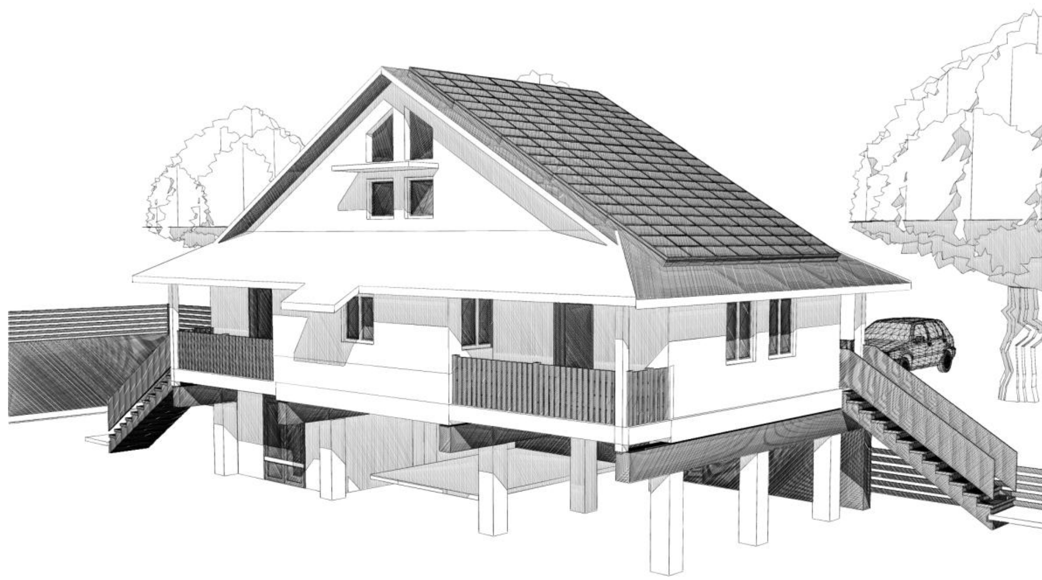
2009

FSU Solar Decathlon House



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INTRODUCTION

The Sustainable Energy Science & Engineering Center (SESEC) at Florida State University (FSU) was established in 2003 to promote education and research in energy conversion and utilization using the sustainable resources guided by the cradle-to-cradle design principles[1]. As part of our center, we are building an Off-Grid Zero Emissions Building (OGZEB) as a laboratory to educate students in an interdisciplinary environment that promotes critical thinking in the broad area of sustainable development, with particular emphasis on using the solar resources. In this approach we have undergraduate and graduate students working on creating affordable and efficient solar energy technologies that incorporate energy storage using hydrogen as a storage medium. As such many of the gas appliances were retrofit for the use of hydrogen. The OGZEB is designed and built to satisfy the requirements of platinum LEED certification.

Prior to the OGZEB project, the student team visited the 2005 Solar Decathlon competitions to learn the intricacies of the houses and the commitment required to compete. Having learnt the time, effort and infrastructure required to compete and win in the Solar Decathlon, it was decided to develop the tools and relationships required (ex: vendor and professional partnerships, interdisciplinary student and faculty participation) through the design and construction of the OGZEB[i]. This provided a comprehensive understanding of the funding, organization and effort required to succeed in the 2009 Solar Decathlon.

The partnerships and interdisciplinary relationships that were formed during the design and construction of the OGZEB will be continued and expanded for the proposed Solar Decathlon house. These will include, architects, engineers, communication specialists, interior designers, film and business students and professionals working together to ensure the success of the project. The different technologies utilized in the house will be developed in concert with corporate partners who design sustainable energy systems and have market experience to widely deploy the products. Many aspects of the house will be incorporated into the curriculum of different disciplines through the course design and project requirements.

The existing partnerships with many (~10) companies will be extended to fulfill the fund raising requirement of the current project. Additionally, we plan to approach foundations for further support of the project. Many of the organizational and project development skills used during the OGZEB project will be implemented here.

TECHNICAL INNOVATION AND DESIGN

Architecture

The first goal of the architectural design is to create an affordable home that is powered completely by alternative energy sources without sacrificing the comfort of the occupants. This will not only provide a home but a building they can be proud to live in, knowing the benefits to the earth and to their health. The key to providing a solar powered building that is also a home is

[1] McDonough W & Braungart M., " Cradle to Cradle: Remaking the way we make things", North Point Press, 2002.

through the use of building integrated systems; PV panels that blend into the building's envelope, hiding control systems in out of the way places while still providing accessibility.

Passive solar design concepts will be incorporated while maximizing day-lighting effects. Exterior surfaces will be minimized thus reducing the thermal losses of the house and increasing efficiency.

The house will provide multi-use rooms that can be transformed depending on need. A room that at night provides sleeping quarters serves as an office by day. Keeping the living spaces open with the ability to use a table to seat ten for a dinner party or folding the table into the floor to provide an open space for exercise; a kitchen island that pushes to the side of the room to create a bar. Multi-purpose spaces are the key to providing the functionality of 1500 square feet (139.35 m^2) in an 800 square foot (74.3 m^2) footprint.

Engineering

The house will be powered exclusively by the solar energy in the form of PV and solar thermal panels. High efficiency, building integrated photovoltaic panels will be used to generate just enough electricity to produce hydrogen and run the lighting, entertainment center including computers and fans. In order to ameliorate the current cost of PV systems the FSU Solar Decathlon House will maximize the use of the medium temperature, non-imaging solar thermal system. Powering the heating, ventilation, and air conditioning (HVAC), refrigerator and the water heater with solar thermal collection, the house will require minimal electricity generation. This will require a significantly larger solar thermal array but will reduce the number of PV panels, saving money and providing a solution that will produce power at a manageable cost of $0.10/kWh over the life of the system.

Comfort Zone

Energy efficiency will first be addressed to ensure that the minimum amount of energy would be required to provide a comfortable living environment. When considering efficiency, each "energy consumer" in the house will be carefully evaluated with different options considered for each item in order to reduce the amount of energy required.

The first system to be considered is the HVAC system, which is the largest energy consumer in most houses. The FSU Solar Decathlon House will utilize a solar thermal driven absorption chiller designed by Yazaki Energy Systems. Partnership is being discussed to modify their larger systems to develop smaller residential systems that will be driven by hot water primarily provided by the solar thermal system with an on-demand hydrogen combustion water heater as backup. Partnering with the company is important to ensure market viability of the modified product.

Although this is a very efficient system, several alterations will be made to the house to minimize the drain of the HVAC system on available power supplies. The first alteration will be to improve the envelope of the house over traditional houses. Insulation with a high resistance (R) value reduces the thermal losses and gains of the house, thus requiring a smaller load on the HVAC system and saving energy.

Structural insulated panels (SIPs), which will be used for the exterior wall and roof system, consist of extruded polystyrene foam sandwiched between oriented strand boards (OSB). Structural insulated panels were chosen for their high R-value foam and lack of studs, which prevents direct conduction of heat into or out of the house. The thickness of the SIPs is also important. A six inch thickness (R24) was chosen for the walls and an eight inch thickness (R30) for the roof. These R-value ratings are misleading for comparison with common wood frame construction due to the fact that the studs of a wood frame wall have a different R-value than the insulation. Typically the R-value is 1.4/inch (0.55/cm) of the stud compared to that of 3.14/inch (1.24/cm) of fiberglass insulation. The typical 6 inch (15.24cm) wall has an R-value of 16.37 instead of 17.27, the typical assumption. Taking the studs into account, a 6-inch (15.24cm) SIPs wall is 32% more efficient than the R16.37.

Structural insulated panels seal better than the average stick built house. This seal reduces air infiltration by 95% (see Fig.1). Air infiltration allows for the unwanted escape of conditioned air from the house, increasing the load on the HVAC system. Double pane, Low E windows will be used to replace traditional windows, which account for a large part of heat transfer in the house, because of their high insulating properties.

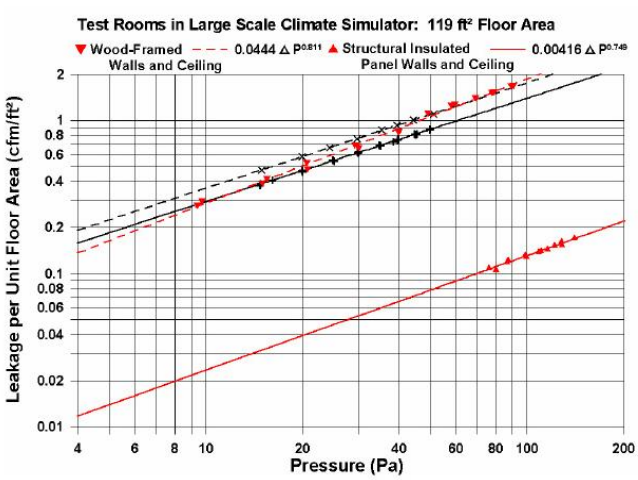

Figure 1: Air Infiltration Chart[ii]

Overhangs were also designed to optimize the sun throughout the year. The sun has a 52 degree average inclination with a variation of ±23.45 degrees depending on the season in Washington, DC.[iii] Overhangs were designed such that they produced an angle of 38 degrees with the wall of the house about the base of the window, where the house is one leg, the bottom of the window is the vertex and the line created the bottom of the window and the tip of the overhang. This overhang provides shade in the summer and direct light in the winter.

The ducting of the HVAC system will be located in the insulated envelope of the house to reduce thermal losses. The supply air discharges into the spaces high on the wall. The return air intake is close to floor level and near the center of the house to allow even air movement through the house and minimize uncomfortable temperature gradients.

The HVAC system itself will be enhanced to minimize energy consumption through the use of advanced direct digital controls (DDC). The DDC system employs a series of self-tuning control sequences that control every powered system component. With temperature, humidity, and occupancy sensors feeding real-time data, the DDC building controller will operate only those components required to maintain the required space conditions. For example, during periods of cooler weather, the supply fan speed will be reduced to match the reduced cooling load. There is a possibility of making the system even more efficient for the house by retrofitting all of the motors to operate on direct current (DC), thus allowing for inversion losses to be avoided.

Hot Water

Water heaters are typically the second largest consumers of electricity. There are several solutions that, when used in combination, minimize the electrical consumption of the water heating. One is the addition of a roof integrated solar thermal system. The system chosen has a 120 square foot (11.148 m^2) thermal collector and a 250 gallon (0.95 m^3) storage tank, which will be located under the house. The 120 square feet (11.148 m^2) of collector will absorb 102,000 BTU (107615.7 kJ) of heat a day. There are times when the solar thermal system will not produce the water temperature that the occupant desires. An on-demand gas water heater will be added to raise the temperature of the water to the occupant's desired temperature. This system will be retrofit to burn hydrogen. Hydrogen, which will be produced using an electrolyzer powered by PVs, burns hotter and cleaner than any other gas available: producing approximately twice as much thermal energy as propane and natural gas per pound, as shown in Table 1.

Table 1: Fuel Properties[iv]

Fuel Type	Percent Hydrogen Content (% Weight)	Energy Content (Btu/lb)	Energy Content (MJ/kg)
Propane	18	21,500	49.9
Natural Gas	25	23,000	54
Hydrogen	100	61,000	141.9

Appliances

In the refrigerator, the typical expansion cooling system will be replaced with an absorption cooling system that will be powered by solar thermal with hydrogen combustion as backup. A partnership is being developed with Yazaki Power Systems for this product as well. Its current refrigerator uses propane but a simple retrofit can be made to allow the refrigerator to use solar thermal and burn hydrogen instead.

The hydrogen retrofit will also be performed on the range. The combustion of gas is more efficient than using electric resistance, especially with hydrogen combustion since there are no negative byproducts. The OGZEB is utilizing hydrogen as a complete backup energy system, but since the FSU Solar Decathlon House will be grid-tied, the hydrogen system will be reduced to generation for hydrogen combustion only.

A new technology is being developed at FSU that greatly improves the efficiency of water electrolysis. This technology allows the use of less expensive metals for the electrodes. With the ability to use inexpensive materials (like metal oxide coated stainless steel) for the electrodes, the capital cost of the electrolysis devices will drop significantly. The hydrogen that is generated will be stored in a tank until heat is needed. Upon demand the hydrogen will be burned.

Electronics like TVs, DVD/VCR, computers, and microwaves will be powered by the PV array and will be chosen for optimal efficiency.

Market Viability

In the design and construction of the OGZEB we have partnered with several companies to develop technologies to make their products, as retrofit for solar or hydrogen power, commercially available. The FSU Solar Decathlon House will continue these partnerships and foster new ones; several companies have shown interest in working with us to develop the intellectual property of the FSU Solar Decathlon House for residential and commercial markets. Contracts and agreements have been signed with these companies to develop the technologies and market them when complete. It is our hope that when people walk into the FSU Solar Decathlon House they will be able to go home and implement its technologies immediately in their homes.

Lighting

Lighting is another large consumer of electricity in a house. In order to address the efficiency of the lighting system, light emitting diodes (LEDs) were chosen as the primary light source. These lights are extremely efficient and produce more lumens per watt than incandescent bulbs and fluorescent bulbs.

Still in their infancy, LEDs are gaining in popularity. Although initial LED lighting encountered problems with color and light transmittance, LED manufactures are resolving these issues. Light emitting diodes are powered by DC power but companies that distribute LEDs add converters that transform alternating current (AC) to DC. The inclusion of this converter results in a loss of 10 percent of the power in the conversion process. The FSU Solar Decathlon House's production of DC rather than AC makes the converter unnecessary there by eliminating the converter inefficiency.

Day lighting will also be used to minimize the amount of false light required during daylight hours. Tubular skylights will be designed with a combination LED and Aerogel modification that will increase the insulation of the skylight while providing light at night. The Aerogel will prevent harmful UV light from entering the house during the day and diffuse the intense light of the LED. Incorporating these into the skylight will prevent an additional light fixture. This light will also assist in the mood of the occupants of the building as it has been shown that sunlight positively affects people's mood and aids in healthy living[v].

Additional LEDs will be placed such that they recreate the day lighting effect at night. The installation of the LEDs will be designed to reflect their light off the ceiling to reproduce day lighting. The interior design calls for light colored wall coverings that will allow reflection of the light throughout the room to create a pleasant living environment.

Energy Balance

Modeling software is currently being developed for the OGZEB that will track the interior comfort levels as well as energy as it enters and leaves the house. The OGZEB was designed to be completely monitored providing data that will be used to calibrate the energy modeling software. With this software we will be able to go a step beyond traditional system design and test certain aspects of the products for the FSU Solar Decathlon House in the OGZEB ensuring that our models provide the most accurate data possible.

Safety Aspects

Safety on the construction site is paramount. Accidents during construction, assembly, and disassembly can be life changing. Individuals working on these phases of the FSU Solar Decathlon House will be required to attend a safety course conducted by a Habitat for Humanity safety officer who is experienced in teaching construction safety to volunteers. Hearing protection, safety glasses, hardhats, and gloves will be provided and their use required. All tools will be inspected to ensure that they are in proper working condition. Any electrical tools will be required to be equipped with safety triggers and automatic brakes. Also, a partnership with a private construction company has been developed to assist SESEC with safety protocol for the construction of the FSU Solar Decathlon House. The FSU building department, that oversees all construction at FSU, will also be consulted in order to ensure that all building practices are met for the safest conditions possible.

Environmental Impacts

Preservation of the environment is the cornerstone of SESEC. In developing the site-specific prototype, the OGZEB, SESEC designed it to be Platinum Green Certified based on the US Green Building Council Leadership in Energy and Environment Design (LEED) point system. This same philosophy will be used in the design and construction of the FSU Solar Decathlon house. Unfortunately LEED certification will not be possible for the FSU Solar Decathlon House since it will not be associated with a specific site as is required by the LEED program. The FSU Solar Decathlon House will be constructed with sustainable materials, water conserving fixtures, recycled materials, and wherever possible, salvaged materials. Internal components will not contain added formaldehyde, volatile organic carbons or other materials which may degrade indoor air quality. The design will be coordinated with material size to ensure that material waste is minimized. The lessons learned in the OGZEB will be applied to the FSU Solar Decathlon House, allowing SESEC to design a truly environmentally friendly house.

FUND RAISING AND TEAM SUPPORT

Over the past two years we have developed a team of students, faculty, and local professionals that have developed the OGZEB. The development of interdisciplinary relationships between the faculty of various departments has been critical in expanding the knowledge base to the level required to adequately design a house of this nature.

We have established partnerships with numerous companies to develop cutting edge technologies that will meet the goals of the Solar Decathlon. A few of these companies are: Viking, who is partnering in the design and manufacture of a range that will burn hydrogen; Johnson Controls, who is partnering in the development of controls and monitoring systems for solar housing; Solar Energy, who is partnering to develop solar thermal systems that will provide the required energy to power absorption systems.

Fund raising for the FSU Solar Decathlon house will be conducted in partnership with the FSU Foundation, a private corporation that works with the colleges, programs, and units of the University to generate private support from alumni and friends. For the past year and a half, SESEC has worked with the FSU Foundation to raise money and has their commitment to continue helping with the fund raising for the approximately $300,000 required to complete FSU Solar Decathlon House. The FSU Foundation has assisted in the completion of grants and has brought companies and individuals to the table that are interested in supporting alternative energy technologies. A network of contacts and resources has already been established and are anxious to assist in the Solar Decathlon.

Fund raising within the community will give a large number of small donors a stake in the success of the FSU Solar Decathlon House and a reason to closely follow its progress. In this, they will learn about energy conservation and production. They will also learn to act responsibly when making energy decisions required for their businesses and their everyday lives.

A relationship with the local media, including radio, television, and newspaper, has also been cultivated. They have anxiously covered our progress on solar and alternative energy projects as well as the design and construction of the OGZEB. A complete publicity plan will be developed by team members from the College of Communications. We also plan to include team members from the FSU School of Film, so that a documentary can be made on the FSU Solar Decathlon House and the Solar Decathlon.

CURRICULUM INTEGRATION AND SPECIAL CONSIDERATIONS

A plan has been developed to utilize the current tracks in several major programs to associate and use course projects to achieve certain deliverables required for the FSU Solar Decathlon House. Allowing the students to complete research that will count toward course credit will reduce the stress of this project on their schedule.

In mechanical engineering alone there are five undergraduate classes that have major group projects requiring design and construction of a system applicable to the class. These classes include Mechanical Systems, Thermal Systems, Senior Design I and II, and Design Systems.

Systems could be assigned to groups in each class that would meet their class requirements while also producing deliverables for the FSU Solar Decathlon House.

There is also a special class that will be provided to graduate and undergraduate students that will allow them to directly study a portion of the house. This class will allow the student to decide on a system of the house that they can focus on for a full year, allowing them to gain class credit for working on the house.

One main theme of conversations with previous teams was the stress that the students felt due to the magnitude of their Solar Decathlon project. Our team is working to reduce this stress by seamlessly incorporating this project into the current education system, including the addition of specialized classes. We are also pursuing the approval of a special interdisciplinary class that will focus on the study of the FSU Solar Decathlon House, teaching the basics of energy conservation, solar energy, and green building practices.

ORGANIZATION AND PROJECT PLANNING

The Sustainable Energy Science and Engineering Center at FSU has developed several tools to assist in the development of the FSU Solar Decathlon House. The first and primary tool is a networked system that will allow for communication, planning, information tracking, and privacy. SESEC has developed a computer system using the Microsoft Office Suite and Microsoft Small Business Server 2003, which will be based around a Project Plan that will track the progress of the deliverables for the Solar Decathlon and will keep the team up to date with status and upcoming requirements. It will also enable the project manager to track not only progress but the load on each team member ensuring that no one person is carrying too much work. This is an all inclusive tool that if properly used will allow the FSU Solar Decathlon House to develop smoothly and efficiently. The computer system will also allow for private emails and proper security of documents as well as routine backups.

A preliminary timeline (Appendix A) has been developed to guide the process of design, construction, and display of the FSU Solar Decathlon house. This timeline addresses each of the deliverables and includes a ten day buffer period for each. This buffer period will allow ensure that there is time for each deliverable to be reviewed and submitted to NREL in a timely fashion.

An organization chart (Appendix B) has also been developed to provide team members with a chain of command. Decisions will be made based on a dynamic governance methodology. The project manager has already been trained in this method and will initiate a training of all team members upon initiation of the project. This decision making method will allow team members to have a voice and affect the outcome of the project while ensuring a decision is made. This method minimizes conflict as much as possible through including everyone and weighing all options. Although this method is relatively new it is being relied upon by several large agencies including the US Green Building Council.

The OGZEB has provided significant experience in the process of designing, scheduling, and constructing a house similar to those of the Solar Decathlon, but it has not provided experience in transporting the building to Washington, DC. The primary method considered is for SESEC to design a significant portion of the house to remain intact for transportation with a size not exceeding 9 ft.(2.74 m) X 36 ft.(10.97 m) X 12 ft.(3.66 m) (the maximum size for rail transport). The additional portions of the house including the rest of the 800 square foot (74.3 m^2) footprint, porches, and supporting systems will be transported in component form and assembled on site at the Mall. Each addition component that does not make up the main section of the house will be assembled to a level minimizing the onsite assembly time. Detailed plans will be developed when the house design is complete. After the house arrives in Washington, DC via train, it will be trucked to the Mall and assembled for the competition. Assembly and disassembly will be designed for optimal safety and speed while ensuring the efficacy of the envelope. Contingency plans will be devised to cover possible issues that might arise.

CONCLUSIONS

Florida State University's Sustainable Energy Science and Energy Center, once becoming aware of the Solar Decathlon in October of 2005, could have immediately jumped into the 2007 Solar Decathlon. Instead, it has spent much of the past two years preparing to compete in the 2009 Solar Decathlon. In preparation, we have, in collaboration with numerous disciplines and private corporations, designed and constructed a site specific Off Grid Zero Emissions Building. As it moves forward to the 2009 Solar Decathlon, it will be hiring a master's level instructor to coordinate the entire process and ensure maximum student involvement. Extensive media coverage and fund raising will also bring the community into the process and educate them to the need for energy conservation and solar energy usage.

An investment of $50,000 per year for two one-year phases will result in the following:

1. Design, construction, and display of an 800 square foot (74.3 m^2) beautifully designed house that can generate energy efficiently to meet the needs of a modern residential dwelling;
2. Integration of the resulting design into an existing national "kit" housing system, with possible use internationally;
3. Education of approximately 120 students in energy efficiency, solar energy production, environmentally friendly construction materials and techniques, and related fields. A total of 400 credit hours of study are expected to be directly related to the Solar Decathlon;
4. Development of new solar energy technologies;
5. Market ready refrigerator and HVAC powered by solar thermal and absorption technology;
6. Market ready range and hot water systems that are powered by hydrogen and solar thermal;
7. A web site dedicated to communicating with and educating the public on the FSU Solar Decathlon house; and
8. Education of 200,000 plus citizens, with the plan to take our media campaign nationwide.

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[i] http://www.sesec.fsu.edu/ogzeb.html
[ii] http://www.ornl.gov
[iii] Goswami, D. Yogi, and Kreith, Frank, and Kreider, Jan F., "Principles of Solar Engineering", 2nd edition (New York: Taylor and Francis Group, 2000)
[iv] http://www.eere.energy.gov/afdc/pdfs/fueltable.pdf
[v] http://www.eere.energy.gov/