Strategy
Center for Housing Innovation

Maintaining construction economy, quality and energy performance throughout the process is a fundamental consideration. Site planning, design and construction features must not only anticipate these changes but accommodate and encourage they be designed and meet to high standards. In this design, the initial purchase is a 'core' house that can be remodeled and expanded

without compromising the privacy, fire safety, structural integrity and energy performance of the original. This 'core' is designed and sited to permit ground and second floor additions to the rear and side, and a future third floor through the roof.

Zone spaces for income generation apart from other spaces

In many urban housing markets, the cost of housing has increased to levels where additional incomes are required to support the cost of home ownership. In some instances unrelated adults enter an economic partnership to share housing. Often both adults maintain separate private quarters, but share public spaces. In other instances, a portion of the house is converted to a small workplace to generate supplementary income. In either case, this zone of the house is subject to a use, occupancy pattern and energy load quite different from that of the rest of the house.

Figure 5.1 - 22
Plan Study of House with Workplace
Sustainable Design Associates

To preserve the economic opportunity of an in-house workplace or joint ownership with an unrelated individual, one bedroom-sized room is situated apart from the others, adjacent to an entrance and a bathroom. This area can be zoned for heating and cooling times and rates that differ from the rest of the house.

5.2 A SINGLE FAMILY WOOD COMPOSITE FRAME AND COMPACT VACUUM INSULATION PANEL HOUSE FOR A COOL CLIMATE

The energy conservation opportunities of a single family house in a cool climate are, like those of the concrete panel multi-family house, profoundly influenced by site and house design. The increasing density of single family development sites has been an effective means to lower the first cost of a house and site, reduce site infrastructure, conserve transportation energy and slow the environmental impact of urban growth. As sites have become progressively smaller, opportunities for unrestricted access to passive energy sources of sun and ventilating breezes have diminished as well.

Single family houses typically experience most of their energy loads as conductive gains and losses of heat through walls and roofs. Accordingly, the design and construction quality of walls and roofs are fundamental means to effective energy conservation in this house type. At the same time, this market demands considerable design variation in plan type, window quantities, styles, materials, orientations, yard configurations, and conveniences – all factors influential for energy conservation. Maintaining economy and effective energy performance across such an extraordinary range of variation and customization is a difficult challenge.

The unprecedented insulating properties of new materials such as compact vacuum insulation (CVI) panels present a unique opportunity. CVI panels are projected to attain thermal resistances of 100 per inch of thickness and can effectively eliminate envelope energy loads in single family houses. Such an energy conservation opportunity for industrialized housing is extraordinary. A CVI panel is a sophisticated building material well-suited to manufacturing. Appropriately developed, it can provide effective energy performance across a virtually unlimited range of design and site variations.

Because CVI panels are costly, significant economies must be realized in other areas to meet economic goals. Among the economies possible are substantial reductions in the weight, material and cost of structure; integration of insulation with interior and exterior finishes; and reduction of space heating and cooling appliance capacities possible with reduced heat losses and gains through the building envelope.

The design and construction implications of CVI panels are also significant and challenging. Walls can become much thinner than insulated wood frame construction. The residential construction practice of overbuilding the structure of a wall to create a cavity adequately sized for insulation will no longer be necessary. Instead, the two wall functions can be separated — thermal requirements may be met by a thin panel and structural requirements by an efficient light engineered frame.

However effective the thermal resistance of a CVI panel, there are significant design and detailing obstacles to overcome. Thermal performance, for example, is dependent on a vacuum which must be protected against puncture and impact damage. There will also be many joints to fuse and seams to seal against leaks. Joinery strategies and technology needed to secure panels to the frame and each other must be developed.

5.2.1 Energy Conservation and Site Design

Apply passive heating and cooling strategies to constrained sites

Given the densities, site dimensions, setbacks, access patterns and building placements common to cool climate cities and suburbs, opportunities for passive heating and cooling will vary significantly with lot configuration and orientation. Designs for houses in this context must be adequately flexible to adapt to sites with limited sun and wind availability and allowable opening areas restricted by proximity to property lines.

Figure 5.2 - 1
Plan Study of Siting Alternative
Center for Housing Innovation

Assuming street access on only one side, the preferred situation is a rectangular lot elongated in a north-south direction with an infill site along a rear, northern property line. An infill house to the rear of an existing house in this situation will have good access to sun and wind through a privately controlled yard or court immediately to the south.

An opposite orientation presents a very different situation. The same site with an infill house along a southern rear property line may have limited access to sun and wind due to obstructions, design and privacy considerations or regulation of openings along property lines. In this situation, sun and wind collection may be through roofs or the upper portions of otherwise opaque southfacing walls.

5.2.2 Energy Conservation and House Design

Limit interior area and volume exposed directly to climate

Small houses are not inherently energy conserving. While of limited conditioned floor area, the ratio of thermal envelope surface to enclosed volume is higher than that of larger houses. Small houses are also potentially cramped and uncomfortable as living places. As a consequence, small houses are frequently designed to appear spacious by organizing their largest, most open interior spaces together, along the longest dimension of the plan with full opportunities to establish thermal zones. Large windows and glazed doors are located to further 'open' the plan and borrow space from the outdoors. The risk of extraordinary heat loss and gain is significant and indicative of, an inherent conflict between an energy conservation goal of an efficient envelope and a design goal of openness.

Rather than elongate or configure the plan to increase contact between interior spaces and the outdoors, the design of this house limits its openness to one living area around which other more closed spaces of the house are gathered. Overall, the additional surface area generated is modest.

Yet, one important and prominent space remains visually open and accessible to other smaller spaces of the house.

Figure 5.2 - 2
Plan Study of an Open Central Living Area
Center for Housing Innovation

Reduce heat loss and airflow at doors and windows

Given the high thermal resistance properties of CVI panel walls, the dominant heat losses and gains will be through doors and windows of lower thermal resistance. Design studies revealed two particularly promising strategies. One is to improve thermal resistance of doors and windows by fitting them with shutters of CVI material. Another is to alter the rate of airflow around openings with sheltering walls and airlocks to reduce undesirable infiltration losses. Airlock porches can be glazed to control cold air infiltration in the winter and screened to facilitate ventilation in summer. Airflow around windows can be improved with short walls that shelter and direct the flow of air.

Figure 5.2 - 3
Site Plan Study of Wind - Sheltered and Airlocked Entrance
 Center for Housing Innovation

Differentiate structural frame from nonstructural insulating cladding

As the technology to manufacture thin panels of high thermal resistance becomes economical, other materials and construction systems will also change in tandem, thus creating an opportunity to improve their construction properties and installation. In contemporary construction practice, for example, wall thicknesses necessary to achieve structural integrity and thermal insulation standards in most wood frame houses are roughly the same, about 6". Superinsulating materials will fundamentally change this relationship. In the future, significantly greater thermal resistance can be achieved in less depth, as much as R-50 in as little as 1/2" (approximately 250% of insulating value in 8% of wall thickness) in the case of CVI panels.

As the structural and thermal functions of the wall become more independent, the materials of each will be engineered and manufactured to different standards and criteria. Structure can be engineered to geometries, spans and material properties that are fundamentally efficient and economical in resistance of loads. Enclosure can be engineered to insulation standards, weather properties and finishes that are fundamentally efficient and economical in resistance of heat and water.

The structural system of this house is an engineered frame of wood composite materials planned on a 48" module. Engineered wood structural systems permit longer spans — the modulus of elasticity of LVL, Micro-Lam, and Parallam lumber is already rated 10% greater than that of select structural Douglas fir. Less material is required. Members are smaller, lighter and 50% fewer in number, creating less dead load, and the number of potential thermal shorts is reduced by at least 1/2 over dimensional lumber framing.

Figure 5.2 - 4
Axonometric Study of Structure and Enclosure System
Center for Housing Innovation

The thermal and weather enclosure of this system consists CVI panels of approximately 1/2" thickness ($R=50$) that can be manufactured with a variety of interior and exterior finished surfaces. These panels can be easily installed, inspected and demounted for repair, replacement or renovation, much as windows and doors are presently accommodated in conventional construction.

Joints between the CVI panels are overlapped and gasketed to minimize thermal weaknesses and air infiltration while permitting thermally induced changes in dimension. Floor / wall joints overlap, as do wall / roof joints, for similar reasons. This installation strategy also facilitates later maintenance, remodeling and recycling of components.

Figure 5.2 - 5
Detail Study of Panel Connection at Column
 Peter Keyes and Virginia Cartwright

Increase the engineering and energy conservation capability of interior finishes

On the interior, cementitious panels are laminated or mechanically fastened to the structural frame. In addition to providing interior finish, these panels stiffen the building frame and contribute acoustic damping and fire resistance. There is additional opportunity manufacture other materials and capabilities as part of this nonloadbearing skin. Encapsulated phase change material (PCM), for example, can be integrated with finish materials to provide thermal storage capability with minimum bulk and weight.

Figure 5.2 - 6
Section Study of Phase Changing Material (PCM) Wainscot
 Peter Keyes and Virginia Cartwright section

Surface mount windows and doors

The design and installation quality of windows and doors are critical factors in maintaining the thermal integrity of any construction system. These openings of lower thermal resistance comprise a significant percentage of exterior wall area. Joints and seams between such openings and the surrounding wall are also potential thermal shorts and sources of infiltration that degrade energy performance.

The thin walls of this house are not of compatible dimension with conventional windows and doors. Most will be of deeper dimension than the panel to which they attach and will, by necessity, be surface mounted and 'project from' rather than 'recess into' the wall. Once windows and doors need no longer match the thickness of walls, an opportunity is presented to alter their

design and installation strategy for improved energy performance. Frames, glazing and operable portions can be redesigned for improved thermal resistance. Thermal envelopes can be made with greater continuity. Frames can lap rather than butt against insulated portions of the wall. Gaskets can be developed for the increased area of contact between frame and wall. Joints can be more easily inspected and maintained.

Figure 5.2 - 7
Section Study of a Surface Mounted Window
Peter Keyes and Virginia Cartwright

Improve the performance and convenience of movable insulation

Minimizing conductive heat losses is a fundamental energy conservation strategy in a cool climate. Large areas of windows and doors present an obstacle to this strategy in any house and a particularly significant obstacle in small houses where opening area tends to be a greater proportion of floor area. A common solution is to provide a movable insulation material that covers the opening when it is not in use. Many examples, such as retractable shades, are of modest

insulating capability. Others with good insulating capability, such as insulated panels, are heavy or too cumbersome to use easily.

The thermal performance of openings in this house is enhanced by using a CVI panel as a shutter. The extraordinary thinness and light weight of this super insulating material is particularly well suited to shutter applications. Mounting hardware need not be heavy duty. Large panels can be concealed in narrow pockets and easily lifted, lowered or swung into place by one person.

Figure 5.2 - 8
Axonometric Study of a Concealed Retractable Window Shutter
Peter Keyes and Virginia Cartwright

Create thermal breaks at panel and frame connections

Minimizing conductive heat losses through structure and fastenings is also critical to the energy efficiency of this construction system. The dimension between conditioned inside and

unconditioned outside is minimal and frequently bridged by connectors that attach CVI panels, opening frames, interior finishes etc., to the structural frame.

5.2.4 Energy Conservation and Service System Design

Utilize concentrated mass passive heating strategies

Several design, construction and manufacturing considerations argue against dependence on direct gain passive heating strategies in this house. Access to unobstructed sunlight will vary with site conditions. The house is small, offers little relief against bright sunlight and may quickly fill with furniture and belongings that shade thermal mass from solar radiation. Yet, providing thermal mass to utilize incoming sunlight and reduce interior temperature swings remains, at the same time, an effective energy conservation strategy in this climate.

Figure 5.2 - 10
Plan Study of Sun Space with Concentrated Mass
Center for Housing Innovation

Solar gain spaces are provided in the design of the house with corresponding emphasis on reducing their size and restricting their location. Solar apertures are oriented to the sky on tight

sites where vertical glazing would not have adequate access. Smaller areas of thermal mass are concentrated in those spaces where there are fewer conflicts with use and furnishings. Supplementary phase changing materials are incorporated with interior finishes.

Recover waste heat from appliances, exhaust air and water systems

Space heating and cooling in this house can be accommodated by a variety of forced-air appliances and fuel types. Given the low rate of heat loss and gain through walls and roofs, this appliance can be of substantially less capacity than those customarily installed in a cool climate house of this size.

Indeed, conservation of waste heat from internal sources may be adequate to meet space conditioning needs much of the year if an economical and effective waste heat recovery system is provided. In this design, heat is recovered from a variety of sources in the house. Included are appliances, exhaust air and gray water.

Figure 5.2 - 10
Diagram Study of an Integrated Heat Recovery System
 Center for Housing Innovation

Match electrical power source to end use

Electrical service in the house is 110 vAC and 12 vDC. These two power systems are segregated to match power source to end use. The higher voltage system is connected to the local utility and used to run motors and pumps. The more energy efficient lower voltage system is connected to a photovoltaic field in the roof or windows of the house and used to run lights and small appliances.

In addition to the inherent energy conservation opportunities, the lower voltage system is more flexible and can be safely distributed in surface mounted chases. It can also be easily and quickly modified by occupants who may wish to change the location of lights or outlets.

Figure 5.2 - 11
Diagram Study of Power Zones
 Center for Housing Innovation

Surface mount service distribution systems

A surface mounted service distribution system is critical to the continuity and integrity of a thin super insulating curtain wall. In this house, a service distribution system is integrated with the architectural wainscot that protects the panels against damage. This wainscot spans between structural framing columns. The lower baseboard portion houses electrical and mechanical system conduits. Above the base is a plenum to route conditioned air to those spaces where interior air distribution is not possible or desirable. The top surface can accommodate switches and controls.

Figure 5.2 - 12
Section Study of a Surface Mounted Power Raceway
Peter Keyes and Virginia Cartwright

Optimize floor and roof cavities as chases and plenums

The space between the inner and outer faces of floor and roof decks can be adapted to service distribution. In both cases, one face of the LVL I-beam joists are sheathed with plywood, wafer board or oriented strand board. The other joist face supports CVI panels laid over a leveling and air seal material. The open space between the two surfaces serves as an insulated plenum or chase for air distribution, venting, electrical and water supply runs.

Figure 5.2 - 13
Section Study of Service Distribution in Roof and Floor Plenums
Peter Keyes and Virginia Cartwright

Improve flexibility of service distribution and connection system

Conduits and outlets for gas, power, water, and communication services are of flexible material and quick-connect technology. Small scale in-room heating and cooling appliances are readily accommodated, providing an opportunity to reduce service system costs and eliminate energy losses due to conduction, friction and leaks associated with centralized systems. Occupants can

zone and size these systems to use and preference.

5.2.5 Energy Conservation and Manufacturing Strategies

Site assemble the house in a top-down continuous process

Once the independent structural frame of this house is erected, construction can proceed from the roof down (rather than the floor up). This installation procedure provides shelter early in the construction process. Materials are kept dry and thermally stable. Insulation is protected from weather degradation. A warm protected work area contributes to the likelihood of quality installation and careful inspection of energy systems and products.

Coordinate performance standards among design, component and material options

Single family housing varies significantly in size, form, quality and style to meet market opportunities, neighborhood norms and owner preferences. These designs demanded by the market will be large as well as small; rectangular as well as L-shaped in plan; with gabled as well as hipped roofs; and subject to extraordinary variety in amenity, appliance and space conditioning options. Other kinds of variations and substitutions will be further made at the manufacturing site, typically on the basis of availability, cost and production factor.

Such flexibility and variety will not easily emerge within one manufacturer's repertoire of parts. Accordingly, the manufacture of this house is 'open' in concept. The manufacturing process will be sufficiently flexible to facilitate a range of design options, components and materials, in much the same way that contemporary production builders work from a limited but varied palette of materials and component alternatives.

Questions of value and performance remain paramount. Design flexibility must not also result in houses of poor design, poor quality, high operating or maintenance costs, and poor energy

performance. Engineering and manufacturing processes must support the design variety and flexibility demanded by the market, without compromise to the safety, integrity or energy performance of the resulting house.

Figure 5.2 - 14
Elevation Study of a Kit of Compatible Parts
 Center for Housing Innovation

Coordinate dimensions of sites, houses, components and energy systems

An important means to realize low first cost, energy efficient houses is development of a limited set of dimensional rules. Both coordination of building components (windows matched to wall sections and room sizes, for example) and the integration of systems (air distribution systems matched to structural components, for example) will contribute significantly to the economy, precision and quality necessary to construct a marketable, energy efficient house.

These rules must be adequately flexible to permit legitimate diversity and variation in design and component choice and at the same time, must improve and simplify coordination of design, engineering and manufacturing. The design capabilities of this dimensional system is particularly critical in small houses where the spaces are few and small, and must be adaptable to multiple functions and roles.

Technical, manufacturing or energy criteria alone do not establish these dimensions. They are instead founded on the sizes of efficient and flexible spaces in which people can comfortably live. Typically these spaces must be both large and small. Each must accommodate a range of alternate arrangements of furnishings, activities and services without becoming overcrowded or poorly zoned. Rooms must also combine with adjacent rooms to appear spacious while minimizing organizational, operational and visual conflicts.

The dimensional coordinating system for this house must be 'open', capable of considerable variety and flexibility, yet adequately restrictive to insure that, in the end, the house can be built from compatible parts that fit together easily. The UNICOM method illustrated below is an example of one such system published by the National Association of Home Builders in the 1960's. This modular dimensional system coordinates planning and design decisions with construction and material conventions.

Energy conservation strategies and standards must be a part of this dimensional system as well. Components must be sized to permit adequate insulation and thermal storage levels; rooms and their openings must be sized and proportioned to heat and cool; groups of rooms must be organized to ventilate and distribute heat efficiently.

6.0 FISCAL YEAR 1991 ACTIVITIES.

This section describes the activities that will take place in task 2.1 Design for Energy Efficiency in fiscal years (FY) 1991, 92, and 93. The 1991 activities are described in detail while only the major activities are described for 1992 and 1993.

As summarized in this report, in FY90 we developed eight building designs and analyzed them to discover their innovative features. Based on this analysis we will develop more detailed designs in FY91. The designs will be rigorously evaluated in terms of the whole building, its building systems and in terms of its design and manufacturing processes.

Overview of 1989-93 Activities

As shown in Figure 6-1, this task had its genesis in the multi-year plan and our analysis of the U.S. and foreign industrialized producers. In 1990 we developed future scenarios in seven areas ranging from demographics to design process. We used those scenarios to develop the problem statements and house designs described in this document. In 1991 we will refine two designs, evaluate them and develop final designs.

Using those designs, one for a single family and one for a multi-family dwelling, we will build one prototype in cooperation with industry in 1992. In 1992 we will also develop additional new problem statements and schematic designs. In 1993 we will evaluate the prototype built in 1992 and refine the new designs developed in 1992. A major thrust of our activities in 1992 and 1993 will be the transfer of technology to industry.

Figure 6 - 1
Overview of Activities in Task 2.1 Design for Energy Efficiency
FY 1989 - 1993

1991 Activities

In 1991 there will be two research activities -- design and evaluation. As illustrated in Figure 6 - 2, these activities are sequential and iterative. The design refinement stage takes place in February and March, and is followed by an evaluation phase lasting from March through September.

Figure 6 - 2

A preliminary evaluation will be completed in June. Its conclusions will establish direction for the first redesign cycle in July. That redesign will in turn feed back and establish the direction for the detailed evaluations that continue through September. Beginning in October, we will finalize the designs and run a designer test of how the proposed housing systems will perform across a variety of simulated situations.

The process of making a house can be understood as using building systems in the design and manufacturing process to make whole buildings. The evaluations described previously will consider these three topics. Several specific evaluations will be undertaken within each topic:

1. Process Evaluation
 - a. manufacturing and assembly
 - b. architectural and engineering design
2. Whole Building Evaluation
 - a. energy
 - b. cost
 - c. architectural
 - d. codes and regulations

3. Building Systems

- a. structure
- b. components and materials
- c. mechanical heating, ventilating, and air conditioning
- d. water and waste
- e. dimensional coordination
- f. electric lighting
- g. electrical and communication

During February and March of FY91, we will develop detailed evaluation methods and criteria in these areas.

Process

The manufacturing process evaluation includes analysis of a proposed factory/field process to determine its effectiveness and costs in terms of factory layout, level of automation, material needs, site installation, labor skills required, and bottlenecks.

The architectural and engineering design process evaluation will determine the level of computerization appropriate for the process and determine the feasibility of developing software tools to support architectural and engineering design. Analyzing links to sales and manufacturing will be of critical importance.

Whole Building

The energy evaluation will determine the loads placed on the buildings by the climate and various use patterns. The envelope, mechanical and electrical systems will be optimized based on this evaluation for a broad range of assumptions concerning envelope

construction, thermal mass, fuel type, mechanical system, utility peaking patterns, etc. Air quality assessments will be part of these evaluations.

The architectural evaluation will address function, market appeal, spatial organization and quality, appearance, siting, community organization, daylighting, ventilation, privacy, acoustics, and flexibility.

The cost evaluation will determine the cost of the proposed building designs based on assumptions about the costs of new materials, manufacturing and design processes, and delivery mechanisms. Costs will be categorized as direct (labor, materials, equipment, subcontract), finished lot (acquisition, infrastructure), indirect (supervision, field expenses), overhead, marketing, financing, and net income.

The code evaluation will determine areas of non-compliance for representative building and zoning codes and recommend required code changes.

Building Systems

The structural analysis will be directed towards optimizing the engineering design of the entire structure and developing specifications for materials, shapes and connections.

The components and their related materials analysis will determine the feasibility of the components proposed and suggests the specifications for new materials to be developed.

The HVAC evaluation will determine the expected level of performance under the load condition resulting from the building design. The evaluation will also include the proposal of alternative systems that may perform better under different load scenarios.

The water and waste evaluation will include an analysis of water input and waste output given various operating and fixture conditions. It will also include a study of alternative materials and distribution methods.

The dimensional coordination evaluation will determine if the proposed dimensional modules are consistent with materials manufacture, building assembly and architectural and engineering design. The dimensional system will be evaluated to determine its tolerance for components sized to other systems, its compatibility with existing and proposed architectural and engineering computerized design systems and its compatibility with proposed manufacturing equipment.

The electric lighting system evaluation will determine the optimum luminaire design and placement to meet the lighting requirements for a range of occupancy types.

The electric and information systems evaluation will determine voltage requirements, develop distribution strategies and specifications for control systems.

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