GLOBAL WARMING, COMPUTERIZED DESIGN TOOLS AND INDUSTRIALIZED HOUSING

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ABSTRACT

This paper reviews the author's and his associates' current research in the areas of global warming, computerized design tools and industrialized housing. The global warming study for buildings in the United States concluded that annual cooling loads will increase at a much greater rate than heating loads will decrease; the timing, magnitude and duration of short term changes, peaks, is as large a concern as the sheer magnitude of the large annual changes in demand due to global warming.

This paper also describes ongoing research on the development of user interfaces for energy software to be used by building designers. In order to develop interfaces, the unique characteristics of the building design process must be understood and used in the creation of software. The two characteristics discussed are (1) that the architectural design process emphasizes synthesis rather than analysis and (2) that the symbols used to transmit knowledge are primarily graphic abstraction, rather than alphanumeric abstractions.

In the United States, housing is becoming increasingly industrialized. At the same time, the need for energy efficiency in housing is increasingly apparent. We are studying how to produce new housing that offers improved energy performance, and uses industrialized production to achieve higher quality at lower cost. The research focuses on three related concerns: energy conservation, industrial process, and housing design.

INTRODUCTION

This paper reviews current research being conducted by the author and his associates at the University of Oregon, University of Washington, the Florida Solar Energy Center and the University of Central Florida. The common theme that runs through all the research work is how and why buildings use energy and how they should in the future. Much of the work is also future oriented attempting to address problems that are on the horizon rather than those in full view. The three research areas discussed are global warming, computerized design tools and industrialized housing.

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GLOBAL WARMING

This study (Loveland and Brown, 1990) is an analysis of the effects of global warming on the energy performance on a population of residential and commercial building in the United States. Building descriptions as generic building energy demand types were created. The physical characteristics of these building types were based on American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) 90.1 prescriptive *whole-building* energy performance standards. These generic building characteristics define the building's skin and internal energy requirements. This array of heat transfer characteristics forms the basis for the description of a representative range of building energy-use types. These building skin and internal energy-use characteristics were graphed and clustered into larger representative categories of energy use. Clusters representing both commercial and residential occupancies were analyzed. Specific types were chosen to represent each cluster. Representative cities of regional climate zones were chosen to guide the climate specific architectural characteristics of the representative building types.

Building types representing energy use clusters were chosen for computer modeling. *Annual* energy simulation of the representative buildings in the cities representing each climate region was performed by *hourly* simulation software. These simulations indicated changes in energy demand both on an hourly peak and seasonal basis. These energy demand changes provided information which revealed the design strategies that maintain standard comfort ranges while holding energy requirements to a minimum. These design strategies formed a basis from which building design and energy-use was assessed. The computer-based projections of changes in building energy demand were based on the climate change scenarios specified by the Office of Technology Assessment of the U.S. Congress (OTA), and were provided by the Goddard Institute for Space Studies (GISS) through the National Center for Atmospheric Research (NCAR).

This method of assembling a mean set of buildings based on average building characteristics that are representative of a broad range of building types was necessitated by the very limited time frame of the study. These specific expedient methods were chosen so as to produce *conservative* results. That is to say, if a more lengthy and precise study were undertaken, we believe the results would indicate less energy use by the new set of buildings, rather than more energy use. We chose to utilize the newest proposed energy use standard for building construction as the design base line for energy conservative construction. Thus, our results will be indicative of a 1989 code-compliant state-of-the-art, homogeneous building design population. We felt that in the intervening 50 years framed by the study and defined by the GISS climatic scenarios, and given difficulty in predicting design changes and life spans of today's buildings, the code-compliant state-of-the -art building of 1989 would most likely become the standard or mean of 2040. We have chosen assumptions that defined a population of buildings for analysis that in the year 2040 will be seen as neither state-of-the-art energy conservative nor energy gluttons.

We used CALPAS 3 as our simulation software. Berkeley Solar Group which supports CALPAS 3 supplied hourly weather tapes for doubling (2 x CO_2) the carbon dioxide units in the atmosphere as described by the National Center for Atmospheric Research and the Goddard Institute for Space Studies. We selected six climates to study represented by the cities Charleston, South Carolina, Fort Worth, Texas, Knoxville, Tennessee, Chicago Illinois, Minneapolis, Minnesota and Seattle, Washington. These cities represent future growth areas and a mix of climates -- cold, cool-humid, hot- arid and hot-humid.

We characterized the types of building in the United States to determine their number, location and energy use characteristic. Upon completion of the building characterization process, it was necessary to cluster the data to narrow the range of types for in-depth simulation. Our goal was to limit the number of building examples so that the final set would represent: a) significant portions of national building stock, b) the range of common energy-load characteristics, and c) buildings with easily modeled occupancy scheduling and other internal loads.

For purposes of clustering data, each building was described in terms of Internal-Load Factor and Envelope-Load Coefficient. The Envelope-Load Coefficient represents the combined effects of skin loads and infiltration for each simulation model. The Internal-Load Factor represents the sum of internal loads (people, lights, and equipment) as determined from ASHRAE 90.1P. The Internal-Load Factor was represented both in terms of the (daily) Averaged Hourly, and the Maximum Hourly summation of internal loading.

Mercantile/Retail -- The retail building as a representative of the Internal Load Dominated Building category represents the largest portion of the commercial sector of buildings, and had the second highest level of internal heat generation while it was occupied. It was second only to Assembly buildings, a much more inconsistently categorized set of buildings with a much smaller proportion of the population of commercial buildings.

Cooling was the predominant thermal energy load for the basecase building in all six cities' 1 x CO2 (non-warmed) climate. Thus, with the 2 x CO2 (warmed) climate, the cooling requirements become even more dominant. In the hot or warm climates of the south and southeast, the annual cooling demands increase between 35% and 45%. In the cooler climates of the north, annual cooling demands increase from 40% or 75%. The predominant cooling load varies with climate region. In cooler climates, the heat generated from electric lights is a dominant load, while in hotter climates, the effects of the extremely hot exterior temperature and heat gain from sunlight dominate the cooling requirements. In all cases, a combination of reducing the internal gains from lighting, the addition of building insulation and the reduction of heat gains from the sun can bring the cooling requirements of the building type back to present levels.

Small and Large Offices -- Office buildings were chosen as a simulation type because of their thermal similarity to the majority of other commercial building types. Secondly, they directly represent the second largest proportion of commercial buildings.

Similar to the Retail type, cooling was the predominant thermal energy load for the basecase building in all six cities' 1 x CO2 (non-warmed) climate. Thus, with the 2 x CO2 (warmed) climate, the cooling requirements become even more dominant. In the hot or warm climates of the south and southeast, the annual cooling demands increase between 35% and 45%. In the cooler climates of the north, annual cooling demands increase from 40% to 75%. The predominant cooling load varies with climate region. In cooler climates, the heat generated from electric lights and the heat gained from solar radiation are dominant loads, while in hotter climates, the thermal effects of interior illumination are much less significant than the effect of the extremely hot exterior temperatures and heat gains from sunlight. In all cases except Seattle, a combination of reducing the internal gains from lighting, the addition of building insulation and the reduction of heat gains from the sun can bring the cooling requirement of the building type back to present levels.

Single Family Detached Dwelling -- This building type represents the "house" as represented by nearly 74% of the population of residential living units. On a per square foot basis, the thermal characteristics of the "house" cluster well with all the other residential types except the mobile home. Thus, this is an absolutely dominant prototype. There are questions as to the depth of penetration of "air-conditioning" into this type as the climate warms. This is particularly true of regions like the Northwest where mechanical cooling is not typical.

As one might suspect by this building type's definition, the dominant thermal energy load for the single family detached dwelling correlates well with the thermal character of the climate region under analysis. Thus, in the hotter climates the dominant load is cooling by as much as a 4:1 margin. In the middle latitudes of the United States where the climate is evenly both cool and warm, the energy loads are equally split. In the northern climate regions the heating loads outweigh the cooling loads by as much as 7:1, as can be seen in Seattle.

While the thermal energy loads were wide ranging under the 1 x CO2 simulation, there was a shift to cooling as the dominant thermal load in all climate regions except the most northern or cold areas. In the colder climates, the increases in energy demand for cooling are more than offset by decreases in heating requirements. Therefore on an annual basis, energy use is decreased under the "warmed" climate scenario. Under closer inspection, the cooling loads for these climates are up between 84% in Minneapolis and 146% Seattle. This is indicative of a large proportional increase in a figure which is originally small. This relative small proportional increase should not be overlooked because of its absolute magnitude. In areas where electric utilities have peak summer loads, the proportional increase in demand may be a better indicator of future energy concerns than the absolute increase. In climate regions generally as warm or warmer than Chicago, the increases in annual cooling requirements are between 56% in Fort Worth and 87% in Chicago. These are extremely large absolute and relative magnitudes of increase in rates of cooling demand in some of the fastest growing regions of the United States.

The increasing thermal energy load for all locations is for cooling. Increasing the insulation of the building, shading it from the effects of the direct rays of the sun are two strategies simulated in this study. Neither strategy can reduce the effects of the overall warming to a prewarming level. Other strategies such as seasonal thermal storage, higher levels of thermal mass within the building shell, evaporative cooling, and night heat flushing may reduce energy demand. However they were beyond the scope of this study.

There are three general conclusions that can be drawn from this study.

1. The annual cooling loads in buildings will greatly increase in all building sectors and in all climate regions of the county. There is a corresponding decrease in heating loads due to the climate warming, but this decrease does not compensate for the increase in cooling demand except in the coldest region of the United States, and then only for the residential sector.

2. The timing, magnitude and duration of the individual changes in the energy demand of buildings is as important a concern as the sheer magnitude of the changes in annual energy demands. The changes in the timing and magnitude of demands, either annually or perhaps more importantly during peak hot climatic events will impact owners of buildings through additional demand charges, utilities through additional demand during limited resource periods, and designers and builders of buildings who will have to adapt their strategies of design and construction of buildings.

3. New methods of energy resource acquisition will have to be implemented to respond to the additional energy demands. The most difficult aspect of this problem may be in implementing the incremental measures to attain these resources between the present and the 2050 GISS Global Climatic Change scenario.

COMPUTERIZED DESIGN TOOLS

Building design is challenging because the artistic and the technical must be considered together. There is a significant interplay between analytic and synthetic thinking. Many individuals exhibit a stronger capability in one than in the other mode of thinking. Because of this difficulty in balancing the synthetic and analytic thought processes, few can design buildings that are both artistically and technically sophisticated. This situation has created a built environment that works but does not inspire or that inspires but does not work.

Building design is a creative process based on iteration: one begins by responding to a situation with an abstract idea. Then one objectifies the idea, by proposing a trial design, evaluates it, redesigns it, develops it, reevaluates it, and so on. The beginning is hardest for many designers. The designer must make a creative leap from abstract description to concrete visual descriptions that synthesize a vast array of widely varying quantitative and qualitative information. In preliminary stages of design, the designer must experiment with many general ideas and combinations of ideas. It is crucial at this stage that available information be suggestive of building form so that it can aid the synthetic process. However, technical information is rarely presented in a form that fits easily with generative spatial thinking. Most types of analysis tell you what you cannot do rather than help you generate ideas about what you might do. Also, most technical design evaluation techniques require that a building be completely designed before it can be evaluated. Experienced designers who are familiar with particular areas of technology, such as energy or earthquake analysis, develop an intuition about the building forms and organization that will work well both artistically and technically for those areas. However, architecture encompasses far more areas of technology than most individual designers can master, so technical considerations may be neglected in the early stages of design.

One frequently neglected technical issue is energy use in buildings. The amount of energy used in a building is a direct result of the climate, the building's use, and the building's form -- that is, its size and shape. But because of the large number of variables that relate climate use, and form, it is very difficult and time consuming to predict performance. Very often designers ignore the complexities of energy considerations in the early schematic design stages and concentrate on artistic or other considerations instead. By the time they are ready to evaluate the design from an energy standpoint, the design has progressed to a point where it is too late to make fundamental changes to the proposed building form.

The two specific problems that our research group has addressed in user interfaces over the past several years are: How to best support the designer's method of working in graphic abstractions and how to support the synthesis part of the design process. I will describe three user interface designs that address these problems (Brown 1990).

A Computer Tool for Preliminary Energy Design

What follows is a description of a user interface developed for software currently being beta tested in university and professional settings. This tool has conceptual and functional innovations that facilitate broad, effective, and sophisticated energy considerations at preliminary design stages. These considerations are extremely important because early form and organizational and operational decisions determine a building's loads and the extent to which mechanical and electrical systems may be optimized. In order for a building to reach its full energy conservation potential, it must be designed to reduce and appropriately schedule its loads before the mechanical and electrical systems are designed. This early consideration of energy in design sets the stage for energy to be considered throughout the project.

Energy software is frequently structured by relatively narrow energy concerns rather than broader architectural concerns. The program is compatible with a large range of architectural considerations because it is centered around drawing as the primary means of design investigation and its nonhierarchical organization allows the designer to concentrate on any aspect of the building design problem in any order. It supports a graphic method of design thinking and integrates its energy evaluations within this environment. The energy concerns do not structure or dominate the design investigation, allowing the designer to consider a full range of architectural issues.

A designer uses drawings during the design process to order information. For example, elements of building walls, finish materials, windows, doors, and roofs are remembered as a group in a category called "elevation". This is distinctly different from the way many programs order information, which is by categories such as windows, doors, or wall. In this system, windows from all elevations would be grouped together, disassociated from their related compositional elements. We use the architectural drawings that the designer creates to order information. So when the designer clicks on, for example, a particular elevation drawing drawer, all the specifications for windows, roofs, walls, etc. for that elevation are made available at the same time so they can be designed together.

In most energy software, the designer must describe the building in numeric abstractions such as R-values. Our software, on the other hand, emphasizes graphic abstractions. Energy information input is handled in two ways. (1) Locations and dimensional data, such as areas and lengths, are "taken off" directly from the on-screen drawings using graphic tools similar to those used to make the drawings. (2) The designer manipulates commonly used materials, such as brick, or assemblies of materials, such as walls, instead of specifying physical properties, such as conductance. In other words, the designer communicates with the program about architectural elements, rather than just energy-related elements. For example, walls are described in terms of their finish or structural materials rather than their R-values. This means that the designer can get an energy evaluation of a proposed design without putting in prematurely detailed or numeric descriptions of those building parts that are normally described in qualitative terms at early design stages. It is crucial that design tools consider issues in these terms, because conceptual design is done with visual abstractions.

A Sunlight Design Tool

This tool is designed to help designers with two aspects of window design -- where to place the window and how to shape it. The prototype deals only with sunlight penetration but has the potential to be applied to other window considerations such as ventilation and daylighting or other room criteria such as comfort. Several tools have been developed that show the sun penetration in a room once a window has been placed. We created a tool whose function is similar to these sun penetration tools but is conceptually very different. Using the sunlight design tool, the designer selects the spot on the floor where the sunlight is desired and the computer calculates where the window should be. In fact, it calculates and displays several window locations related to times and dates selected. What the designer sees displayed is a window "idea" that she would not have anticipated when she drew the light on the floor. The program is, therefore, form provocative to designers. It suggest ideas that were previously "invisible" to the designer.

Metaphors Prototype

The two interfaces that have been discussed, the preliminary energy design tool and the sunlight design tool, are a beginning step towards creating user interfaces that are both graphic and provocative. We have created another interface that is a step beyond those just described. This is a nonfunctional prototype, called Metaphors, intended to help the designer find the physical manifestation of an abstract thought. The first step in this method is to aid the creative leap from abstract to concrete by developing poetic word statements, like metaphors, similes, and analogies, which suggest spatial ideas or evoke images of three-dimensional forms.

To encourage designers to consider energy conservation in buildings, we use figures of speech that generate an image in which energy is a primary player. For example, when designing a building for a cold climate, we might say: "Arrange the rooms in the building like campers gathered with their packs around a fire on a cold night." This simile is evocative of energy-related concerns because it implies a climatic condition that should be designed for (cold), the location of a heat source (central), an arrangement of rooms (clustered), and the relationship of the rooms to the cold night (away from) and to the heat sources (facing). Certain buildings' energy-conserving response to cold is similar to a camper's response to cold so the building that is likely to result from this simile is appropriate for a cold climate. The simile also contains information that may add to the architectural richness of a design proposal. It suggests a community of rooms, a relationship to the landscape, the destination of a journey, a ceiling of stars, a quality of light, and a texture of materials. As a first step in this design method, the designer imagines a host of feelings and ideas that are suggested by the figure of speech that can carry over into a building idea. The designer then sketches a preliminary building design that is suggested by the metaphor and its rich associations.

Next, the designer applies a collection of metaphors, similes, and analogies to typical questions that arise in the design process, such as, "How should the major rooms be related to the storage rooms?" or "What are the possible ways of orienting the primary building axes?" By reviewing these questions in light of a powerful image, the designer can identify the most important organizational characteristics of the scheme.

Then, using variations on these primary characteristics, the computer can generate a matrix of related design alternatives. Within this morphological matrix, the designer can discover a scheme that is related to the original one but that satisfies a broader range of criteria or promotes a different understanding of the problem. Once an association has been made between a figure of speech and a building form or organization, the association can be reused with other building types to generate design alternatives.

Conclusion

The three example interfaces discussed all utilized primarily graphic abstractions to communicate with designers. The last two interfaces, sunlight tool and metaphors tool, present information to designers in a way that is provocative or generative of architectural form. By combining these two with the preliminary energy design tool, we believe it is possible to design interfaces for that will help architects visualize energy-conscious buildings they could not have imagined otherwise.

INDUSTRIALIZED HOUSING

This section will discuss the potential for conserving energy by using industrial processes to produce housing. The United States is undergoing a metamorphosis from site built to factory built housing, with more than half its current housing produced in a factory. The connection between industrialization of housing and energy efficiency is not causal. Japan, for example, produces highly industrialized housing which is energy <u>in</u>efficient, while Sweden produces housing that is both industrialized and very energy efficient.

Industrialization of U.S. housing production varies from mobile home builders who ship furnished houses *to* the site, to production builders who assemble factory produced components *on* the site. Such housing can be divided into four major categories: HUD coded (mobile) homes, modular houses, panelized houses, and production built houses. There are many hybrids of these categories.

The industrialization process has been defined as investment in equipment, facilities, and technology with the purpose of increasing output, saving manual labor, and improving quality. Successful industrialization is characterized by centralization of production, mass production, standardization, specialization, sophisticated organization, and integration of design, production, and marketing. There are important differences between the industrialization of buildings and other products -- mainly multiple building locations, long product life, little standardization, large numbers of different tasks requiring manual skills, large work areas requiring worker movement, harsh environment, high worker turnover and divided authority among the main players in the building business. It is important to realize that industrialization of housing implies many things beyond the standardization and mechanization of the construction process -- including increasing company size, increased resources available to foster innovations in sales, design and manufacturing processes, vertical integration of raw material processing, production, sales, land development and financing, increased market sensitivity, etc.

The most obvious examples of the connection between industrialization and energy is the use of energy efficient materials that can only be economically used in a factory like low emmisivity glass coatings or stamped steel doors (which control infiltration better over a long period). A second group of overlaps are related to material/assembly processes that can be done economically only in the factory. An example would be the Swedish thermal break "truss stud" which is too flimsy to economically erect in the field, but is easily done in the factory using jigs. Both materials and assembly affect the energy performance of the building's fabric. Another less obvious set of examples will result from an increase in company size, the need to provide customer design flexibility, standardization of parts and assembly procedures and increasing computerization. The customer will be able to design using the company's computer and construction system and get instantaneous feedback on first cost of construction as well as the amount of energy used to heat and cool the house and that energy cost.

U.S. Industrialized Housing

Our analysis (Berg, Brown, Kellett 1990) of the U. S. industrialized housing revealed two characteristics. The first is a general increase in degree of industrialization throughout the home building industry -- increasing use of factory-made components and more sophisticated tooling, with one result that value added per worker in the structural wood member industries has quadrupled since the early seventies. The second characteristic is an increasing in market share claimed by the more highly industrialized segments of the industry, the modular and panelized producers. From 1980 to 1989 their combined fraction of the market has risen from 34% to 42%. These characteristics suggest that U. S. housing is particularly susceptible to energy conservation through innovations based on industrialized approaches.

Computer Use

We determined the extent of software use in industrialized housing by a combination of literature search, phone interviews and site visits (Brown, 1990a). Computers' first penetrations into the housing industry were in component design and manufacture. This process began with computer generated engineering calculations for truss design and progressed to automatic lumber cutting procedures, jigging and truss plate attachment.

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

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

Manufacturing enterprises are increasingly automated. Research in the field of industrialized engineering is focusing on manufacturing process from business functions to design to inventory control. Because of the emphasis on the engineering function, many firms have already embraced computing in some aspect of their manufacturing process. Extensive research is being conducted at universities in the development of expert systems, computers modeling, and robotics with applications in manufacturing and construction. The U.S. housing industry is becoming increasingly industrialized. In the process, housing production is becoming more standardized and rationalized. Both standardization and rationalization have the potential to make computerization of the production process easier.

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

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

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

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

21st Century Housing

As a way to establish a vision for the future and identify the research tasks that are necessary to reach that vision we have started work on the design of the 21st century energy efficient industrialized house. We have recently completed the problem statements (Kellett, Brown et al 1990) for a set of four houses and we are currently designing them.

The four houses we have identified are:

STARTER HOUSE IN A HOT-AIRD CLIMATE

TYPE:	Multi-family attached units
AREA:	800 sf plus expansion
DENSITY:	12 - 16 units per acre
CONTEXT:	Fringe urban/suburban tract, Phoenix, Arizona
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:	5% more efficient than California Title XXIV Energy Code. 79% - 95% passive energy. No peak demand.
INNOVATIONS TESTED:	Hybrid of passive and unducted mechanically assisted air systems. Lightweight, manufactured thermal storage materials. Photovoltaic electricity generation. 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, Florida
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:	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. 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 of existing house; 500-600 sf addition
DENSITY:	Existing neighborhood of approximately 16 units per acre.
CONTEXT:	Urban neighborhood. Seattle, Washington
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 conserving specialties for renovation construction: Insulation finishes. Thermally broken framing. Retrofit window integrated heat pump. 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, Minnesota.
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:	High R-value compact vacuum insulation panels. Ductless air distribution and return. Factory integration of fragile high thermal performance panels with conventional construction materials.

Conclusion

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

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