FESC
Florida Energy Systems Consortium

University of South Florida

Creation of Carbon Sequestration Data, Technologies and Professional Cohorts for Florida

(Final Report)

PI: Mark Stewart **Co-PIs:** Jeffrey Cunningham, Maya Trotz
Students: Arlin Briley, PhD, Mark Thomas, PhD

Description: Rising concerns over increasing levels of greenhouse gases, especially carbon dioxide, have led to suggestions to capture carbon dioxide at fixed sources, such as fossil fuel power plants, and sequester the carbon for millennia by injecting it underground. Florida overlies many thousands of feet of carbonate rocks which may be suitable for geologic sequestration of carbon dioxide. This project is investigating the potential for geologic sequestration of carbon dioxide in Florida, the physical and chemical changes that may occur as a result of injection, assess the potential for escape of injected carbon dioxide, determine the risk, if any, to aquifer systems used for water supplies, develop methodologies for Florida utilities to predict the performance and risks of proposed sequestration projects, and educate a cohort of geologic sequestration professionals to create a carbon sequestration industry in Florida. This project has graduated two PhD students, Tina Roberts-Ashby, US Geological Survey, and Roland Okwen, Illinois State Geological Survey, one post-doctoral student, Anwar Shadab, Missouri University of Science and Technology, and currently supports two PhD students.

Budget: $479,640
Universities: USF
External Collaborators: TECO, RTI, ECT, DOE

Executive Summary

Rising concerns over increasing levels of green house gases, especially carbon dioxide, have led to suggestions to capture carbon dioxide at fixed sources, such as fossil fuel power plants, and sequester the carbon for millennia by injecting it underground. Florida overlies many thousands of feet of carbonate rocks which may be suitable for geologic sequestration of carbon dioxide. This project is investigating the potential for geologic sequestration of carbon dioxide in Florida, the physical and chemical changes that may occur as a result of injection, assess the potential for escape of injected carbon dioxide, determine the risk, if any, to aquifer systems used for water supplies, develop methodologies for Florida utilities to predict the performance and risks of proposed sequestration projects, and educate a cohort of geologic sequestration professionals to create a carbon sequestration industry in Florida. This project has graduated two PhD students, Tina Roberts-Ashby, US Geological Survey, and Roland Okwen, Illinois State Geological Survey, one post-doctoral student, Anwar Shadab, Missouri University of Science and Technology, and currently supports two PhD students.

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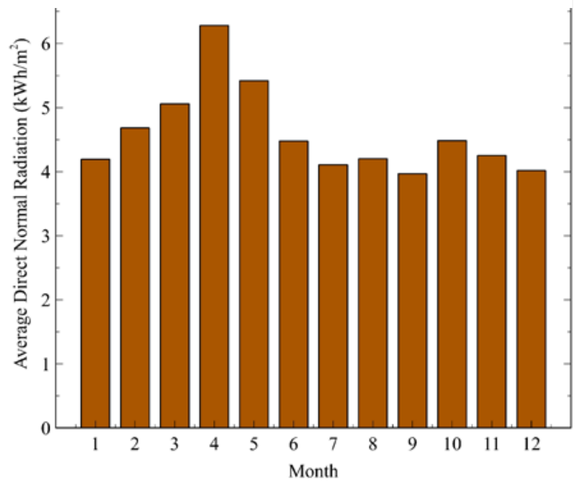
UNIVERSITY OF SOUTH FLORIDA

Design, Construction and Operation of CSP Solar Thermal Power Plants in Florida
(Progress Report)

PI: D. Yogi Goswami **Co-PIs**: Elias Stefanakos, Muhammad M. Rahman, Sunol Aydin, Robert Reedy
Students: Gokmen Demirkaya (Ph.D.); Ricardo Vasquez Padilla (Ph.D.);
Huijuan Chen (Ph.D.); Jamie Trahan (Ph.D.)

Description:
Florida utilities are mandated to achieve 20% renewable energy contribution to their generation mix by 2020. While technologically feasible with solar energy, the capital costs are high – presently, capital costs range from \$6,000-\$7,000/kW for PV and \$3,500-\$4,000/kW for concentrating solar thermal power. This project targets the development of solar thermal power technology for bulk power and distributed generation, which will diversify energy resources in Florida and reduce greenhouse emissions by utilizing renewable sources. Also, there will be economic impacts with the establishment of new power industry in Florida, which will help the electrical utilities of the state to meet the renewable portfolio standards. The project has three main tasks; the first one is to develop design methodologies and standards for the proven solar thermal power technologies in combination with bio or fossil fuels based on Florida conditions and resources. Secondly, the project aims to set up demonstration and test facilities for these technologies for optimization for Florida conditions, and the final task is to develop and commercialize innovative technologies based on new thermodynamic cycles.

FIG. 1 DIRECT NORMAL RADIATION FOR TAMPA, FL



Budget: \$882,000
Universities: USF, UF, UCF
External Colaborators: Sopogy Corporation

Progress Summary

Research Objectives for Current Reporting Period:

The main research objectives for the current reporting period include the development of a test facility and pilot demonstration systems based on parabolic trough technology.

Progress Made Toward Objectives during Reporting Period

Daily integration (DI) approach was used to obtain the average direct normal solar radiation for the location of the pilot demonstration solar plant (USF, Tampa, Fl). The direct normal solar radiation obtained for Tampa is shown in Fig. 1. The annual average for this location is 4.6 kWh/m^2-day. These solar radiation values and the solar shading analysis for solar collector rows were used for the solar field calculation. Picture in Fig. 2 show status on the installation of 50kWe solar power system. The Soponova 4.0 (Sopogy Inc.) parabolic trough collectors will be used in the solar field for providing 430 W/m^2 of thermal energy after losses. The solar field is being designed to work in conjunction with a thermal energy storage system which will use phase change material (PCM) as a storage material.

The remaining thermal energy will be provided by a natural gas boiler, which will work in series with the solar field and supply thermal energy to the power block when the solar energy is not available.

The power block that will convert the thermal energy to electricity is based on Organic Rankine Cycle. This power block will have a nominal capacity of 50 kW_e. A preliminary study on condensation methods for solar thermal plants is also conducted and more research will be devoted to the development of cost effective dry cooling technology.

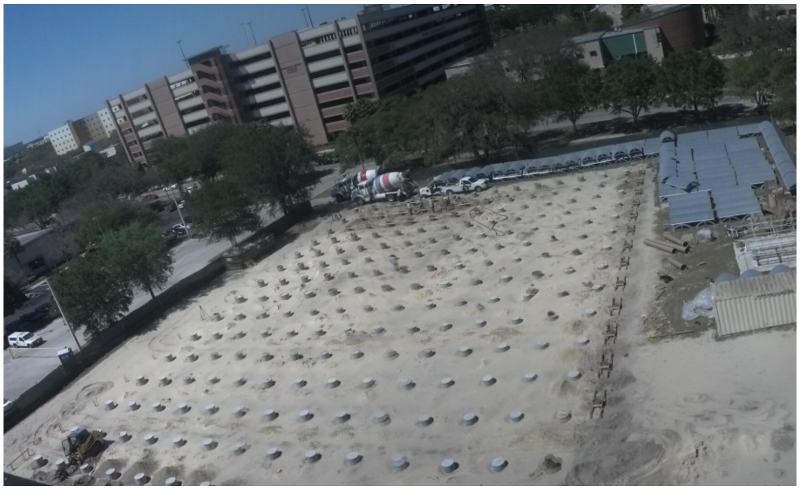


Fig.2. Solar Field for 50 kWe power generation

The following describes a summary of the background research that was needed to move forward with the design and construction of the power plant.

Parabolic Trough Concentrators

The performance of parabolic trough based solar power plants over the last 25 years has proven that this technology is an excellent alternative for the commercial power industry. Compared to conventional power plants, parabolic trough solar power plants produce significantly lower levels of carbon dioxide, although additional research is required to bring the cost of concentrator solar plants to a competitive level. The cost reduction is focused on three areas: thermodynamic efficiency improvements by research and development, scaling up of the unit size, and mass production of the equipment. The optimum design, performance simulation and cost analysis of the parabolic trough solar plants are essential for the successful implementation of this technology. A detailed solar power plant simulation and analysis of its components is needed for the design of parabolic trough solar systems which is the subject of this research.

Preliminary analysis was carried out by complex models of the solar field components. These components were then integrated into the system whose performance is simulated to emulate real operating conditions. Sensitivity analysis was conducted to get the optimum conditions and minimum levelized cost of electricity (LCOE). A simplified methodology was then developed based on correlations obtained from the detailed component simulations.

A comprehensive numerical simulation of a parabolic trough solar power plant was developed, focusing primarily on obtaining a preliminary optimum design through the simplified methodology developed in this research. The proposed methodology is used to obtain optimum parameters and conditions such as: solar field size, operating conditions, parasitic losses, initial investment and LCOE. The methodology is also used to evaluate different scenarios and conditions of operation.

The new methodology was implemented for a parabolic trough solar power plant for two cities: Tampa and Daggett. The results obtained for the proposed methodology were compared to another physical model (System Advisor Model, SAM) and a good agreement was achieved, thus showing that this methodology is suitable for any location.

Power Cycles for Solar Thermal Power

Low-grade heat sources below 300ºC, are abundantly available as industrial waste heat, solar thermal using low cost solar concentrators, and geothermal, to name a few. However, they are under-exploited for conversion to power because of the low efficiency of conversion. The utilization of low-grade heat is advantageous for many reasons. Technologies that allow the efficient conversion of low-grade heat into mechanical or electrical power are very important to develop.

Supercritical Rankine cycles were investigated for the conversion of low-grade heat into power. The performance of these cycles was studied using ChemCAD linked with customized excel macros written in Visual Basic and programs written in C++.

The selection of working fluids for a supercritical Rankine cycle is of key importance. A rigorous investigation into the potential working fluids was carried out, and more than 30 substances were screened out from all the available fluid candidates. Zeotropic mixtures were proposed to be used in supercritical Rankine cycles to improve the system efficiency. Supercritical Rankine cycles and organic Rankine cycles with pure working fluids as well as zeotropic mixtures were optimized for efficient conversion of low-grade heat into power. The results show that it is theoretically possible to extract and convert more energy from such heat sources using the cycle developed in this research than the conventional organic Rankine cycles. A theory on the selection of appropriate working fluids for different heat source and heat sink profiles was developed to customize and maximize the thermodynamic cycle performance.

The outcomes of this research will eventually contribute to the utilization of low-grade waste heat more efficiently.

Combined Power/Cooling Cycle

Binary mixtures exhibit variable boiling temperatures during the boiling process, which leads to a good thermal match between the heating fluid and working fluid for efficient heat source utilization. This study presents a theoretical and an experimental analysis of a combined power/cooling cycle, which combines the Rankine power cycle and the absorption refrigeration cycle to produce power and refrigeration in the same cycle, while power is the primary goal. This cycle, also known as the *Goswami Cycle*, can be used as a bottoming cycle to utilize the waste heat from a conventional power cycle or as an independent cycle using low to mid-temperature sources such as geothermal and solar energy. A thermodynamic analysis of power and cooling cogeneration was conducted. The performance of the cycle for a range of boiler pressures, ammonia concentrations, and isentropic turbine efficiencies were studied to find out the sensitivities of net work, amount of cooling and effective efficiencies. The thermodynamic analysis covered a broad range of boiler temperatures, from 85 °C to 350 °C. The first law efficiencies of 25-31%

are achievable with the boiler temperatures of 250-350 °C. The cycle can operate at an effective exergy efficiency of 60-68% with the boiler temperature range of 200-350 °C. An experimental study was conducted to verify the predicted trends and to test the performance of a scroll type expander. The experimental results of vapor production were verified by the expected trends to some degree, due to heat transfer losses in the separator vessel. The scroll expander isentropic efficiency was between 30-50%, the expander performed better when the vapor was superheated. The small scale of the experimental cycle affected the testing conditions and cycle outputs. This cycle can be designed and scaled from a kilowatt to megawatt systems. Utilization of low temperature sources and heat recovery is definitely an active step in improving the overall energy conversion efficiency and decreasing the capital cost of energy per unit.

Task 1: Development of simulation and design methodology for parabolic trough and parabolic dish
The objective of the task one is to develop a simulation and design methodology for the parabolic trough and parabolic dish based technologies for Florida conditions. Solar radiation, solar collector and thermal storage topics are the subtasks, and following progresses have been made during the period.

Parabolic trough solar systems are currently one of the most mature and prominent applications of solar energy for production of electricity. Compared to conventional power plants, parabolic trough solar power plants produce significantly lower levels of emissions and carbon dioxide. Thermal simulations and cost analysis of the system are used to evaluate the economic feasibility. Complex models and components are integrated to emulate real operating conditions, such as: Solar Radiation Model, Solar Thermal Collector, Thermal Energy Storage, Solar Field Piping, Power Block, Cost Analysis, and Integration of all Systems. This progress report presents a preliminary design method to calculate solar radiation data and thermal collector efficiency which are used to determine the size and the cost of solar field.

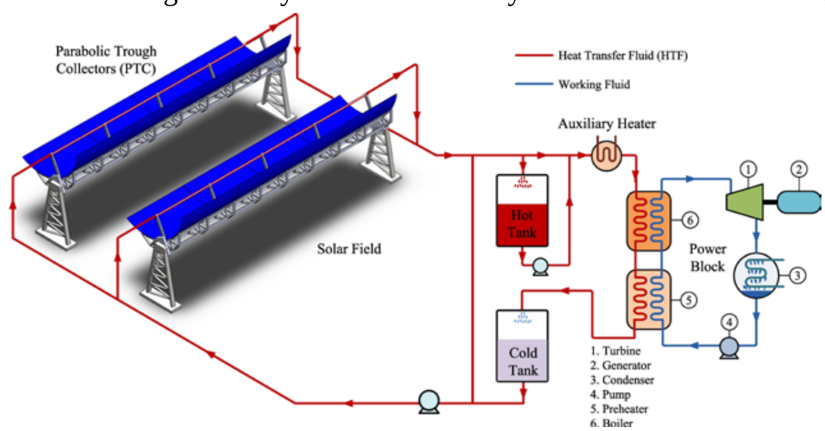


FIG. 4 PARABOLIC TROUGH POWER PLANT

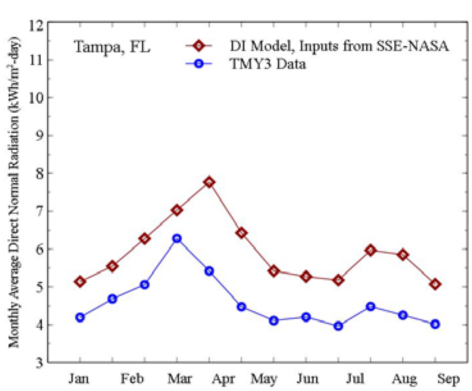


FIG. 3 COMPARISON OF TWO

An hourly solar radiation model is necessary to calculate the energy input that come from the sun, since the solar collector performance changes during the whole day. The inputs for the hourly solar radiation model are the long term average values of total horizontal and diffuse radiation, which can be obtained by ground or satellite measurements. Satellite data provide information about solar radiation and meteorological conditions in locations where ground measurement data are not available. Gueymard developed a Daily integration approach model to predict the monthly-average hourly global irradiation by using a large dataset of 135 stations with diverse geographic locations (82.58N to 67.68S) and climates. The results showed that the daily integration model is most accurate than previous hourly models.

The second part of this report is about the numerical heat transfer model. The receiver consists of an absorber surrounded by a glass envelope. The absorber is typically stainless steel tube with a selective absorber surface. The glass envelope is an antireflective evacuated glass tube which protects the absorber from degradation and reduces heat losses. The Solar receiver uses conventional glass to metal seals and bellows to achieve the necessary vacuum enclosure and for thermal expansion.

The heat transfer model is based on an energy balance between the heat transfer fluid and the surroundings (atmosphere and sky). A comprehensive radiation model between the absorber and the envelope is included in this study. The results showed that the new model has lower RMSE than the NREL Model (0.985% and 1.382% respectively). The numerical heat transfer model integrated with the solar radiation model can be used for evaluating the performance of solar collectors for any location.

Task 2: Development of a test facility and pilot demonstration

The second task targets the development of a test facility and pilot demonstration systems based on parabolic trough and dish technologies. The experimental combined power and cooling setup will be used as a preliminary study of the demonstration system that will be developed.

2.1 PERFORMANCE ANALYSIS OF A RANKINE-GOSWAMI COMBINED CYCLE

Improving the efficiency of thermodynamic cycles plays a fundamental role for the development of solar power plants. These plants work normally with Rankine cycles which present some disadvantages due to the thermodynamic behavior of steam at low pressures. These disadvantages can be reduced by introducing alternatives such as combined cycles which combine the best features of each cycle. In the present study a combined Rankine-Goswami cycle is proposed and a thermodynamic analysis is conducted. The Goswami cycle, used as a bottoming cycle, uses ammonia-water mixture as the working fluid and produces power and refrigeration while power is the primary goal. Figure 5 shows a schematic of the Rankine-Goswami cycle.

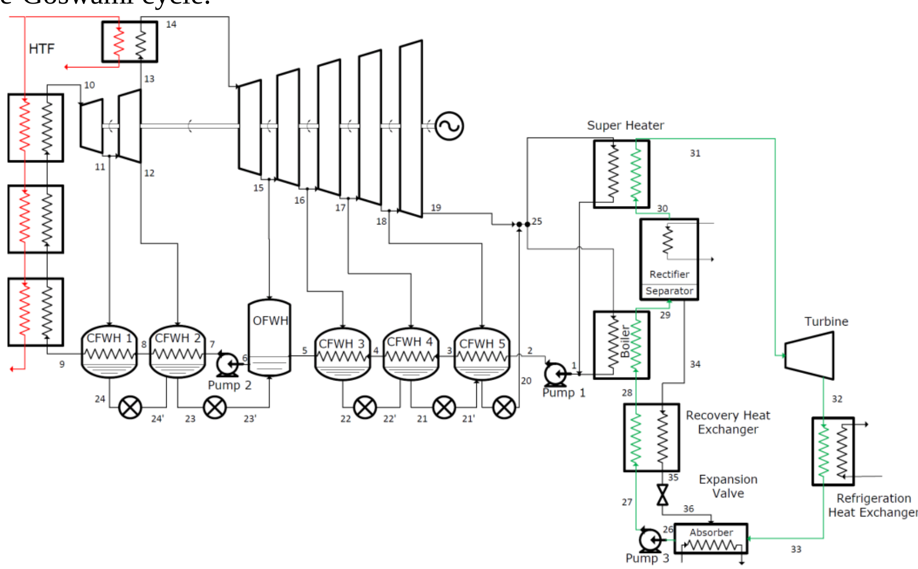
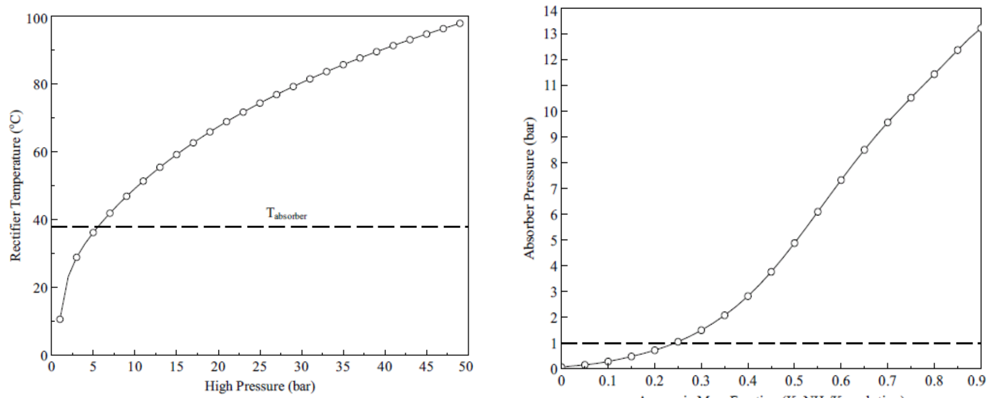


Fig.5

The detailed explanation about the parameters that were used for simulation is given in the paper. Different cases were also considered for parametric studies which are shown below.

Case	Rectifier	Superheater	Controlled Parameter
R	Yes	No	$x_{rectifier} = 0.995$ $T_{superheater} = T_{rectifier}$
R+S	Yes	Yes	$x_{rectifier} = 0.98$ $T_{superheater} = T_{boiler}$
B (Base)	No	No	Saturated vapor condition at the boiler exit

The thermodynamic properties of water and steam were implemented in Python 2.6 by using the international-standard IAPWS-IF97 steam tables. For the Goswami cycle, the properties of ammonia water were obtained from a Gibbs free energy formulation given by Xu and Goswami. In this study the amount of the electric work obtained from the topping cycle was held constant at 50 MWe while for the bottoming cycle the turbine work was considered as an output parameter. Figure 6 shows the effect of the high pressure side on the rectifier temperature and absorber concentration, In this case, the ammonia concentration range was selected such as the absorber was kept at least under atmospheric pressure.

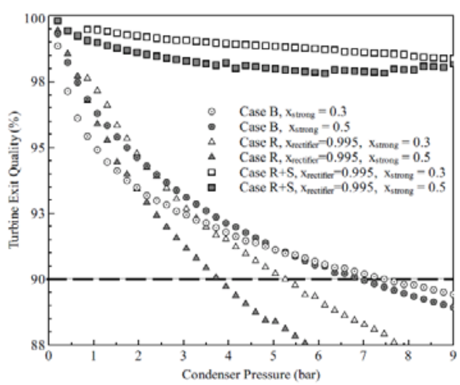


(a) Rectifier Tempearture, $x_{rectifier} = 0.995$

(b) Absorber Pressure, $T_{absorber} = 38.3°C$

Fig 6

Figure 7 shows the effect of the condenser pressure on the Goswami bottoming cycle exit quality for different cases and ammonia mass fraction. Moreover, Figure 8 shows the effect of the variations of the net -work with the condenser pressure for ammonia mass concentration of 0.3, in all the studied cases.



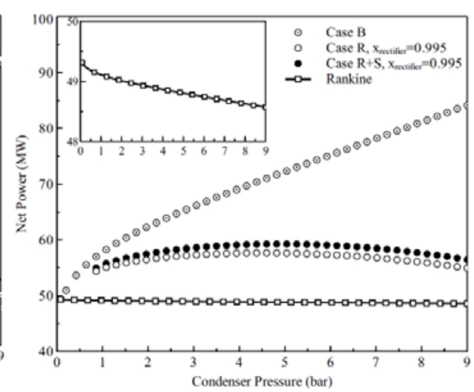


Fig.7 Fig. 8

The effect of condenser pressure on the effective First Law efficiency is also illustrated in Figure 9 while the cooling capacity of the Goswami bottoming cycle is presented in Figure 10. The effective exergy efficiency in the cycle as a function of the condenser pressure and ammonia mass fraction is also presented in Fig.11.

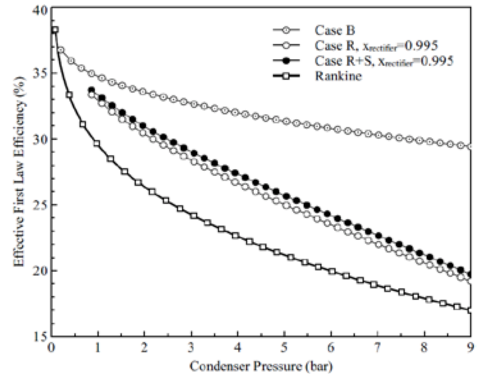


Fig. 9

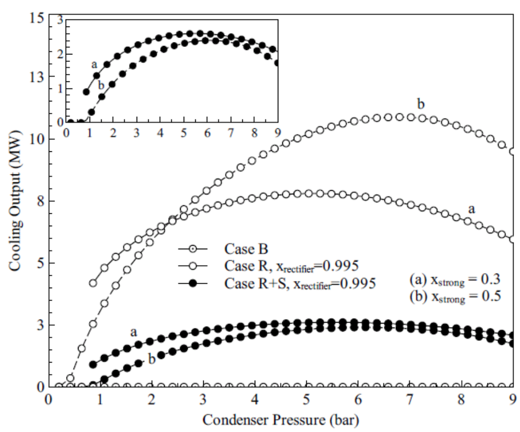


Fig. 10

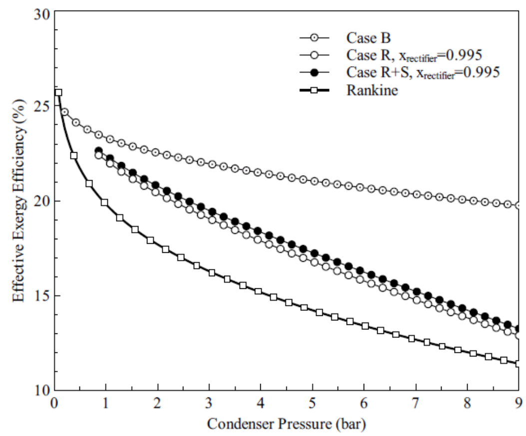


Fig. 11

Task 3. Installation and Operation of 50kWe Solar Power Plant

Sopogy Inc. Honolulu, Hawai is the main contractor for installation and operation of 50kWe Solar Power Plant at USF. Parabolic collectors (Soponova 4.0) were received from Sopogy and were assembled. Power block for generating electricity from GulfCoast Green Energy was also received. Power block is a Green Machine Elite 4000 manufactured by Electratherm. This machine will produce about 50kWh electricity from the thermal energy produces by solar field that will have 199 Soponova 4.0 parabolic concentrators from Sopogy Inc. Concrete foundation for installation of collectors is complete (see picture as shown in Fig. 2). Work will soon start to install collectors on the concrete foundations and complete installation of other parts.

Task 4: Thermal Energy Storage

We are currently working on the development of low cost thermal energy storage (TES) systems for Concentrating Solar Power (CSP). The objective is to research and develop a thermal energy storage system (operating range 300^{0}C – 450 ^{0}C) based on encapsulated phase change materials (PCMs). The system will be able to meet the utility-scale base-load concentrated solar power plant requirements at much lower system costs compared to the existing TES concepts. This project is developing a TES system concept that will allow for an increase of the capacity factor of the present CSP technologies to 75% or greater and reduce the cost to less than \$10/kWh$_{th}$ as compared to the present cost of about \$40/kWh$_{th}$.

We have successfully prepared porous pellets of phase change materials that will allow for the volumetric expansion during PCM melting and hence impose less stress on the encapsulating material. We have developed the encapsulation techniques and selected the low cost encapsulating materials that will be used to encapsulate the PCM. Currently we are optimizing the process for encapsulating the PCMs for various salts and salt eutectics in the temperature range from 300 to 1000^0C.

Publications

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7. Chen, H., Goswami, D.Y., and Stefanakos, E.K. (2010) "A Review of Thermodynamic Cycles and Working Fluids for the Conversion of Low-Grade Heat," *Renewable and Sustainable Energy* Reviews, 14 (9), 3059-3067.
8. Chen, H., Goswami, D.Y., Rahman, M.M., and Stefanakos, E.K. (2011) "Energetic and Exergetic analysis of CO_2- and R32-based Transcritical Rankine Cycles for Low-Grade Heat Conversion," *Applied Energy*, 88, pp. 2802-2808.
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Current and Pending Support

4/18/2013

Investigator: Goswami, Dharendra Yogi

Support: Current Role: PI

Title: Performance Evaluation Energy Saving Potential of VaporGenics Organic Rankine Cycle Ait-Conditioning Unit

Source of Support Florida Power and Light Company

Total Award Amount $113,516 Award Period: 12/1/2012 to 12/31/2013

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 1.00 Type: Sum

Award ID 21311019 Proposal ID 130000547 Proposal Date 10/26/2012

Support: Current Role: PI

Title: Innovative Latent Thermal Energy Storage System for Concentrating Solar Power Plants

Source of Support E-ON, International

Total Award Amount $646,359 Award Period: 1/1/2011 to 12/31/2013

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 0.50 Type: Sum

Award ID 21311009 Proposal ID 100001206 Proposal Date 03/10/2010

Support: Current Role: PI

Title: Development of a Low Cost Thermal Energy Storage System Using Phase Change Materials with Enhanced Radiation Heat Transfer
(Adv. Research Proj. Agcy-Energy)

Source of Support Department of Energy

Total Award Amount $1,523,872 Award Period: 12/5/2011 to 12/4/2014

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 0.75 Type: Sum

Award ID 21311015 Proposal ID 110001529 Proposal Date 05/19/2011

Investigator: Goswami, Dharendra Yogi

Support: Current Role: PI

Title: Development and Demonstration of an Innovative Thermal Energy Storage System for Baseload Power Generation

Source of Support Department of Energy

Total Award Amount $769,286 Award Period: 8/1/2010 to 7/31/2014

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 1.00 Type: Sum

Award ID 21311007 Proposal ID 100000475 Proposal Date 10/19/2009

Support: Current Role: Co-PI

Title: Removal of Off-Flavor Compounds in Aquaculture Food Products: Optimizing New Techniques for Sustainable Aquaculture Systems

Source of Support Florida Aquaculture Review Council

Total Award Amount $114,714 Award Period: 7/1/2012 to 6/30/2013

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 0.25 Type: Sum

Award ID 21071068 Proposal ID 110001120 Proposal Date 05/13/2010

Support: Current Role: Co-PI

Title: Linear-Focus Concentrating Solar Collector Based on a Novel Receptor-Development and Demonstration

Source of Support NCSR Demokritos

Total Award Amount $19,212 Award Period: 2/1/2013 to 1/31/2015

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 0.10 Type: Sum

Award ID 21311018 Proposal ID 130001030 Proposal Date

Support: Pending Role: PI

Title: Solar Energy Research Institute for India and the United States

Source of Support National Renewable Energy Lab

Total Award Amount $252,002 Award Period: 1/1/2012 to 12/31/2016

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: Type:

Award ID Proposal ID 120000218 Proposal Date 08/04/2011

Page 2

Investigator: Goswami, Dharendra Yogi

Support: Pending Role: PI
Title: Innovative High Efficiency High Temperature Combines Cycle Power Generation
Source of Support Department of Energy
Total Award Amount $934,301 Award Period: 7/1/2012 to 6/30/2015
Location of Project: University of South Florida, Tampa, FL
Person-Months per year Committed: 1.00 Type: Sum
Award ID Proposal ID 120001165 Proposal Date 02/06/2012

Support: Pending Role: PI
Title: Field Testing of Gas Heat Pump
Source of Support Associated Gas Distributors of Florida
Total Award Amount $199,966 Award Period: 7/1/2012 to 6/30/2013
Location of Project: University of South Florida, Tampa, FL
Person-Months per year Committed: 0.20 Type: Sum
Award ID Proposal ID 120001688 Proposal Date 05/24/2012

Support: Pending Role: PI
Title: Field Testing of Gas Heat Pump
Source of Support Associated Gas Distributors of Florida
Total Award Amount $199,966 Award Period: 7/1/2012 to 6/30/2013
Location of Project: University of South Florida, Tampa, FL
Person-Months per year Committed: 0.20 Type: Sum
Award ID Proposal ID 130000396 Proposal Date 05/24/2012

Support: Pending Role: PI
Title: Evaluation of VaporGenics Air Conditioning Unit using Natural Gas Technology
Source of Support Associated Gas Distributors of Florida
Total Award Amount $50,000 Award Period: 2/1/2013 to 1/1/2014
Location of Project: University of South Florida, Tampa, FL
Person-Months per year Committed: 0.10 Type: Sum
Award ID Proposal ID 130001135 Proposal Date 03/04/2013

Investigator: Goswami, Dharendra Yogi

Support: Pending Role: PI

Title: MRI: Development of An Automated Engineering Test Bench to Support Research and Training of Terahertz Devices

Source of Support National Science Foundation

Total Award Amount $506,032 Award Period: 8/1/2011 to 7/31/2014

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: Type: Sum

Award ID Proposal ID 110001078 Proposal Date

Support: Pending Role: PI

Title: Hydrogen rich gas production from Supercritical Gasification of Biomass

Source of Support U.S.-Egypt Science & Technology Joint Fund

Total Award Amount $67,501 Award Period: 1/3/2012 to 1/3/2015

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: Type: Sum

Award ID Proposal ID 120000867 Proposal Date

Support: Pending Role: Co-PI

Title: Novel Chromism in Nanocomposite Materials for Energy Saving Applications

Source of Support National Science Foundation

Total Award Amount $429,415 Award Period: 7/1/2013 to 6/30/2016

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 0.30 Type: Sum

Award ID Proposal ID 130001020 Proposal Date 02/12/2013

Support: Pending Role: Co-PI

Title: High Energy Density supercapacitors based on novel materials and fabrication techniques

Source of Support National Science Foundation

Total Award Amount $313,766 Award Period: 7/1/2013 to 6/30/2016

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 0.10 Type: Sum

Award ID Proposal ID 130001059 Proposal Date 02/20/2013

Investigator: Goswami, Dharendra Yogi

Support: Pending Role: Co-PI

Title: Production of synthetic Crude from biomass via thermochemical conversion: An integrated cradle to grave approach

Source of Support Department of Energy

Total Award Amount $3,500,000 Award Period: 6/1/2013 to 5/31/2016

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: Type:

Award ID Proposal ID 120001504 Proposal Date 04/17/2012

Support: Pending Role: Co-PI

Title: Innovative High Efficiency, High Temperature Combined Cycle Power Generation

Source of Support Department of Energy

Total Award Amount $900,000 Award Period: 7/1/2012 to 6/30/2015

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: Type: Sum

Award ID Proposal ID 120000774 Proposal Date 11/22/2011

Support: Pending Role: Co-PI

Title: SusChEM/GOALI: Removing off-flavor compounds from food-fish production through sustainable technologies

Source of Support National Science Foundation

Total Award Amount $600,001 Award Period: 8/15/2013 to 8/24/2016

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 0.20 Type: Sum

Award ID Proposal ID 130001066 Proposal Date 02/19/2013

Support: Pending Role: Co-PI

Title: Production of Synthetic Crude Biomass via Thermochemical Conversion: An Integrated Cradle to Grave Approach

Source of Support Department of Education

Total Award Amount $4,816,895 Award Period: 1/1/2013 to 12/31/2016

Location of Project: University of South Florida, Tampa, FL

Person-Months per year Committed: 3.00 Type:

Award ID Proposal ID 130000174 Proposal Date 04/17/2012

University of South Florida
Energy Delivery Infrastructures
(Final Report)

PI: Alex Domijan (No longer with USF) **Co-PIs:** Zhixin Miao; Lee Stefanakos
Students: L. Piyasinghe (Ph.D.), L. Xu (Ph.D.), M. Alhaider (Ph.D.)

Description: The purpose of the project is to simulate the effects of a renewable energy generation system (renewable energy distributed generation and a battery system), in a micro-grid, on the distribution grid system during critical conditions such as power peaks. Existing simulation tools can be used to properly represent dynamic and transient behaviors of microgrids.

Budget: $485,184
Universities: USF

Executive Summary

The proposed project is to simulate the effects of a renewable energy generation system in a microgrid context to the distribution grid system. The proposed project is to simulate the combination of renewable distributed generation and a battery system to assess the effects during critical conditions such as power system peak.

A research opportunity is to investigate how existing tools can be applied to properly representing ynamic and transient behaviors of microgrids. Therefore, in this project we propose using simulation tools to odel a microgrid and investigate how well we can reproduce its measured behavior in the field.

This project report summarizes three on-going tasks: 1) Microgrid power management scheme analysis; 2) Control and operation of a battery system in a microgrid; 3) Impacts of pulse power loads on a microgrid.

Microgrid power management scheme analysis: With the increasing use of renewable energy resources and energy storage devices, inverter-based distributed energy resources (DERs) become the important components in microgrids. As diesel generators with direct ac connections are the current most cost effective and reliable power sources, the stability investigation of microgrids should include both types of DERs. In this project, dynamics of diesel generation are included and the interaction of the diesel generators and the inverter-based DERs will be investigated using eigenvalue analysis and time-domain simulations. The significant contributions of this research project include: 1) identification of the stability problem in microgrids with inverter-based DERs and conventional generators and 2) investigation of the interaction problem of inverter-based DERs and conventional generators in islanded microgrids..

Control and operation of a battery system in a microgrid: the objective of this task is to investigate the control strategies of a Li-Ion battery group with a PV array within a microgrid. At the grid-connected mode, the battery and the PV array operate at power control mode, while at the autonomous mode the battery provides voltage and frequency control instead. The contributions of this work include: (i) a detailed model of battery including state of charge (SOC) modeling, short-time and long-time transient characteristics and a detailed model of PV array have been built; and (ii) effective control strategies for a battery with the PV array system to operate at both the grid-connected and the autonomous modes have been developed. A test microgrid consisting of a voltage source converter (VSC) interfaced battery, a PV array, passive loads and an induction machine is built in PSCAD/EMTDC. Simulations are carried out and demonstrate the proposed control strategies could coordinate independent distributed generation effectively..

Impacts of pulse power loads on a microgrid: the objective is to investigate the pulse power load (PPL) impact on the stability of a microgrid with power electronic converters. The PPLs are largely employed in areas of high power radars, lasers, high energy physics experiments and weapon systems such as rail guns. The peak power of a pulse load can be vary from several hundred kilowatts to several hundred megawatts and the time duration is typically from microseconds to seconds. Hence for the proposed work, a microgrid with Voltage Source Converter (VSC) based inverters and synchronous generators are considered in order to provide better approach towards the smart grid. The study is conducted in PSCAD/EMTDC and Matlab/SimPowersystems.

University of South Florida

Energy Efficient Technologies and the Zero Energy Home Learning Center
(Final Report)

PI: Stanley Russell **Co-PI:** Yogi Goswami
Students: Mario Rodriguez (MA), Sean Smith (MA), Jon Brannon (MA), Jean Frederic Monod (MA)

Description: The project is to create and evaluate an affordable residential scale Zero Energy building that will function as an exhibition of energy efficiency and Zero Energy Home [ZEH] technology on the University of South Florida campus. The project will feature the most cost-effective combination of renewable solar energy with high levels of building energy efficiency. The building will incorporate a carefully chosen package of the latest energy efficiency technologies and renewable energy systems to achieve the most successful and reliable results.

The building will utilize Photovoltaic solar electricity and solar domestic hot water heating systems using the grid as an energy storage system, producing more energy than needed during the day and relying on the grid at night. Plug-in hybrid automobile technology offers a promising means of providing distributed energy storage for such homes. Using a systems approach to couple zero energy home technology with PHEVs we will explore opportunities to develop marketable products that meet Florida's energy and environmental goals.

Budget: $344,600

Universities:
USF-School of architecture, College of Engineering, College of Mass Communications, School of Business
FSU-College of Engineering
UF- Department of Interior Design
UF-Rinker School of Building Construction
UCF-Florida Solar Energy Center

External Collaborators:
Palm Harbor Homes
Beck Construction
Hees and Associates Structural Engineers

Executive Summary

The project is to create and evaluate an affordable residential scale Zero Energy building that will function as an exhibition of energy efficiency and Zero Energy Home [ZEH] technology on the University of South Florida campus. The project will feature the most cost-effective combination of renewable solar energy with high levels of building energy efficiency. The building will incorporate a carefully chosen package of the latest energy efficiency technologies and renewable energy systems to achieve the most successful and reliable results.

The building will utilize Photovoltaic solar electricity and solar domestic hot water heating systems using the grid as an energy storage system, producing more energy than needed during the day and relying on the grid at night. Plug-in hybrid automobile technology offers a promising means of providing distributed energy storage for such homes. Using a systems approach to couple zero energy home technology with PHEVs we will explore opportunities to develop marketable products that meet Florida's energy and environmental goals.

Design Development was completed in November of 2010. The 889 square foot Zero Energy House Learning Center is a flexible, modular, pre-fabricated, net zero energy prototype that can adapt easily to different site situations and client needs. The key factor shaping the design approach is Florida's mild climate and an indoor outdoor lifestyle. FLeX House combines the wisdom of vernacular Florida houses, ZEH research, with cutting edge technologies to make a holistic systems engineering based, zero energy building package. The project will feature the most cost-effective combination of energy-.efficiency technologies and renewable energy systems. The ZEHLC will serve as a teaching and learning tool on campus while promoting the use of ZEH technologies throughout the southeastern US.

The prefabrication process maximizes efficiency and quality control and reduces waste when compared to the site built counterpart. Once fabricated, the main body of the house can be shipped to the site on a single truck minimizing transportation costs. The main body contains sliding modules that are deployed from the main body to complete setup at the site quickly with a minimum use of equipment and labor. The modular system is easily expandable and reconfigurable according to the wants and needs of the client and the site situation.

The plan is laid out on the east west axis to maximize shading and natural ventilation and minimize direct solar gain. Because of the hot climate, the living spaces focus on the cooler, north side of the site. The entire north wall, composed of sliding glass panels can be opened combining the interior living spaces, the exterior deck and the garden into one continuous indoor/outdoor space. The interior space can be left open with a continuous flow from the kitchen to the master suite/office area, or it can be partitioned to separate the living and bedroom areas for privacy and to create two separate thermal zones for energy conservation.

As a net zero energy house FLeX House utilizes Photovoltaic panels for site based, clean renewable energy generation. The grid tied 5 kW array will send electricity back to the municipal electric utility grid during peak hours of generation and FLeX House will take electricity from the grid in the evening or on cloudy days. Over the course of a year the net consumption from the grid will equal zero.

Flex House is equipped with low flow fixtures to conserve water. Rain water is diverted from the roof into a cistern where it is stored and used for irrigating the organic vegetable garden. To

keep energy consumption to a minimum FLeX House includes high efficiency energy star rated appliances. To reduce the amount of energy required for lighting, FLeX House was designed to make the best use of natural day light for its interior spaces with large glazed areas on the north and south facades and light colored interior finishes that reflect the light and brighten the interior spaces.

The HVAC system consists of a heat pump and solar thermal panels that circulate refrigerant or heated water to two interior fan coils to cool or heat the house. The energy recovery ventilator [ERV], by precooling the outside supply air, allows the chilled water system to run more efficiently. The ERV combined with a liquid desiccant dehumidifying system allows the fan coil temperatures to exceed the dew point while still maintaining good indoor air quality.

Flex house is designed to meet Florida's demanding hurricane code. All exterior finish materials have been tested for impact in hurricane winds and have obtained the required Florida product approvals. The building skin is durable, galvanized corrugated metal and the wood lovers are made from cypress which has a natural resistance to rotting and intrusion from insects. In the off season the bedroom and entry modules can be slid back into the main body of the house and the entire exterior can be shuttered to protect the house from the weather and vandalism.

Construction Documents were completed in March and a contract between Beck Construction and USF was finalized. After delays in the contract process, construction began in mid-May, 2 months behind the original schedule. Construction continued through the summer and was completed in early September. The house was disassembled and shipped to Washington DC on September 12th. FLeX House was successfully reassembled in West Potomac Park in DC and was exhibited in the 2011 Solar Decathlon. Tens of thousands flocked to the popular house which was second in total attendance among the 19 houses on display. The house was disassembled and shipped back to Tampa where it is scheduled to arrive in the morning of 10/14. Once reassembled in its permanent location on campus the house will begin its life as the ZEHLC.

Before beginning design on the ZEH Learning Center we studied vernacular precedents and more recent building and research projects that have aimed at zero energy or near zero energy status. We looked at Vernacular Florida architecture as precedent for passive cooling, heating and daylighting. Building design in Florida changed considerably with advancements in mechanical systems in the mid- 20th century. Up until that time houses typically had wide overhangs to shade the walls and windows, wide covered porches for outdoor living and high ceilings with crawlspaces under the floor to induce natural ventilation. After air conditioning became popular houses were built to close out the heat with smaller windows, compartmentalized interiors, and low flat ceilings. Passive solar design was experimented with during the energy crisis of the 1970s and although it was mostly applied to cold climates, many of the lessons learned during that period are once again relevant in the current movement toward zero energy buildings.

Because the thermal comfort range of the average American has changed since the proliferation of air conditioning, it would be difficult for most to live in a passively cooled home especially in Southern Florida. Regardless, the principles of vernacular buildings and passive solar design can complement advances in 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. South Korea for example, has set a standard of not less than 26c [79f] in the summer for air conditioning and not more than 20c [68f] in the winter for heating in public buildings. In Japan, air conditioning in public buildings is mandated at not less than 28 [82f] degrees in the summer season.

Many of the examples of near zero and zero energy houses in Florida are projects implemented by The Florida Solar Energy Center® (FSEC), a research institute of the University of Central Florida. Since 1998 with funding from the department of energy's building America program FSEC has built and monitored several zero energy and near zero energy houses in the State of Florida. Data gathered from monitoring the performance of these houses is a valuable resource for ZEH research. The FSEC projects made it clear that combining energy efficiency in building design and appliances with PV and solar thermal systems for clean renewable energy generation can result in affordable zero energy houses.

The *Off Grid Zero Energy Building* [OGZEB] at Florida state university is an off grid zero energy test house which is just beginning to yield data. In addition to Photovoltaic panels, the OGZEB incorporates hydrogen fuel cells for storage and production of electric power. The *Florida House Learning Center* in

Sarasota Florida, like the proposed ZEH Learning Center, was established to showcase sustainable building technologies to builders and the general public. The Florida House contains exhibits of various green building products and the building itself has explanatory text in various locations to describe the technologies at use. I traveled to Japan in June and met with engineers at two of Japan's largest housing manufacturers Misawa Homes and Sekisui Haimu. Misawa Homes produced its first Zero Energy House Model in 1998 and since then has sold thousands throughout Japan. Both companies take a systems approach to life cycle cost, energy use and CO_2 emissions with their highly efficient manufacturing processes. The experience in Japan made the advantages of factory built homes evident and led us to pursue a housing manufacturer as an industry partner.

In addition to documenting what has already been accomplished in the field of building energy efficiency we also feel that it is important to know about the emerging technologies that will transform Zero Energy Building design in the near future. Some of these are already beyond the testing stage and in commercial production but are expensive compared to more conventional alternatives. This is often a function of supply and demand and in many cases it can be assumed that an increased demand for these products will lead to lower prices. We think that raising public awareness to increase demand for quality products is one important function of the Zero Energy House Learning Center. Technologies like Aerogel insulation, vacuumed insulated glass, electro-chromic glass, building integrated photovoltaic materials and OLED lighting will revolutionize building design and construction when they reach an affordable level. Liquid desiccant cooling and dehumidification show promise for the next generation ZEH in the hot and humid southeast. Liquid Desiccant solar cooling systems developed as part of the Department of Energy's SBIR program convert hot water from solar thermal panels into cooling and dehumidification.

We are also interested in the interface between the ZEHLC and other related systems. The key to energy efficiency in the future will undoubtedly lie in smart grids that will regulate the flow of electricity to and from buildings according to peak and low demand periods. The plug-in hybrid electric vehicles, soon to be released by several auto makers, will be key elements in regulating this flow and storing energy for the grid and will be considered as an integral part of the ZEHLC design.

The Solar Decathlon is an event held every other year on the Mall in Washington DC to showcase the latest advances and emerging technologies for energy efficient buildings. 20 Teams are chosen from an international pool of applicants to design and build energy efficient buildings on the Mall. In answer to the RFP for the 2011 Solar Decathlon I assembled a team of experts from FSU, UF, UCF and USF in the fall of 2009 to make a proposal. Our proposal was deemed competitive in January 2010 and we were asked to submit a schematic design proposal by March of 2010. Based on the strength of our submission, Team Florida was chosen as one of 20 teams to compete in the 2011 Solar Decathlon. Participation in the 2011 Solar Decathlon expands the potential of the ZEHLC as a learning tool and facilitates additional funding and input from experts across the state.

Based on our research from the first year we began looking at architectural and engineering innovations that could improve on current ZEH technology and construction practices. The closed nature of recent Florida houses and early attempts at ZEH was identified as a problem that we wanted to address with the ZEHLC. We maintain that contemporary Florida houses can significantly reduce their annual energy consumption by incorporating the same passive solar strategies that were commonly used in Florida homes before the advent of air conditioning. A building envelope that is well sealed and insulated and can be opened during the cooler/dryer months of the year and closed when temperature and humidity levels are too high, can have a more open feeling and save energy at the same time. Furthermore, studies at FSEC have shown that the majority of heat gain comes through the roof of Florida homes and attic spaces reach extremely high temperatures in the range of 140^0. We considered the use of a shading device that would cover the entire roof and east and west walls of the house to significantly reduce or eliminate direct solar radiation coming in contact with the building envelope. A ventilated space between the shading device and the house would prevent the buildup of hot air that commonly occurs in the attic space of Florida houses. According to a life cycle assessment of energy use, we looked at a modular, factory built house to minimize construction waste and maximize efficiency in labor and energy use during the construction process. Innovative mechanical systems including a liquid desiccant system for controlling humidity levels and reducing latent heat load; a solar thermal system that takes advantage of a high thermal conversion of solar radiation and uses it for a variety of energy end uses and a heat pump tied to the solar thermal system to increase efficiency in both systems.

To test the effectiveness of different building envelope alternatives, we built 3- 8'x8'x8' structural insulated panel modules, each with a different envelope system. Module 1, the control case, had no additional treatment of the envelope. Module 2 had a 3/4" ventilated airspace on the exterior skin of the roof and walls. Module 3 had a shading device covering the roof and east and west walls.



Fig. 1 module construction | Fig. 2 module 2 complete | Fig. 3 testing module 3

The 3 modules were monitored under identical conditions simultaneously over an 8 hour period with a Campbell Scientific PS100 Data logger and 3 temperature and relative humidity sensors attached to determine the most efficient and economical configuration of the building envelope. The results confirmed that the module with the shading device had the lowest interior temperature at the end of the 10 hour period. The temperature difference within the modules continued to grow as the hours passed and the insolation continued to raise the temperature disproportionately in the unprotected module 1.

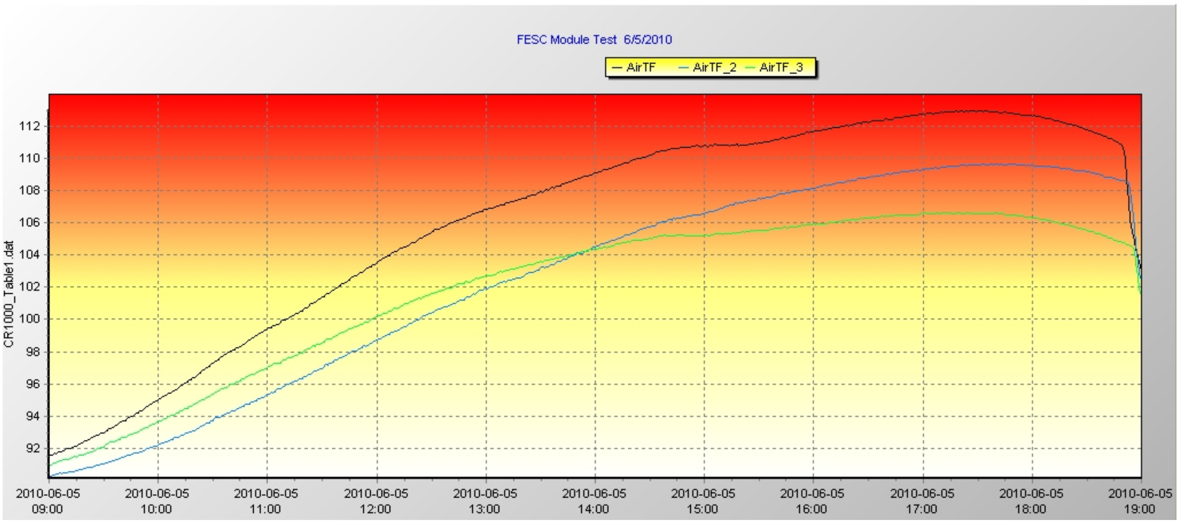

Fig.4 black line is module 1, blue line is module 2, green line is module 3

We applied our research from the first 11/2 years of the grant period to our schematic design concept. Based on our research we were convinced that contemporary houses can significantly reduce their annual energy consumption by incorporating passive solar strategies. We decided on a hybrid approach to the building envelope combining current thinking in ZEH technology with vernacular wisdom with an envelope that can be opened during the cooler/dryer months of the year and naturally ventilated and closed and mechanically cooled when the outdoor temperature and humidity levels are too high to achieve an acceptable comfort range by natural ventilation.

The entire north elevation is sliding glass panels that can be opened to the garden to allow natural ventilation and a sense of connection with the landscape promoting a healthy and energy efficient indoor/outdoor Florida lifestyle. On the south elevation all of the glass is shaded by louvers to eliminate insolation during most of the year. During winter when the sun is lowest in the sky there are typically several cold days when afternoon temperatures are low enough to require space heating. Louvers on the south side of the building will be adjustable so that the sun can be allowed to penetrate the space on cold days but can also shade the sun on warm winter afternoons.

A shading structure made of steel tubing and wood lovers will completely shade the roof and east and west walls of the house stopping the hot solar rays from radiating through the building envelope. An 18" space separating the shading device and the building will allow air to pass through freely and prevent the buildup of hot air between the two. The umbrella will also support the PV array and solar thermal panels making them easily accessible without disturbing the building envelope. The house is designed for pre fabrication to minimize construction waste and maximize efficiency in labor and energy use during the construction process. Since we plan to ship the house in one piece the exterior dimensions are limited by shipping restrictions. Portions of the building that go beyond the prescribed shipping width are designed to telescope out from the main building envelope making the house economical to ship and quickly deployable at the site. A 5 KW PV array will provide electric power to the house; a liquid desiccant system will control humidity levels and reduce latent heat load; a solar thermal system that takes advantage of Florida's high thermal conversion of solar radiation will be used for space heating, hot water and to regenerate the liquid desiccants. Hot and chilled water will be circulated around the house to fan coil units in 3 zones for localized control of temperatures and reduced temperature fluctuations when compared to forced air systems.

Design Development was completed in November of 2010 complete with a BIM model of the building a detailed half inch scale model and a digital animated walk thru. The scale models were exhibited at the International builder's show in Orlando in January 2011. A 70 page set of Construction Documents was completed in March of 2011 and a contract between Beck Construction and USF was finalized for the construction of FLeX House. After delays in the contract process, construction began in mid-May, 2 months behind the original schedule. Construction continued through the summer and was completed in early September. The house was disassembled and shipped to Washington DC where it was successfully reassembled in West Potomac Park and exhibited in the 2011 Solar Decathlon. Tens of thousands flocked to the popular house which was second in total attendance among the 19 houses on display. The Solar Decathlon gave students the opportunity to tour the other 18 houses and exchange ideas with their peers as well as explain their ideas to the thousands of visitors to the house. The 3 week event was an exceptionally intense and rich learning experience for the students involved. The house was disassembled and shipped back to Tampa where it is scheduled to arrive on the morning of 10/14. Once reassembled in its permanent location on campus the house will begin its life as the ZEHLC and become an exhibition of energy efficient technologies as well as a living laboratory for energy efficiency research.

ZEHLC research has been presented at the following conferences and meetings:

1. Russell S.R., *Reaching Zero Energy in Florida's Hot Humid Climate,* ARCC 2011 CONSIDERING RESEARCH: Reflecting upon current themes in Architectural Research, Detroit MI, spring 2011,
2. Russell S.R., Weston M., Goswami Y., Doll M. *Flex House,* ASME 2011 5th International Conference on Energy Sustainability & 9th Fuel Cell Science, Engineering and Technology Conference, Washington D.C. Summer 2011
3. Russell S.R. *Energy Efficiency and the Zero Energy Home Learning Center,* ACSA National Conference, RE.building, New Orleans Louisiana, Spring 2010
4. Russell S.R. *Evolution of the American Zero Energy House,* Eco-Architecture 2010, La Coruna Spain, Spring 2010
5. Russell S.R. *Evolution of the American Zero Energy House,* International Conference On Building Science And Engineering, Johor Bahru, Malaysia, December 2009
6. Eco House Symposium- Kanagawa University, Kanagawa Japan- summer 2011
7. AIA Florida Annual Conference- Naples Florida- summer 2011
8. ASME Tampa Bay Annual Meeting- FLeX House- summer 2011
9. AIA Tampa Bay Designer's Luncheon Lecture Series- fall 2010- 2011 Solar Decathlon - FLeX House
10. CSI Luncheon - FLeX House- spring 2011

ZEHLC research has been published in the following journals:

1. Russell S.R. *Hybrid ZEH for Florida's Hot Humid Climate*, The International Journal of Design & Nature and Ecodynamics, WIT Press.

The ZEHLC design model has been exhibited at the following venues:

1. Title- *U.S. Department of Energy Solar Decathlon 2011 Finalists: A Special Presentation,* Venue- National Building Museum, Washington DC Date- 5/ 1- 7/25, 2010
2. Title- *U.S. Department of Energy Solar Decathlon* Venue- Orange County Convention Center Date- 1/12-1/15, 2011
3. Title- *U.S. Department of Energy Solar Decathlon* Venue- McCormick Place Chicago IL. Date- 1/12-1/15, 2011
4. Title- *U.S. Department of Energy Solar Decathlon 2011 Finalists* Venue- Portland Downtown Marriot Waterfront, Portland, Oregon Date- 8/11-8/14, 2010
5. Title- *U.S. Department of Energy Solar Decathlon 2011 Finalists* Venue- National Renewable Energy Laboratory Visitor Center Date- April 2010
6. Title- *Zero Energy House Learning Center* Venue- ASCA National Conference Poster Session, Montreal, Canada Date- 3/ 2011

We applied for and received a $100,000 from the DOE for the 2011 Solar Decathlon. Our team raised $55,000 in cash donations and an additional $75,000 in gifts in kind.