Energy Efficiency and the Zero Energy Home Learning Center

STANLEY RUSSELL
University of South Florida

INTRODUCTION

Today's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. In 2006, the Residential Sector consumed 37 percent of all electricity produced in the United States. According to the US Department of Energy only 2 percent of annual Buildings Sector energy consumption has been from renewable energy, each year since 1997. Space heating and space cooling are the largest energy end-uses in the residential building sector with water heating and electronics in the next two spots. From this data it is clear that the design and construction of energy efficient homes offers tangible benefits to homeowners and occupants and the U.S. as a whole. Homeowners can lower their energy costs by 50 percent or more while lessening maintenance and capital costs. In the process, building occupants will realize increased comfort, health and productivity and the country will conserve energy resources and enjoy cleaner air and a healthier environment[1]. To be implemented on a broad scale home owners need more information about energy efficient technologies and zero Energy homes. The Zero Energy Home Learning Center will educate Students, Faculty, and the general public about the technology, economics and environmental impacts of ZEH construction, operation and maintenance.

ENERGY EFFICIENT BUILDINGS IN THE U.S.

Attempts at reducing energy use in buildings began in the U.S. just before World War II with work at the Massachusetts Institute of Technology on solar heated structures[2]. During the energy crises of the 1970s, for the first time, a concerted effort was made to reduce energy use in U.S. homes. Books like Ed Mazria's *Passive Solar Energy Book* were written to make the concepts of passive solar design accessible to professionals and the average person alike. Mazria writes in the acknowledgements that at the time he began writing the book in 1975 that "information concerning passive solar design was virtually non-existent". Passive solar design utilized insulated south oriented glazing systems, Trombe walls, flat plate collectors and sunspaces. Roof overhangs were once again thought of as a necessary feature requiring precise design. The properties of materials, their thermal mass and reflectivity became important considerations as did the natural circumstances of the site and its micro-climate. The 2100 sq.ft. Kelbaugh

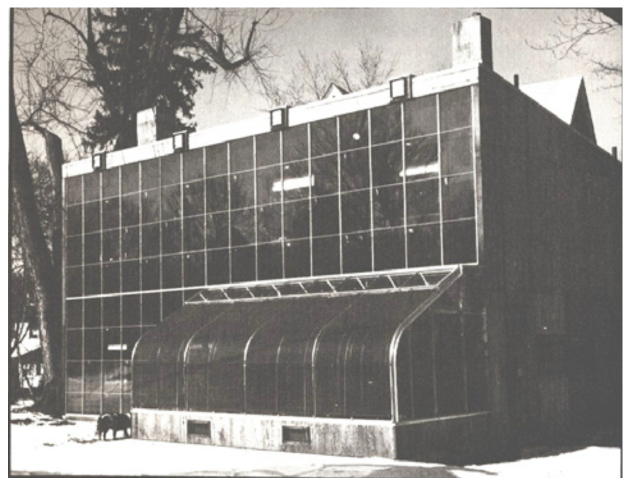

Fig. 1 Kelbaugh House

House built in Princeton, New Jersey [40^0 N. Latitude] is representative of passive solar buildings of that era. The house features a Trombe wall solar collection system consisting of a 15″ concrete wall, painted black with two sheets of double strength window glass placed in front of the wall. Heating is mainly accomplished by radiation and convection from the inside face of the Trombe wall. Vents located at the top and bottom of the wall also allow for daytime heating by convection over the warm outside facing side of the wall. According to data gathered over a one year period from 1975 -1976 the passive system reduced space heating costs by 76%[3]. At about the same time researchers at the University of Illinois were trying to reduce the heating and cooling loads in buildings by constructing a highly insulated envelope. The "Low Cal House" designed by Wayne Schick stood for "low calorie." Schick did a computational study of how much energy you could save with high levels of thermal insulation, airtight construction and heat recovery ventilation using air-to-air heat exchangers. Although never built, the Lo-Cal House attracted a great deal of national publicity and was influential in subsequent built projects like The Leger House in Pepperell, MA, one of the first double-wall super-insulated houses in the world. The 1979 heating bill for the Leger House was $38 and remained less than $50 per year for at least the next IO years[4].

The sudden influx of accessible information about passive solar design and super insulation coupled with the sudden high price of petroleum set off a temporary energy efficiency movement among architects that spread to a small counter culture but never acquired the momentum necessary to make it a popular movement. By the time the oil crisis ended and energy prices returned to an affordable level the construction of passive solar buildings all but died out. If anywhere, a lasting effect was felt in the arid western regions of the US where passive solar design is so well suited to the climate and the advantages are obvious. The solar houses of the 70's had a certain functional aesthetic that was largely rejected during the historicism of the postmodern 1980's. The lack of a perceived energy crisis seemed to deal a lethal blow to the short lived energy efficiency movement in the US. While there were particular successes in the reduction of heating energy, except for certain climates, cooling was not effectively dealt with nor were many other home energy end uses. Photovoltaic panels were beginning to be discussed at that time but their cost made them impractical in most applications.

THE ZERO ENERGY HOUSE

Throughout the late 1980s, the cost of solid state solar electricity production with photovoltaic panels declined in price such that the possibility of using PV for individual house, distributed generation became increasingly feasible. In the state of Florida where the climate defies many passive solar design techniques the affordability of PV technology opened the door to active solar systems that would take advantage of the state's wealth of insolation that ranks second in the country only to Arizona. In 1998 the Florida Solar Energy Center began its Zero Energy Homes research program in collaboration with the City of Lakeland municipal utility and builder Rick Strawbridge.

The team constructed a 2400 sq.ft. energy-efficient photovoltaic residence (PVRES) and a standard model (the Control) and tested them for more than a year. In one year, the PVRES home used 6960 kWh of electricity and had a PV system production of 5180 kWh. For the same year, the control used 22,600 kWh. The yearly energy savings due to differences in energy efficiency of the two homes is 70%. Putting the PV system production into the numbers shows that the PVRES house's net energy use for the entire year was only 1780 kWh. When comparing the PVRES house energy, including the energy it produced, against the standard house, the PVRES house had a 92% utility energy savings compared to the standard house. Perhaps even more important than annual energy use is the fact that during periods of peak electric demand, the PVRES home, due to the PV system, placed nearly zero net demand on the utility system.

The building envelope of the PVRES house has a white tile roof. The control home's roof is conventional popular gray-brown asphalt shingles. The solar reflectance of the white tile tested at 77% while the reflectance of the gray-brown architectural asphalt shingle was only 7%. When the outside summer air temperatures were at their peak the coincident peak attic air temperature difference was 40°F lower in the white tile test cell (91.4°F) than the construction with black asphalt shingles (131.5°F). For solar control on walls and windows, the PV home has a 3 foot overhang around the perimeter of the building while the standard home has one and a half foot overhang. At 11:10 AM on October 1st, 1997 the standard home, with a 1.5 foot overhang casts a shadow length of just 36 inches. At the same time, the shadow cast on the PV home is nearly 72 inches long. The overhang shades most of the wall and at least 75% of the south and east window area. In conventional residential construction in Florida, walls are insulated with R-3 to R-5 insulation on the interior of the masonry walls. However, the concrete block walls of the PVRES home were insulated on the exterior both in order to assist with reducing the cooling system size and to utilize the thermal mass inside the building. An exterior application of 1¼" *Tuff-R* was used to encapsulate the building in R- 10 insulation so that the masonry portion of the building could be pre-cooled during the daytime hours when solar availability is high and the PV system output is at its maximum to utilize the thermal capacitance of the building and its masonry and help to reduce air conditioning needs during the late afternoon and early evening hours. The windows in the PVRES home are a low-E glass product with Argon gas fill, a SHGC of only 0.38, but with a daylight transmittance of 73%. The center-of-glass U-value is 0.24. The improved glass reduces the size for the air conditioning system by 0.64 tons compared to single pane glass.

The mechanical systems of the two buildings also had marked differences. The HVAC systems of the two buildings were designed based on a 95°F [35^{0}C] outdoor design temperature with a 75°F [24^{0}C] interior temperature. The calculations indicated a 3.88 ton cooling system for the standard home (4 tons) and 1.73 ton (2 tons) for the PVRES house. The Trane two-ton heat pump and a variable speed indoor air handler with a combined Seasonal Energy Efficiency Ratio (SEER) of 14.4 Btu/W were selected to provide optimum efficiency, humidity removal and quiet operation. For the standard home a standard efficiency 4-ton Trane heat pump with a SEER of 10.0 Btu/W was used. In conventional houses the ducts and often the air-handler are located in uninsulated attic space. In Florida, the attic sometimes reaches 130^o F and studies show that heat transfer to the duct system can reduce the cooling capacity of the air conditioner by 30%. In the PVRES house the ductwork is placed within the conditioned space of the building. Any heat gained by the duct system is removed from the conditioned space itself so there is no reduction in cooling capacity of the air conditioner. The duct system was oversized to provide better air flow across the evaporator, reduce air handler fan power, improve system efficiency, and reduce noise.

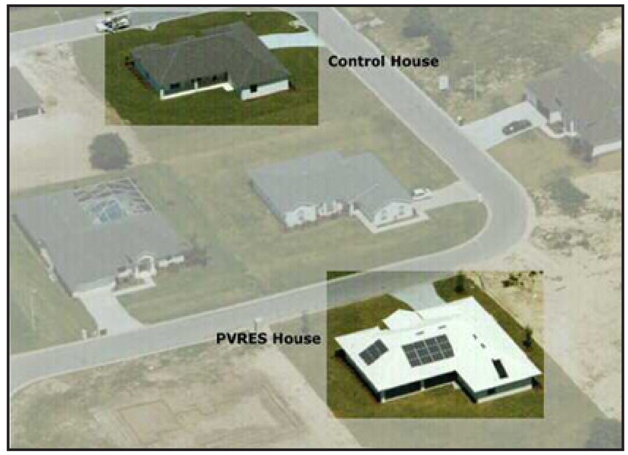

Fig.2 FSEC Lakeland Project

The PV generation system was sized to provide power that would offset most of the daytime household electrical loads. Based on the predicted loads for a peak day, it was determined that a 4kW solar array should be installed. As a *Utility Interactive System,* the photovoltaic system is owned and maintained by the electric utility company and the power generated is supplied to the utility side of the meter. The output of the system is monitored by the utility company to evaluate the system performance and to troubleshoot problems. Systems installed such as this one increase the capacity of a service provider and can help reduce the total operating hours required for fuel-burning generators. The photovoltaic arrays were installed in panels, comprised of three 75W modules each and connected in series. Thirty-six modules or 12 panels make up the south-facing sub-array and 18 modules or six panels were installed on the west face of the roof. An AC power inverter was selected to convert the array's DC power to AC for interaction with the utility grid.

The PVRES home uses a solar water heating system with propane back up. The system consists of a forty square foot solar collector mounted on the south side of the home's roof. The collector is rated at an energy production of 45,600 Btu/day at the low temperature (95°F) rating. The Control home contains a standard electric resistance 52 gallon storage tank in the garage, rated to use 4,828 kWh/year The PVRES water heater has a rated energy factor of 0.65 with the measured tap hot water temperature 130°F. Approximately 66% of the system's water heating is solar and the remainder is supplied by propane gas. Daily hot water use averaged 37.8 gallons per day against a daily propane consumption of only 3.2 ft3 - about 0.09 gallons per day.[5]

The Lakeland project was instrumental in the formation of the U.S. Department of Energy's Building America program which has led to many zero energy home and near zero energy home projects around the country. The Build-ing America Program is responsible for reengineering new and existing American homes for energy efficiency, energy security, and affordability. Building America works with the residential building industry to develop and implement innovative building energy systems. This industry-led, cost-shared partnership seeks to reduce average whole-house energy use by 30%–90% and reduce construction time and waste, improve indoor air quality and comfort, integrate clean onsite power systems [leading to Zero Energy Homes], and increase the energy efficiency of existing homes by 20%–30%. The DOE has posed the "Builder's challenge" to the homebuilding industry — to build 220,000 high performance homes by 2012.[6]

Fig.3 Beddington Zero-energy Development

ZERO ENERGY COMMUNITIES AND BEYOND

With several successful examples of ZEH built across the country, the focus in recent years has become ZEH communities. In 2003 San Francisco Bay area production builder Clarum Homes partnered with Building America to build the nation's largest zero-energy home community called Vista Montana, in Watsonville, California. The development of 177 single-family homes, 80 townhouses, and 132 apartments opened in August 2003 and sold out in its first year. Clarum initially advertised prices of $379,000 to $499,000 but some units sold for as much as $600,000. Every home features a slew of energy-efficiency measures throughout plus a 1.2 to 2.4 kW photovoltaic system on the roof in a package of zero energy features that Clarum offered standard at Vista Montana. Clarum partnered with ConSol and others to develop its *Enviro-Home* package of energy efficiency and solar power features, designed to reduce homeowner energy bills by up to 90%. Each Enviro-Home has been professionally designed, certified, and inspected to reduce energy consumption and use sustainable resources while improving comfort. The program has also earned the U.S. Environmental Protection Agency's ENERGY STAR® seal, ConSol's *Comfort-Wise* designation, and the California Building Industry Institute's California Green Builder certification. In addition to a solar electric home power system, each *Enviro-Home* in the Vista Montaña community features a tankless on-demand water heater, and a high-efficiency furnace as standard features. The homes also feature a foam-wrapped building envelope, increased insulation, radiant roof barrier, advanced HVAC technology, tightly sealed ducts, and low-E energy-efficient windows. Ceiling fans, fluorescent light bulbs, water conserving plumbing fixtures, and water conserving landscaping are also incorporated, providing homeowners further utility savings. The *Enviro-Home* incorporates sustainable building materials, such as engineered lumber, recycled decking material, and fiberglass doors, and offers recycled content carpet, bamboo flooring, cork flooring, environmentally friendly paint as optional items. According to the developers, the *Enviro-Home* features that are included as standard equipment will provide more than $20,000 of added value to homebuyers at no extra cost to them. Clarum works with Building America to use their cost and energy savings analysis to point to the most cost-effective combination of features for the climates it builds in. Once a cost-effective combination is chosen, economies of scale can be achieved through volume purchasing and training of subcontractors. Clarum is building four super-efficient demonstration homes in Borrego Springs, California where temperatures routinely soar past 100°F 6 months of the year. The homes are equipped with cutting edge wall, cooling, heating, water heating, ventilation, and PV systems.

On an even more holistic level, the NREL is assessing the feasibility of developing "renewable energy Communities" with sustainable planning, net zero-energy homes, advanced vehicles, and innovative utility interconnections that could significantly decrease energy use, as well as its associated emissions and climate change impacts, both in the U.S. and worldwide. Although there have not been any of these communities developed yet in the US, The *Beddington Zero-energy Development (BedZED in England,* is being designed to be carbon neutral, with strong emphasis on roof gardens, sunlight, solar energy, reduction of energy consumption, and waste water recycling. BedZED includes a green transport plan that promotes walking, cycling, and the use of public transport, including a car pool for residents.[7]

EMERGING TECHNOLOGIES

The sustainability movement in the U.S. and world wide has stimulated research and development of many new materials and products that will be useful in building the Zero energy house of the future. With the government's pledge to invest in renewable energy and energy conservation the list of new and innovative technologies is sure to grow quickly in the near future. In early examples of ZEH Photovoltaics have been the primary source of site generated renewable energy. Hydrogen batteries and fuel cells also hold the promise of clean renewable fuel with abundant domestic sources although they are still in the development stage. Projects are currently under way at the DOE and the NREL to develop Hydrogen fuel cells for various uses from vehicles to large scale power generation to the grid and localized power generation for buildings.

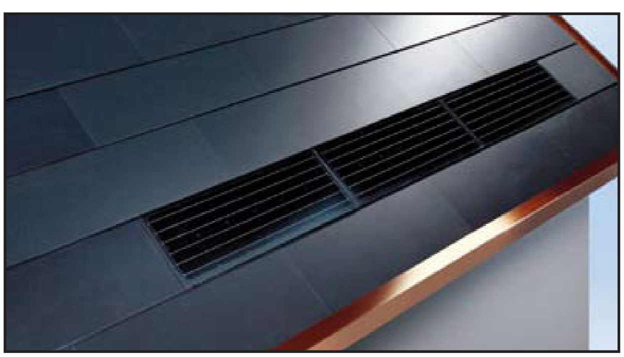

Fig. 4 Building Integrated PV

To minimize the need for energy in buildings, insulation systems are critical and several promising materials are on the horizon. *Aerogel*, a material first discovered in the 1940s, is made by drying a gel of its liquid contents without collapsing or shrinking its matrix structure. Aerogels are a more efficient, lighter-weight, and less bulky form of insulation than the polyurethane foam. Products utilizing aerogels including roofing, glazing, insulation, and exterior wall and roof panels are currently in commercial production. Vacuum insulated glass has the potential to provide insulation values comparable to a standard insulated 2×4 stud wall [R-13]. Advances in PV thin film technology have made building integrated PV systems a reality in recent years and this technology is poised to become even more pervasive in the near future. Thin film materials that replace or become a part of traditional roof or wall coverings, while maintaining and improving their insulation and protective properties are now available. As one of the top three building end uses efficient lighting systems are critical to an energy efficient building. A Light Emitting Diode (LED) is a semiconductor device which converts electricity into light. LED lighting has been around since the 1960s, but is just now beginning to appear in the residential market for space lighting. LEDs are small in size, but can be grouped together for higher intensity applications. Currently, more than 130 companies and universities and over a dozen organizations are working on OLED lighting. Compared with the other major lighting technologies in the market — incandescent, fluorescent, high intensity discharge (HID) lamps, LEDs and electroluminescent (EL) — OLED lighting has several advantages. OLED lighting devices emit from the surface, can be made flexible/rollable, and even transparent like a window or reflective like a mirror. In hot humid climates air conditioning is the largest energy end use.

The use of desiccant cooling for residential use is being explored in conjunction with energy recovery ventilators (ERV). The development of micro-scale compact-type absorption chillers for residential and light commercial buildings in 2003 represents the maturation of the absorption chiller industry. The first generation of micro-scale compact-type chillers is a series of two-stage, water-LiBr based, and natural gas direct-fired systems with cooling tower. Four types of compact absorption chillers, categorized by their cooling capacity, are now on the market.

THE ZERO ENERGY HOME LEARNING CENTER

The Zero Energy Home Learning Center will take the lessons of previous ZEH projects and introduce new and emerging technologies that have not been addressed previously to make a holistic systems engineering based zero energy building package to be constructed on campus. With awareness among the general public of environmental issues and the need for alternative approaches to energy utilization, at an unprecedented level the time is right for a high profile building on campus that is designed to allow visual access to all of the energy efficiency and zero energy technologies, that will serve as a teaching and learning tool and promote the use of ZEH technologies in central Florida and throughout the southeastern US.

The Zero Energy Home Learning Center will introduce affordable, new and emerging building energy systems and energy efficiency strategies for central Florida's hot/humid climate. Students of various disciplines will collaborate with experts and building industry professionals to design and build the center. The building will be powered by onsite sources such as PV power and hydrogen fuel cells will be attached to the city grid and will send power back to the grid during peak load periods and draw from the grid during periods of low production. The net energy usage of the building will be zero or better and its performance will be monitored over a long period of time for benefit/cost analysis and grid interactions. The project seeks to develop new approaches to energy efficiency in buildings through an assimilation of current know-how and innovation with a multi disciplinary team of experts together with agencies including the Department of Energy, The Florida Solar Energy Center, and the USGBC and building industry partners.

The latest advances in building components, passive systems and home energy end uses will all be considered. The latest in PV and PHEV, Bio fuels and fuel cell technology will be combined with "Zero Energy Home" technology in a systems approach that holds promise for the development of new products in the building, renewable energy and transportation industries. Data will be compiled which documents the initial cost of Zero Energy Homes and the payback period during which lower operating costs offset the initial investment to establish the current cost/benefit of energy efficient buildings and zero energy home Technologies. The Learning center will be monitored for an extended period to document its specific cost/ benefit.

The Zero Energy House Learning Center will showcase the University's and the State of Florida's commitment to energy efficiency and renewable energy on one of the largest campuses in the state. A successful project can be expected to result in an expanding niche market for ZEH that could flourish with the pressure of higher future energy prices. An accessible and well publicized learning center will raise awareness of energy efficiency and ZEH technologies among students, faculty, builders, local governments, local utilities, planners and statewide policy makers. Data gathered from energy monitors within the Learning Center will bring awareness to energy use and how it matches the renewable energy source. Information gathering from monitoring the building will be the basis for new curriculums that teach ZEH technologies.

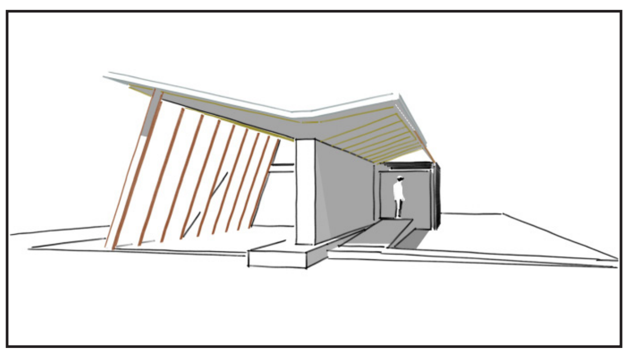

Fig.5 ZEH Learning Center Image Sketch

At a larger scale, the facility will serve as a demonstration to public utilities commissioners of how such buildings could influence Florida's energy future. Enhanced awareness will lead to higher expectations and higher energy efficiency building standards and increased ZEH production across the state. Public outreach, media coverage, publications and on-line resources will make the project available for the education of the wider public. Such coverage and information on the project will illustrate to Florida citizens how the ZEH concept is not futuristic, unreliable or inconvenient, but rather is readily achievable and affordable with greater indoor comfort and greater power reliability.

CONCLUSION

With the exception of a few individuals with a broader perspective, the energy efficiency movement of the 1970's was largely a response to an economic crisis. As such, it lacked a broad backing once the economic aspect of the energy crisis was temporarily resolved. The current sustainability movement is fundamentally different in that it is based on a broadly acknowledged worldwide environmental crisis of which energy and economics are just two components. Unlike the passive solar building movement, the sustainability movement has permeated all sectors of society and has broad acceptance and support. Even within the broad perspective of a sustainable world, buildings are being singled out along with transportation as the largest consumers of energy and contributors to CO_2 emissions.

Since the proliferation of Central heating and air conditioning in the mid-20th century the thermal comfort range of the average American has changed several degrees and it would be difficult for people in extreme climate zones to live in entirely passively climate controlled homes. However, the principles of passive solar design can compliment highly efficient mechanical systems to greatly reduce the energy consumption of buildings. There is also evidence that comfort levels can be gradually altered when standards are placed on heating and cooling levels in buildings. In Japan, for example, the Koizumi administration fixed air conditioning in public buildings at 28 degrees and not less during the hot summer season. Lower building energy demand through conservation and more efficient, building envelopes, mechanical systems, appliances and passive solar strategies coupled with on-site, grid interactive, renewable energy generation through PV, fuel cells and other emerging technologies is a proven formula for net Zero Energy Buildings that will almost certainly become the norm in the U.S. in the very near future. The ZEH Learning Center will be a hub of information, teaching and learning to help usher in the new era.

REFERENCES

1. National Energy Technology Laboratory, "2008 Buildings Energy Data Book", D&R International, Ltd., November 2008
2. MIT Libraries, http://libraries.mit.edu/guides/subjects/architecture/architects/solar/solar4.html, "Solar houses: Solar IV" MIT Libraries, Cambridge, MA
3. Edward Mazria, "The Passive Solar Energy Book", Rodale Press, Emmaus, Pa, 1979
4. Joseph Lstiburek, "Westford House", Building Science Insight, http://www.buildingscience.com/documents/insights/bsi-018-westford-house/, Building Science.com, 5/22/09
5. "ZEH: Lakeland Fl." http://www.fsec.ucf.edu/en/research/buildings/zero_energy/lakeland/ Florida Solar Energy Center, Orlando Fl., 2007
6. National Renewable Energy Laboratory,"Whole-House Approach Benefits Builders, Buyers, and the Environment", PDF, U.S. Department of Energy, Washington DC, 10/2004
7. Bill Dunster Architects, "BedZED – Beddington Zero Energy Development, Sutton", The Government's Energy Efficiency Best Practice programme, Crown, March 2002