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

Presented to

Future Buildings Forum
International Energy Agency (IEA)

Technical Research Centre of Finland (VTT)
Espoo, Finland
1 - 3 September 1992

by

Ronald Kellett
Associate Professor of Architecture
Energy Efficient Industrialized Housing Research Program,
Center for Housing Innovation,
University of Oregon,
Eugene, OR, USA

503.346.3647
503.346.3626 fax

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

Ronald Kellett, Associate Professor of Architecture
Energy Efficient Industrialized Housing Research Program,
Center for Housing Innovation, University of Oregon, Eugene, OR, USA

Synopsis
This paper presents work in progress in 'Design for Energy Efficiency', one of fifteen task areas within the United States Department of Energy sponsored Energy Efficient Industrialized Housing (EEIH) research program. In this task area, the design, engineering and manufacturing disciplines of the program seek to generate an agenda of energy related research and development priorities from visions of industrialized housing systems for the year 2030.

Of the several housing and energy demand scenarios explored, this paper illustrates one — a low cost concrete panel system for housing at multi-family densities in hot arid, cooling dominated climates (Arizona). This particular scenario explores the opportunity of industrialized technologies to passively condition housing in this context. Aspects of both the long term vision — as system performance specifications, and the short term research priorities — as a roster of proposed research activities, are presented.

1.0 Research Program and Task Area Overview

The Energy Efficient Industrialized Housing (EEIH) research program was established in 1989 to improve the energy efficiency of houses as the processes and materials from which they are designed and made become increasingly industrialized. This U.S. Department of Energy sponsored research program — jointly based at the Center for Housing Innovation at the University of Oregon and the Florida Solar Energy Center — was established to advance industrialized materials, components, design strategies, and production processes toward a goal of 25% greater energy efficiency than that required by the most stringent U.S. codes, at no increase in first cost.

In pursuit of this goal, the EEIH research program investigates energy efficient technologies in parallel with issues of economics, production and design in housing. While the technology of energy efficiency is the research focus, it is investigated 'in context' to ensure that new technology develops to be compatible with marketable houses suited to the needs of people and the communities in which they live.

'Design for Energy Efficiency' is the generative, future-oriented task with this agenda. It is intended to be a forum through which a multi-disciplinary research team would consider housing and energy efficiency 'whole', at the scale of one house, in place, inclusive of market, design and production forces. Task products are short and medium term research priorities derived from long term visions of housing systems and technologies possible in the future — nominally the year 2030.

Several methods and phases of work (Figure 1) were undertaken to formulate these priorities and the visions from which they emerged. Early in 1990, team

members set out to define a context for housing and energy conservation in the future. Literature surveys were undertaken in seven areas of anticipated influence. Fifty-five trends were identified. From them, four housing design scenarios or problem statements were compiled. Eight architectural design studies were commissioned, developed and evaluated.

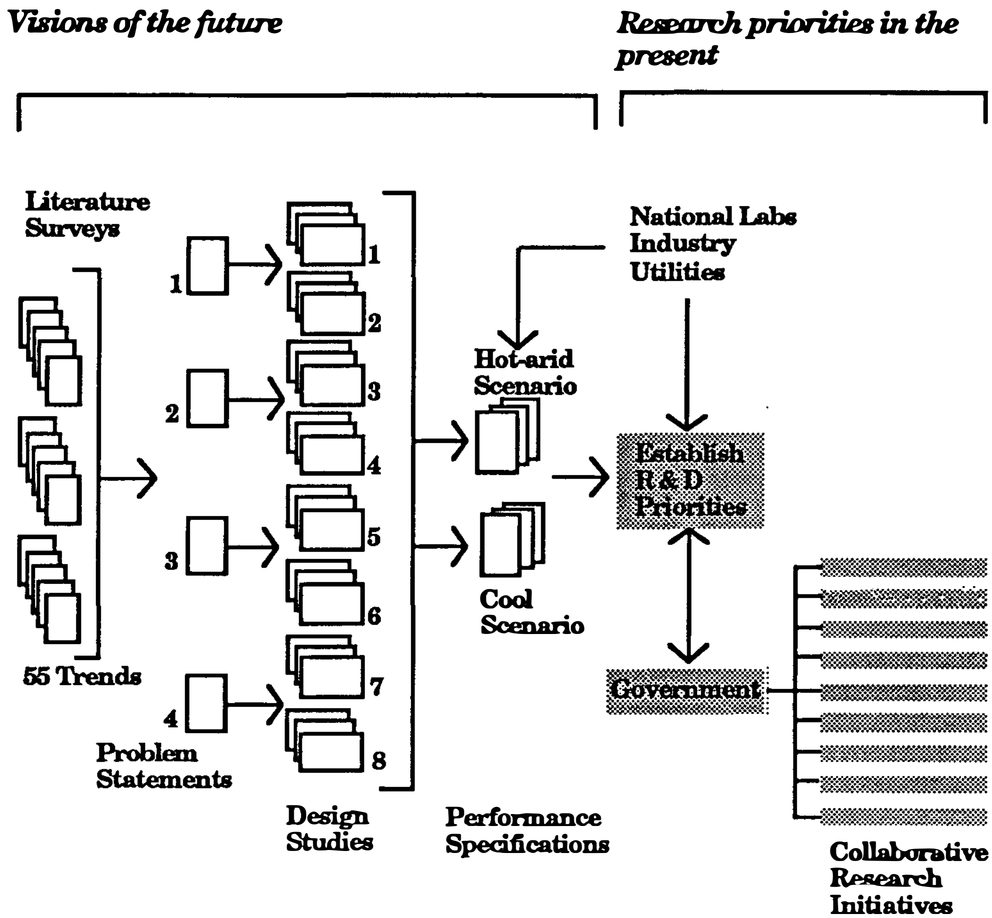

Figure 1
Organization and Method of Design for Energy Efficiency Task

In 1991, focus narrowed to systems development (structure, mechanical, manufacturing, etc.), of two scenarios — one for a hot-arid climate and a second for a cool climate. At this writing, specifications that quantify projected and desired advances in the performance characteristics for each are in final stages of preparation. From these specifications, a preliminary roster of research priorities have been proposed and is currently in review.

Literature surveys 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 and distilled to fifty-five trends which were in turn combined to create four problem definition statements.

Problem Definition Statements Problem definition statements sought to establish points of convergence and opportunity between and among trends. Points where opportunity for innovation toward energy conservation paralleled anticipated change in demand, design and manufacturing across a range of house types, markets, construction systems and climates were identified and elaborated as illstrated by the following examples.

The 'Starter House for a Hot-Arid Climate' (Phoenix, AZ) problem statement, for example, explores such opportunities that might result from trends anticipating strong demand for small, low cost multi-family houses in suburbs of the southwestern states. Also explored were the implications of diversifying household composition, declining wood resources, advancing concrete panel manufacturing technology, increasing site density, and increasing competition for cooling energy.

The 'Extended Family House for a Cool Climate' (Minneapolis, MN) problem statement explores opportunities that might result from trends anticipating demand for median cost single family housingto infill northern metropolitan suburbs. Also explored were the implications of significantly increased thermal performance in panelized insulation, 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 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 opportunities that might result from trends anticipating strong future demand for remodels, additions and upgrading of existing houses in the northwestern states. Also explored were the implications of increasing sophistication in '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 were compared. Innovative energy conserving design and manufacturing principles were inventoried.

The scope of investigation narrowed to two scenarios and increased in depth from schematic design to systems development. The two selected — a concrete panel system for multi-family housing in hot arid climates and, a wood composite

frame and thin insulation panel system for single family housing in cool climates — match national residential energy conservation needs with industrialized housing opportunity. The former investigates a very first cost sensitive market in a cooling energy demand climate and the latter a median cost market in a heating energy demand climate. Both regions anticipate strong sustained demand for housing into the next century. The materials and construction systems explored — manufactured panels of engineered wood composites, thin insulations and concrete composites — are representative of the design and installation flexibility sought in future industrialized housing systems.

Performance Specifications Performance specifications quantify projected and desired advances necessary to realize the systems of each design study. Figure 2 illustrates the range of performance specifications written for each scenario.

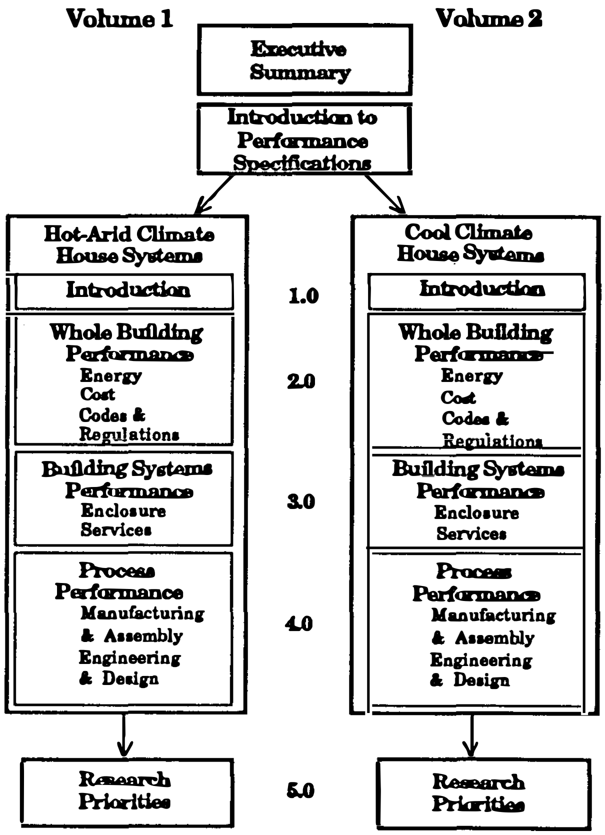

Figure 2
Overview of Performance Specification Scope and Organization

'Whole Building Performance Specifications' quantify performance goals for overall house energy use; cost, architectural design and, regulatory systems. 'Building Systems Performance Specifications' quantify performance goals for envelope systems (walls, roofs, floors, foundations and apertures), and service systems (heating, ventilation and air conditioning; water and waste; power, lighting and communications), 'Process Performance Specifications' quantify performance goals for design and manufacturing systems.

Research Priorities The Design for Energy Efficiency task generates research priorities — an agenda of short and medium term research and development activities directed toward a long term vision. Designation as a research priority is a function of the degree to which the likely outcomes of the research meet criteria in evaluation areas of feasibility (technical, operational and regulatory measures), marketability (measures of cost, value and consumer fit), investment opportunity (measures of probable interest to collaborators and co-sponsors) and the common good (measures of contribution to the environment and public interest).

2.0 The Hot Arid Climate Scenario

Of the two scenarios advanced to systems performance specifications, the hot arid scenario is directed toward passive heating and cooling strategies suited to the higher densities and low first cost typical of the lowest strata of the homeownership market in the United States. In this scenario, concrete panel building systems are investigated for opportunity to significantly advance the design flexibility and manufacturing economy of thermally massive construction. The dense site plans of attached houses possible with these systems offer lower land and site infrastructure costs per unit, increased opportunity for public transportation, reduced heat transfer through common walls as well as opportunity to amortize service system costs over multiple units.

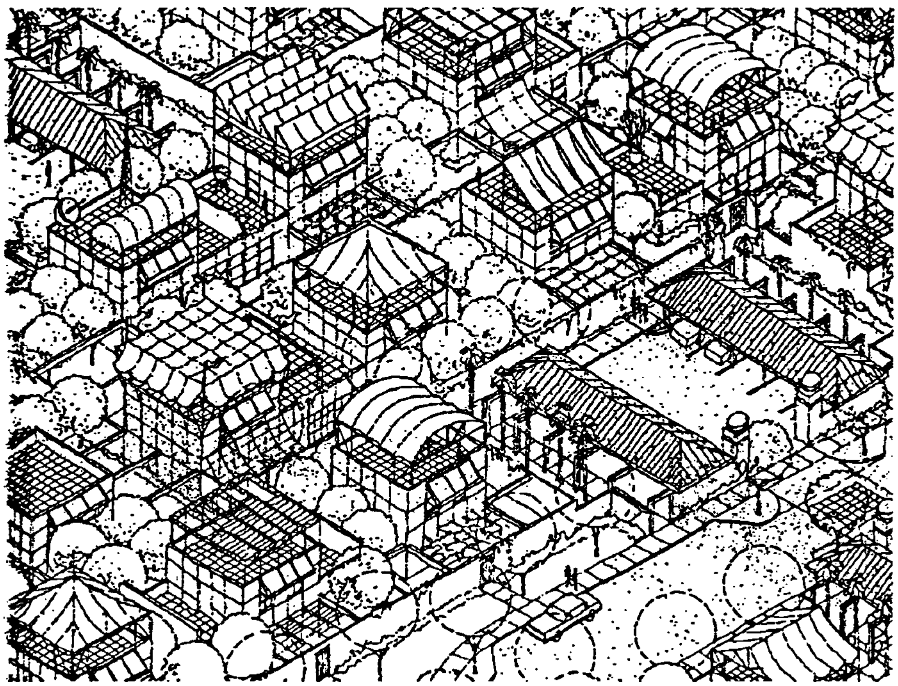

Figure 3.
Illustrative Axonometric of Hot Arid Scenario Site Design Performance Goals

Business Structure The housing delivery system assumed in this scenario is that of a vertically integrated housing company — one that integrates management of the entire delivery process from sales to production. This business specializes in multiple unit applications of concrete panel systems and markets at other price

ranges and densities beyond that defined in this scenario. Such projects demand a business with the ability and capacity to manage the technical, financial and regulatory expertise and complexity of larger scale development, streamline development costs and make volume purchases of materials and components.

While vertically integrated in project management, such a company does not necessarily provide all services 'in house' and collaborates or subcontracts with a range of suppliers, service providers and professionals familiar with their system. Since many units are defined and delivered at the same time, the company is able to control most aspects of project planning, design and implementation. Economic advantages are anticipated at a variety of points and scales in this process. Design, engineering, financial and legal services, for example can be coordinated to optimize levels of service and cost on a project by project basis.

2.1 Whole Building Performance Specifications

Whole Building Performance specifications establish performance goals for design, energy, cost and regulatory change. Of these, portions of design performance including site (Figure 3) and house (Figure 4) scale systems, energy and cost are excerpted below.

Site Design Housing from systems developed in this scenario are intended to achieve densities of 20 dwellings per acre (50 dwellings per hectare) with reductions in road, parking and utility infrastructure. Houses can be attached or grouped in duplex, rowhouse, courtyard or cluster site plan variations. Every household is provided access to site energy sources. Houses, secondary structures and plantings temper the climate of outdoor living areas.

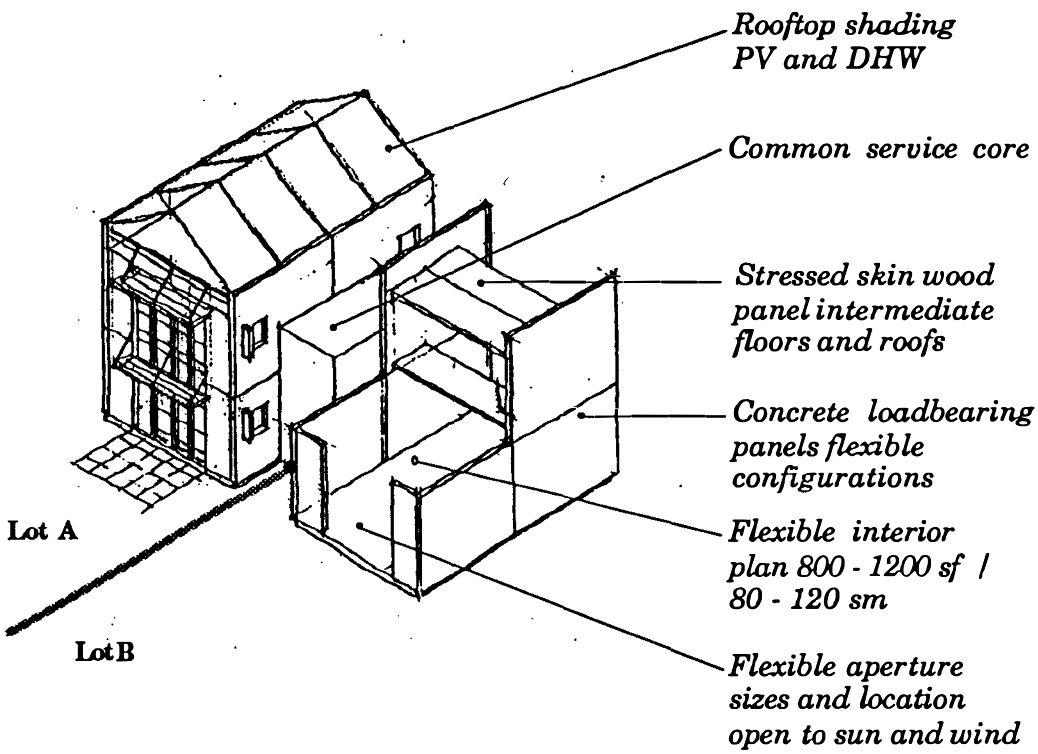

Figure 4.

Illustrative Axonometric of Hot Arid Scenario House Design Performance Goals

House Design Systems specified in this scenario are intended to achieve houses of two three stories with typical floor plans of 800 — 1200 ft² (80 — 120 m²). All houses allow ground to sky ownership but may vary in size, configuration, roof form, intermediate floor location, interior partition layout, window size and location. Perimeter loadbearing structure facilitates orientation of major rooms and openings to sun and wind. Expansion and remodeling can be undertaken by users working in small increments with widely available materials, tools and skills.

Energy To accelerate the rate at which energy efficient technologies emerge in this research area, a performance goal of zero net energy consumption was established for all scenarios. That is, housing systems specified are intended to be able to produce, on an annual basis, an amount of energy equal to its consumption. In this scenario, utility distributed electrical energy demand is balanced by on-site generation from roof-mounted solar domestic hot water and photovoltaic systems. This performance goal is technically feasible now and anticipated to be economically feasible with design and manufacturing innovation and energy cost increases by 2030.

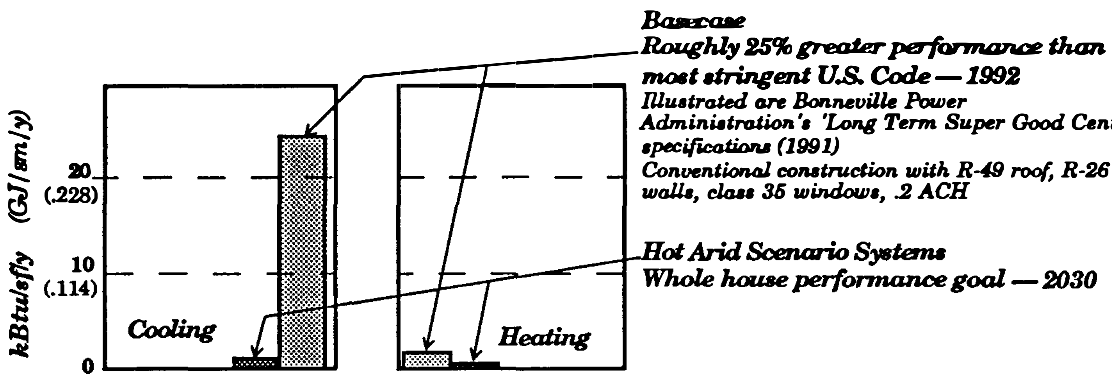

Figure 5.
Annual Space Conditioning Load Goals for Mechanical Cooling and Fuel Heating
(CALPAS3 analyses of architecturally equivalent 1000 ft² (100 m²) designs)

Cooling dominates the anticipated annual space conditioning load (Figure 5). Natural ventilation in tandem with thermally massive materials and careful design, meets about 40% of the annual cooling load. These renewable energy strategies must be supplemented with mechanical ventilation and evaporative cooling to meet the remaining 60%. As illustrated in Figure 5, this represents a performance goal several times more efficient than the current EEIH research program goal.

Cost The lowest cost houses constructed from systems envisioned in this scenario are intended to be affordable to purchase and operate at 60% median household income. Were this goal to be met in 1986, the lowest cost house would be about $ 50,000 (US) or about 15% less than what was available in this housing

market that year (U.S. Departments of Commerce and Housing and Urban Development, 1989). To meet a comparable performance goal in 2030, systems described in this scenario are intended to reduce development costs (land, infrastructure, design, fees, overhead etc.) by approximately 15% while maintaining construction costs (labor, materials etc.) stable as a percentage of delivered whole house cost.

2.2 Building Systems Performance Specifications

Building Systems Performance specifications establish performance goals for house enclosure and service systems. Enclosure systems (Figure 6) include wall, floor, roof, foundation, and aperture systems. Service systems include (Figure 7) heating, ventilation and air conditioning, water and waste, and power, lighting and communication systems. Of these, portions of wall, floor, roof, foundation, and heating, ventilation and air conditioning system specifications are excerpted below.

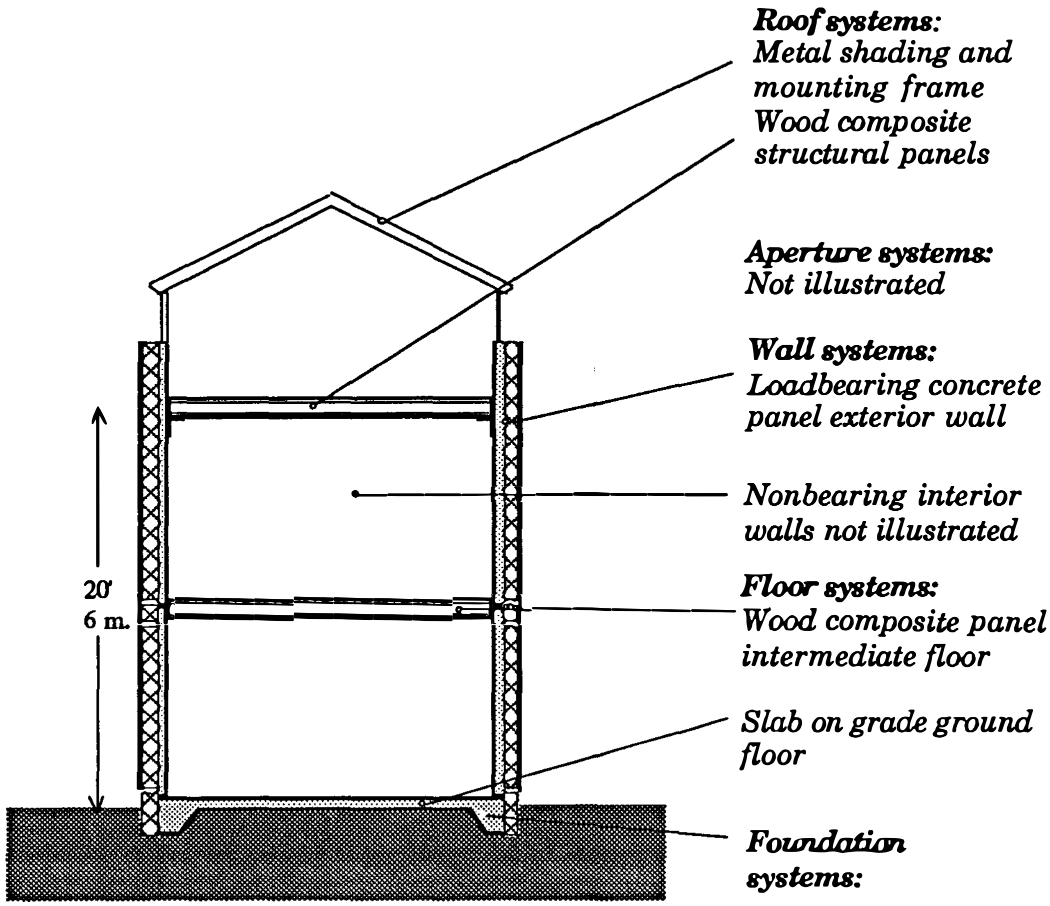

Figure 6.
Schematic Section of Hot-Arid Scenario Enclosure Systems

Enclosure Systems Enclosure system specifications (Figure 6) set out to increase the ability of these materials and assemblies to capture and utilize renewable energy sources without production cost increase. Loadbearing wall elements, for example, are volume manufactured concrete sandwich panels with the following performance specification: An inner whythe of fiber reinforced concrete is

bonded to an outer whythe of rigid insulation of R30 (5.30 m^2 K/W). The concrete mix is engineered to reduce weight to 80 lbs / ft^3 (1280 kg / cm) and to reduce conductivity while increasing thermal storage capability.

Panels are manufactured in sizes of — 8 - 10 in. (200 - 250 mm) thicknesses, 8 - 10 ft. (2.4 - 3 m) widths and 10 - 30 ft. (3 - 10 m) lengths — for material handling and design flexibility. A range of optional interior and exterior coatings and claddings are anticipated. Joints are detailed for assembly, disassembly, and control of moisture and heat transmission. Services are routed within the thermal envelope.

A site cast slab on grade foundation system anchors the house, resolves gravity loads, lateral loads and soil settlement, and provides a setting out platform for wall panels and subsequent construction. Each house and site is unique in design and geological conditions and each foundation must, in turn, adapt to these conditions. Structural performance requirements in most situations, however are low and shear reinforcement is seldom required. Slabs are typically 4 in (100 mm) thick of a concrete mix engineered to reduce conductivity and enhance thermal storage capabilities.

Intermediate floor and roof systems are lightweight stressed skin panels of wood composite material and, where required, insulation up to R40 (7.00 m^2 K/W). Both roof and floor panels are manufactured in a range of thicknesses, 4 - 8 ft (1.2 - 2.4 m) widths and lengths up to 20 ft (6m) to bear on perimeter loadbearing walls. Joints are detailed to control heat, air, and water vapor flow, rain penetration, sound and fire, and to facilitate field assembly and disassembly. Connections to wall panels maintain envelope structural and thermal continuity. Service distribution systems are accommodated within chases. Both roof and floor elements accept a variety of interior finishes and can be remodeled or repaired with hand tools.

Roof panels are manufactured to provide opportunities for terraces, decks, exposed ceilings, two story spaces, skylights,and dormers. A variety of claddings, including tile, shingles, sheet roofing and decking are provided. Above the panel roof system, an optional metal frame system supports shading, solar domestic hot water and photovoltaic systems. A variety of fabric, screen or lattice materials can be attached to this frame to shade outdoor spaces and the insulated roof surface. These shapes and materials also afford wide design variety to an otherwise undifferentiated, repetitive roof form.

Aperture systems include all windows, doors and openings intended to admit daylight and natural ventilation to living spaces. Minimum Daylight Factors specified include: 3.0 % to provide 30 fc (300 lux) average illumination in kitchen and home work spaces; and, 2.0 % to provide 20 fc (200 lux) average illumination in bedrooms, living and dining areas. Glazing is specified to achieve visible transmittance greater than .70; emissivity less than .05; UV transmittance less than .05; and sound transmission losses greater than 32 dB. Window units are specified to achieve overall U values less than .10 Btu/hr. ft^2 °F (.568 W/m^2 K) and infiltration rates less than 0.37 cfm / ft (0.57 L/s / m) of sash crack.

Service Systems Service system specifications (Figure 7) acknowledge the

renewable energy opportunity of enclosure systems and significantly decrease the number, size and capacity of utility dependent services in a house. Among the strategies pursued are flexible, common service centers intended to amortize the cost, maintenance of operation of HVAC systems, water and waste systems, and power and communication systems over two or more dwellings.

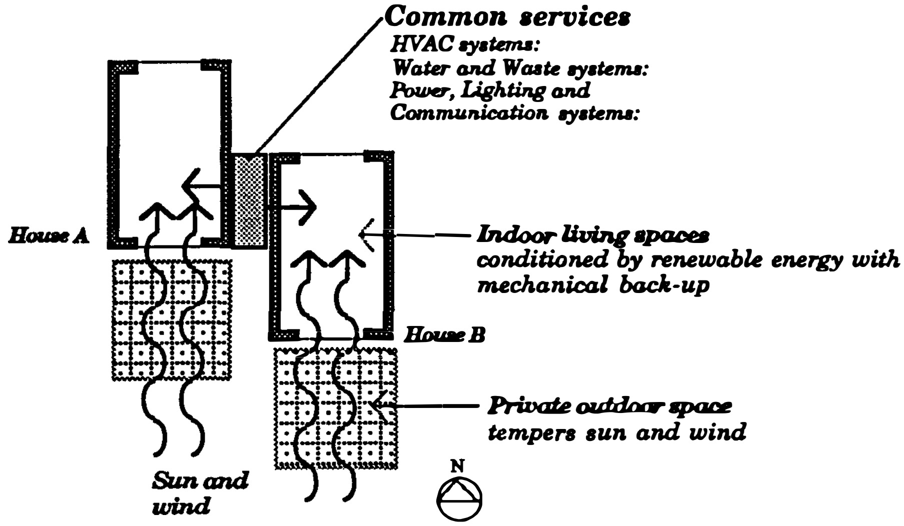

Figure 7.
Schematic Plan of Hot-Arid Scenario Service Systems

A range of shared HVAC system options, for example, can be accommodated in cores, common walls or remote distribution centers. Selection of a particular alternative will vary with site planning, design, first cost, operation and performance priorities established on a project by project basis. In one alternative studied, a duplex core installed example system at an 80 °F (26.6 °C) setpoint would be required to meet an annual mechanical cooling load of 700 kBtu (738.5 MJ) and peak loads of 9.4 kBtu (9.9 MJ) in a 1000 ft² (100 m²) house with one common wall. If envelope systems maintain similar low loads across an acceptable range of design variation, less efficient, lower first cost equipment would meet this performance goal without significant increase in operating cost.

2.3 Process Performance Specifications

Process Performance specifications establish performance goals for design, engineering and manufacturing systems. Design systems (Figure 8) include specifications for integrated computerized processes of sales, site design, house design and description for production. Manufacturing systems include (Figure 9) production specifications for housing system components, manufacturing processes, facilities and management.

Design Design system specifications set out to decrease development, planning and design time and expense while increasing the complexity of information considered and managed in design decisions.

Among the performance goals of this design process specification are computerized hardware and software technologies to network marketing, sales, deign, engineering, production and management areas with each other and to a

variety of external suppliers, regulatory institutions and financial services. Energy performance is intended to be considered and evaluated throughout this process using design and evaluation tools fully integral with the graphic, object oriented programming languages anticipated to characterize these networks in the future. Project feasibility phases in particular are specified to evaluate renewable site energy sources in parallel with design, economic and regulatory parameters considered in early phases of project definition and site planning.

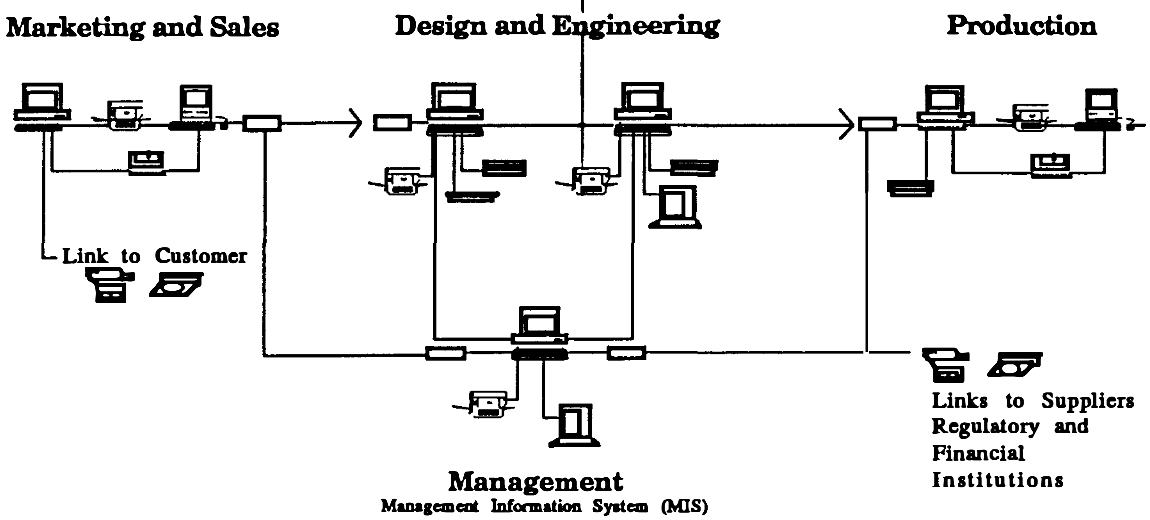

Figure 8.
Design Process Systems Schematic

Manufacturing Manufacturing system specifications set out to decrease the manufacturing and material handling cost of concrete and stressed skin wood panel systems while increasing the quality, flexibility and range of design variation possible.

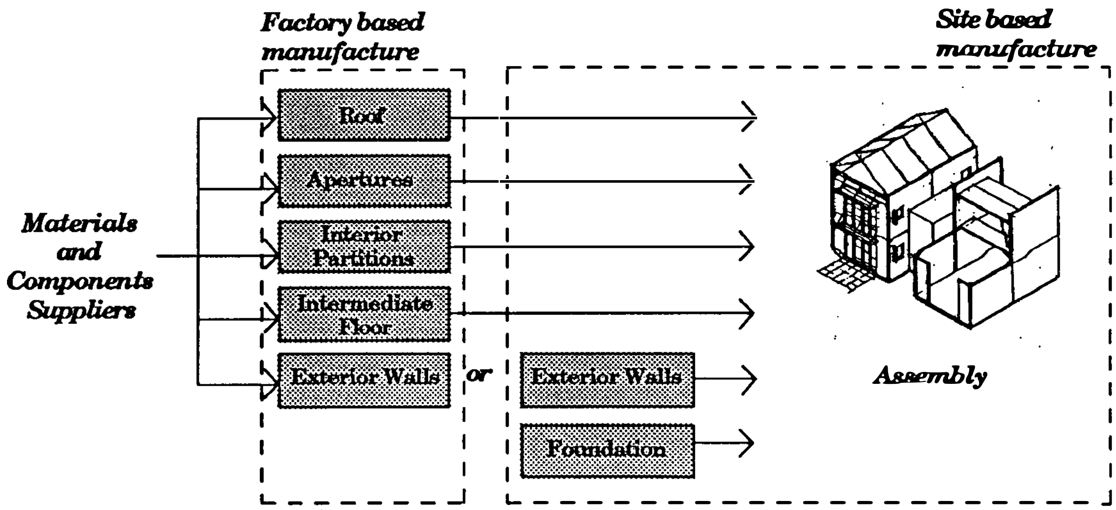

Figure 9.
Manufacturing and Assembly Process Schematic

Among the performance goals of this manufacturing process specification are

production rates in excess of five houses per day with site or factory production options for concrete elements. Systems developed for the manufacturing facility are intended to realize a range of design and product options with flexibility in production rate and volume. Facility size, processes, operations and personnel allocations are configured to expand and contract accordingly. Computer aided process and manufacturing resource planning systems are specified to achieve a continuous flow, just-in-time manufacturing system based on hybrids of automated, mechanized and manual techniques and tools.

3.0 Research Priorities

Among the promising future systems, technologies, design strategies and production processes envisioned in this scenario, several begin with research that can be initiated today as short (one to one and a half years) and medium term (two to four years) research and development activities at the instigation of the U.S. Department of Energy in collaboration with institutions and industry.

Examples of proposed priorities within the scope of topics covered in this paper include:

- *Prototype a design and manufacturing technology for a flexible, low cost service distribution center .*

- *Prototype a design and manufacturing technology for a product line of lightweight, low cost, thermal storing concrete sandwich panels .*

- *Prototype computerized design process tools to evaluate site scale energy conservation strategies at early stages of design process.*

- *Prototype computerized service system controls to manage power demand and performance of shared residential space conditioning equipment.*

- *Develop a system to integrate shading and solar energy systems with roof systems in high density site situations.*

- *Develop integrated finish materials to improve the peak load characteristics of concrete panels.*

- *Develop a device or system less than costly than a crane to place large panels and bulky materials on construction sites.*

Subsequent to this writing, these and other research priorities developed in the 'Design for Energy Efficiency' task area will be discussed and evaluated with representatives of government, the national research laboratories and industry. For those priorities selected for further development, a technical plan of research objectives and methodologies will be established and submitted for implementation.

4.0 Acknowledgements

Work described in this paper was co-authored with Mark DeKay, Brook Muller, Donald Peting, Rudy Berg, G.Z. Brown at the Center for Housing Innovation at the University of Oregon and, Michael Mullens at the Department of Industrial

Engineering and Management Systems of the University of Central Florida. Technical consultation was provided by Subrato Chandra of the Florida Solar Energy Center, Robert DeVault of Oak Ridge National Laboratory, Waqidi Falicoff of the Logic Handle and, Francis Rubinstein of Lawrence Berkeley Laboratory. Design studies for the hot-arid house were provided by Pliny Fisk III and Richard MacMath of Sustainable Design Associates, Austin, TX; Michael Pyatok, William Pettus and Daniel Koch of Michael Pyatok Architect, Oakland, CA; and Ronald Kellett, Brook Muller, and Patrick Gay of the Center for Housing Innovation at the University of Oregon, Eugene, OR.

5.0 References

1. KELLETT, R., DEKAY, M., GAY, P., MCGINN, B. J., BROWN, G.Z., HUBBARD, G. MEACHAM, M., SKALANGYA, G., and WILSON, C., Center for Housing Innovation, University of Oregon with MULLENS, M., University of Central Florida, 'Problem Statements for the 21st Century House' Energy Efficient Industrialized Housing Research Program, U.S. Department of Energy Contract No. DE-FC03-89SF17960, October 1990.

2. KELLETT, R., BERG, R., PAZ, A., and BROWN, G.Z., Center for Housing Innovation, University of Oregon with MULLENS, M., University of Central Florida, 'Progress Report: Design for Energy Efficiency' Energy Efficient Industrialized Housing Research Program U.S. Department of Energy Contract No. DE-FC03-89SF17960, March 1991

3. KELLETT, R., DEKAY, M., MULLER, B., PETING, D., BROWN, G.Z., and BERG, R., Center for Housing Innovation, University of Oregon with MULLENS, M., University of Central Florida, 'Systems and Technologies for a Multifamily Concrete Panel House in a Hot-Arid Climate' Energy Efficient Industrialized Housing Research Program, U.S. Department of Energy Contract No. DE-FC03-89SF17960, July 1992.

4. KELLETT, R., DEKAY, M., MULLER, B., PETING, D., BROWN, G.Z., and BERG, R., Center for Housing Innovation, University of Oregon with MULLENS, M., University of Central Florida, 'Systems and Technologies for a Single Family Wood Composite Frame and Thin Insulation Panel House in a Cool Climate' Energy Efficient Industrialized Housing Research Program, U.S. Department of Energy Contract No. DE-FC03-89SF17960, Forthcoming, 1992.

5. U.S. DEPARTMENT OF COMMERCE (Bureau of the Census) and U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT (Office of Policy Development and Research), 'Amercian Housing Survey for the Phoenix Metropolitan Area in 1985', Current Housing Report H-170-85-12, August, 1989.