

'Performance Specifications for the Design and Manufacture of Energy Efficient Housing in the 21st Century'

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Abstract

This paper reports on work in progress in 'Design for Energy Efficiency', one of fifteen task areas of the U.S. Department of Energy sponsored Energy Efficient Industrialized Housing research program. In this task, design studies establish performance goals for systems and technologies leading to energy efficient housing in the year 2030. Methods and results of work in progress are summarized, emphasizing areas where principles of design, engineering and manufacturing have converged to realize program goals of energy performance, economy and design quality.

Introduction

The Energy Efficient Industrialized Housing (EEIH) research program was established in 1989 to improve the energy efficiency of houses as the materials and processes from which they are designed and made evolve toward industrialization. This U.S. Department of Energy sponsored research program — jointly based at the Center for Housing Innovation at the University of Oregon, the Florida Solar Energy Center and Department of Industrial Engineering of the University of Central Florida — was established to develop technologies, design strategies, and production processes to make energy efficiency a part of this evolution.

This research program and its approach are unique in several respects. The program considers energy efficiency integral with parallel questions of economy, production, engineering and design at the scale of a whole house. While the technology of energy efficiency is the research focus, energy is investigated in a context of design and production to ensure that technology is an integral part of economical, energy efficient, marketable houses that meet the needs of people and the communities in which they live.

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The focus of this paper is 'Design for Energy Efficiency', one of fifteen research tasks within the program. In this task, the design and engineering disciplines of the research team have sought to establish visions of the systems and technologies toward which energy efficiency and housing might evolve in four climate zones in the year 2030.

Why 2030? If the historical record of design and technological change in mature industries such as housing construction holds, change defined today may not be in common practice for two generations. Forty or fifty years may lag between the initial awareness or knowledge of an innovation to its recognition, passage through decision making, regulatory and learning processes to ultimate acceptance and adoption in practice.

This task has not been, and will not become, a search for the '21st century house design'. It is instead a forum through which a research team of design and engineering can consider the future and energy efficiency 'whole', at the scale of one house, in one place, inclusive of market, design and production forces.

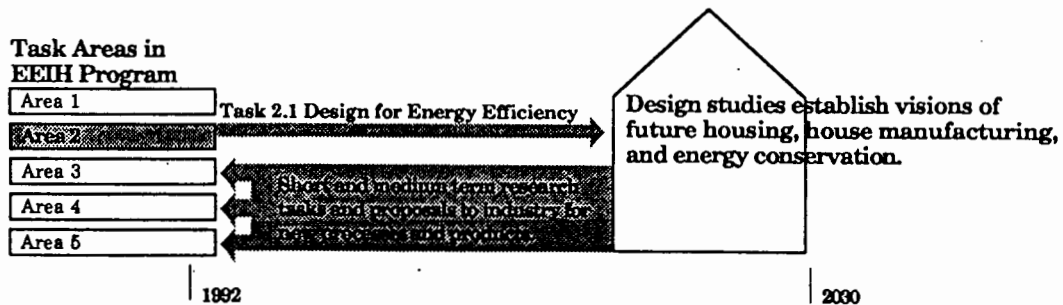


Figure 1.
Research Role of Design for Energy Efficiency Task

Figure 1 summarizes the relationship of Design for Energy Efficiency to other task areas of the Energy Efficient Industrialized Housing research program. Task products are performance specifications for housing technologies and systems toward which short and medium term hypotheses and research objectives can be directed.

Several methods and stages of work (Figure 2) were undertaken to formulate this vision. Early in 1990, team members set out to define a context for housing and energy conservation in the future. Literature surveys were undertaken to identify and assess trends in seven areas of influence. Fifty-five trends were identified and from them, four housing design scenarios or problem statements were compiled. Eight architectural design studies were commissioned, developed and evaluated.

In 1991, focus narrowed to systems development (structure, mechanical, manufacturing, etc.), of two design studies — a multi-family concrete panel house for a hot-arid climate, and a single family

composite wood frame and thin insulation house for a cool climate. At this writing, specifications that quantify projected and desired advances in the performance characteristics of each system are in final stages of development and preparation.

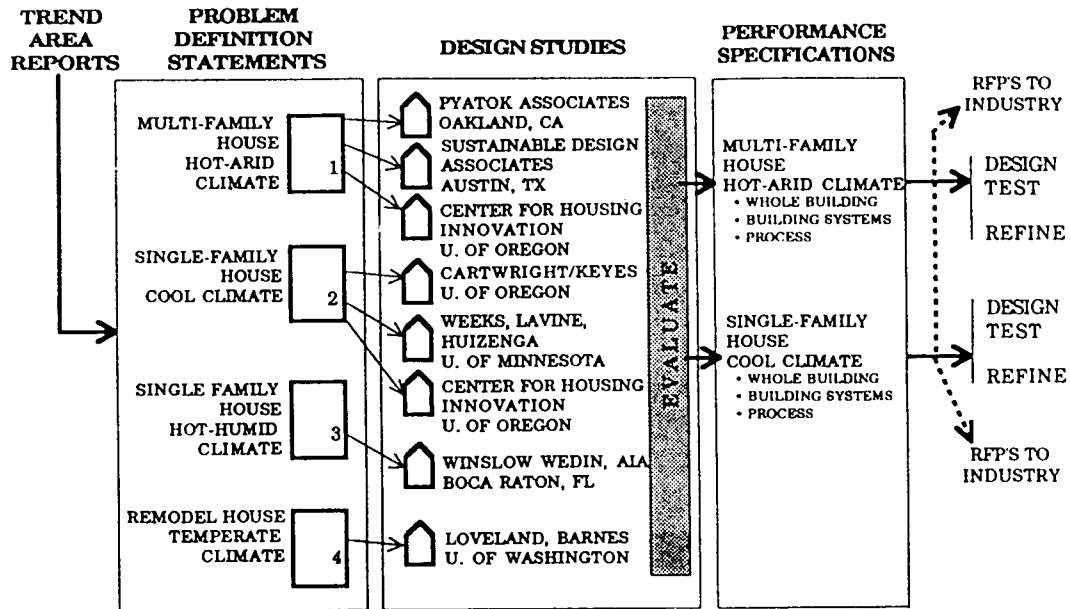


Figure 2. Overview of Stages of Development Design for Energy Efficiency Task

Trend Areas

In an effort to be systematic and substantive about the future, a research team set out with an agenda of specific questions. What are the forces that will motivate or significantly influence design, energy and manufacturing priorities for housing through the beginning of the next century? Who will live in them? Where will they be? How will they be sold and financed? How will they be made? Of what materials? By what processes? and so on.

Literature surveys were undertaken in design processes; manufacturing processes; materials, components and constructions systems; energy and environment context; demographic context; economic context and, planning policy and regulatory context. Findings were compiled, compared, cross-referenced and distilled to a list of fifty-five trends over the seven search areas. While the results are lengthy and beyond the scope and focus of this paper, many are evident in the problem definition statements below.

Problem Definition Statements

The problem definition phase of this work sought to establish points of convergence among trends by looking for points where opportunity for innovation in energy conservation paralleled anticipated trends in

housing demand, design and manufacturing across a range of house types, markets, construction systems and climates.

Of the many future scenarios which could result, effort ultimately concentrated on four scenarios for four climate zones and housing types — Starter House for a Hot-Arid Climate; Move-up House for a Hot-Humid Climate; Extended Family House for a Cool Climate; and Renewable House for a Temperate Climate.

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

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

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

The 'Renewable House for a Temperate Climate (Seattle, WA)' problem statement explores energy conservation opportunities that might result from trends anticipating strong future demand for remodels, additions and upgrading of existing houses, increasing sophistication of 'do-it-yourself' building materials and components, increasing computerization of design, engineering and construction management processes, decreasing availability of dimensional lumber, increasing recycling and regulation of toxicity levels in building materials.

Design Studies

Eight design studies were commissioned of designers and architects selected for their expertise in housing design, energy conservation and construction processes. Each study proposed a schematic design for a house and site to the requirements of the problem statement. All eight were evaluated against goals and criteria established in the problem

statements. Computer simulations of energy performance on four typical days in December, March, June and September were compared. Conclusions were drawn and innovative energy improving design and manufacturing principles inventoried.

Studies (for example, Figure 3) of the 'Starter House' (Phoenix) problem revealed opportunities for passive heating and cooling innovations suited to the density, compactness and economy required of low cost multi-family houses. Low cost shading, ventilation and thermal mass could be achieved across a range of construction techniques and site planning strategies.

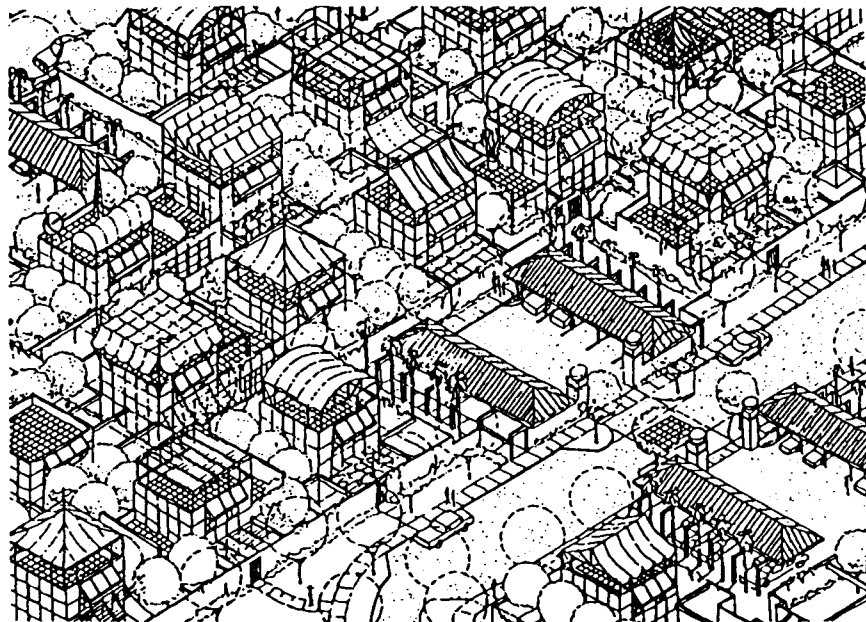


Figure 3
Axonometric of Site Plan Starter House Design Study
Michael Pyatok Architect

Space heating demand could be virtually eliminated and cooling demand deferred to off-peak periods. All studies eliminated heating and cooling loads on a typical December day. Off-peak mechanical cooling was required to meet heat gains of March, June and September days. HVAC, hot water and power systems of higher first cost but greater energy efficiency could be economically shared from common walls and cores.

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

Studies (for example, Figure 4) of the 'Extended Family House'

(Minneapolis) problem revealed opportunities for improvement in the thermal resistance of an envelope appropriate to the design variety and flexibility of light frame construction. High performance insulating materials on very light wood frame construction strategies brought parallel opportunities to reduce structural material requirements by as much as one half and streamline site assembly by weeks.

The high thermal performance envelope substantially reduces space heating requirements and virtually eliminates need for cooling. Much of the heating demand could be met through recovery of waste heat. Three studies eliminated or virtually eliminated heating and cooling loads on typical June and September days. Mechanical heating was required to meet heat losses in March and December.

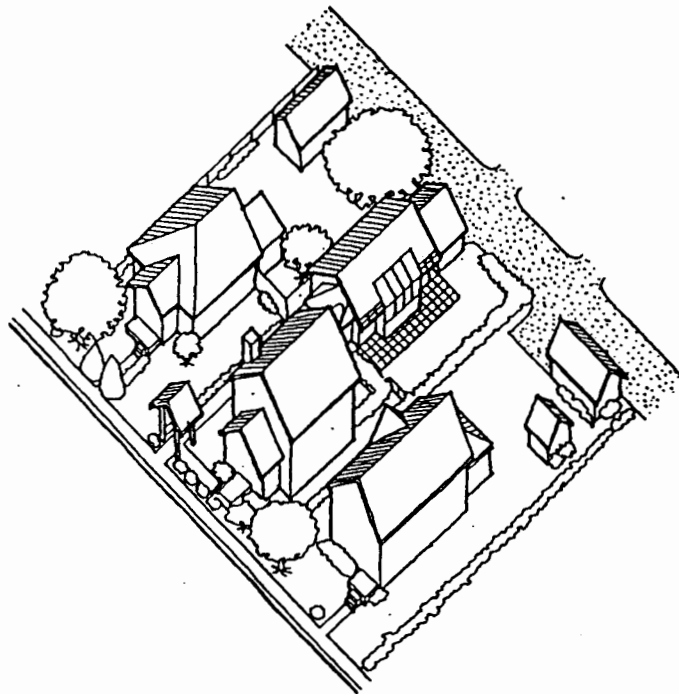


Figure 4.
Axonometric of Site Plan Extended Family House Design Study
Center for Housing Innovation

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

Studies of the 'Renewable House' (Seattle) problem revealed opportunities to upgrade energy performance in existing residential construction in conjunction with owner built additions and remodels.

Among the effective strategies are upgraded insulation levels in walls and windows, improved plan zoning, windows and finishes for passive heating, and upgraded space conditioning appliances.

Energy simulations of the study submitted revealed that the renewed house used less energy than the original house alone. This study eliminated heating and cooling loads on a typical June day and required mechanical cooling on a September day, and mechanical heating on a March and December day.

Following evaluation of the eight studies, the scope of investigation narrowed to two study areas and increased in depth from schematic design to systems development. The two selected — a multi-family lightweight concrete panel house for a hot arid climate; and, a single family wood composite frame and thin insulation panel house for a cool climate — match national residential energy conservation needs with industrialized housing opportunity.

The former is a single family house for a heating climate and the latter a multi-family house for a cooling climate. Both represent regions anticipated to sustain strong housing demand into the next century. Their materials and construction systems — engineered wood composites, lightweight concrete in manufactured panels — are representative of the design and installation flexibility sought in industrialized housing systems.

Systems for a Multi-family Concrete Panel House for a Hot-Arid Climate.

The multi-family house design study proposes technologies and systems for low cost (affordable at 60 - 80% median household income) 2 and 3 story attached houses of concrete panel construction at densities of approximately 16 dwellings per acre. Low first cost is a prime consideration. A manufactured panel system promises cost and energy savings through optimization of the load bearing, fire resistance, acoustic and thermal storage properties of concrete. At the same time, the technology and economics of low cost concrete panel building presents significant limitations to site planning and design variation and may limit passive design opportunities to maintain comfort in the house.

The energy conservation challenge is to define energy efficient design strategies and construction technologies with low first cost, operation and maintenance. Dense site plans and attached house designs offer lower land and site infrastructures cost per unit, reduced heat transfer through common walls and opportunities for public transportation. At the same time, there is a design challenge to preserve access to passive energy sources while retaining private space and privacy at this density. While opportunities for low cost mechanical systems occur with common or clustered space conditioning, hot water and plumbing,

emphasis in systems development however, is on renewable, natural energy and fuels.

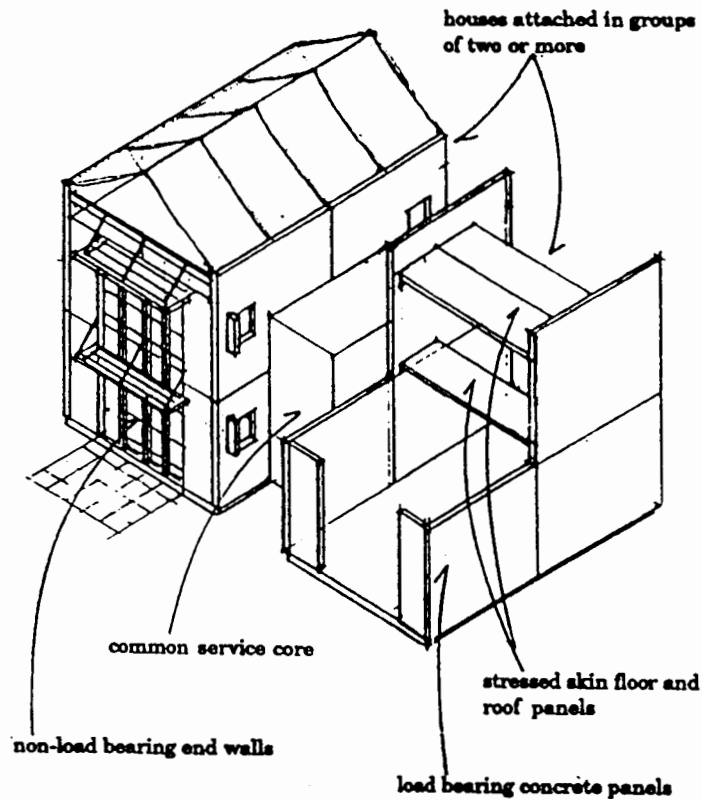


Figure 5
Summary Axonometric of Multi-family Concrete Panel House System

The manufacturing scenario investigated in this study is that of a vertically integrated housing company — a combination land developer, marketing, sales, design, build and finance company. Since the manufacturer will control much of the design, development and construction process, economic benefits can be realized across and between customary cost categories. Design, engineering, manufacturing, financial, and legal services, for example, could be coordinated to optimize levels of service, performance and cost.

Principles guiding design development are summarized in Figure 5 and include the following. Each and every household maintains ground to sky ownership and control. Site planning consolidates roads, parking and utilities and preserves access to sun, wind and light for each house. Open spaces are naturally shaded and humidified. Houses are attached in groups of two or greater to improve the ratio of floor to exposed surface area. Load bearing structure is oriented parallel to the direction of sun and wind to permit flexibility of roof form, intermediate floor heights, interior partition layout, window size and location. Interiors are organized for contact and control of sun, wind and light. Space conditioning systems integrate passive solar heating, natural

ventilation, mechanical ventilation of thermal mass and evaporative cooling. Water and waste systems include cistern storage, and greywater recycling.

Systems for a Single Family Wood Composite Frame and Thin Insulation Panel House.

The single family house design study develops systems and technologies for moderate cost (affordable at 100% median household income) 1 and 1 1/2 story detached houses of manufactured engineered wood composite frame and thin, high thermal performance panels. Each system and variation must facilitate design and construction for dispersed, potentially constrained sites and house designs of diverse size and character.

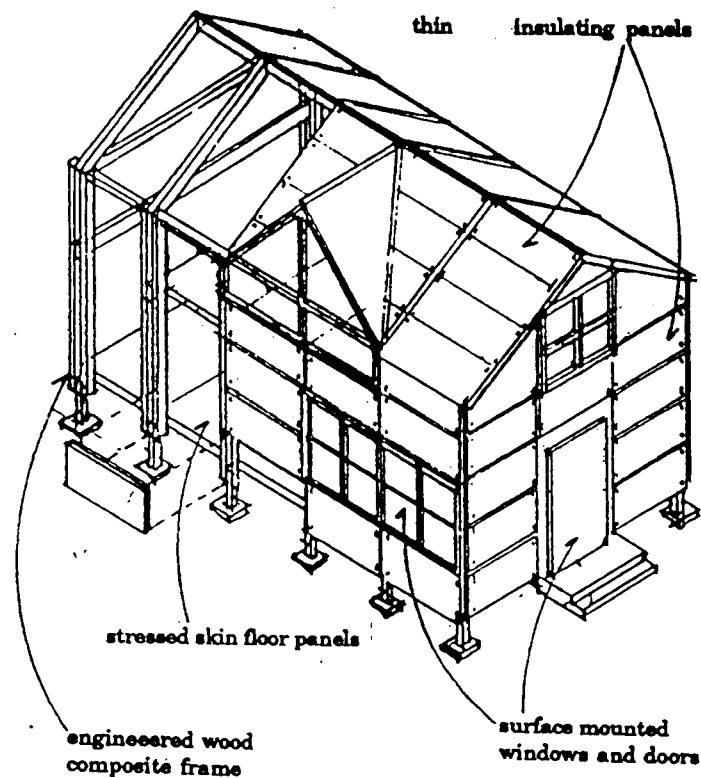


Figure 6
Summary Axonometric of
Single Family Wood Composite Frame House Systems

Principles guiding design development are summarized in Figure 6 and include the following. The proposed construction system consists of thin nonbearing insulation panels of 1/2 - 1" attached to a laminated veneer lumber structural frame in many alternate plans, sections and elevations. While of high first cost, wood composites and high performance insulations can be manufactured in volume and offer the opportunity of unlimited siting and design variation with little variation in performance. At thermal properties approaching R-100 per inch,

wall, roof and floor assemblies can become significantly thinner, and lighter. Structural and thermal attributes of each can be disengaged and separately engineered for material economy and efficiency.

The proposed manufacturing scenario is that of a future design / build contractor, a moderate volume designer, builder and expediter specializing in scattered site projects and remodels for existing suburban neighborhoods. In much the same manner that contemporary kitchen remodelers represent a limited range of cabinet, finish and appliance manufacturers, this housing company represents several frame and panel manufacturers across a range of price and quality options. The construction system must be 'open', based on components and materials from competing, complementary sources.

The energy conservation questions posed are several. Given high thermal performance in an envelope system, the impact of design and opening variation and demand for mechanical space conditioning systems is significantly less. Opportunities for thermal storage materials are decreased, while the potential impact of doors, windows and service distribution networks are significantly increased on a thin, lightweight shell.

Performance Specifications

At this writing, a cycle of performance specifications has been completed to quantify the projected and desired advances in computerized design processes, materials, components and manufacturing automation necessary to realize each design study. Included are performance specifications in areas of process, whole building performance and building technologies and systems.

Process Performance Specifications establish performance goals for manufacturing and assembly; and, architectural / engineering design systems. Whole Building Performance Specifications establish performance goals for whole house energy loads; costs of materials, manufacturing processes and delivery mechanisms; architectural design; and, codes and regulations. Building Systems Performance Specifications establish performance goals for whole house structure, materials, components and connections; mechanical systems of heating, ventilation and air conditioning; water and waste systems; power, lighting and communication systems and controls; and dimensional coordination of materials, manufacturing, assembly and design processes.

Later in 1992, a second generation of design and evaluation will be undertaken to assess implications and opportunities of these specifications, and to identify a roster of technologies, design strategies, and production processes for short and medium term research and development.