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Integrated Engineering Education Through Multi-Disciplinary Nationally Relevant Projects: The Solar Decathlon Project.

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Abstract

In the education and training of students in the technical disciplines, our goal is to not only equip the students with knowledge and skills necessary to effectively practice their profession but to successfully function in a multi-disciplinary, multi-cultural and interdisciplinary environment. This is the real society in which they will live and practice the profession. As most real life projects will be complex, involving experts and artisans from other fields, it is crucial the students gain exposure to emerging applications to the various disciplines in engineering, architectural design, construction and the environment. In choosing a project, it is necessary and advantageous to consider projects that fit in with National priorities and are, also, within current cutting-edge technologies. These factors are important to students in terms of employability and tend to enhance students enthusiasm and persistence during project execution. The College of Engineering, Architecture & Physical Sciences at Tuskegee University has successfully participated in National Competition, "Solar Decathlon" at the National Mall in Washington D.C. The overall challenge of this competition was to design, build and operate a 500-squre foot solar powered house. The energy source for this house was completely provided by renewable energy incident upon the specified space that the house occupies. No other pre-stored form of energy or fuel was allowed. The Tuskegee University team consisted of students from Electrical Engineering, Mechanical Engineering, Computer Science, Architecture and Construction Science and Management Departments, and five academic advisers encompassing the different departments. This paper presents the strategies employed by the Solar Decathlon Team to successfully complete the project and the business management strategies that contributed to its success. It discusses the lessons learned by students working on the project and from interaction with students from other universities during the competition. Lessons from the post competition analysis, including strategies for future competitions are discussed. Finally, the overall impact resulting from the project on the training of engineering students, curriculum development and update strategies are discussed.

Keywords: Integrated Engineering Education, Multi-Disciplinary, Nationally

Relevant Projects, And Solar Energy.

1.0 Introduction

In February 2001,Tuskegee University participated in a proposal competition to design and build a 500-square foot completely solar energy sufficient house. The house is to utilize solar energy, in particular, to provide heat, cooling, illumination and electricity. This energy is to meet the requirements for the domestic and home-office activities of a typical American family. Eleven universities were selected in March 2001 by the National Renewable Energy Laboratory (NREL) working on behalf of the United States of America Department of Energy (DOE). The number of universities participating was subsequently expanded to fourteen. The following universities competed:

1. University of Puerto Rico
2. Texas A&M
3. University of Delaware
4. University of Missouri-Rolla and the Rolla Technical Institute
5. Virginia Polytechnic Institute and State University
6. University of Virginia
7. Auburn University
8. University of North Carolina at Charlotte
9. Crowder College
10. University of Texas at Austin
11. University of Colorado at Boulder
12. Carnegie Mellon University
13. Tuskegee University
14. University of Maryland

The kickoff ceremony was held in April 2001 in Washington D.C. At this ceremony, the seed money of $ 5000 was given to each of the participating universities and colleges. This was to be completely students' project with the professors acting, only, as academic advisers. The tasks of the advisers could then be stated as follows:

- Arouse students' interest to participate and successfully complete the project.
- Charge the students to come up with a winning design
- Facilitate cordial and cooperative interaction between students from various departments involved in the project.
- Solicit sponsorship from industry to build the solar house and equip it with modern energy efficient appliances.
- Meet progress deadlines as specified by NREL.

2.0 Project Objectives

The overall goal of the competition was to design and build a 500-square foot, solar powered house. The energy source for this house was completely provided by renewable energy incident upon the specified space the house occupies. No other pre-stored form energy or fuel was allowed. The specific objectives were:

2.1 Supplying the energy requirements necessary to live and work using only renewable energy incident on the house during the competition.
2.2 Exemplifying design principles that will increase public awareness of the aesthetic and energy benefits of solar energy, resulting in increased utilization of these design principles and technologies.
2.3 Stimulating the acceleration of research and development (R&D) of renewable energy, particularly in the area of building application.

From these objectives the following ten scoring events (decathlon) were developed:

- **Energy production** able to supply all the energy needed for its occupants to survive and prosper in today's society.
- **Energy efficiency** that reduces consumption and enables more work to be accomplished with a given amount of energy.
- **Design** that improves effectiveness, efficiency, function, and comfort.
- **Heating and air conditioning** necessary for health and comfort.
- **Refrigeration** for food preservation
- Adequate **hot running water.**
- Adequate **lighting** to improve functionality, safety, education, and quality of life.
- **Print and electronic and video communication** to save time and improve safety and quality of life by providing information necessary in making critical decisions.
- **Transportation** provided by electric car to save time and improve productivity.
- **Efficient modern appliances** necessary to save time and physical work and improve quality of life.

3.0 Developed Strategy for Executing the Project

Our first task was to meet with Tuskegee University Administration including the president, the provost, the dean of the college of engineering and the various departmental heads to solicit their support, not necessarily financially, but in kind. The second task was to publicize the Solar Decathlon Project to the student body and invite students from Engineering, Architecture and Construction Science and Management, Computer Science, Business, Biology and English Departments to a general informative meeting. Over fifty students attended this inaugural meeting. From this first meeting, initial groupings encompassing Architecture, Construction, Electrical Engineering, Mechanical Engineering, Website Design, Media Relations and Transportation to Washington D.C. were raised.

It was clear to the academic advisers that to kickoff the project in earnest, preliminary core design groups of engineering and architecture students were needed to begin work immediately on the project. These were selected as follows to do the preliminary design work during the summer of 2001:

3.1 Electrical Engineering Design Group

The tasks for this group included:

- Review of the basic theory and fundamental of solar energy technologies.
- Perform a market survey of energy efficient appliances necessary to satisfy the requirements of a completely solar powered modern one-bedroom house.
- Perform energy audit in ampere-hours for the daily consumption of this house.
- Identify major electrical components for the house, including control equipment for energy management.
- Perform cost analysis for identified components and appliances.

3.2 Mechanical Engineering Design Group

This group was required during the summer of 2001 to:

- Review of the basic theory and fundamental of solar energy technologies.
- Design the preliminary water-heating requirement, including identifying available manufacturers and making recommendations with cost analysis included.
- Review HVAC requirement for the house, including understanding the use of energy analysis software such as ‘Energy Plus” and “Energy 10” programs.

3.3 Architecture Design Group

The tasks for this group included:

- Review of the basic theory and fundamental of solar energy technologies.
- Reviewing the requirements for passive solar design.
- Producing an initial design to satisfy the contest requirements.

3.4 Faculty Advisory groups

The faculty advisers were broadly grouped as follows:

- **Fund raising group** to identify and solicit funds from industry, especially, electric power utilities. This group was also to coordinate website development and media relations activities.
- **Engineering group** to advise students on technical issues, including safety, electrical and mechanical services and computer science.
- **Architecture and building construction group** to advise students on architectural and construction requirements including the need for modularity as the house would have to be dismantled, transported to washing ton D.C. and reassembled for the competition. The process would have to be repeated after the competition and return to Tuskegee University.

4.0 Selection of Final Design

By September of 2001, we had received report from the various preliminary design groups. In order to enrich the architectural design, the college of Engineering, Architecture and Physical Sciences decided to have an architectural design competition, open to all students in the Department of Architecture with awards for the winning first three designs. Some of the design objectives for the competition included:

- Strong, suitable, appropriate building materials
- Balance between solidity and portability
- Integration of special, enclosure, structural and mechanical and electrical systems
- Sense of entry and legible path
- Clear zoning between public/private areas and between served/service spaces
- Comfortable fit between spaces and associated functions
- Unusual use of ordinary material or use of extraordinary materials
- Strong inside/outside relationship
- Development of all four elevations

Twenty entries were received. Using internal and external judges from the industry the best three designs were chosen. These three students worked together to improve on the winning design to produce the Tuskegee design. This is a two-story design with a southern-styled screened porch and breezeway.

5.0 Project execution

By January 2002, we were fortunate to secure sponsorship from Tennessee Valley Authority (TVA). An industry liaison officer was appointed by TVA to oversee the successful execution of the project. Working with the TVA representative a schedule of work was developed as shown in figure1. Guidelines and tentative schedules for group and general meetings were developed. Major components of the project execution included:

5.1 Energy requirement and electrical services

For the execution of the project the electrical group crystallized in into two subgroups. One group refined the market survey for efficient appliances and energy audit including the use of compact fluorescent lamps, which is cooler and more efficient than incandescent lamps. This group calculated the total energy requirement, the amount of PV panels based on a 160 watt Bp Solar model, and the number storage batteries for a five consecutive no sun days. Based on the recommended appliances, the group also chose the operating voltages of 48 VDC and 220/120 VAC for the inverter including the charge regulator. The seasonal load analysis also produced by the group is shown in table 1. The second group was in charge of the energy management including fault detection. This group developed monitoring scheme, the algorithm to compute the state of charge and state of health of the storage battery bank and the control algorithm for efficient management of the load. The monitoring and control scheme is shown in figure 2

A program for the calculation and analysis of energy requirements for a standalone photovoltaic home that will work anywhere in the Nation was developed by the computer science group working with the electrical engineering group.

5.2 HVAC System and Hot Water System

The preliminary designs, performed in the summer of 2001, were updated and implemented. Energy analysis was performed using the Energy 10 computer software.

5.3 Architectural Design

The design was fully developed and construction drawings produced. The service of an outside structural engineer was procured for the house using guidelines given by NREL. In the structural work portability and transportation were of utmost importance. The platform on wheels was designed by the structural engineer and built by a company in Birmingham and split into two halves to meet the transportation requirements. The construction drawings were, therefore modified accordingly.

The furnishing of the house, including the color of paints, was determined by the architecture group.

5.4 Construction and Transportation

The construction of the house was led by the group from Building Science and Management Department. The construction was executed in accordance with the advice of the structural engineer. It was also a very practical experience for students from all the other departments, especially in the installation of the electrical and mechanical services and in the painting of the house.

Our sponsor TVA provided transportation arrangement, including necessary permits for interstate trucking.

5.5 Web Design and Media Relations

Electrical engineering and computer science students designed the web site. They received input from the advisory group and a representative of the Public Relations Department of the University, who also coordinated the media relations for the project.

6.0 The Competition

The competition proper was held between September 25, 2002 and October 5, 2002 with all the fourteen universities and colleges participating. Actual unloading and construction at the mall in Washington D.C. began on the night of September 18, 2002 and dismantling and packing out of the mall was accomplished between October 6-8, 2002. Nine students and five faculty advisers made up the Tuskegee University team. For the team it was three exciting weeks of learning, work and interaction with students and faculty from other universities and colleges. This is a type of learning and inter-university interactions and cooperation that would normally not be available to the students.

7.0 Broader Impact of the Solar Decathlon Competition

The twenty first century will present the nation with challenges that demand more sophisticated energy technologies. The conservation of nonrenewable resources and the preservation of the global ecology are among today's pressing goals. This first ever-solar decathlon event has forced the students to seriously consider renewable technologies, in particular solar energy for sustainable living. It has demonstrated to administrators and educators the following:

- The importance of working with nature in developing national priorities
- The importance and practicality of developing sustainable energy technologies.
- Efficient energy utilization as a cardinal component of future national energy planning.
- The importance of interdisciplinary cooperation between engineering, architecture, computer science and business students.
- The importance of involving students in future national priorities since they will eventually determine future policy implementations
- The gain in acquainting students in the practice and application of cutting-edge technologies.

8.0 Lessons Learnt

The Solar Decathlon Project was a practical and beneficial learning experience to both students and the academic advisers.
The lessons learnt include:

- Students are excited and enthusiastic when assigned a project that is of national importance and practically realizable.
- Students can rise to high levels of responsibility in terms of research and implementation when challenged with projects, which offer employment and entrepreneurship opportunities.
- Interdisciplinary cooperation broadens the students' knowledge and increases the students' ability to undertake complex practical projects.
- Interaction of the students with students from other universities and colleges during the competition was an inspiring experience increasing their levels of performance and responsibility
- It is necessary to assign specific works to individual students even when they are working in a group. This increases learning and interest. The expectation of other members of the group acts as an added incentive for individual productivity. The

understood goal of each group is to shine during the biweekly technical presentations.
- The adoption of biweekly presentations for the whole project, so that each group is aware of the progress or non-progress being made by other groups spurs healthy competition. This accelerates the overall project.
- One of the major difficulties that became evident as the project progressed is the exchange of vital data and information necessary for design between groups. For example, the mechanical engineering student who performed the energy analysis needed information from the architectural group on material resistances and from the electrical students data on appliances and equipment. This was solved by having monthly review meetings in additional to the biweekly technical meetings.
- It is important to have a good schedule early in the project execution and have regular meetings to review progress and schedule adjustments as circumstances detect.
- In costing a project, it is necessary to consider minute details to avoid very unexpected large expenditures during execution.
- Getting an industrial sponsor and developing a budget that will be approved and meet unforeseen variations during construction is an aspect requiring particular attention.
- A careful examination reveals that the solar decathlon project satisfies all the a-k ABET criteria for effective engineering education, hence the title of this paper.

9.0 Integrating Project into curriculum

The project is being integrated into the electrical Engineering project using two approaches. The approach is to integrate the PV technology into laboratory experiments and senior design projects. Very early in the project, we purchased a demonstration PV system model consisting of a 60 W PV panel, a charge controller, a battery and an inverter. Students have performed experiments on the I-V characteristic of the panel and on the potential for PV technology application in Tuskegee. This experiment/project is being updated with a new 160 W Bp Solar panel. Senior projects have included the design of an automatic window shutter to regulate power consumption in the solar house.

We have designed a new course on modern electric drive with a good content of power electronics to replace an existing course on electric machines. We have written a proposal to the National Science Foundation (NSF) for funds to improve our laboratory facilities to support this course. It is expected that the proposed course will attract more students and also increase their employment opportunity in the job market. Power electronics and electric drive are key components for future development of renewable energy technologies.

10.0 Roadmap for the Future

The ultimate goal of the power group in the EE Department is the establishment of a renewable energy research center with solar and wind energy as the focus. We have two graduate students working on their master's theses based on the solar house. We are in the process of sending out a proposal on wind energy as the next step towards the goal. There is much data needed to be developed for the Tuskegee area and we hope to design undergraduate and graduate level projects to meet this need.

11.0 Acknowledgement

Our main sponsor, Tennessee Valley Authority, made this project possible. For this we are very grateful and thank the CEO and his Management team for this great support. We would specially thank Mr. Robert Phillips who represented TVA on this project for his many hours of service We also like to thank the University Administration for their support especially, the Dean, the Deans office (particularly Ms Velma Moore), the Purchasing department, the Accounts Payable, Office of Sponsored Program and the Central Receiving section of the physical facilities. Our gratitude also go the sponsors of this event-The U.S. Department of Energy, the National Renewable energy Laboratory, the American Institute if Architects, BP Solar and Home Depot Corporation.

12.0 Conclusion

Participating in the 2002 Solar Decathlon competition was a great learning experience to the students, the faculty advisers and our sponsors. We completed the project and met all the deadlines established by NREL. The project has also enriched our educational system and will continue to be a motivating force for future curriculum development. The next solar decathlon competition is scheduled for 2005. With the experience gained and lessons learnt, we will participate in this competition with great expectations.

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Table 1: SEASONAL LOAD ANALYSIS

			Dec., Jan., Feb.		Mar., Apr., May, Sep., Oct., Nov.		June, July, Aug.	
Load description	**Qty.**	**P. (Watts)**	**Hr/day**	**AH/day**	**Hr/day**	**AH/day**	**Hr/day**	**AH/day**
Kitchen lights	3	45	4	1.5	4	3.75	4	3.75
Dining Lights/living room	24	360	8	60	7	52.5	6	45
Bedroom lights	4	60	1	1.25	1	1.25	1	1.25
Bathroom Lights	2	30	1	0.625	1	0.625	1	0.625
Corridor/Step Lights	3	75	0.1	1.56	0.75	1.175	0.5	0.775
Carport/utility Rm/Security lights	3	75	1	1.56	1	1.56	1	1.56
Refrigerator	1	85	7	12.5	7	12.5	7.5	13.25
Advantium Cooker	1	1000	0.5	10.4	0.5	10.4	0.5	10.4
TV/CR	1	120	4	10	4	10	4	10
Stereo	1	60	2	2.5	2	2.5	2	2.5
Water Pump	1	200	1	4.175	1	4.175	1	4.175
Fans	3	150	0	0	0	0	8	25
Extraction Fans	3	150	0.5	1.575	0.5	1.575	0.5	1.575
CPU	1	50	2	2.075	2	2.075	2	2.075
Monitor	1	75	2	3.125	2	3.125	2	3.125
Laser Printer	1	225	0.5	2.33	0.5	2.33	0.5	2.33
Range	1	3600	0.5	37.5	0.5	37.5	0.5	37.5
Washer/Dryer	1	1472	0.5	15.3	0.5	15.3	0.5	15.3
Heat Pump	1	1800	4	150	4	150	4	150
Air Handling	1	1800	4	150	4	150	4	150
Hair Dryer	1	700	0.25	3.6	0.25	3.6	0.25	3.6
Total Load		12132		471.57		465.94		483.79

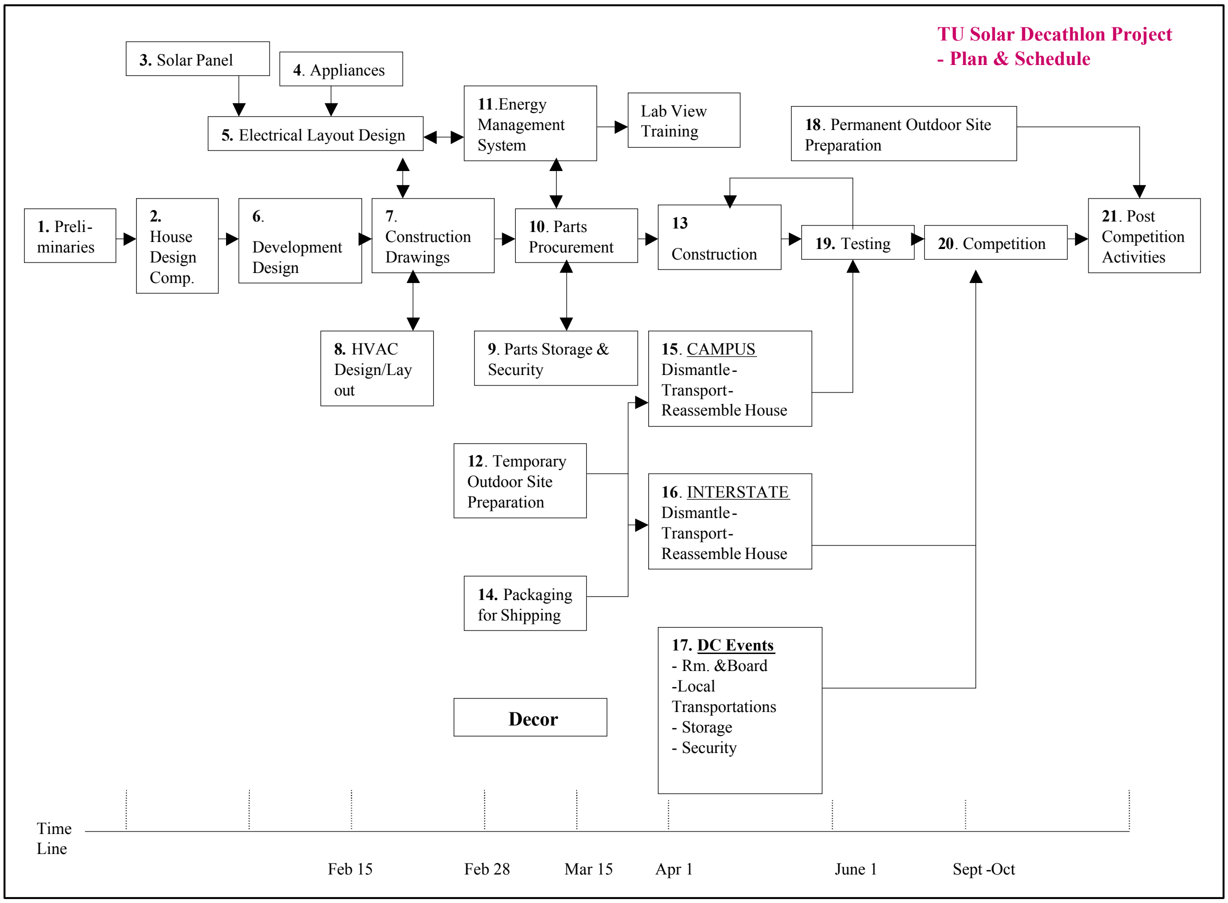

Figure 1: Tuskegee University Solar House Work Schedule

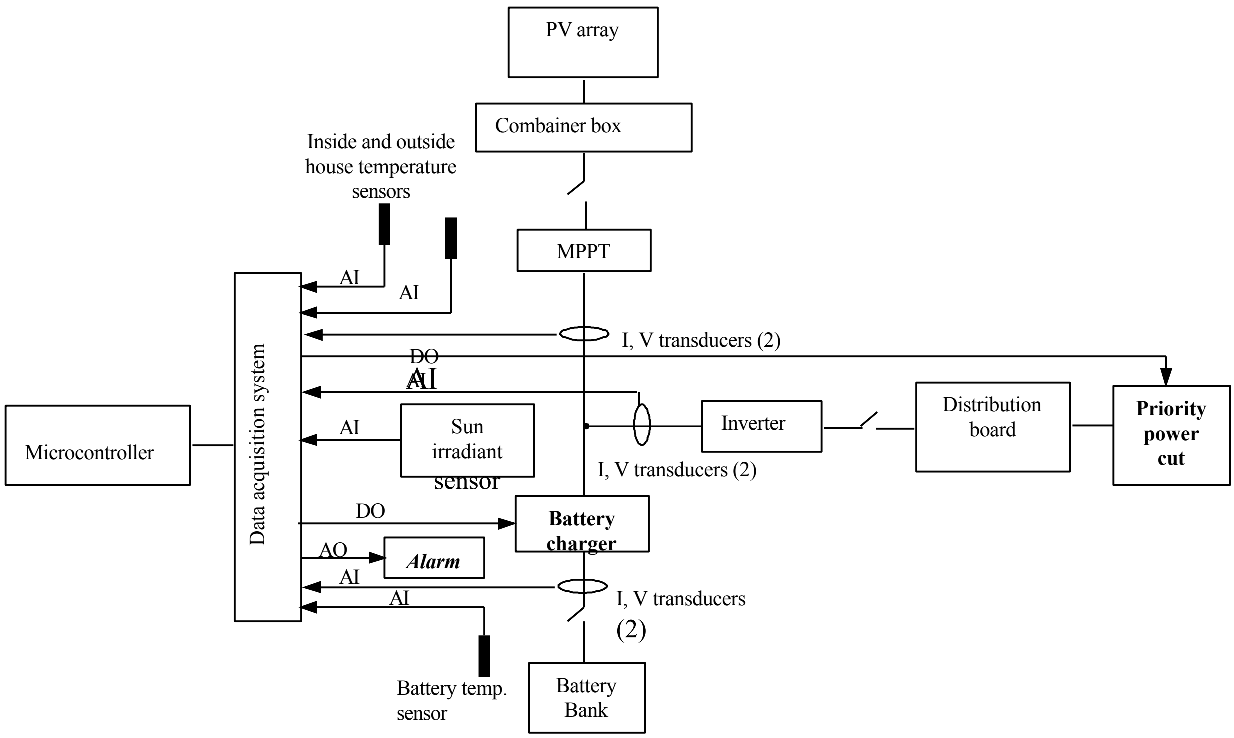

Fig. 2 Block diagram of monitoring/control of a stand-alone solar house