ENERGY EFFICIENT INDUSTRIALIZED HOUSING RESEARCH PROGRAM

CONSORTIUM FOR INDUSTRIALIZED HOUSING RESEARCH

A JOINT INITIATIVE OF THE
UNIVERSITY OF OREGON
AND THE
FLORIDA SOLAR ENERGY CENTER

A Proposal for an

ENERGY EFFICIENT INDUSTRIALIZED HOUSING RESEARCH PROGRAM

From the

CONSORTIUM FOR INDUSTRIALIZED HOUSING RESEARCH

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INTRODUCTION

New homes built in the United States use substantially more energy than similiar homes built in Sweden and Denmark. This is because residential construction in these countries is industrialized and homes utilize designs and manufacturing processes which emphasize energy conservation. Most homes in the U.S., in comparison, are still stick built on-site by small builders who cannot economically take advantage of the energy conserving designs and processes available in industrialized construction. This results in continuing high energy demand, making home ownership more expensive and leaves the U.S. housing market vulnerable to foreign companies offering more energy efficient industrialized housing.

Important reductions in residential energy use has resulted from DOE sponsored research on individual components which have been incorporated into traditional building practice. However, DOE programs have neglected one construction sector which offers even greater potential for energy-saving improvements and promises to provide an increasing share of the residential market: industrialized housing. We expect the industrialized housing research program to produce housing designs that are at least 25 to 30% more energy efficient with no increase in production costs.

Industrialized housing includes all manufactured goods from building components to complete houses developed through a factory production process. The term comprises component-scale elements (such as trusses and precut walls), intermediate-scale elements (such as finished, wired and plumbed wall panels) and large-scale elements that include whole room modules and complete houses. This definition of industrialized housing includes "factory built/manufactured housing," or mobile homes, but is not limited to the appearance, dimensions or quality of construction and finishes commonly associated with mobile homes.

The U.S. home building industry is also moving toward industrialization and about half the houses now being built use some factory-built parts. However, most U.S. manufacturers are small compared to their foreign counterparts. They employ traditional, not advanced technology methods, such as the robotics used by house manufacturers in Japan. Industrialized housing is likely to be the wave of the future and it is important that research be completed to insure that it is energy efficient.

This proposal outlines the joint interest of the University of Oregon and the Florida Solar Energy Center in establishing an energy efficient industrialized housing research program. The Oregon - Florida Research Consortium will have coordinated national agenda and a regional focus. The program will be a combined effort of the U.S. Department of Energy, the two state governments and the residential construction and building products industries. The purpose of this document is to explain the potential and importance of energy conservation in industrialized housing and to outline several benefits to the United States when a federal, state and industry supported research program is established. If properly designed, energy efficient industrial housing can help address other major housing problems such as affordability, foreign competition, employment, housing quality, and increased product export.

POTENTIAL FOR SAVING ENERGY

Energy use in residential buildings in the U.S. seems extravagant when compared to that of other industrialized countries with similar standards of living. These countries use energy efficient technologies such as industrialized housing that could be adapted and developed for use in the United States. The Department of Energy's Energy Research Advisory Board pointed out that because "buildings represent a complex interaction of thermodynamic processes, an integrated systems approach is necessary to expose the more significant opportunities for energy savings. Past DOE programs have emphasized the development of individual energy technologies and materials with less regard to the integration process in whole buildings... Integrated system studies, of course, complement and guide R&D on individual technologies; they are not substitutes for them."

The national benefits from this program could be substantial if industrialized housing realizes its potential to provide good quality, energy efficient housing at a reasonable price. The United States is less successful than several other industrialized countries in conserving energy in residential buildings. While we decreased energy use in residences by 20% between 1973 and 1980, the average Swedish home still consumed 35% less energy than the average U.S. home in 1980. If industrialized housing were 30% more efficient than current site-built houses and captured approximately 50% of new housing starts, the energy savings could be roughly 250 trillion BTUs by the year 2000. These savings would continue to accrue over the life of the houses.

Energy conservation achievements in housing to date have come from the combined effects of new energy codes, improved building technology, public energy policy, and increased personal awareness of energy use. The practical potential of many of these readily available methods of conserving have been exhausted and we need to look at more innovative approaches.

Industrialized housing has tremendous potential to help the United States create an energy efficient housing stock. While industrialized housing touches on many research areas and can address a broad spectrum of housing issues, its foundation is in energy research. Without such research, industrialized housing could well follow the pattern of the mobile housing industry in the United States and produce relatively energy inefficient homes. Most residential energy research has been based on site-built construction practices and must be modified to apply to industrialized housing. The potential for industrialized housing to conserve energy by using new materials, such as selective coatings, and new assemblies based on controlled factory conditions has not been explored in the United States. For example, infiltration, a major source of energy use, could be greatly reduced by developing better joints between walls, roofs, and floors based on factory tolerances rather than field tolerances. Building walls and windows together makes it possible to eliminate the crack (and the need to fill it) that usually exists between a rough opening and a manufactured window. This would reduce infiltration, save material by not duplicating structure in the wall and window, and reduce window installation time.

A Department of Commerce article on prefabricated housing described a major factor in the efficiency of Swedish houses: an air and vapor barrier, a .2 mm. polyethylene membrane, which is installed before the innermost layer of framing. It states that, "penetration of the membrane for wiring and plumbing is avoided, since all the necessary installations are within the innermost framing. The factory setting allows for careful sealing around windows and doors."

DEPARTMENT OF ENERGY ACTIVITIES

The Department of Energy has sponsored research to reduce residential energy consumption, which comprises 21% of U.S. energy use. Before 1975, most U.S. homes used more than 10 BTU/^{o}F/Ft^{2}, but new homes now use approximately 5 BTU/^{o}F/Ft^{2}. This dramatic cut in energy consumption was possible in part because of successful DOE programs such as window research. The DOE's Energy Research Advisory Board believes that the U.S. can further improve energy efficiency. In countries with coordinated energy programs, home energy use is substantially below that of the U.S. When adjusted for climate and size of homes, for example, the average home heating energy use in Sweden is 2/3 that of the U.S. and Danish homes perform almost as well.

Most energy conserving innovations in industrialized housing have focused on heating, infiltration, and ventilation. There is a need in the United States, however, to also examine potential reductions in cooling. The U.S. housing stock has changed dramatically since 1966 when 25% of new single-family homes had air-conditioning, to 1983 when almost 70% did.

AFFORDABLE HOUSING

The cost of housing has been increasing dramatically, making home ownership difficult for many. In 1973, the average household allocated just over 22% of its gross income for purchasing a home; by 1983, the figure increased to almost 34%. If the U.S. economy continues to shift from an industrial to a service-based economy, wage levels could severely restrict the ability of working class families to afford housing. Land prices have also increased from 11% of total project cost in 1949 to 24% in 1982. Future housing developments may include fewer single family detached homes and more attached medium density projects.

The benefits of energy efficient industrialized housing accrue to all classes of home owners from individual citizens to the military. Savings will include lower initial costs for heating and cooling systems as well as lower utility rates. The Office of Technology Assessment estimates that a savings of 11% in the cost of housing is possible immediately by applying known technology to site-built housing. In addition, the residential construction industry accounts for 8% of the gross national product and affects most segments of the economy. Increasing housing starts would have beneficial effects throughout the economy.

U.S. AND FOREIGN HOUSING INDUSTRIES

The U.S. housing industry has remained a craft industry, using traditional "handmade" skills. There has not been much transfer of the tremendous technological developments in other industries to the housing industry. One result, unfortunately, is the decreasing productivity of construction workers. Since 1977, levels of productivity have actually declined by almost 20%.

Housing is not a concentrated industry: in 1983, the 20 largest home builders produced only 8% of total housing production and relatively small contractors accounted for about 59% of housing production. Because of its structure and the cyclical nature of the housing industry, very little research and development is promoted by the construction industry. Management of the housing industry is similarly fragmented. Traditionally, the industry is divided into design, construction, development, sales, and financing companies that are not integrated. This limits innovation within the whole housing delivery system. By contrast, Swedish housing companies are vertically integrated with design, fabrication, erection, sales, and financing combined in a single corporate entity.

Foreign industrialized housing has made significant progress over the past several years and now poses a potential threat to the domestic housing industry. The need to replace housing destroyed during World War II in Europe and Asia led to a vigorous industrialized approach to housing production. Experience with the application of advanced technology to housing has resulted in significant innovations in single family housing construction, especially in Sweden and Japan. To this was added a commitment to conservation to reduce energy imports and vulnerability in the 1970s.

INTERNATIONAL COMPETITIVENESS

The Swedish housing industry is probably the most advanced and represents the most immediate threat to conventional U.S. housing markets. Three government policies have determined development of the "factory-crafted" housing industry in Sweden. They are 1) a resolve that adequate housing is a fundamental right of all citizens; 2) a commitment to eliminating reliance on nuclear energy by the year 2000, which led to strict residential energy goals; and 3) consumer production concerns mandating 10 year guarantees on all industrially-produced goods, including housing. To satisfy these policies, the housing industry has had to develop very high standards of construction quality, which is more readily attainable in a factory environment. Industrialized single family housing has expanded in Sweden from 60% of the market in 1971 to 90% in 1983. Swedish factory-crafted housing has successfully entered the markets of Europe and the Middle East and is currently testing the U.S. housing market. While the cost is quite high, partially because of the fall of the dollar, foreign manufactured housing could have substantial potential in construction and wood products industries. Now is the time for the U.S. housing industry to develop new and innovative methods of production and design which will produce a product comparable to or better than that produced by foreign housing manufacturers.

II. RESEARCH PLAN

ACTIVITIES AND BUDGET

We request five years of federal support to initiate and establish a research program in energy efficient industrialized housing. This support will be supplemented by state and industry funds. After the initial five year period the research program will become self-sufficient with support coming from federal, state and industry grants and contracts. The funds requested from the federal government are: year 1 - $900,000; year 2 - $1,500,000; year 3 - $1,500,000; year 4 - $1,000,000; and year 5 - $1,000,000.

We envision five major activities within this research program: 1) Identify and evaluate the applicability of energy efficient foreign technology to U.S. resources, manufacturers and markets; 2) Determine the optimum levels of industrialization for energy conservation; 3) Encourage energy efficient new product and system innovations within the industrialized housing field; 4) Develop computerized energy design and evaluation tools for the industrialized housing designer; 5) Design, construct and monitor full size, base-line and prototype energy efficient industrialized houses.

These five activities, further described below, will be adjusted and refined in a detailed five year research plan under the guidance of an advisory council composed of representatives from material suppliers, manufacturers, federal agencies such as HUD and DOE, researchers from national laboratories and universities and associations such as NAHB and NIBS.

Applicability of Foreign Technology

The objective of this activity is to work cooperatively with U.S. industries to analyze foreign energy efficient industrialized housing to determine which products and methods are applicable and desirable in the U.S.

A number of studies have determined foreign industrialized housing to be very energy efficient. Some of the manufacturing methods used to produce this housing are documented, but much of the technical design information remains anecdotal. There is no systematic documentation of foreign production techniques which examines their contribution to the energy efficiency of the completed house. Foreign manufacturers, particularly the Swedish, think that their factories can be built and operated in the U.S. and that their products will sell in U.S. markets. However, there has been no evaluation of American industry to determine the validity of this belief. Nor, has there been an analysis of the possible influence of foreign competition on present American production methods. It must be determined which foreign manufacturing techniques will work given our material resources, manufacturing equipment, and labor force. Foreign housing must be further evaluated to see if it can be modified to fit mainstream American market demands without compromise to energy performance.

Optimum Levels of Industrialization

The first objective of this study is to determine which techniques for industrialized housing production have the potential to enhance the energy performance of the end product. The second objective is to determine the optimum level of industrialization for each of the most promising techniques;

that is, to determine what combination of industrialized processes and conventional site building will balance production cost and energy savings.

High performance energy conserving homes in the United States are most often site specific designs which are custom-built at a substantial cost. Present American industrialized housing, particularly the mobile home, achieves a low first cost but the nature of the product results in a very high fuel use for both heating and cooling. In contrast to both, Swedish factory-crafted housing employs a high level of industrialization and yet the energy efficiency is among the best in the world. Clearly there is a connection between the mode of industrialization which is used and energy performance. Some strategies for industrialization foster improved energy performance while others do not. Research is needed to determine the relationship between industrialized building and energy performance and to select and develop new production techniques which support strategies for energy conservation in residential construction.

Industrialization can be applied to housing at many levels from the use of factory components (windows) to the pre-assembly of complete units (modular homes). Most residential construction strategies employ a mix of industrialized and site-built elements. This mix is largely determined by first cost criteria and varies with the market segment and geographic location. When energy performance is considered, the optimum blend of prefabrication and site building might be substantially different. For example, a housing producer who wishes to market homes in a broad range of micro-climates may choose to industrialize the mechanical cores of the house (bathrooms and kitchen) while the envelope is left to be built on site. Within a single climate zone, the level of industrialization may again vary with the specific energy strategy employed. For instance a building envelope of high thermal mass might be best built on site due to transport difficulties whereas a light, highly insulated shell might be factory-built for quality control. The builder must determine the optimum level of industrialization considering both first cost and operating (energy and maintenance) costs. The builder is also faced with determining how this optimum may vary from one climate to another and from one energy strategy to another.

New Product and System Innovation

The objective of this project is to make energy-related technologies from other fields available to the housing industry in such a way that they become a catalyst for new products and system developments within the industrialized housing field.

The level of funding for research in the building industry is low when compared with other industries and with the housing industries in other countries. As a result technological innovation has occurred more rapidly in non-housing areas in the U.S. Many of these innovations can increase the energy efficiency of industrialized housing; they have potential application in the housing industry but require special development and characterization in order to appeal to the fragmented residential construction industry. Particularly interesting are developments in manufacturing processes, composite materials and electronics and non-building research conducted by NASA, NSF and the military.

Technology transfer must do more than make technical reports available. Successful technology transfer puts exactly the right information in a usable form directly in the hands of the user. In the case of housing innovation, it will involve developing product and system concepts that show explicitly how the research can be used to create energy efficient industrialized housing.

Computerized Design and Evaluation Tools

The objective of this program is to develop computerized design tools which would be used throughout the energy efficient design process from product sales to manufacturing specifications. An example of this kind of design tool would be a computer display of a three-dimensional image of the building which the user could manipulate to develop a design. Using information derived directly from the graphic image, the computer could do energy and cost calculations based on the manufacturers' products and assembly techniques. Output from the program would be compatible with other software which would produce manufacturing specifications or perform other design tasks such as structural analysis.

There are several computerized energy analysis tools currently available for housing designers, but they have serious shortcomings when applied to industrialized housing. They use numeric abstractions rather than graphic representations of houses, so they are awkward for housing designers (buyers, salespeople, developers, contractors, manufacturers) to use. Because these computer tools were designed for site-built housing they do not fully accommodate the limitations of standardized products and assembly techniques. Therefore, they don't facilitate design given a specific manufacturers' requirements and costs. Furthermore, they are not readily compatible with software used in manufacturing processes.

When designing an energy efficient house, a house designer should understand which design features conserve energy and how much of their initial cost can be justified by energy savings. The calculations necessary to determine energy use and economic analysis are time consuming and beyond the capacity of many house designers. House designers have difficulty forming the connection between the abstract numeric descriptions of a house that are necessary for energy and economic analysis and the concrete visual images of the house they desire. It is therefore difficult to fully consider energy as the house is being designed. The size of industrialized housing producers and the degree of industrialization of their product varies throughout the U.S. which impedes the development of design tools that have broad applicability.

Testing Base-line and Prototype Houses

The objective of this study is to establish accurate performance data based on field testing of the thermodynamic and luminous environments of base-line and prototype houses. These data will make the accurate energy evaluation of proposed design changes possible and facilitate a broad range of other evaluations ranging from market acceptability to cost analysis.

We will establish two housing research parks with several industrialized houses at FSEC or UOR research facilities. These houses will be solicited from the industry via a cost shared arrangement and will encompass a wide spectrum of costs and energy efficiencies. Since Eugene, OR (UOR) is a predominately heating climate and Cocoa, FL (FSEC) is a cooling climate, these sites will complement each other in determining the heating and cooling energy benefits and liabilities of each energy conservation strategy. The two locations also facilitate the investigation of different markets, labor forces, regulatory environments, materials and manufacturing capabilities.

The houses will be subjected to simulated occupancy (thermal and moisture) and monitored in detail. The monitoring will be detailed enough to evaluate not only whole-house performance but also subsystem and component level performance so that we can determine the heat loss/gain through the roof, wall, windows and foundation as well as whole-house infiltration, leakage and the COP of mechanical equipment, duct work losses, etc. By comparing measured data with detailed simulations we can calibrate computer codes. More importantly, we can then assess the cost effectiveness of proposed improvements over the base-line. In concert with industry, we will then assess the feasibility (e.g., manufacturability, cost benefits, etc.) of various possible improvements such as a radiant barrier roof manufactured in the factory or an improved floor plan. At this point we will settle on ideas, determine optimum levels of industrialization of each idea and then develop the idea. The prototype development will probably be best done at an industrial site under a cost sharing arrangement much like the DOE photovoltaic program which develops improved manufacturing methods through long-term cost shared contracts and competitive bidding. We will get improved prototype modules and other products from industry. These will be tested in the FSEC and UOR research parks as retrofits or as completely new units. The thermal efficiency of the newer homes and components will be compared to the base-line data. Marketability, durability and other factors will also be determined at this time. This process will create field proven technologies which because they were created in consort with the industry will be readily transferable to the industry at large. The performance cost and benefits of these improved homes and technologies in other climatic areas will be determined by computer modelling.

FIVE YEAR PLAN

ACTIVITY	1989	1990	1991	1992	1993
1. Planning & Oversight Committee					
a. Form Advisory Committee	*				
b. Draft 5 year plan	*				
c. Revise plan and review progress		*	*	*	*
2. Applicability of Foreign Technology					
a. Assemble existing data & identify missing data	*				
b. Establish foreign technology advisory committee	*				
c. Obtain missing data	*				
d. Compare foreign & U.S techniques, market, industries, etc.	*				
e. Report on most energy efficient & applicable techniques		*			
3. Optimum levels of Industrialization					
a. Characterize climate zones & industrialized techniques	*				
b. Develop cross classification system for industrialization/energy strategy	*				
c. Develop production scenarios		*			
d. Compare 1st & operation costs at various levels of industrialization		*			
e. Review regulatory & institutional barriers to industrialization		*			
f. Propose prototypes for incorporation into housing research parks			*		

ACTIVITY	1989	1990	1991	1992	1993
4. New product & system innovation					
a. Identify potential areas of product & system innovation		*			
b. Develop data base of research & products which have potential application			*		
c. Convene industry, research, design, academic working groups to develop potential housing applications				*	
d. Develop catalyst documents for industry				*	
e. Test and evaluate innovations					*
5. Computerized design tools					
a. Survey existing software	*				
b. Develop a picture of industrialized housing production process & place exising software	*				
c. Determine appropriate levels of simulation		*			
d. Determine hardware & software simulation		*			
e. Develop software			*	*	*
6. Housing Research Parks					
a. Solicit home for baseline	*				
b. Erect homes/instrument		*			
c. Monitor base-line performance		*			
d. Design and install retrofit strategies		*	*		
f. Design and install prototypes of improved subsystems and homes				*	*
g. Monitor/report performance/simulations		*	*	*	*

III. CAPABILITIES

A consortium of the University of Oregon and Florida Solar Energy Center has the benefit of coordinating its activities on a national scale to avoid unnecessary duplication of effort while using important strengths of its individual institutions. The Florida Solar Energy Center and the University of Oregon each have a strong history of energy research. Yet the character of the institutions, their personnel, and their geographical location give them quite different perspectives and capabilities. Together they form a powerful and complementary team.

The University of Oregon

The State of Oregon is the center of a primary industry in U.S. housing production. Softwood lumber and plywood from Oregon have long been standards in the domestic market. Now there are new technologies available to extend the range of these basic materials, particularly in application to energy efficient industrialized housing. Oregon government and business leaders have experience with international trade around the Pacific Rim. The development of industrialized housing components and systems which are appropriate for these markets will greatly improve the value of U.S. exports to Pacific Rim trading partners.

The University of Oregon provides a research base with an extremely broad range of expertise. Because it is a teaching as well as a research institution, students will directly benefit from faculty involvement in energy efficient industrialized housing research and will be better prepared to enter and influence the housing industry upon graduation.

One of the specific areas of expertise that makes the University of Oregon an ideal location for the proposed research activity is energy research within the Department of Architecture. Architecture faculty members who specialize in energy issues are nationally known for their outstanding research contributions. This expertise will be available to directly support the proposed energy efficient housing research. The School of Architecture and Allied Arts at the University of Oregon is one of ten regional daylighting research centers in the U.S. The School recently received a generous gift to endow a chair in architectural design with an emphasis on light and lighting. This endowment will attract internationally known practitioners to augment the existing strengths in energy and environmental control systems research. The Department of Architecture has a significant track record in conducting research in these areas, working both independently and through the University of Oregon's Solar Energy Center, which brings together a number of departments, faculty and community members with common interests.

The Department of Architecture is also nationally recognized for the strength of the design faculty. Much of this reputation has been built in housing design and research. Members of the staff have completed award-winning housing projects for both public and private clients. Innovative projects have also been carried out in Puerto Rico, Mexico, Colombia, Israel, Jordan, and Turkey. Careful attention to climate and energy consumption has been characteristic of all this work. This experience will be invaluable in the design of housing that has market acceptability in both domestic and foreign locations, which is vital for improving the competitiveness of the U.S. housing industry.

The College of Business Administration maintains the Forest Industries Management Center with the goal of stimulating research and education related to the forest products field. The International Business program collaborates with the International Studies program to teach and research aspects of international marketing management and commerce. The Department of Economics faculty who specialize in international economics, private industry, and public policy are available to consult on this program of energy efficient industrialized housing.

The University of Oregon is on the leading edge of developing joint venture relationships with government and private industry. The development of its Riverfront Research Park is meant be a catalyst for regional research projects related to economic development. The energy efficient industrialized housing research program will be located in the park. The University also participates in a number of economic development planning activities that have established the Universtiy as an active participant in the transfer of academic research and technology to private industry. The University is located at the center of the Northwest forest products industry with many large and significant forest products plants located within a one hour drive from the campus. This kind of access places the University of Oregon in close and continuous communication with a critical element of the U.S. housing industry. The University intends to work with Oregon State University on research issues relating to technical considerations for wood products/materials science. The thrust of this research program in the areas of design, marketing and energy issues make the Department of Architecture at the University of Oregon a logical site for energy efficient industrialized housing research.

The Florida Solar Energy Center

The Florida Solar Energy Center (FSEC) is a research institute of the State University System of Florida. FSEC is located in Cape Canaveral and is administered by the University of Central Florida in Orlando. FSEC has an offsite research area in Cocoa that will house the housing research park.

The buildings research program at FSEC is a major activity and attracts over 50% of FSEC external research funding. Other major programs at FSEC are Photovoltaic Energy Systems, Solar Water Heating, Hydrogen, Power Electronics for Energy Conservation in Electrical Motors and Systems, and Ocean Thermal Energy Conversion.

Current buildings research projects at FSEC are externally funded at an annual level of over $1.5 million from DOE, the Gas Research Institute, local utility companies and private industry. It is staffed by thirteen full-time professionals and technicians and several students. FSEC is experienced in conducting large interdisciplinary projects funded by several sponsors. A prime example is the multimillion dollar multi-year solar cooling project to develop building integrated cooling and dehumidification technologies for hot-humid climates. Initiated in fall 1986, in response to a 1985 congressional initiative, the project is guided by a steering committee which meets annually.

Buildings research at FSEC started in 1980 with investigation of attic radiant barriers and innovative ventilative cooling solutions. The unique Passive Cooling Laboratory (PCL) was designed and built in 1981-82. The PCL is a residential scale, reconfigurable test facility which has been used extensively to research radiant barriers and ventilative cooling designs. Fenestration and heat pipe research started in 1983 and research in moisture absorption and desorption began in 1984. The newest program, electrical end use research and thermal storage, started in 1986. Detailed monitoring of energy use in buildings has been integral part of FSEC's research efforts since 1982.

The overall program objective is to research and develop technologies to significantly reduce energy consumption in buildings located in hot-humid climates without adversely affecting the utility load shape. Another key objective is to develop energy efficient dehumidification cooling technologies so important in a hot-humid climate. A detailed understanding of moisture transport in buildings through development of analytical models is a prerequisite to such activities and is also another major goal of the building research program.

The FSEC buildings research program seeks to advance building science by developing innovative solutions to real world problems. The research is strongly based on experimental data from highly instrumented facilities. Detailed analytical models are developed and validated with the data. Systems analysis, cost-benefit analysis and technology transfer follow. This methodology, when practiced by dedicated and capable researchers, works quite well and has led to the following accomplishments:

First to show effectiveness of attic radiant barriers in reducing cooling loads and air-conditioning peak demands with a payback of 6 years or less. FSEC research was later confirmed by Oak Ridge National Laboratories and others and forms the basis for inclusion of attic radiant barriers as a conservation measure in the Florida Model Energy Code.

First to raise the issue of moisture absorption/desorption (MAD) in building materials. Our experiments and analysis have shown MAD to have a large effect on air-conditioner cooling loads especially for ventilated buildings. Current research is seeking to use moisture storage in building materials for developing passive cooling and off peak cooling solutions.

Developed wing-wall designs to naturally ventilate classrooms with only one outside wall. This has been accepted as an alternate solution by the Florida Department of Education. Several schools have been constructed with wing walls.

Designed heat pipe assisted air-conditioning systems to increase dehumidification in a large candy storage warehouse (Bob's Candies in Albany, GA). This system is saving the owners significant amounts of money and attracted industry support from Carrier Corporation and Georgia Power Company.

Designed low energy consuming solution to condition the equipment room in a PV/Wind powered off-shore platform for the Navy. This design, utilizing radiant barriers, heat pipes and energy efficient air conditioning is currently under construction.