PROBLEM STATEMENTS
FOR
THE 21ST CENTURY HOUSE

ENERGY EFFICIENT INDUSTRIALIZED HOUSING
RESEARCH PROGRAM

CENTER FOR HOUSING INNOVATION
UNIVERSITY OF OREGON

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EXECUTIVE SUMMARY

Since 1989, the U.S. Department of Energy has sponsored a research program, the Energy Efficient Industrialized Housing program (EEIH) to improve the energy efficiency of industrialized housing design and construction. 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 outside the Department of Energy 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 one sub-task of Task 2.1: Design for Energy Efficiency, a task established to integrate consideration of energy efficiency with questions of housing design and manufacturing. In this sub-task, a series of design problem statements have been developed to define the circumstances, goals and requirements of four energy conserving industrialized houses of the 21st Century.

Included is an explanation of principles and procedures that underlie the problem statement development process and summaries of the four design problem statements that are its conclusions. The following four design problems were selected and developed to establish a vision of energy conservation opportunities in critical regions, market segments, climate zones and construction strategies significant to industrialized housing in the 21st Century.

STARTER HOUSE IN A HOT-ARID CLIMATE

TYPE:	Multi - family attached units
AREA:	800 sf plus expansion
DENSITY:	12 - 16 units per acre
CONTEXT:	Fringe urban / suburban tract, Phoenix AZ
CONSTRUCTION:	Panelized
MATERIALS:	Concrete, glass fiber and foam insulation composite panel.
SERVICE SYSTEMS:	Integrated mechanical core
ECONOMIC GOAL:	Affordable at 60% - 80% median household income
ENERGY GOAL:	25% more efficient than California Title XXIV Energy Code. 75 - 95% passive energy. No peak demand
INNOVATIONS TESTED:	**Energy** Hybrid of passive and unducted mechanically assisted air systems . Lightweight, manufactured thermal storage materials. Photovoltaic electricity generation.

Manufacturing
Full service, vertically integrated house manufacturing company with automated factory production of concrete composite panels.

MOVE-UP HOUSE IN A HOT-HUMID CLIMATE

TYPE:	New single family house.
AREA:	2000 sf
DENSITY:	6 - 10 units per acre
CONTEXT:	Planned cluster development. Miami, FL.
CONSTRUCTION:	Modular.
MATERIALS:	Engineered reconstituted wood and laminated veneer lumber with metal connections and tensile elements. Wood and gypsum composite interior partitions.
SERVICE SYSTEMS:	Central heat pump. Small diameter plastic pipe and variable air volume distribution system.
ECONOMIC GOAL:	Affordable at 200% median household income.
ENERGY GOAL:	25% improvement over California Title XXIV Code. Zero net electrical use. No peak demand.
INNOVATIONS TESTED:	**Energy** High efficiency heating and cooling core maintained by local utility. Zoned miniature VAV distribution system. Phase changing interior finishes. Dessicant bed dehumidification. Photovoltaic electricity generation. **Manufacturing** Flexible custom design, fittings and fixture capability. Integrated manual and automated production processes. Factory installed air distribution system.

RENEWABLE HOUSE IN A TEMPERATE CLIMATE

TYPE:	Remodel and addition to wood frame single family house.
AREA:	1300 sf existing house; 500 - 600 sf addition
DENSITY:	Existing neighborhood of approximately 16 units per acre.
CONTEXT:	Urban neighborhood. Seattle, WA
CONSTRUCTION:	Panelized.

MATERIALS:	'Do-it-yourself' recyclable wood composites and by-products.
SERVICE SYSTEMS:	Zoned heat pump
ECONOMIC GOAL:	Affordable at median household income for central city.
ENERGY GOAL:	Upgrade existing house. New construction 25% more efficient than California Title XXIV energy code. No mechanical cooling
INNOVATIONS TESTED:	**Energy** Energy conserving specialties for renovation construction: Insulating finishes. Thermally broken framing. Retrofit window integrated heat pump. **Manufacturing** Specialized energy conserving systems and materials integrated with construction components suited to remodel. Manufactured building products and assembly systems for 'Do-it-yourself' applications. Manufacturing with renewable, low toxicity wood products.

EXTENDED FAMILY HOUSE IN A COOL CLIMATE

TYPE:	Single family 'infill' house
AREA:	700 - 800 sf.
DENSITY:	12 dwellings per acre including existing houses. Share 5000 sf lot with existing 1800 sf house.
CONTEXT:	Existing single family suburb . Minneapolis, MN.
CONSTRUCTION:	Panelized frame.
MATERIALS:	Lightweight glass fiber reinforced concrete composite on laminated veneer lumber frame.
SERVICE SYSTEM:	Unducted integrated HVAC / DHW recovery core heat pump.
ECONOMIC GOAL:	Affordable at 80% - 100% median household income. Low monthly operating costs.
ENERGY GOAL:	25% more efficient than California Title XXIV energy code.
INNOVATIONS TESTED:	**Energy** High R-value compact vacuum insulation panels. Ductless air distribution and return. **Manufacturing** Factory integration of fragile high thermal performance panels with conventional construction materials.

Each problem statement was developed from surveys of future oriented literature in seven pertinent topical areas: computing and design process; manufacturing industrial process; construction materials, components and systems; energy and environment; demographic context; economic context; and planning policy and regulatory context. Future trends were identified in each area, assessed for potential impact on housing and energy, and compiled into statements of related or interdependent trends and impacts. Design, energy and manufacturing criteria were developed and quantified.

These problem statements will be given to designers who will develop whole, marketable house and site designs that meet the parameters defined in each statement, emphasizing solutions to energy, materials and construction components. The resulting designs will be analyzed and evaluated. The innovative ideas, principles and visions identified can be further developed and disseminated through other tasks in the project.

This process will be iterative, roughly on an annual cycle. With each evaluation, we will reconsider, supplement and refine the assumptions, scenarios and criteria defined in the problem statements. Problem components and the design studies they inspire will be added, expanded, dropped, combined or merged with one another until the best ideas and questions can be identified and inventoried. Immediately achievable innovations and ideas will be diverted to project Research Area 3: Catalysts for Utilization. Ultimately, a promising multi-family and single family prototype will be developed for construction and testing.

PROBLEM STATEMENTS
FOR THE
21st CENTURY HOUSE

"A problem well stated is half solved"
John Dewey

PROBLEM STATEMENTS FOR THE 21st CENTURY HOUSE

Ron Kellett, Center for Housing Innovation, University of Oregon.

1.0 ABSTRACT

A problem statement is a summary of circumstances, goals and requirements that define a design study.

This report summarizes the Problem Statement sub-task of Task 2.1 Design for Energy Efficiency of the Energy Efficient Industrialized Housing Research Project. It includes an overall explanation of principles and procedures that underlie development of the following four problem statements:

- Starter House for a Hot-Arid Climate
- Move - up House for a Hot-Humid Climate
- Renewable House for a Temperate Climate.
- Extended Family House for a Cool Climate

These problem statements define the design, energy conservation and manufacturing ingredients of housing demand scenarios for the year 2030. For each statement, designers will develop a house and site design that achieves stated goals and requirements. The resulting designs will be analyzed, evaluated and tested. In this process, innovative conclusions, principles and ideas that warrant dissemination, development or further research through other task areas of the project will be defined.

1.1 INTRODUCTION

Project context

The Energy Efficient Industrialized Housing (EEIH) research program is a multi-year project to develop knowledge and technologies from which a future generation of energy efficient, affordable industrialized housing can emerge. The knowledge and technologies developed through this research will improve the quality and livability of housing, especially that of low and moderate income individuals, and be 25% more energy efficient than required by the most stringent U.S. residential codes, at a lower first cost.

In pursuit of these goals, the project as a whole is 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; and Area 3: Catalysts for Utilization. Each area includes several tasks illustrated as rectangles in Figure 1.1 - 1, which are described in detail in Summary FY 1989 Research Activities, February, 1990; and Multiyear Research Plan: Energy Efficient Industrialized Housing, June, 1989.

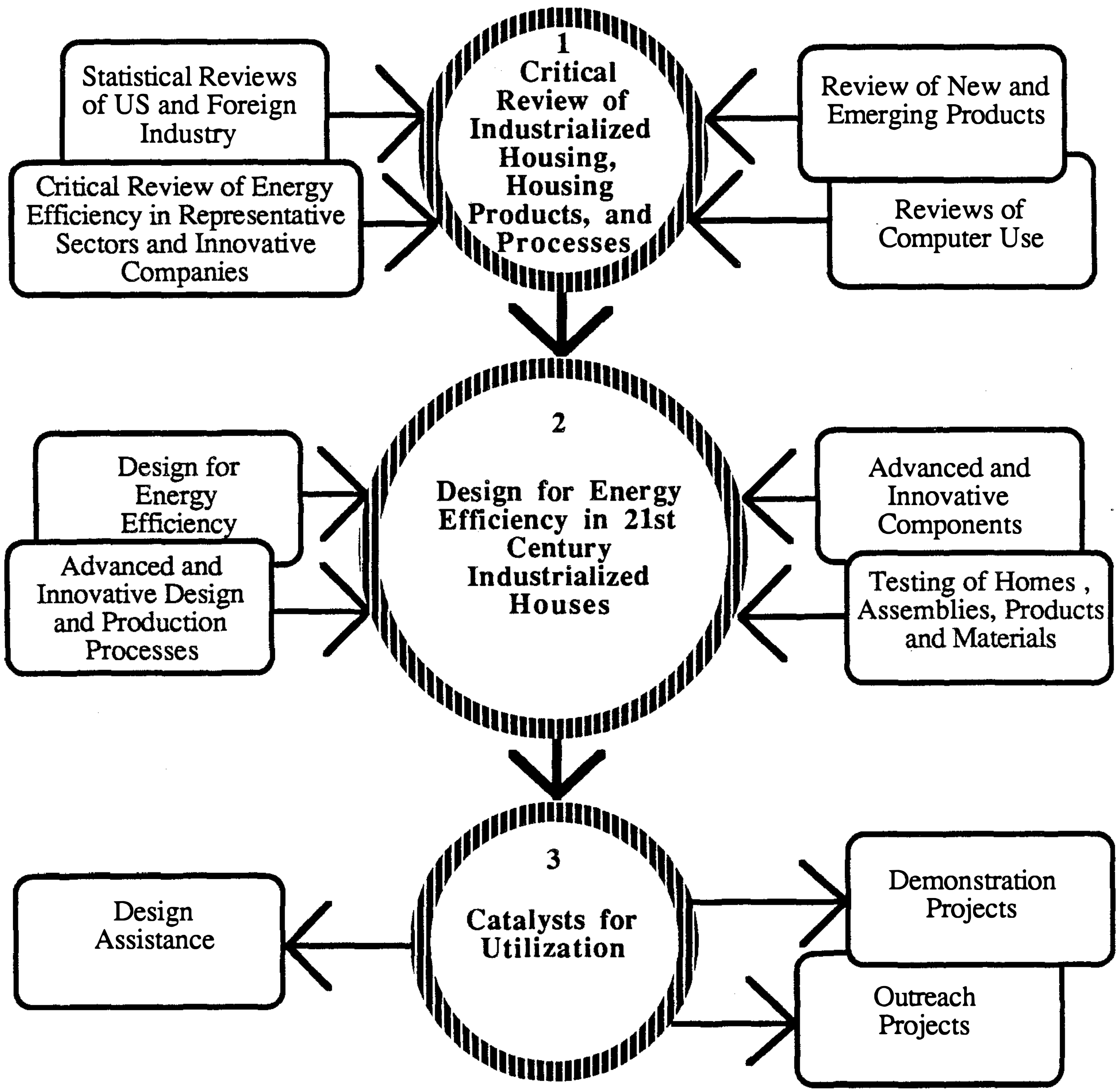


Figure 1.1 - 1
Research Areas and Tasks
Energy Efficient Industrialized Housing Research Project
Source: Summary FY 1989 Research Activities

The 21st Century House

Research Area 2: Design for Energy Efficiency in 21st Century Industrialized Houses is directed toward the future. The year is approximately 2030, 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 market place. This assumption is both a practical beginning and a focal point for this research. The reasons are several.

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 three research areas on eleven 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 transition of unknown duration and outcome. Although we are confident of the opportunity industrialization brings to the housing industry and energy conservation, the forms that opportunity will assume are unclear. The future provides a means through which we look beyond that which 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.

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 means 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).

Research Area Context

Figure 1.1 - 2 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.

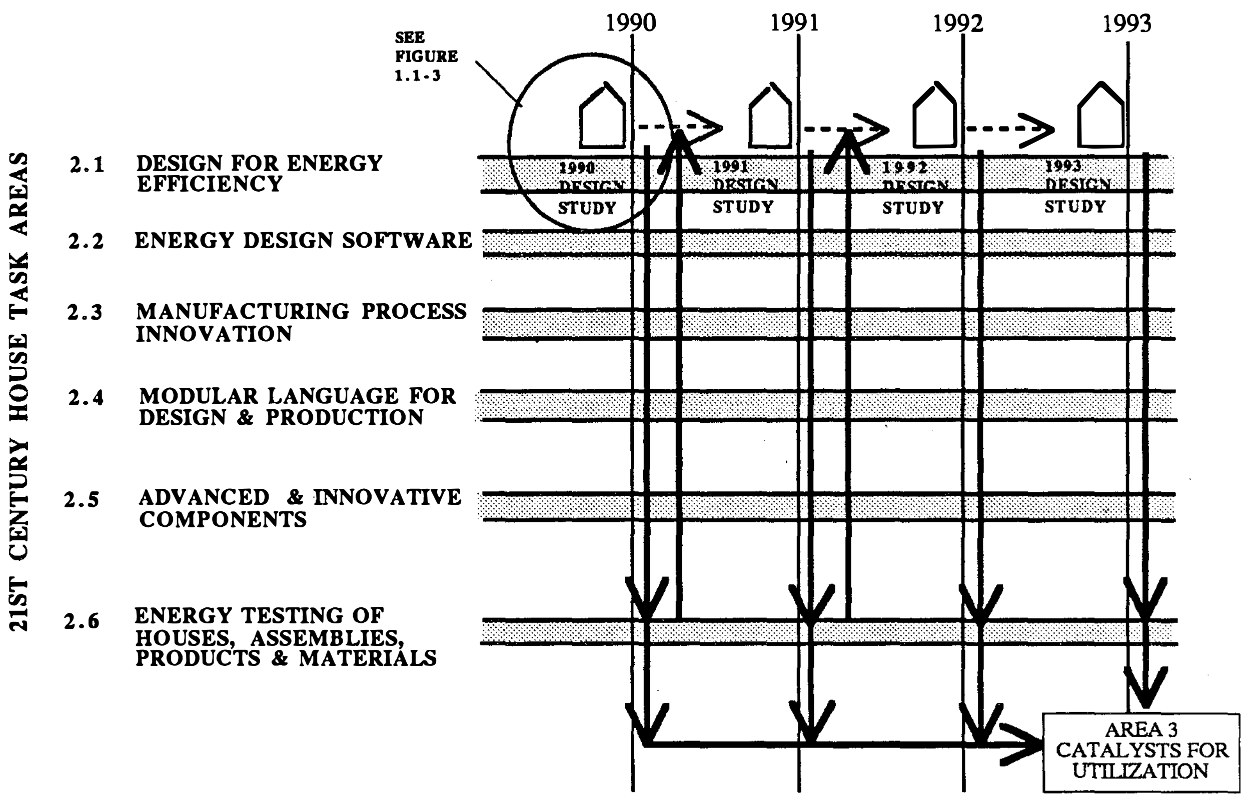


Figure 1.1 - 2
Relationships Among Tasks of Area 2:
Design and Energy Efficiency in 21st Century Industrialized Houses

Task 2.1 Design for Energy Efficiency

Research undertaken in Task 2.1 Design for Energy Efficiency develops and applies industrialized housing concepts suited to the markets, materials, processes and designs that will realize 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, manufacturing and construction strategies that optimize site opportunity, design quality, energy efficiency and production cost.

The scope of this task can easily overwhelm. The U.S. housing industry and its markets are large and diverse. Included are two dominant house forms — single family and multi-family; four climate zones — cold, temperate, hot-arid and hot-humid; four design contexts — urban, suburban, rural and remodel; and an infinite range of construction and material variables. To streamline and focus this scope, we have concentrated initial effort in this task on single and small scale multi-family houses in markets, climate zones, design contexts and construction types that promise significant energy conservation opportunities.

In 1990, the first year of the task, we will generate prototype designs for three single and one multi-family house, four climate zones, three design contexts, three market levels and four manufacturing, material and construction strategies.

1.2 THE 21st CENTURY HOUSE DESIGN PROBLEM

"The process . . . . is to pull the problem apart into its different elements . . . "
Charles F. Kettering

Problem Definition in Design

If design is a process of problem solving, problem definition is a process of problem seeking. Unlike many other kinds of problems, design problems are typically broad missions of ambiguous scope and order. Unlike problems customarily encountered in mathematics or engineering, for example, neither the goal nor the means to achieve it are evident. Parameters and criteria are not apparent and must be coaxed into view. Consequently, the initial phase of any design process is one of defining the limits of the problem, fixing compatible goals, establishing requirements and specifying criteria.

While the focus and emphasis of the project may be narrow, its context and consequences are broad and inclusive. Energy consumption in houses is the consequence of many interacting variables. Among them are variables of climate, siting, design, materials, production quality and occupancy that establish energy demand and performance. Accordingly, our problem definition effort approaches energy conservation from a point of view that integrates rather than isolates questions of energy from those of design or manufacturing. We seek to consider 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.

We wish to assign physical and quantitative dimensions to these variables where possible. At the same time, we do not wish to define these future oriented problems so thoroughly that a designer has inadequate latitude to develop a creative interpretation or synthesis of problem variables that we could not foresee or expect. Design problems can never be fully stated comprehensively and impossible to determine that all aspects and criteria vital to a successful solution have emerged (Lawson, 1990: 88). They are instead legitimately full of uncertainty with respect to criteria and their priority. Some objectives and priorities may never fully emerge and others are likely to change as good ideas and solutions emerge in design.

We have throughout these problem statements sought to develop appropriate degrees of definition and specificity appropriate to the problem and the process. In the accompanying statements, we have defined market, energy, construction and manufacturing components of each problem to a greater level of detail and specificity than others, such as style, room sizes, siting and so on — aspects we have intentionally left less defined, open to interpretation and development in design.

Problem Definition Process in Task 2.1

Defining the design problem of the 21st Century House is in part a task of defining the future. Although defining the future frequently commands much popular attention, the rigor and reliability of the practice has a diverse and inconsistent record. Many future visions have been attempted, most have not endured and seem, with the passage of time, more willful images than substantive analyses. To help researchers visualize and pursue a substantive future vision we undertook a systematic and comprehensive study to arrive at our design futures.

A first step defined the range of issues and trends anticipated to motivate or significantly influence housing design, energy conservation and manufacturing in the year 2030. From these trends a second step defined what impact these might hold for housing, linking trends and impacts with one another to create scenarios of future housing and energy demand to which we added additional criteria and detail to become problem statements. A third step, yet to be completed, develops the design studies that respond to the conditions of each statement.

Figure 1.2-1 illustrates the Task 2.1 Problem Definition Process. In this diagram, 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 step and its methodology is described in detail following.

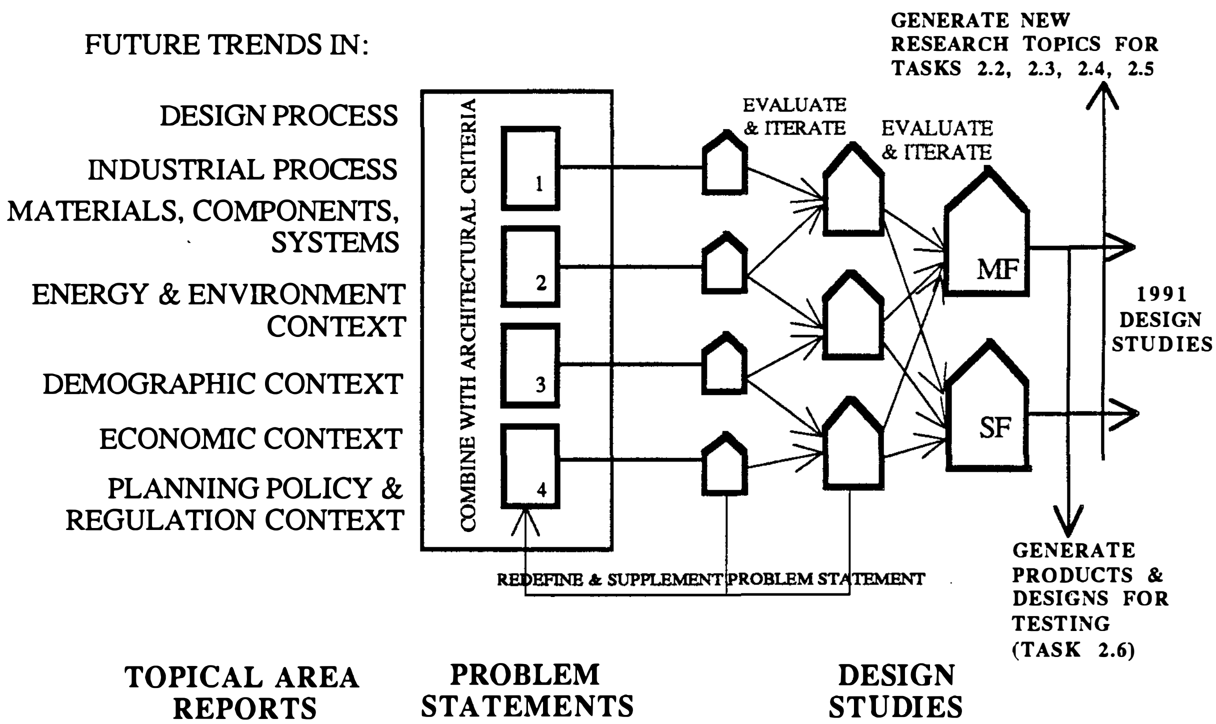


Figure 1.2 - 1
Task 2.1 Problem Definition Process

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 series of literature searches was initiated in seven topical areas. These included:

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

For each area, members of our research team undertook a comprehensive search and analysis of future oriented literature. From these searches, internal working documents, called Topical Area Reports, were developed summarizing trends and circumstances likely to influence demand, design or energy characteristics in industrialized houses. Seven 10 - 20 page reports were prepared to the following outline:

- **Introduction to the topical area:**
  What is its scope? What is included? How has the area influenced housing, manufacturing and energy conservation in the past?

- **Trends in the topical area:**
  Specific trends, events, ideas, issues etc. in the area that will change or persist in housing, energy conservation and manufacturing by the year 2030.

- **Implications of trends:**
  Assessment of the anticipated influence and impact of identified trends for housing, energy conservation and construction.

- **References:**
  Summary of the literature, people and resources used to define trends and assess implications.

Drafts of reports were circulated to individuals knowledgeable in each area for review and comment.

Problem Statements

It has not been the intention of this project to seek or imply a single, universally applicable vision of energy conservation, housing design and industrialized construction. On the contrary, researchers on the project are committed to realizing visions that are responsive to critical regional and market segment variations.

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 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 might act cumulatively or in concert, to significantly influence design, construction or energy demand in particular regions, market segments or design scale. In this study, trends identified in each topical area were reduced to those deemed to have direct impact on housing design and energy performance. Each trend was evaluated across eight scales of housing design, asking at each, 'How might this trend affect energy conservation at this scale of design?'.

Figure 1.2-2 illustrates a portion of the combinatorial matrix format through which these comparisons 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 from neighborhood to component.

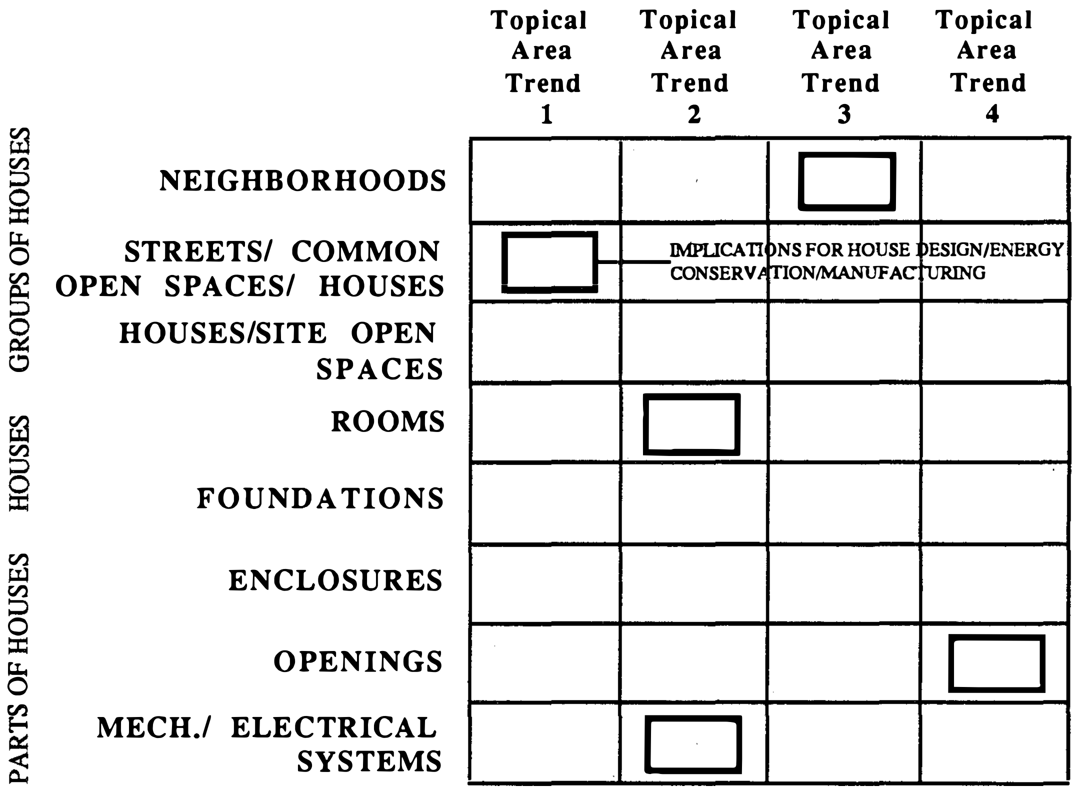
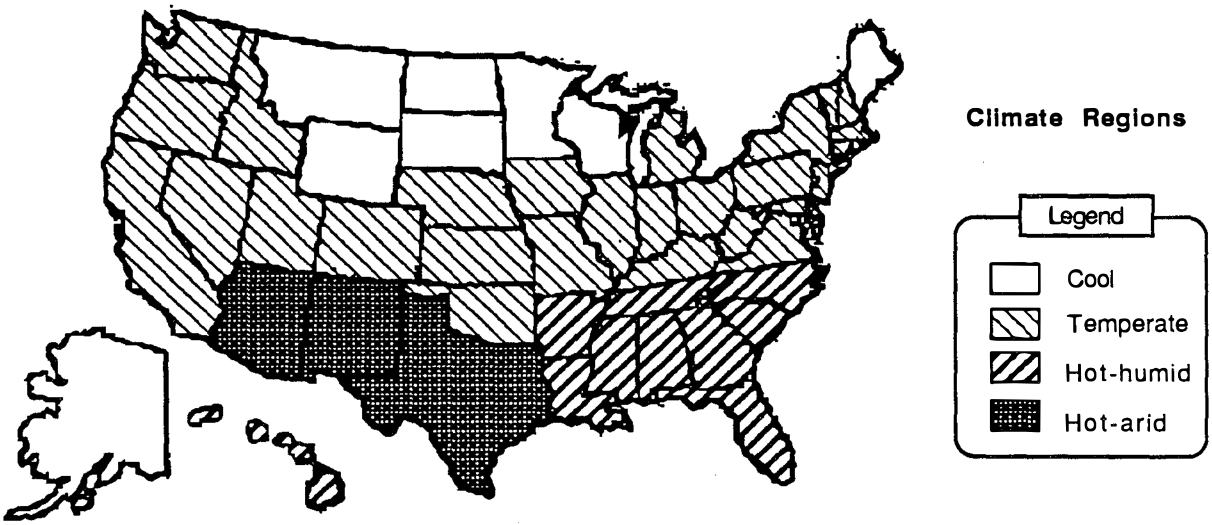


Figure 1.2 - 2
Assessing Design and Energy Implications of Topical Area Trends

Working in group idea-generating sessions, we summarized in diagram the potential consequences of a particular trend intersecting a particular design scale. As we went through this process several times, we looked for points where trends and design scales frequently converged or linked with one another. From such points of congruence and linkage, a series of future housing demand scenarios were sketched around mutually reinforcing trends / design scales that warranted investigation as a design study.

While several potential housing scenarios could be identified and developed from 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 are summarized in Figure 1.2-3.



1 **Starter House for a Hot -Arid Climate:**
A low cost entry level multifamily house for high growth western sun-belt states.

2 **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 **Renewable House for a Temperate Climate:**
A 'do-it-yourself' remodel and addition kit for wood houses in the northwest.

4 **Extended Family House for a Cool Climate:**
An economical single family house for suburban infill sites in northern states.

Figure 1.2 - 3
Selected Problem Statement Contexts

Comprehensive statements of goals, requirements and criteria were developed for each of the above problem topics. Each statement is written for a design audience as a set of background ideas and 'instructions' intended to inform and inspire effective and creative solutions. Within each statement, salient questions, circumstances, objectives and requirements were summarized and where appropriate quantified to the following outline:

- **Introduction:**
  Summary statement of the design problem scenario highlighting the design, energy and manufacturing focus and background of the problem statement.

- **Delivery Scenario:**
  Characteristics of the housing delivery system summarizing major participants and roles, marketing and sales methods, financing strategies and so on.

- **Design Program:**
  Design goals and requirements including house type, space requirements, occupants and architectural context.

- **Energy Conservation Program:**
  Energy conservation goals and circumstances including a design summary of climate, fuels, energy demand and utility context.

- **Materials, Components and Systems Program:**
  Specification of construction materials, components and service systems including industrialization strategy, envelope and structure, service systems and energy systems.

- **Manufacturing Scenario:**
  A manufacturing and production scenario defining the processes and procedures through which the house and its components are fabricated, transported and assembled.

- **Evaluation:**
  Specific energy, design and economic goals, objectives and criteria against which design study will be evaluated

- **References**

Design Studies

Each statement will be given to a designer or designers with instructions to design a quality, marketable house to meet the parameters of the problem statement emphasizing solutions to its energy, materials and construction components. Design studies will be initiated to find whole innovative solutions to problem components through a design for a house and its site. Each design study will produce the following:

- **Design summary:**
  1/8" house plan / site plan, elevations and axonometric and 1/2" construction section drawings; explanatory narrative and statistics (floor area etc.).

- **Construction scenario:**
  A summary of construction steps and procedures and inventory of material innovations attempted.

- **Energy analysis:**
  A summary of energy performance and analysis of energy innovations and principles attempted.

- **Cost analysis:**
  A summary of anticipated cost allocations and analysis of design and construction economies attempted.

- **Problem statement critique:**
  Summary of aspects of the problem statement for which further detail, guidance or elaboration is suggested or required.

Each of the above design cycle products will be evaluated against criteria specified in the problem statement. This process will be iterative, roughly on an annual cycle. With each evaluation, we will reconsider, supplement and refine the assumptions, scenarios and criteria defined in the problem statements. Problem components and the design studies they inspire will be added, expanded, dropped, combined or merged 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, a promising multi-family and single family prototype will be developed for construction and testing.

1.2 REFERENCES

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PROBLEM STATEMENT
FOR THE 21st CENTURY HOUSE

STARTER HOUSE
IN A HOT-ARID CLIMATE

SYNOPSIS

TYPE:	Multi - family attached units
AREA:	800 sf plus expansion
DENSITY:	12 - 16 units per acre
CONTEXT:	Fringe urban / suburban tract, Phoenix AZ
CONSTRUCTION:	Panelized
MATERIALS:	Concrete, glass fiber and foam insulation composite panel.
SERVICE SYSTEMS:	Integrated mechanical core
ECONOMIC GOAL:	Affordable at 60% - 80% median household income
ENERGY GOAL:	25% more efficient than California Title XXIV Energy Code. 75 - 95% passive energy. No peak demand
INNOVATIONS TESTED:	**Energy** Hybrid of passive and unducted mechanically assisted air systems. Lightweight, manufactured thermal storage materials. Photovoltaic electricity generation. **Manufacturing** Full service, vertically integrated house manufacturing company with automated factory production of concrete composite panels.

2.0 PROBLEM STATEMENT FOR A 'STARTER' HOUSE IN A HOT-ARID CLIMATE

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Michael Mullens, Department of Industrial Engineering, University of Central Florida.

Introduction

The 'Starter House' problem statement explores the energy conservation and economic opportunity of a fully integrated housing company developing entry level housing in 2030. In this statement, a tract of multi-family dwellings is developed to meet demand for small affordable houses at low to medium density (12-16 units per acre).

The residents are a diversity of family and non-family households. Many are comprised of members who have formed households 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 itself is basic, sited on little land, yet preserves the opportunity to expand and improve as residents change needs, save or make gains in household income.

Scenario

M a project manager with Century 22 housing company must balance the opportunity and uncertainty of an 'affordable housing enterprise zone'. The company has an option on a potentially profitable tract of suburban land in Phoenix and a large pent-up market of first time housebuyers. Other segments of the housing market are somewhat slow in the 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 living in rental housing, the city will relax economically restrictive site planning regulations and the utility will offer low interest 'energy' mortgages to offset the cost energy conserving materials and mechanical systems.

Uncertainty stems from the fact that the project depends on thin margins, volume sales and changing interest rates. Futhermore while the city is willing to relax some planning requirement, it is at the same reluctant to approve projects that will strain transportation, sewer and water resources. Evaluations and reviews of uncertain resolutions to these problems could *easily delay the project and compromise what is already a thin margin of profit and overhead.*

Design, Energy and Manufacturing Challenges:
This problem statement recognizes three difficult and potentially contradictory market forces — energy conserving design and construction, densely developed sites and low first cost.

Design challenges:

- Many heads of the entry level households of 2030 will have grown up in single family houses yet find themselves faced with multi-family alternatives. Can single family amenity be realized at multifamily density?
- Economical site planning — maximizing density while minimizing service and infrastructure requirements.
- Maintaining privacy in dense, compact houses and sites.
- Designing basic, compact houses for a diverse range of household sizes and compositions many of which require income generating uses in the house.
- Anticipating and preserving future remodel opportunities.

Energy challenges:

- Energy conserving design, materials and construction quality at low first cost.
- Passive energy conserving design strategies with spatial flexibility and amenable to owner initiated change.
- Eliminating demand at electrical utility peaks.

Manufacturing challenges:

- Economical manufacturing of cementitious panels.
- Maximizing the economic and technical opportunity of a vertically integrated housing company.
- Maximizing the economic and technical opportunity of a fully automated mass production panelizing plant.
- Components, distribution strategies, assembly standards and processes for multifamily applications and small densely packed sites.

Problem context:
The cost of housing has and will continue to rise faster than real income through the end of the century. Already the rate of home ownership is at its lowest point since the depression. Barring significant favorable change in one or more of the four main elements of housing cost — land,

financing, construction and fees — new households have little choice but indefinite deferral of homeownership.

Low and middle-income American households have experienced increasing difficulty affording a home or apartment. There is a "widening gap" between personal incomes and the costs of owning and operating housing, a situation exacerbated by inflation, tax reform, increased land use, site planning and building regulations, cutbacks in federal housing aid, and deregulation of the finance industry (Dreier & Atlas,1989: 27-28 and Goetze, 1983: 3-10)

In the 1980's, national home ownership rates declined for the first time in three decades as the real cost of housing has out-paced income. 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. 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).

Questions of affordability are, as a consequence, increasingly measured beyond direct construction costs and inclusive of a comprehensive range of direct and indirect costs. These include: 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.

The Joint Center for Housing Studies, for example, 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, 1989: 11/12: 2)

Among the several programs and policies initiated have been encouragement of innovative and economical site planning practices that increase density or integrate income generating uses with housing, and reconsideration of codes and regulations that increase the cost of site infrastructure, utilities and building materials.

The Starter House Market of 2030

The market segment likely to seek out starter houses in 2030 will likely be one comprised of small households of diverse composition and needs. On average, new households are 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 Weidermann, 1990). Other households will be less dominated by children and will be instead organized around the needs of individuals or employed couples with little time for maintenance and domestic chores.

In any of several possible scenarios, houses will be less like those to which builders are accustomed and will challenge conventional expressions of house and household. Nonfamily households and variations of family households may find the economic and social contact possible in multifamily housing desirable. There will be greater need for design flexibility to meet an increasingly diverse kinds of families, living arrangements and requirements. The single and single parent family house, layout may become organizationally more open and flexible. Houses occupied by multiple or nonfamily households may demand greater compartmentalization to meet the privacy needs of unrelated persons or places of work. Yard size demands may shrink in response to land costs and fewer children per household. Demand for low maintenance designs, materials and equipment that reduce time commitments by employed adults may increase.

It is possible, though not likely, that house size and per household energy consumption will decrease with smaller households. More likely, the sizes of houses may decline in terms of numbers of rooms, while square feet per person remains the same or increases as areas previously allocated to bedrooms etc., are dispersed or allocated to other functions.

Housing Demand in Metropolitan Phoenix

The region selected for this design problem is projected to be among the high growth centers of the country. Population growth for the West (and South) in general will be about four times the rate of the rest of the country . Of particular cities, the large metropolitan areas (cities of 1 - 5 million) of the hot South and West states have and will grow the fastest. At the end of the 1980's, the fastest growing city overall was Phoenix with an annual growth rate of 30% (U.S. Bureau of the Census, P-25 No 1039, 1989). Much of that population increase has come from immigration, a situation that creates immediate housing demand.

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. In order to meet this market, industrialized housing will evolve designs acceptable to older neighborhoods and construction strategies suited to physically constrained and scattered sites.

Multi-family houses and smaller sites will likely become more prevalent typically in low rise high density developments pattern. 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.

Affordable Site Development

Many of the innovations that will realize affordability are likely to occur at the site scale of housing design — accommodating more houses on less land with less infrastructure. Communities have supported efforts to realize affordable housing stock through review of the land development standards specified in zoning and subdivision ordinances. Standards that govern density, lot size, coverage, setbacks, street widths, sidewalks, parking and utility installation have been either relaxed or modified. Lawns and driveways become smaller; gardens occupy greater proportions of lots. The loss of supplementary open space may have to be met in cluster scale common areas and neighborhood scale parks.

When density increases while lot size decreases, land becomes subdivided and reconfigured to counteract the accompanying loss of spaciousness and visual privacy. As the density of single family housing developments approaches 12 dwelling units per acre, the boundaries between neighbors become more critical and the conventions defining those boundaries more complex (Richardson 1988: 16). Visual evidence of land ownership will become more abstract as the subdivision of land reflects the need to create private open space and apparent views in very little real space (Schnidman 1988: 4).

In spite of smaller lots and increased densities, the appearance if not the reality of the single family house will persist. Builders will seek to provide the apparent spaciousness of the suburb of 1950, at four times the density (Adler,1990: 73). Careful integration of house and land design will increasingly be fundamental to the housing design problem. House and site fit will become more complex as the norm of simple free-standing forms spatially apart from its neighbors will give way to tightly packed irregular forms more carefully fitted to the privacy and amenity opportunities of smaller irregularly shaped sites. Recent examples of houses for zero lot line, 'Z' and wide / shallow lots are illustrative cases in point where house configuration, interior planning and site planning are carefully fitted to one another.

The high cost of land will also encourage the mixing of income generating functions and commercial land uses with housing. In house businesses, mixed residential, commercial and institutional uses, accessory apartments etc. — all generate income or otherwise reduce the homeowner's share of land cost. Visual and acoustic privacy, fire safety, traffic conflicts etc. become increasingly significant design issues.

To mediate 'soft' development costs, housing suppliers will increasingly use systems that assemble quickly to minimize amount of time on site to reduce the carrying costs of the construction period. Developers will be drawn to site development and construction systems that assemble quickly and minimize site construction periods and the carrying costs of construction loans.

Affordable House Design

Starter houses will be smaller or less finished than those built today. According to a survey in Housing Economics, consumers are willing to sacrifice formal rooms of the house if space is added to less-formal rooms, for instance a large family room at the expense of the living room. (Ahluwalia, 1989: 6-9)

The house will be more compact and open. Outdoor rooms will be designed with indoor rooms, connected by large glazed openings and sliding glass doors. There will be fewer interior partitions of the house. "The unstoppable wave of informality that has engulfed domestic life will continue its assault on the interior partitions of the home, swallowing dining rooms, living rooms, kitchens and dens into a vast hassock-filled hollow."(Adler, 1990: 72)

The House as a Place of Work and Income.

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).

The schedules of workers may become more diverse as alternatives to the five day 40 hour work week 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. A work force increasingly comprised of two worker and single parent family households may 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.

Through the latter decades of the 20th century, 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 problem of distance in the provision of services, as well as 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 are less overall (Garnick, 1983).

Self-employment in general, and in information based segments of the economy in particular, has and will continue to increase, reversing a 25 year decline (Fain, 1980 and Garnick, 1983). This trend brings with it, among other implications, 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).

Technology and the home office may ease commuting constraints in housing choices. 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 may work from their houses or partly from 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.

2.1 DELIVERY SCENARIO

The housing developer, in this problem statement is a large and fully integrated 'state of the art' housing company — a combination land developing, manufacturing, contracting, marketing and sales company.

The 'Affordable House' Building Company:

Although history has demonstrated that well capitalized companies with state of the art manufacturing technology are not necessarily 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 minimize the number of independent participants in the housing delivery process, make volume purchases, concentrate expertise and streamline procedures.

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

The opportunity of this concentration is significant. Surveys of construction cost data (Trent, 1990: 4) confirm a long term decline in labor and material components and increase in land and financing components of housing cost. In 1949, for example, the national average of labor and materials costs comprised approximately 69% of the price of a new house. By 1989, this share had fallen to 53% while over the same period, the land component alone doubled from 11% to 22%.

2.2 DESIGN PROGRAM

Occupancy:

While there are several, very different alternatives residencies 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.

Design requirements:

Multifamily cluster of 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 configured in an 'open' spatial organization to work with unducted central mechanical system.

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)

1.25 off-street parking spaces / unit.

Neighborhood, site and architectural context:
The neighborhood is a suburban mix of single and multi-family dwellings. Adjacent buildings are a mixed material palette of 2 - 4 story residential, commercial and industrial structures. Public recreation and open space can be assumed immediately adjacent to the site. Public transit, commercial, recreational and some institutional services are within walking distance.

The site is a 20 acre undeveloped tract of 'marginal' land. There are no existing streets or site infrastructure. Zoning permits PUD type cluster planning and transportation system, 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.

Household income:
In 1985, median household income for homeowners in the Phoenix metropolitan area was approximately $ 27,400 (American Housing Survey: 1985). In this problem statement, household income is assumed to be between 60% and 80% of median or $ 16,500 to $ 21,900 in 1985 dollars.

Household income available to acquire and maintain a house has been estimated in Table 2.2 - 1. Mortgage terms are estimated based on a 9% housing company and utility financing. Cash requirements are assumed to be met through savings or though equity built-up in a lease / purchase agreement such as that possible through a non-profit land trust or co-operative corporation. Income and with it dollars available for housing assumed in this problem statement can increase with the addition an income generating use (household business or tenancy) incorporated in the house.

	$ / Month	%
GROSS INCOME		
Annual $ 21,900	$ 1,825.	**100.0%**
AVAILABLE FOR HOUSING	600.	**33.0%**
Taxes [$ 100]		
Insurances [$ 50]		
Energy [$ 50]		
Principal and interest	400.	
ASSUMED MORTGAGE		$ 50,000.00
($ 400 over 30 year fixed mortgage at 9 %)		
MAXIMUM PURCHASE PRICE		**$ 55,000.00**
(110% of assumed mortgage)		
CASH REQUIRED		$ 7,000.00
Down payment (10% of maximum purchase)		
Closing costs [$ 2,000]		

Table 2.2 - 1
Household Income Pro Forma (1985 $)
Extrapolated from American Housing Survey: 1985

2.3 ENERGY CONSERVATION PROGRAM

The Ford Foundation estimates that 90% of all energy conservation potential exists within space conditioning and water heating (Ford Foundation, 1974). Current and projected population concentration in the South and West has created rapid expansion of demand for central air conditioning in houses in virtually all market segments. Reducing the subsequent increased demand for space cooling energy, especially at peak periods is a prime aspect of the energy program in this problem statement.

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.

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 2.3 - 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.

Demand Context:

As a national trend, residential energy use continues to climb despite improved energy efficiency. Since 1975, the number of residences has increased 22% while per household energy use has risen 4% (U.S. Department of Energy, 1988). Forecasts indicate a decrease in the national share consumed by space heating, and rapid growth in consumption of space cooling, lighting, water heating, and other miscellaneous appliances .

	Current National Average	Anticipated change 1986 - 2010
Total demand	**100%**	**+ 40%** (total)
By end-use:		
Space Heating	54%	+ 22%
Space Cooling	5%	+ 62%
Water Heating	18%	+ 38%
Lighting /		+ 55%
Other	23%	+ 52%

Table 2.3 - 2

National Average Residential Energy Consumption by End Use

Source: U. S. Department of Energy, Energy Conservation Multi-Year Plan '90-'94, 1988 and Household Energy Consumption and Expenditures: 1987 Part 1: National Data, 1987.

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; utility underwrites construction cost of conservation measures. The company will underwrite a mortgage for durable energy conserving hardware and systems.

Passive energy conserving design strategies

The house designed from this problem statement is anticipated to emphasize passive energy conserving design strategies. Primary passive cooling strategies are evaporative cooling and thermal mass; either can address over three fourths of cooling hours. Ventilation can achieve comfort in about two fifths of cooling hours. Combinations of passive strategies can achieve comfort conditions in all but about 8% of cooling hours.

Cooling Strategies:

- Minimize solar gain.
- Promote natural ventilation in Spring and Fall
- Flatten diurnal temperature variations.
- Minimize conductive heat flow during closed building periods.
- Promote evaporative cooling.

Heating Strategies:

- Promote solar gain.
- Minimize conductive heat flow.

Design Rules of Thumb:

South facing glazing

For a house of approximately 1000 s.f. in the Phoenix area, south facing glazing should be within 20% of 13% of floor area.

Source: Brown, Sun, Wind and Light: p. 92 - 94

Thermal mass

In direct gain heating applications:

- 3 - 6 s.f. masonry of 4" minimum thickness / s.f. south facing glazing.

In night ventilating cooling applications:

- 1.5 - 3 s.f. masonry of 2" minimum thickness / s.f. floor area

Source: Brown, Sun, Wind and Light: p. 123

Solar domestic hot water

- Batch systems:
  .45 - .65 s.f. of glazing / gallon
- Flat plate collector:
  (to meet approximately 50% annual hot water demand)
  12 - 25 s.f. / person
  1 - 1.5 gallon storage / s.f. collector
  Collector angle = ° latitude or less

Source: Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Photovoltaics

- Current products:
  13% cell efficiency = 11.5 w / sf collector at peak w
- In research and development:
  30 % cell efficiency = 26.5 w / sf collector peak w
  Source: Florida Solar Energy Center

Phase changing gypsum board

- 2.0 s.f. material / s.f. floor area

Source: Florida Solar Energy Center

Additional references

Designers are further advised to consult the following references for climate responsive architectural design principles and design rules of thumb:

A.I.A. Research Corp. for U. S. Dept. of Housing and Urban Development. Regional Guidelines for Building Passive Passive Energy Conserving Homes, HUD-PDR-355. U. S. Govt Printing Office, Nov. 1978.

G. Z. Brown, Sun Wind and Light: Architectural Design Strategies, Wiley, 1985.

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Donald Watson and Kenneth Labs. Climatic Design, Energy Efficient Building Principles and Practices. McGraw Hill, 1983.

2.4 MATERIALS, COMPONENTS AND SYSTEMS PROGRAM

The construction system specified in this problem statement is a lightweight concrete panel system that can be set into or onto grade. The mechanical service system is an unducted central integrated heat pump appliance distributing and returning air through the 'open' plan of the house.

Foundation

EnerG Block interlocking plastic blocks with an integral concrete frame set on grade beams.

Envelope and structure:

Narrow (approximately 3') lightweight concrete panels with foam insulation core. Installed panels are reinforced horizontally and vertically with thermally broken precast fiber-glass reinforced concrete keys. Intermediate floors can be attached at horizontal joints.

Floors and roofs

Engineered laminated veneer lumber (LVL) box beams with 3/4" plywood sheathing of 50% biomass derived phenol-fromaldehyde resin.

Mechanical system:

Integrated service systems combine ventilation, cooling, heating and domestic hot water using storage tanks and heat pumps. This problem statement explores the opportunity of the most economical, a centrally located mechanical core, an 'open' plan air distribution system.

Electrical system:

Surface mounted lighting and electrical services. Floor and wall junction mounted multiple carrier plug-in strip of extruded temperature resistant plastic.

2.5 MANUFACTURING SCENARIO

A major long term trend is that manufacturing operations are increasingly automated (Brody, 1987; Krouse, 1987). Automation ranges from fully integrated 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 (Nag, 1986).

Automation often entails a high degree of risk (Nag, 1986). In response to these potential pitfalls of automating, most companies have adapted 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 using an increased blending 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).

The Automated Factory Manufacturing

Elements of the automated factory include:

- **Computer–aided design (CAD)** – The CAD system 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 design process with respect to design feasibility, cost and energy efficiency, generation of architectural and structural drawings and development of a bill of material which can be passed to the Manufacturing Resource Planning (MRP II) system.

- **Computer–aided process planning (CAPP)** – The CAPP system will be driven by input from 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 Resource Planning (MRP II)** – The MRP II system will be driven by input from CAPP system. MRP II features will include development of material procurement schedules and manufacturing schedules to meet customer commitments and better utilize manufacturing resources.

- **Operations control system** – The operations control system will be driven by CAPP and MRP II systems. The operations control system will be responsible for directing 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)** – The CAM system 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** – An automated material handling system will be driven by the operations control system. The system will store, move and stage materials between manufacturing workstations. Several key design features will facilitate material handling on the manufacturing floor.
  - A Just–In–Time (JIT) based manufacturing strategy will minimize the materials that are moving on the floor.
  - The manufacturing layout will support the JIT strategy and minimize material movements.

Potential alternatives include automated electrified monorail, power & free, or automated guided vehicle (AGV) for panel handling and powered conveyor or AGV for small parts handling.

2.6 EVALUATION

Submission requirements:
Each design study will include the following:

- **Design summary**
  1/8" house plan / site plan, elevations and axonometric; 1/2" construction sections; explanatory narrative and statistics (floor area etc.).

- **Construction summary**
  Summary of construction steps and procedures; inventory and evaluation of manufacturing or material innovations attempted.

- **Energy analysis**
  Summary of energy performance; inventory and evaluation of energy related innovations and principles attempted.

- **Cost analysis**
  Summary of anticipated cost allocations; inventory and evaluation of design and construction economies attempted.

- **Problem statement critique**
  Summary of problem statement ingredients for which revisions or further detail, guidance and elaboration is suggested.

Design Goals:

- **Site:**
  Orientation and siting to realize passive cooling.
  Siting and organization to minimize infrastructure requirements.
  Climate tempered private outdoor space

- **House:**
  Efficient plan suited to compact house and site
  Flexibility to accommodate privacy, in house work or rented bedroom if desired.
  Utilization of passive design strategies
  Design variation with limited parts.

- **Construction**
  Acoustic and fire separation between units.
  Construction systems 'open' to remodeling

Energy Goals:
How to realize 75% - 95% passive energy systems or conservation measures with low first cost materials, design and construction principles?

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.

This standard can be interpreted as a prescriptive standard based on the following table or as a performance standard. A performance standard can be established for particular structure by calculating total energy that would be consumed if the prescriptive standards were followed. This figure is the performance goal and specific prescriptive standard need not be followed provided this goal is met. For additional calculation detail and procedures consult Building Efficiency Standards, California Energy Commission.

ANNUAL WATER HEATING BUDGET	18700 Btu/Yr.
SPACE CONDITIONING BUDGET:	
BUILDING ENVELOPE	
Insulation Minimums [1]	
Ceiling	R 48
Walls	R 24
Slab Floor Perimeter	R 7
Raised Floor	R 24
GLAZING [2]	
Maximum U Value	0.50
Maximum Total Area	16%

SHADING COEFFICIENT [3]	
South Facing Glazing	0.27
West Facing Glazing	0.27
East Facing Glazing	0.27
North Facing Glazing	0.50
THERMAL MASS [4]	
W/ Slab Floor	25%
W/ Raised Floor	10%
INFILTRATION CONTROL	
Continuous Barrier	REQ
Air-to-Air Heat Exchanger	REQ
SPACE HEATING SYSTEM	
Gas, seasonal efficiency	72%
Central Heat Pump, ACOP	2.5
Seasonal performance factor (HSPF)	6.6
SPACE COOLING SYSTEMS [5/6]	
Air conditioner, SEER =	9.5

Figure 2.6 - 1
California Title XXIV Standards
Converted for Phoenix Climate and Increased by 25%.

Source: Converted from Building Efficiency Standards, California Energy Commission

1. R-Value for insulation is value for insulation between wood framing members. Ceiling U-Value with insulation between framing members must be equivalent to U value of insulation at specified R-Value with insulation continuous above or below framing members.
2. Assume maximum glazing area, equally distributed in each of the four cardinal orientations.
3. U- Value for glazing only, not including effects of frame. South facing glazing includes horizontal. All glazing directions include sloping glazing and vertical facing the respective direction.
4. Thermal mass may be distributed in floors, ceiling or walls; must be exposed to conditioned space. Calculate as percentage of conditioned floor area.
5. Assume cooling system is central.
6. Energy required for building cooling must be included in the design energy budget.

Economic Goal

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% (see Table 2.2-1) a house valued at approximately $ 55,000 would have met this goal in 1985.

Estimated costs of houses that use material and processes that do not yet exist are, at best, difficult to project. It is, however, possible to make a target estimation of the relative or proportional cost of particular elements within the whole project. Table 2.6 - 2 summarizes and compares average proportional cost of seven elements that comprise the total cost of delivering a house to a prospective owner. From a baseline national average site-built house of 1989, target cost of elements are developed to reflect the estimated economic impact of materials and processes defined in the problem statement as they vary from this baseline. In this example, the assumed lower direct cost of simple volumes and the unfinished or partially finished components such as the lightweight panels as well as the moderate site development costs associated with a dense reduced infrastructure project are considered.

Total project costs are targeted over the following pro forma:

	SITE BUILT HOUSE 1989 AVERAGE %	**STARTER HOUSE** 2030 TARGET
SALES COST	100.0 %	
DIRECT COSTS Construction labor, materials, equipment and subcontracts.	50.0%	less 10%
FINISHED LOT COSTS Acquisition, infrastructure and area / yard work.	25.0%	less 10%
INDIRECT COSTS Production supervision, field labor, field expenses.	4.0%	less 1%
OVERHEAD Wages and salaries, insurance and offices.	4.0%	less 1%
MARKETING Salaries, commissions and sales expenses.	5.0%	less 1%
FINANCING	5.0%	less 1%
NET INCOME (before taxes)	7.0%	less 1%

Table 2.6 - 2

Project Cost Pro Forma

Sources: Site Built 1989 Average%'s is a national average derived from NAHB '1989 Single Family Builder Profit and Loss Study' and Hallahan Associates. Starter House Target by CHI.

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PROBLEM STATEMENT FOR THE 21st CENTURY HOUSE

MOVE - UP HOUSE IN A HOT-HUMID CLIMATE

SYNOPSIS

TYPE:	New single family house.
AREA:	2000 sf
DENSITY:	6 - 10 units per acre
CONTEXT:	Planned cluster development. Miami, FL.
CONSTRUCTION:	Modular.
MATERIALS:	Engineered reconstituted wood and laminated veneer lumber with metal connections and tensile elements. Wood and gypsum composite interior partitions.
SERVICE SYSTEMS:	Central heat pump. Small diameter plastic pipe and variable air volume distribution system.
ECONOMIC GOAL:	Affordable at 200% median household income.
ENERGY GOAL:	25% improvement over California Title XXIV Code. Zero net electrical use. No peak demand.
INNOVATIONS TESTED:	**Energy** High efficiency heating and cooling core maintained by local utility. Zoned miniature VAV distribution system. Phase changing interior finishes. Dessicant bed dehumidification. Photovoltaic electricity generation. **Manufacturing** Flexible custom design, fittings and fixture capability. Integrated manual and automated production processes. Factory installed air distribution system.

3.0 PROBLEM STATEMENT FOR A 'MOVE-UP' HOUSE IN A HOT-HUMID CLIMATE

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Introduction

The 'Move-up House' design problem explores energy conservation opportunities in joint venture projects of a custom quality industrialized builder and a local utility. In this scenario, the house is an upper middle end of market segment single family dwelling in a planned unit neighborhood of low density (6-10 units per acre).

The residents are a family of four. The parents are about to enter semi-retired 'empty-nest' years that will include a decline in household income and expenses. They have owned several houses previously and are moving down in size but up in quality. The house itself is average size and sited on a small but well designed and maintained site.

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 contibuted to a steady increase in the S's discretionary income. A circumstance that 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 desireable 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.*

Design, Energy and Manufacturing Challenges:

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 of design, engineering, components integration and quality possible with a 'state of the art' housing design and manufacturing factory.

Design challenge:

- Integrating low maintenance, low operating cost energy conservation features with a 'custom' designed house of above average but value conscious budget.
- Reconciling thermal zoning and energy conserving envelope with occupancy requirements.

Energy challenge:

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

Manufacturing challenge:

- High quality construction and finish standards.
- Factory integration of high performance mechanical services.

Problem context

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 of older households 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 desireable 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 in the Sunbelt attributable to cooling. Faced with long term management of a difficult power planning future and short term management of peak loads, some Sunbelt utilities have agressively pursued incentive programs.

3.1 DELIVERY SCENARIO

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.

The Custom Housing Industries Company

Custom Housing Industries (CHI) is a regional company that does not manufacture 'whole' houses. The company is a subsidiary of a large private utility. It 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 pre-serviced modular shells marketed to other builders. The remaining half is a design and build market operated from storefronts in high growth areas of the region.

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

In this market, they have recently initiated several joint venture projects with the utility parent company 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 'state of the art' network of site service systems and space conditioning appliances. These systems are designed not only to reduce demand but also generate energy, returning electricity and 'cool' to the utility for redistribution.

3.2 DESIGN PROGRAM

Occupancy:

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

Design requirements:

2,000 sf two storey 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 desireable lot with approximately 20 houses proposed. Zoning permits PUD type cluster planning and circulation system, as well as site scale solutions to waste, utilities and services.

Household income:

In 1986, median household income for homeowners in the Miami metropolitan area was approximately $ 26,000 (American Housing Survey: 1986). In this problem statement, household income is assumed at approximately 200% of median or $ 52,000 in 1986. Income available to acquire and maintain a house has been estimated in Figure 3.2 - 1. It should be noted that in the occupant scenario, household income will decline with retirement within ten years as will household expenditures in support of college age children. Mortgage terms are estimated based on a 30 year mortgage at 11%. Cash requirements are assumed to be met through savings and equity built-up in previous houses.

	$ / Month	**%**
GROSS INCOME Annual $ 52,000	$ 4,300.	**100.0%**
AVAIL. FOR HOUSING	$ 1, 085.	**25.0%**
Taxes		
Insurance		
Energy		
Principal and interest	800.	
ASSUMED MORTGAGE ($ 800 over 30 year fixed mortgage at 11 %)		$ 85,000.00
MAXIMUM PURCHASE PRICE (130% of assumable mortgage)		**$ 110,000.00**
CASH REQUIRED Down payment (30%)		$ 25,000.00

Table 3.2 - 1
Household Income Pro Forma (1986 $)
Extrapolated from American Housing Survey: 1986

3.3 ENERGY CONSERVATION PROGRAM

The Ford Foundation estimated that 90% of all energy conservation potential exists within space conditioning and water heating (Ford, 1974). Current and projected population concentration in the South and West has created rapid expansion of demand for central air conditioning in houses in virtually all market segments. Reducing the subsequent increased demand for space cooling energy, especially at peak periods is a prime aspect of the energy program in this problem statement.

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 generally 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 a quarter of the time and uncomfortable due to humidity alone about half of the time.

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 3.3 - 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.

Demand Context:
As a national trend, residential energy use continues to climb despite improved energy efficiency. Since 1975, the number of residences has increased 22% while per household energy use has risen

4% (U.S. Department of Energy). Forecasts indicate a decrease in the national share consumed by space heating, and rapid growth in consumption of space cooling, lighting, water heating, and other miscellaneous appliances.

	Current National Average	Anticipated change 1986 - 2010
Total demand	**100%**	+ **40%** (total)
By end-use:		
Space Heating	54%	+ 22%
Space Cooling	5%	+ 62%
Water Heating	18%	+ 38%
Lighting /		+ 55%
Other	23%	+ 52%

Table 3.3 - 2

National Average Residential Energy Consumption by End Use

Source: U. S. Department of Energy, Energy Conservation Multi-Year Plan '90-'94, 1988 and Household Energy Consumption and Expenditures: 1987 Part 1: National Data, 1987.

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 system of electricity 'buy-back'.

Passive energy conserving design strategies

Shading is required most of the year. Primary passive cooling strategies are ventilation, dehumidification, or 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.

Cooling Strategies

- Minimize solar gain.
- Promote natural ventilation
- Avoid creating additional humidity.
- Minimize conductive heat flow during closed building periods.

Heating Strategies

- Promote solar gain.
- Minimize conductive heat flow.

Design Rules of Thumb

South facing glazing

For a house of approximately 1000 s.f. in the Miami area, south facing glazing should be within 20% of 5.4% of floor area.

Source: Brown, Sun, Wind and Light; p. 92 - 94

Thermal mass

In direct gain heating applications:

- 3 - 6 s.f. masonry of 4" minimum thickness / s.f. south facing glazing.

In night ventilating cooling applications:

- 1.5 - 3 s.f. masonry of 2" minimum thickness / s.f. floor area

Source: Brown, Sun, Wind and Light; p. 123

Solar domestic hot water

- Batch systems:
  .45 - .65 s.f. of glazing / gallon
- Flat plate collector:
  (to meet approximately 50% annual hot water demand)
  12 - 25 s.f. / person
  1 - 1.5 gallon storage / s.f. collector
  Collector angle = ° latitude or less

Source: Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Photovoltaics

- Current products:
  13% cell efficiency = 11.5 w / sf collector at peak w
- In research and development:
  30 % cell efficiency = 26.5 w / sf collector peak w

Source: Florida Solar Energy Center

Dessicant bed dehumidification

- .3 s.f Grade 40 silica gel dessicant / s. f. floor area

Source: Florida Solar Energy Center

Phase changing gypsum board

- 2.0 s.f. material / s.f. floor area

Source: Florida Solar Energy Center

Additional references

Designers are further advised to consult the following references for climate responsive architectural design principles and design rules of thumb:

A.I.A. Research Corp. for U. S. Dept. of Housing and Urban Development. Regional Guidelines for Building Passive Passive Energy Conserving Homes, HUD-PDR-355. U. S. Govt Printing Office, Nov. 1978.

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3.4 MATERIALS, COMPONENTS AND SYSTEMS PROGRAM

The construction system specified in this problem statement is a modular wood and composite wood frame. The mechanical service system is a central mechanical core using a concealed small diameter pipe distribution system with variable air volume control dampers.

Foundation

Treated wood foundation wall panels.

Envelope and structure:

Engineered modules of reconstituted wood and laminated veneer lumber (LVL) frame with metal connectors that expedite site alignment and tuning of structure. Frame is sheathed with extruded wood-fiber concrete panels on the exterior and wood fiber gypsum panels on the interior. Machine cut insulation is set in between framing members.

Mechanical system:

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 electonic ballast electrodeless HID lighting is mounted on walls and reflected.

3.5 MANUFACTURING SCENARIO

In this scenario of 'instant' housing demand precipitated by rapid growth, the 'non-material' or soft costs of housing and manufacturing (interest rates, labor etc.) escalate faster than others. Housing developers must initiate and complete projects under substantial time pressure and respond quickly and effectively to change in the market, in particular the unique needs and interests of their diverse clientele.

The following manufacturing scenario explores the consequences and opportunties of the continued evolution from a narrow, standard product line to a directly market and customer motivated range of choice and flexibility. Aspects of this evolution include a flexible and high-quality manufacturing plants based on networked computerized design and production tools, integrated systems of machine tools which manufacture parts with the flexibility to build a family of products, install a range of options (and alternates that may come from another source) and efficiently adjust production levels.

The houses produced will experiment with materials, components and modules that support this level of manufacturing and take advantage of the significant levels of sub-system (mechanical, electrical, control systems, appliances, finishes etc) sophistication and integration possible with a skilled work force using sophisticated tools in the controlled environment of a factory.

Modular Automated Manufacturing

Manufacturing operations are increasingly automated (Brody, 1987; Krouse, 1987). Automation ranges from fully integrated 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 (Nag, 1986). Automation often entails a high degree of risk (Nag, 1986). In response, most companies have adapted a more pragmatic approach, automating procedures incrementally, only where it makes the most sense, given the associated complexity, cost and risk factors involved (Cullinane, 1989). Termed modular automation, it focuses on automating in controlled, manageable phases (instead of the full blown automated factory). Using this strategy, most manufacturers are using an increased blending of automation, mechanization and manual techniques.

World Class Manufacturing Facility

This manufacturer will focus on the fundamentals of manufacturing, embracing key components of proven manufacturing strategies such as total quality, continuous flow manufacturing, design for manufacturing and assembly, flexible manufacturing, etc. Improvement will focus on human resources in conjunction with technology, equipment and systems. Operators will be well–trained and will assume significant responsibilities for generating continuous improvements in quality and efficiency.

Key features of the scenario include:

- Quality improvements – resulting from a total organizational commitment to quality:
  - From design through manufacturing
  - From upper management to operator
  - From vendor to manufacturer
- Quality improvement efforts will be extensive, with justification based on the to cost of quality, not on the narrow, immediate consequences.

- Lower labor cost – although direct labor may not decrease significantly (compar to the automated scenario), indirect labor such as incoming inspection, stockroom personnel, material control and material handling will decrease drastically as a result of continuous flow manufacturing / just – in – time efforts.
- Lower inventory levels – driven by continuous flow manufacturing / just–in–time efforts, both at the vendors and within the factory.
- Shorter lead time – resulting from the continuous flow manufacturing / just–in–time efforts to reduce work–in–process inventory levels.
- Greater manufacturing flexibility – accommodating design variations over a limited range.
  – Flexibility to manufacture products outside of the target range. Automation typically limits this flexibility.
  – Flexibility to efficiently expand or contract production levels.
  – Flexibility to retrofit the operation, process and/or facility should the need arise.
- Much lower capital requirement than the automated scenario – an increased capability to cut costs during market downturns.

Automated Components

Computer–aided design (CAD)

The CAD system 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 material which can be passed to the Manufacturing Resource Planning (MRP II) system.

Computer–aided process planning (CAPP)

The CAPP system will be driven by input from 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 Resource Planning (MRP II)

The MRP II system will be driven by input from CAPP system. MRP II features will include development of material procurement schedules and manufacturing schedules to meet customer commitments and better utilize manufacturing resources.

Operations control system

The operations control system will be driven by CAPP and MRP II systems. The operations control system will be responsible for directing 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.

Selected computer–aided manufacturing (CAM)

Potential applications include:

Material handling – The automated material handling system will be driven by the operations control system. The system will store, move and stage materials between manufacturing workstations. Several key design features will facilitate material handling on the manufacturing floor.

- A Just–In–Time (JIT) based manufacturing strategy will minimize the materials that are moving on the floor.
- The manufacturing layout will support the JIT strategy and will minimize material movements

3.6 EVALUATION

Submission requirements:

Each design study will include the following:

- **Design summary:**
  1/8" house plan / site plan, elevations and axonometric; 1/2" construction sections; explanatory narrative and statistics (floor area etc.).

- **Construction summary:**
  Summary of construction steps and procedures; inventory and evaluation of manufacturing or material innovations attempted.

- **Energy analysis:**
  Summary of energy performance; inventory and evaluation of energy related innovations and principles attempted.

- **Cost analysis:**
  summary of anticipated cost allocations; inventory and evaluation of design and construction economies attempted.

- **Problem statement critique:**
  Summary of problem definition statement ingredients for which revisions or further guidance and elaboration is suggested.

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.

- **Construction:**
  Integration of miniature electronic and mechanical systems in shell.

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.

This standard can be interpreted as a prescriptive standard based on the following table or as a performance standard. A performance standard can be established for particular structure by calculating total energy that would be consumed if the prescriptive standards were followed. This figure is the performance goal and specific prescriptive standard need not be followed provided this goal is met. For additional calculation detail and procedures consult Building Efficiency Standards, California Energy Commission.

ANNUAL WATER HEATING BUDGET	20900 Btu / Yr.
SPACE CONDITIONING BUDGET	
BUILDING ENVELOPE	
Insulation Minimums [1]	
Ceiling	R 48
Walls	R 24
Slab Floor Perimeter	R-7
Raised Floor	R 24
GLAZING [2]	
Maximum U Value	0.50
Maximum Total Area	16%
SHADING COEFFICIENT [3]	
South Facing Glazing	0.27
West Facing Glazing	0.27
East Facing Glazing	0.27
North Facing Glazing	0.50
THERMAL MASS [4]	
W/ Slab Floor	25%
W/ Raised Floor	10%
INFILTRATION CONTROL	
Continuous Barrier	REQ
Air-to-Air Heat exchanger Req.	REQ
SPACE HEATING SYSTEM	
Gas, seasonal efficiency	72%
Central Heat Pump, ACOP	2.5
Seasonal performance factor (HSPF)	6.6
SPACE COOLING SYSTEMS [5/6]	
Air conditioner, SEER =	9.5

Table 3.6 - 1
California Title XXIV Standards
Converted for Miami Climate and Increased 25%

Source: Converted from Building Energy Efficiency Standards, California Energy Commission

1. R-Value for insulation is value for insulation between wood framing members. Ceiling U-Value with insulation between framing members must be equivalent to U value of insulation at specified R-Value with insulation continuous above or below framing members.
2. Assume maximum glazing area, equally distributed in each of the four cardinal orientations.

3. U- Value for glazing only, not including effects of frame. South facing glazing includes horizontal. All glazing directions include sloping glazing and vertical facing the respective direction.
4. Thermal mass may be distributed in floors, ceiling or walls; must be exposed to conditioned space. Calculate as percentage of conditioned floor area.
5. Assume cooling system is central.
6. Energy required for building cooling must be included in the design energy budget.

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% (see Table 3.2 - 1) a house valued at approximately $110,000 would have met this goal in 1986.

Estimated costs of material and processes that do not yet exist are, at best, difficult to project. It is however possible to make a target estimation of the relative or proportional cost of particular elements within the whole project. Table 3.6 - 2 summarizes and compares average proportional cost of seven elements that comprise the total cost of delivering a house to a prospective owner. From a national average baseline site-built house of 1989, target cost of elements are developed to reflect the estimated economic impact of materials and processes defined in the problem statement as they vary from this baseline. In this example, the cost of custom design, systems integration in envelope and construction quality are considered.

Completed project costs are projected over the following pro forma:

	SITE BUILT HOUSE 1989 AVERAGE %	MOVE-UP HOUSE 2030 TARGET
SALES COST	100.0 %	
DIRECT COSTS Construction labor, materials, equipment and subcontracts.	50.0%	plus 5%
FINISHED LOT COSTS Acquisition, infrastructure and area / yard work.	25.0%	reduce 5%
INDIRECT COSTS Production supervision, field labor, field expenses.	4.0%	reduce 1%
OVERHEAD Wages and salaries, insurance and offices.	4.0%	reduce 1%
MARKETING Salaries, commissions and sales expenses.	5.0%	
FINANCING	5.0%	reduce 1%
NET INCOME (before taxes)	7.0%	

Table 3.6 - 2

Project Cost Pro Forma

Sources: Site Built 1989 Average %'s derived from NAHB '1989 Single Family Builder Profit and Loss Study' and Hallahan Associates. Move-up House Target by CHI.

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PROBLEM STATEMENT FOR THE 21st CENTURY HOUSE

RENEWABLE HOUSE IN A TEMPERATE CLIMATE

SYNOPSIS

TYPE:	Remodel and addition to wood frame single family house.
AREA:	1300 sf existing house; 500 - 600 sf addition
DENSITY:	Existing neighborhood of approximately 16 units per acre.
CONTEXT:	Urban neighborhood. Seattle, WA
CONSTRUCTION:	Panelized frame.
MATERIALS:	'Do-it-yourself' recyclable wood composites and by-products.
SERVICE SYSTEMS:	Zoned heat pump system.
ECONOMIC GOAL:	Affordable at median household income for central city.
ENERGY GOAL:	Upgrade existing house. New construction 25% more efficient than California Title XXIV energy code. No mechanical cooling
INNOVATIONS TESTED:	**Energy** Energy conserving specialties for renovation construction: Insulating finishes. Thermally broken framing. Retrofit window integrated heat pump. **Manufacturing** Specialized energy conserving systems and materials integrated with construction components suited to remodel. Manufactured building products and assembly systems for 'Do-it-yourself' applications. Manufacturing with renewable, low toxicity wood products.

4.0 PROBLEM STATEMENT FOR A RENEWABLE HOUSE IN A TEMPERATE CLIMATE

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Introduction

The 'Renewable House' problem statement explores opportunities to improve the energy conservation standards of older houses as they are remodeled and expanded by their owners. 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.

Scenario

"This house is simply too valuable to tear down" is a familiar comment among the owners of well constructed wood-frame houses of mature urban neighborhoods of the Pacific Northwest. The land on which they are built is well located extraordinarily valuable. 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.*

Design, Energy and Manufacturing Challenges:

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 challenges:

- Design and construction integration of new with existing components of dissimilar form and construction technology.
- Do-it-yourself design and construction processes must be simple and enable persons unskilled in design or construction to build and be adequately informed to control basic design decisions.
- Construction processes that are 'transparent', their sequences of steps and decisions easily understood by persons without specialized knowledge or experience.

Energy challenges:

- Development of 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.

Manufacturing challenges:

- An 'open' easily understood system of parts coordinated in modular dimensions yet manufactured by several sources.
- Integration of specialized energy conserving products with conventional materials.
- Efficient closed panel fabrication with renewable, low toxicity wood materials.
- Construction technology accessible to the skills and physical capability of one or two persons with basic tools and skills.
- Development of joining and installation procedures that are 'reversible' so that installers can tentatively attempt any step, confirm that it is desirable and correct and then change or complete it.
- Development of surface integrated electrical distribution option with closed panel manufacturing.

Problem context:

The renovation and repair of existing buildings is a significant and potentially dominant component of the energy efficient industrialized housing future. The proportion of residential energy consumption attributable to existing buildings alone makes a compelling argument.

The rate of housing stock replacement suggests that, over the short and medium term, improvement of existing houses will realize 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 net conservation of roughly 0.5% (or less) of residential energy use at the year 2000 (20% energy savings in 2.5% of all houses).

The Remodel Market of 2030

With rapidly rising land and financing costs, renovation and remodel of existing houses will more frequently become a housing alternative of choice for households that might have previously 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, limited only by 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 manufacture '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. The illustrative examples of modular kitchen cabinets and flexible, quick connect plumbing components are cases in point.

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

Environment and housing

Knowledge that current resources and energy sources are finite is becoming widely known and accepted. Public opinion polls show that Americans are deeply concerned about environmental issues, recognize the strong links between environmental quality and energy production, and favor energy efficiency by substantial margins. (Carlsmith et al., 1989: 28-29).

Global warming, clean air, acid rain, protection of forests, nuclear waste disposal — 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. The poll also shows that half of the public would rather use energy more efficiently than produce more energy (Rader,1989: 1-5).

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).

Global warming

"Scientists now expect 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 15,000 years." The most worrisome compounds are released from coal, oil, and natural gas (Postal, 1986: 5).

Although there continues to be significant scientific uncertainty over the magnitude of climate change from a given increase in greenhouse gases, there is a scientific consensus that increased levels of greenhouse gases will cause a change in climate. The two greenhouse gases of importance in the buildings sector are carbon dioxide (CO_2) and chlorofluorocarbons (CFCs) (Norberg-Bohm, 1990: 1).

The buildings sector, which encompasses residential and commercial energy use, currently generates about 25% to 30% of global CO_2 emissions (Norberg-Bohm, 1990: iv). In 1985, the direct burning of fossil fuels in the buildings sector accounted for 14% of the global anthropogenic emissions of CO_2. The buildings sector is responsible for over half of the 23% of emissions attributable to electricity generation (Norberg-Bohm, 1990: 1-2).

The U.S. National Aeronautics and Space Administration 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 causes 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).

Clean Air

Roughly 150 million people live in areas whose air is considered unhealthy by the EPA. The major air pollutant used to be coal, discharging almost twice the carbon per BTU as natural gas but the primary sources now are automobiles and industries (French, 1990: 27) and sulfur which for every two tons of sulfur dioxide emitted adds one ton of sulfur to the air (Postal, 1986, p.5)

Policy has been influential in cutting sulfur oxides emissions by 28% between 1970 and 1987 and particulates by 62 %. To continue to address air pollution, energy, transportation, and industry, policy structures must be reoriented toward prevention. 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: 28-31)

Motor vehicles are already responsible for nearly 20 percent of global carbon dioxide emissions from fossil fuels. In 1987, gasoline-powered vehicles added 739 million tons of carbon to the atmosphere. Diesel added another 300 to 350 million tons. Each year, 45 million new vehicles take to the world's roads. The cars average 30 mpg, far below the 60 - 100 mpg prototype vehicles auto companies have so far been unwilling to produce in quantity. Public policy in certain cities has sought to reduce automobile produced pollutants in the air. The city of Toronto, for example, has committed to reducing emissions 20 percent by 2005 while Los Angeles plans to have 10,000 electric vehicles in operation by 1995 (Lenssen, 1990: 22 - 24).

Indoor air quality.

Inside buildings, the increasing air tightness and reduced rates of infiltration and air change that accompany energy conserving construction practices has precipitated recent investigations of the scope and severity of indoor air pollution. The problem is only recently the focus of rigorous scientific and engineering scrutiny and testing.

The sources of indoor air pollution are diverse, including such widely varying situations as the incomplete exhaustion of combustion gases from furnaces, the accumulation of off-gassing products from finishes and building materials in poorly ventilated spaces, mold growth following moisture intrusion as well as the intrusion and concentration of exterior pollutants such as radon (Small, 1985: 4-5).

Although no legislated standards yet exist to define acceptable indoor air quality levels, conditions in some houses are sufficiently dangerous that residents have become ill (Robinson, 1984) considerable design and engineering attention has focused on developing design and construction methods to reduce and control indoor air pollution.

Protection of forests

The harvest of old growth forests that have traditionally supplied lumber and wood products to the residential construction industry is likely to be restricted in the future. The reasons are several instigated by a variety of ecological, political and technological purposes. Among them are preservation of wildlife habitats, restriction of timber export, control of global warming and emerging medical and scientific interest in various forest species. The resulting restriction of forestry practices will affect both the quantity and quality of timber cut from federal land. This in turn will affect the quantity and quality of timber stock for construction well into the next century.

Second and third growth forests of smaller faster growing species will likely become the norm. The trees available for harvest will likely be softwood, shorter, of less diameter, lower quality and lower strength. Wood products in general will likely become progressively more expensive. Heavy timber construction will likely be rare and of prohibitive cost for other than specialized building types. An unprecedented range of engineered wood products, composites, reconstituted and / or reprocessed wood products are likely to emerge as substitutes for dimensional lumber in residential construction.

Nuclear power

Nuclear proponents claim that under normal operation, nuclear plants are environmentally clean (Balzhiser, 1990: 184). Others argue that nuclear power produces up to four times more carbon dioxide (CO_2) than equivalent electricity production by renewable energy options when energy used in mining and preparing uranium fuel is considered. (Rader, 1989: 1-4).

Recognizing the environmental problems of nuclear disposal, Sweden has made the decision to phase out all nuclear power generation by 2010. This forces them to concentrate on a substantial restructuring of Sweden's energy supply system. 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 (Rader, 1989: 1 - 4).

4.1 DELIVERY SCENARIO

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 safie, low toxicity, renewable systems and materials.

The 'Green' House Store.

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.

4.2 DESIGN PROGRAM

Occupancy:

While there are several, very different 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.

Design 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 to 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 rowhouses 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.

Household income:
In 1987, the median household income for owners of recently constructed houses in the Seattle metropolitan area was approximately $ 47,250, and $ 37,550 for all owner occupied houses (American Housing Survey: 1987). In this problem statement, household income is assumed to be at median for new construction, equivalent to approximately $50,000 in 1987.

Household income available to to acquire and maintain a house has been estimated in Table 4.2 - 1. Mortgage terms are estimated based on a thirty year fixed term at 11%. Cash requirements are assumed to be met through savings among the members of the partnership.

	$ / Month	%
GROSS INCOME Annual $ 50,000	$ 4,200	**100.0%**
MAX. AVAILABLE FOR HOUSING Taxes [85] Insurances [22] Utilities [130] Principal and interest [1,100]	$ 1,380	33.0%
ASSUMED MORTGAGE ($ 1,100.00 over 30 year fixed mortgage at 11 %)		$ 120,000.00
MAXIMUM PURCHASE PRICE (120% of assumable mortgage)		**$ 144,000.00**
CASH REQUIRED Down payment (20%)		$ 24,000.00

Table 4.2 - 1
Household Income Pro Forma (1987 $)
Extrapolated from: American Housing Survey 1987

4.3 ENERGY CONSERVATION PROGRAM

The Ford Foundation estimates that 90% of all energy conservation potential exists within space conditioning and water heating (Ford Foundation, 1974). The Seattle area experiences energy demand for both heating and cooling that could be met with conservation and passive means.

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 4.3 - 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.

Demand Context:
As a national trend, residential energy use continues to climb despite improved energy efficiency. Since 1975, the number of residences has increased 22% while per household energy use has risen 4% (U.S. Department of Energy, 1988). Forecasts indicate a decrease in the national share consumed by space heating, and rapid growth in consumption of space cooling, lighting, water heating, and other miscellaneous appliances .

	Current National Average	Anticipated change 1986 - 2010
Total demand	**100%**	**+ 40%** (total)
By end-use:		
Space Heating	54%	+ 22%
Space Cooling	5%	+ 62%
Water Heating	18%	+ 38%
Lighting /		+ 55%
Other	23%	+ 52%

Table 4.3 - 2
National Average Residential Energy Consumption by End Use
Source: U. S. Department of Energy, Energy Conservation Multi-Year Plan '90-'94, 1988 and Household Energy Consumption and Expenditures: 1987 Part 1: National Data, 1987

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)

Passive energy conserving design strategies

Heating strategies:

- Promote solar gain.
- Minimize conductive heat flow.
- Protect from cold winter winds.
- Minimize infiltration

Design Rules of Thumb:

South facing glazing

For a house of approximately 1000 s.f. in the Seattle area, south facing glazing should be within 20% of 7.3% of floor area.

Source: Brown, Sun, Wind and Light: p. 92 - 94

Thermal mass

In direct gain heating applications:

- 3 - 6 s.f. masonry of 4" minimum thickness / s.f. south facing glazing.

In night ventilating cooling applications:

- 1.5 - 3 s.f. masonry of 2" minimum thickness / s.f. floor area

Source: Brown, Sun, Wind and Light: p. 123

Solar domestic hot water

- Batch systems:
  .45 - .65 s.f. of glazing / gallon
- Flat plate collector:
  (to meet approximately 50% annual hot water demand)
  12 - 25 s.f. / person
  1 - 1.5 gallon storage / s.f. collector
  Collector angle = ° latitude or less

Source: Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Photovoltaics

- Current products:
  13% cell efficiency = 11.5 w / sf collector at peak w
- In research and development:
  30 % cell efficiency = 26.5 w / sf collector peak w

Source: Florida Solar Energy Center

Additional references

Designers are further advised to consult the following references for climate responsive architectural design principles and design rules of thumb:

A.I.A. Research Corp. for U. S. Dept. of Housing and Urban Development. Regional Guidelines for Building Passive Passive Energy Conserving Homes. HUD-PDR-355. U. S. Govt Printing Office, Nov. 1978.

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Edward Mazria. The Passive Solar Energy Book, Expanded Professional Edition. Rodale Press, 1979.

V. Olgyay, Design With Climate: Bioclimatic Approach to Architectural Regionalism, Princeton University Press, 1963.

Donald Watson and Kenneth Labs. Climatic Design, Energy Efficient Building Principles and Practices, McGraw Hill, 1983.

4.4 MATERIALS, COMPONENTS AND SYSTEMS PROGRAM

The construction system specified in this problem statement is a closed panel system of renewable wood products. The mechanical service system specified employs a dispersed network of heat pumps installed in window apertures.

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

Foundation
Treated wood panel foundation walls.

Envelope and structure:
Closed panel of low toxicity, renewable wood and wood by-products including pressed and formed wood fiber cladding and sheathing board; composite I-section optimized for factory manufacturing processes; and interior sheathing of wood fiber gypsum board.

Mechanical system:
Zoned heat pump system of several dispersed units installed in window apertures. Each element of the system can function as an independent 'stand-alone' unit or be networked with a constant-temperature heat sink / source water line connected to 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 or into a crawl space or basement.

4.5 MANUFACTURING SCENARIO

Associated with market oriented product lines is the need for increased flexibility in manufacturing (Seal, 1989; Tompkins, 1989). Flexibility may take several forms:

- Flexibility to manufacture a family of products with high quality and cost efficiency.
- 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 by cutting back options and installing hard automation.

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.

Although the strict application of FMS probably does not apply to industrialized housing, a more generic definition of FMS is certainly applicable. Key features would include:

- Flexibility to build a family of products
- Flexibility to install (or not install) a range of options.
- Flexibility to efficiently expand or contract production levels.
- Flexibility to retrofit the operation/process and/or the facility should the need arise.

'Outsourced' Manufacturing Scenario

Manufacturers will outsource more components / services at higher levels, thereby reducing their level of vertical integration. Components will be outsourced when they can be procured at a lower cost and/or higher quality than they can be manufactured. An example of this strategy is the auto industry, where major manufacturers have outsourced 70% of the content.

In housing manufacturing, outsourcing results in a factory shell–site finish integrated manufacturing and construction scenario. In this scenario, a factory or factories perform all operations up to the level of assembly which maximizes profitability (sales price – manufacturing cost). Manufacturing costs will include materials, labor, equipment, facilities, etc.

Key housing components will be manufactured in "focused" factories, dedicated to manufacturing a narrow line of components. The focused factories will manufacture components of higher quality and at a lower cost than large, vertically integrated manufacturers.

The focused factory concept will encourage capital investment since it can be amortized over higher production levels and since total capital for any manufacturer will be kept low, thus, reducing vulnerability during market downturns.

House components will be sold to a customer, in this problem statement a project manager, at this assembly level and the customer will co-ordinate erection of the house on–site. Since there will be multiple suppliers supplying the same component to multiple manufacturers, a standardized system of interchangeable, compatible parts will be a prerequisite for success.

Industrialized housing assembly plants of this scenario will be simpler than the current large, vertically integrated manufacturing facilities. They will be downsized with respect to facilities, equipment, materials, personnel, etc. They will need to be more flexible to accommodate relative changes in manufacturing cost, sales price, customer acceptance or regulation.

5.6 EVALUATION

Submission requirements:

Each design study will include the following:

- **Design summary:**
  1/8" house plan / site plan, elevations and axonometric; 1/2" construction sections; explanatory narrative and statistics (floor area etc.).

- **Construction summary:**
  Summary of construction steps and procedures; inventory and evaluation of manufacturing or material innovations attempted.

- **Energy conservation analysis:**
  Summary of energy performance; inventory and evaluation of energy related innovations and principles attempted.

- **Cost analysis:**
  Summary of anticipated cost allocations; inventory and evaluation of design and construction economies attempted.

- **Problem statement critique:**
  Summary of problem statement ingredients for which revisions or further guidance and elaborations are suggested.

Design Goals:

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

- **House:**
  Utilization of passive design strategies
  Stylistic variation with limited parts.

- **Construction:**
  Integration of industrialized with existing wood frame construction
  Adaptation of 'do-it-yourself' capability and 'after market' energy conserving products and materials to industrialized construction.

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.

This standard can be interpreted as a prescriptive standard based on the following table or as a performance standard. A performance standard can be established for particular structure by calculating total energy that would be consumed if the prescriptive standards were followed. This figure is the performance goal and specific prescriptive standard need not be followed provided this goal is met. For additional calculation detail and procedures consult Building Efficiency Standards, California Energy Commission.

ANNUAL WATER HEATING BUDGET	20800 Btu / Yr.
SPACE CONDITIONING BUDGET	
BUILDING ENVELOPE	
Insulation Minimums [1]	
Ceiling	R 38
Walls	R 14
Slab Floor Perimeter	R 7
Raised Floor	R 24
GLAZING [2]	
Maximum U Value	0.50
Maximum Total Area	16%
SHADING COEFFICIENT [3]	
South Facing Glazing	0.50
West Facing Glazing	0.50
East Facing Glazing	0.50
North Facing Glazing	0.50
THERMAL MASS [4]	
W/ Slab Floor	25%
W/ Raised Floor	10%
INFILTRATION CONTROL	
Continuous Barrier	REQ
Air-to-Air Heat exchanger	REQ
SPACE HEATING SYSTEM	
Gas,seasonal efficiency	72%
Central Heat Pump, ACOP	2.5
Seasonal performance factor (HSPF)	6.6

SPACE COOLING SYSTEMS [5/6]

Air conditioner, SEER =	8.9

Table 4.6 - 1
California Title XXIV Standards
Converted for Seattle Climate and Increased by 25%.
Source: Converted from Building Efficiency Standards, California Energy Commission

1. R-Value for insulation is value for insulation between wood framing members. Ceiling U-Value with insulation between framing members must be equivalent to U value of insulation at specified R-Value with insulation continuous above or below framing members.
2. Assume maximum glazing area, equally distributed in each of the four cardinal orientations.
3. U- Value for glazing only, not including effects of frame. South facing glazing includes horizontal. All glazing directions include sloping glazing and vertical facing the respective direction.
4. Thermal mass may be distributed in floors, ceiling or walls; must be exposed to conditioned space. Calculate as percentage of conditioned floor area.
5. Assume cooling system is central.
6. Energy required for building cooling must be included in the design energy budget.

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% (see Table 4.2-1) a house sold at approximately $ 120,000 would have met this goal in 1987.

Estimated costs of houses that use material and processes that do not yet exist are, at best, difficult to project. It is, however, possible to make a target estimation of the relative or proportional cost of particular elements within the whole project. Table 4.6 - 2 summarizes and compares average proportional cost of seven elements that comprise the total cost of delivering a house to a prospective owner. From a national average baseline site-built house of 1989, target cost of elements are developed to reflect the estimated economic impact of materials and processes defined in the problem statement as they vary from this baseline. In this problem statement the value of owner supplied labor, management and construction financing has been considered.

Completed project costs are projected over the following pro forma:

	SITE BUILT HOUSE 1989 AVERAGE %	RENEWABLE HOUSE 2030 TARGET
SALES COST	100.0 %	
DIRECT COSTS Construction labor, materials, equipment and subcontracts.	50.0%	less 15%
FINISHED LOT COSTS Acquisition, infrastructure and area / yard work.	25.0%	less 10%
INDIRECT COSTS Production supervision, field labor, field expenses.	4.0%	less 2%
OVERHEAD Wages and salaries, insurance and offices.	4.0%	less 2%
MARKETING Salaries, commissions and sales expenses.	5.0%	less 4%
FINANCING	5.0%	
NET INCOME (before taxes)	7.0%	

Table 4.6 - 2
Project Cost Pro-Forma
Sources: Site Built 1989 Average%'s derived from NAHB '1989 Single Family Builder Profit and Loss Study' and Hallahan Associates. Renewable House Target by CHI.

4.7 REFERENCES

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PROBLEM STATEMENT FOR THE 21st CENTURY HOUSE

EXTENDED FAMILY HOUSE IN A COOL CLIMATE

SYNOPSIS

TYPE:	Single family 'infill' house.
AREA:	700 - 800 sf.
DENSITY:	12 dwellings per acre including existing houses. Share 5000 sf lot with existing 1800 sf house.
CONTEXT:	Existing single family neighborhood . Minneapolis, MN.
CONSTRUCTION:	Panelized frame.
MATERIALS:	Lightweight glass fiber reinforced concrete composite on laminated veneer lumber frame.
SERVICE SYSTEM:	Unducted integrated HVAC / DHW recovery core heat pump.
ECONOMIC GOAL:	Affordable at 80% - 100% median household income. Low monthly operating costs.
ENERGY GOAL:	25% more efficient than California Title XXIV energy code.
INNOVATIONS TESTED:	**Energy** High R-value compact vacuum insulation panels. Ductless air distribution and return. **Manufacturing** Factory integration of fragile high thermal performance panels with conventional construction materials.

5.0 PROBLEM STATEMENT FOR AN 'EXTENDED' FAMILY HOUSE IN A COOL CLIMATE

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Introduction

The 'Extended' Family House problem statement explores energy conservation opportunities in an emerging market demand for new housing infilling existing low density single family neighborhoods. In this problem statement, a small second house is added to an existing single family lot.

There are several potential resident scenarios. One is a retired single 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.

The house in this problem is a small detached dwelling of low operating cost and maintenance. It can be sited behind or between existing houses. Access and open space is shared with the adjacent dwellings, but each is otherwise a private and distinct dwelling.

Scenario

"I don't want to spend my golden years cleaning three bathrooms". Mrs. E a former travel agent and now 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 household committed to purchase the old house, she contracts with 'Suburban Systems' a company specializing in small scale construction and conversions. The design for the new house is motivated primarily by practical and economic decisions — it should be small, secure, easy to maintain and inexpensive to run. It is at the same time an important commitment to stay in social contact and proximity to a social extended family of friends, children, grandchildren and business associates.

Design, Energy and Manufacturing Challenges:

This problem statement is focused on finding design, industrialized construction and energy conservation strategies suited to small scale suburban sites and housing stock. Housing of this type presents an opportunity to create new housing stock that requires no costly new infrastructure and rejuvenates existing neighborhoods at the same time. New residential units constructed in existing neighborhoods further have an opportunity to conserve energy in transportation as well as residential sectors.

Design challenges:

- Neighborhood planning to realize higher densities preserving the scale and openness of single family neighborhoods.
- Site planning to preserve privacy, access and identity on small, densely packed sites.
- Architectural integration of houses of differing scale and materials.
- Planning and design integration of passive energy conservation strategies.
- Utilization of construction processes and materials for constrained sites.
- Interior space planning and detailing for an elderly resident.

Energy challenges:

- Demonstration of a residential energy conservation strategy in tandem with transportation energy conservation and concern for the environmental impact of sprawl and duplication of services and networks.
- Realizing passive ventilation and solar gain on constrained sites and orientations.
- Realizing thermal performance in lightweight construction materials.
- Maintaining indoor air quality at low infiltration rates.
- Low maintenance energy conservation systems for an elderly resident.

Manufacturing challenges:

- Realizing fabrication flexibility suited to small, one of a kind sites and clients.
- Component and attachment compatibility between manufacturers systems.
- Factory integration of fragile high thermal performance panel with more durable construction materials.
- Developing components, distribution strategies, assembly standards and construction processes for small, dispersed and restricted site situations.

Problem context:

In the 1970's and 1980's much of the metropolitan population 'spread out' into the housing stock. Rather than live with others, many elderly, young and divorced persons came to head their own households. There is, as a consequence, more housing space per capita in this country than anywhere else in the world — more rooms per person, more rooms per household and more land per house.

House size as a function of household size have become increasingly mismatched. Over the past thirty years, house sizes have increased from 800 square feet and one and a half baths, to 1600 square feet and two and a half baths. At the same time average household size has decreased, from 3.37 persons in 1950 to 2.75 persons in 1980 (Hayden, 1984: 174).

In many cities, dwelling counts increased even as population declined. Boston, for example, housed 640,000 persons in 232,000 dwellings in 1970 and less than 580,000 persons in 240,000 dwellings, a 13% drop from 2.76 persons per dwelling to less than 2.4 in only 10 years (Goetze 1983: 8). The inventory of housing and land stock potential is significant and substantial. According to Baer of the University of Southern California, over half the housing units in the United States have 'excess space' (more than 2 habitable rooms per person) (Goetz 1983: 14) — a resource increasingly valuable to those 'overhoused' homeowners facing declining real income in the face of rising energy costs, taxes, maintenance, mortgages and living expenses.

There is a diversity of terms that refer to the housing form that has emerged to meet this need and opportunity — accessory apartment; accessory dwelling unit; mother-in-law apartments; mother-daughter homes; secondary residences and so on. However named, all refer to an independent detached housing unit that typically shares an entrance, yard and parking with a primary housing unit. These housing units have been appearing in the U. S., in both legal and illegal forms. Although there are no firm data on the subject, the 1980 census indicated there may have been as many as 2.5 million conversions of single family houses to accessory units between 1970 and 1980 (Hare 1981: 1).

There are several infilling strategies that will create small low cost secondary housing units in and adjacent to existing houses. One is conversion and addition, a strategy through which a multi-dwelling is created through remodel or expansion of a single family dwelling. Properly sited and 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 of college towns and successful resort communities to estimate the significance of this housing opportunity. These units, often converted or carved illegally out of large underutilized single family houses, can be a vital component of the affordable energy conserving housing stock of the future.

A second infilling strategy adds a second, often separate, dwelling to a single family lot without change to the existing house. In this strategy, neighborhoods grow more dense over time as initial housing is supplemented with these separate, infilling housing structures. A third infilling strategy, a variation of the second, involves consolidation of several lots to create adequate space for the added dwelling.

These housing forms have developed in response to several coincident issues and circumstances — the already high and rising cost of new housing, a high rate of household formation and the underutilization of existing suburban land and housing stock. Of these, economic forces (escalating land, financing and construction costs) that limit housing choices and demographic forces that accelerate housing demand (increasing 'empty-nest' families and single households, growth of employment among women, postponement of marriage, high divorce rates etc.) are frequently recognized and analyzed. Less predictable but no less influential are future changes in transportation, work patterns, housing construction and technology that will make adaptation, expansion and rehabilitation of existing housing units economical and desirable.

Several cities are beginning to support the small scale change over time suggested by all three infilling strategies. Among the programs and policies initiated have been the encouragement of innovative and economical site planning practices to increase density or introduce income generating uses with housing. This process has included substantive reviews of codes and regulations that create costly site infrastructure, services and networks. Zoning and planning regulations have and will evolve to permit subdivision and / or consolidation of houses and lots (Hare 1988: 10 and Vernez-Moudon, Sprague, 1982: 54-55).

The 'Extended' Single Family Housing Market in 2030

The single family suburb as we know it can be expanded, altered and generally transformed to meet escalating demand for affordable housing for an increasing diversity of households and lifestyles. Space around each existing house offers new sites with direct sunlight, ventilation and access. The materials of construction are lightweight and familiar. Construction 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. Compared to building new houses on unserviced land, 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. Development, general contracting and labor costs can be reduced in the order of 40% , limited only by the skill and enthusiasm of the owner.

An important market consequence of housing of this kind is the significant increase in neighborhood density and coverage and subsequent decrease in lot size and configuration options as new dwellings are added. Developing a marketable, energy efficient house for this context links site planning, housing design, construction and energy conservation decisions from the very beginning of the process. Decreasing lot size and restricted access establishes the location, size and configuration of the building footprint on a site, while increasing density and coverage exacerbates design problems of access to sun and wind, fire safety, acoustic and visual privacy and identity. In extreme cases, these considerations may limit design and construction options to predetermined structural envelopes within which only interior variation is possible.

Infill Housing Demand in Metropolitan Minneapolis

While the growing sunbelt experiences shortages of developed land and housing stock, colder climate regions of the U.S. have significant residential land and housing stock reserves in existing suburban neighborhoods. Many northern and midwestern cities encompass low to moderate density residential districts which were formerly inner suburbs around a city core. Several have initiated analyses of the opportunity they present for new housing.

Metropolitan Minneapolis has two such rings of suburbs established in periods of low land cost and rapid expansion (Dougherty, Cuthbert, Moreno, 1988: 6-7). The city is growing and these suburban neighborhoods, because of their advantageous location and well developed services and infrastructure, present considerable opportunity for development, increased density and redefinition of uses. The economic pressure to develop further is considerable and many of these neighborhoods will be faced with loss of the quality and character for which they are desirable in the market without sensitive solutions to density and diversification.

5.1 DELIVERY SCENARIO

The housing provider 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, each representing a particular market segment and quality.

The Suburban Conversion Company

The Suburban Conversion Company's (SCC) 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 client need 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 several ways. Often, projects 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.

5.2 DESIGN PROGRAM

Occupancy:

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

Design requirements:

700 - 800 sf single story studio house with two bedrooms, two baths 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. Spatial organization must be 'open' to work with unducted central mechanical systems.

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 and landscape 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 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 rowhouses 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.

Household income:
In 1985, median income for homeowners in the Minneapolis metropolitan are 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.

Household income available to acquire and maintain a house has been estimated in Table 5.2 - 1. Mortgage terms are estimated based on 11% bank financing. Land costs are assumed to be negligible. Cash available is assumed to be from equity built-up in the existing house.

	$ / Month	%
GROSS INCOME Annual $ 24,700	$ 2,060.	**100.0%**
AVAILABLE FOR HOUSING Taxes [100] Insurances [20] Energy [70] Principal and interest [480]	680.	**33.0%**
ASSUMED MORTGAGE ($ 480 over 30 year fixed mortgage at 11 %)		$ 50,000.00
MAXIMUM PURCHASE PRICE (150% of assumable mortgage)		**$ 75,000.00**
CASH REQUIRED Down payment (50%) Closing costs (5,000)		$ 30,000.00

Table 5.2 - 1
Household Income Pro Forma
Source: Extrapolated from American Housing Survey: 1985

5.3 ENERGY CONSERVATION PROGRAM

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 (ave 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.

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 5.3 - 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.

Demand Context:

As a national trend, residential energy use continues to climb despite improved energy efficiency. Since 1975, the number of residences has increased 22% while per household energy use has risen 4% (U.S. Department of Energy, 1988). Forecasts indicate a decrease in the national share consumed by space heating, and rapid growth in consumption of space cooling, lighting, water heating, and other miscellaneous appliances .

	Current National Average	**Anticipated change 1986 - 2010**
Total demand	**100%**	**+ 40%** (total)
By end-use:		
Space Heating	54%	+ 22%
Space Cooling	5%	+ 62%
Water Heating	18%	+ 38%
Lighting /		+ 55%
Other	23%	+ 52%

Table 5.3 - 2

National Average Residential Energy Consumption by End Use

Source: U. S. Department of Energy, Energy Conservation Multi-Year Plan '90-'94, 1988 and Household Energy Consumption and Expenditures: 1987 Part 1: National Data, 1987.

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.

Passive energy conserving design strategies
The house designed from this problem statement is anticipated to emphasize passive energy conserving design strategies. Primary passive heating strategies are thermal mass and zoned plans, cooling strategies are ventilation and thermal mass.

Cooling Strategies:
- Minimize solar gain.
- Promote natural ventilation.

Heating Strategies:
- Promote solar gain.
- Minimize conductive heat flow.
- Protect from cold winter winds.
- Minimize infiltration
- Reduce diurnal temperature swings.

Design Rules of Thumb
South facing glazing
For a house of approximately 1000 s.f. in the Minneapolis area, south facing glazing should be within 20% of 9.5% of floor area.

Source: Brown, Sun, Wind and Light: p. 92 - 94

Thermal mass
In direct gain heating applications:
- 3 - 6 s.f. masonry of 4" minimum thickness / s.f. south facing glazing.

In night ventilating cooling applications:
- 1.5 - 3 s.f. masonry of 2" minimum thickness / s.f. floor area

Source: Brown, Sun, Wind and Light: p. 123

Solar domestic hot water

- Batch systems:
  .45 - .65 s.f. of glazing / gallon
- Flat plate collector:
  (to meet approximately 50% annual hot water demand)
  12 - 25 s.f. / person
  1 - 1.5 gallon storage / s.f. collector
  Collector angle = ° latitude or less

Source: Watson and Labs, Climatic Design, Energy Efficient Building Principles and Practices, 1983.

Photovoltaics

- Current products:
  13% cell efficiency = 11.5 w / sf collector at peak w
- In research and development:
  30 % cell efficiency = 26.5 w / sf collector peak w

Source: Florida Solar Energy Center

Additional references

Designers are further advised to consult the following references for climate responsive architectural design principles and design rules of thumb:

A.I.A. Research Corp. for U. S. Dept. of Housing and Urban Development. Regional Guidelines for Building Passive Passive Energy Conserving Homes, HUD-PDR-355. U. S. Govt Printing Office, Nov. 1978.

G. Z. Brown, Sun Wind and Light: Architectural Design Strategies, Wiley, 1985.

Edward Mazria. The Passive Solar Energy Book, Expanded Professional Edition. Rodale Press, 1979.

V. Olgyay, Design With Climate: Bioclimatic Approach to Architectural Regionalism, Princeton University Press, 1963.

Donald Watson and Kenneth Labs. Climatic Design, Energy Efficient Building Principles and Practices, McGraw Hill, 1983.

5.4 MATERIALS, COMPONENTS AND SYSTEMS PROGRAM

The construction system specified in this problem statement is a high thermal performance lightweight non-bearing panel system attached to an engineered wood frame.

The mechanical service system specified uses a central core designed to distribute conditioned air from a central point without ducting.

Foundation
Wood pier foundation.

Envelope and structure:
Glass fiber reinforced concrete weather skin fused with compact vacuum insulation (CVI) panel of very high thermal resistance. Panels are attached to an exposed laminated veneer lumber (LVL) frame using factory installed metal connectors and tensioning elements.

Mechanical system:
Centrally located and 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 exterior 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 as a wainscot height

5.5 MANUFACTURING SCENARIO

Associated with market oriented product lines is the need for increased flexibility in manufacturing (Seal, 1989; Tompkins, 1989). Flexibility may take several forms:

- Flexibility to manufacture a family of products with high quality and cost efficiency.
- 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 by cutting back options and installing hard automation. 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. Although the strict application of FMS probably does not apply to industrialized housing, a more generic definition of FMS is certainly applicable. Key features would include:

- Flexibility to build a family of products
- Flexibility to install (or not install) a range of options.
- Flexibility to efficiently expand or contract production levels.
- Flexibility to retrofit the operation/process and/or the facility should the need arise.

'Outsourced' Manufacturing Scenario

Manufacturers will outsource more components / services at higher levels, thereby reducing their level of vertical integration. Components will be outsourced when they can be procured at a lower cost and/or higher quality than they can be manufactured. An example of this strategy is the auto industry, where major manufacturers have outsourced 70% of the content.

In housing manufacturing, outsourcing results in a factory shell–site finish integrated manufacturing and construction scenario. In this scenario, a factory or factories perform all operations up to the level of assembly which maximizes profitability (sales price – manufacturing cost). Manufacturing costs will include materials, labor, equipment, facilities, etc.

Key housing components will be manufactured in "focused" factories, dedicated to manufacturing a narrow line of components. The focused factories will manufacture components of higher quality and at a lower cost than large, vertically integrated manufacturers.

The focused factory concept will encourage capital investment since it can be amortized over higher production levels and since total capital for any manufacturer will be kept low, thus, reducing vulnerability during market downturns.

House components will be sold to a customer, in this problem statement a project manager, at this assembly level and the customer will co-ordinate erection of the house on–site. Since there will be multiple suppliers supplying the same component to multiple manufacturers, a standardized system of interchangeable, compatible parts will be a prerequisite for success.

Industrialized housing assembly plants of this scenario will be simpler than the current large, vertically integrated manufacturing facilities. They will be downsized with respect to facilities, equipment, materials, personnel, etc. They will need to be more flexible to accommodate relative changes in manufacturing cost, sales price, customer acceptance or regulation.

5.6 EVALUATION

Submission requirements:
Each design study will include the following:

- **Design summary:**
  1/8" house plan / site plan, elevations and axonometric; 1/2" construction sections; explanatory narrative and statistics (floor area etc.).

- **Construction summary:**
  Summary of construction steps and procedures; inventory and evaluation of manufacturing or material innovations attempted.

- **Energy conservation analysis:**
  Summary of energy performance; inventory and evaluation of energy related innovations and principles attempted.

- **Cost analysis:**
  Summary of anticipated cost allocations; inventory and evaluation of design and construction economies attempted.

- **Problem statement critique:**
  Summary of problem statement ingredients for which revisions or further guidance and elaborations are suggested.

Design Goals:

- **Site:**
  Separation / integration of new house and circulation with existing houses.
  Orientation and siting to realize passive heating and cooling.

- **House:**
  Efficient plan suited to compact house and site
  Resolution of public and private spaces
  Utilization of passive design strategies
  Resolution of stylistic variation with limited interchangeable parts.

- **Construction**
  Integration of new and existing
  Resolution of technical limitations imposed on industrialized construction in constrained infill context

Energy Goals:

Throughout this problem statement is a commitment to demonstrate the potential for total energy conservation in existing neighborhoods and conservation using systems of low maintenance and complexity suited to elderly users.

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.

This standard can be interpreted as a prescriptive standard based on the following table or as a performance standard. A performance standard can be established for particular structure by calculating total energy that would be consumed if the prescriptive standards were followed. This figure is the performance goal and specific prescriptive standard need not be followed provided this goal is met. For additional calculation detail and procedures consult Building Efficiency Standards, California Energy Commission.

ANNUAL WATER HEATING BUDGET 22900 Btu / Yr.

SPACE CONDITIONING BUDGET:

BUILDING ENVELOPE:	
Insulation Minimums [1]	
Ceiling	R 48
Walls	R 24
Slab Floor Perimeter	R 9
Raised Floor	R 24
GLAZING [2]	
Maximum U Value	0.50
Maximum Total Area	16%
SHADING COEFFICIENT [3]	
South Facing Glazing	0.50
West Facing Glazing	0.50
East Facing Glazing	0.50
North Facing Glazing	0.50
THERMAL MASS [4]	
W/ Slab Floor	25%
W/ Raised Floor	10%
INFILTRATION CONTROL	
Continuous Barrier	REQ
Air-to-Air Heat Exchanger	REQ
SPACE HEATING SYSTEM	
Gas,seasonal efficiency	72%
Central Heat Pump, ACOP	2.5
Seasonal performance factor (HSPF)	6.6
SPACE COOLING SYSTEMS [5/6]	
Air conditioner, SEER =	8.9

Table 5.6 - 1
California Title XXIV Standards
Converted for Minneapolis Climate and Increased by 25%.

Source: Converted from Building Efficiency Standards, California Energy Commission

1. R-Value for insulation is value for insulation between wood framing members. Ceiling U-Value with insulation between framing members must be equivalent to U value of insulation at specified R-Value with insulation continuous above or below framing members.
2. Assume maximum glazing area, equally distributed in each of the four cardinal orientations.
3. U- Value for glazing only, not including effects of frame. South facing glazing includes horizontal. All glazing directions include sloping glazing and vertical facing the respective direction.

4. Thermal mass may be distributed in floors, ceiling or walls; must be exposed to conditioned space. Calculate as percentage of conditioned floor area.
5. Assume cooling system is central.
6. Energy required for building cooling must be included in the design energy budget.

Economic Goals:

The house defined in this problem statement is intended to be affordable at or near median income in the Minneapolis region. In 1985 this median income was $ 30,900 for all homeowners (American Housing Survey: 1985).

Estimated costs of material and processes that do not yet exist are, at best, difficult to project. It is however possible to make a target estimation of the relative or proportional cost of particular elements within the whole project. Table 4.6 - 2 summarizes and compares average proportional cost of seven elements that comprise the total cost of delivering a house to a prospective owner.

From a baseline national average of a site-built house of 1989, target cost of elements are developed to reflect the estimated economic impact of materials and processes defined in the problem statement as they vary from this baseline. In this example, the assumed increase in direct cost is attributed to the constrained construction site and custom design to elderly standards, and decreased cost of site acquisition and development are considered.

Completed project costs are projected over the following pro forma:

	SITE BUILT HOUSE 1989 AVERAGE %	**EXT. FAM. HOUSE** 2030 TARGET
SALES COST	100.0 %	
DIRECT COSTS Construction labor, materials, equipment and subcontracts.	50.0%	plus 5%
FINISHED LOT COSTS Acquisition, infrastructure and area / yard work.	25.0%	less 20%
INDIRECT COSTS Production supervision, field labor, field expenses.	4.0%	
OVERHEAD Wages and salaries, insurance and offices.	4.0%	

MARKETING Salaries, commissions and sales expenses.	5.0%
FINANCING	5.0%
NET INCOME (before taxes)	7.0%

Table 5.6 - 2
Project Cost Pro-Forma

Sources: Site Built 1989 Average%'s derived from NAHB '1989 Single Family Builder Profit and Loss Study' and Hallahan Associates. Extended Family House Target 2030 by CHI.

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