The Solar Decathlon and ABET EC 2000

P. Paxton Marshall, David Click, Shana Craft
Department of Electrical and Computer Engineering
University of Virginia

Abstract

In October 2002 the University of Virginia (UVA) Solar House team placed second in the inaugural Solar Decathlon, sponsored by the U.S. Department of Energy (DoE), culminating a two year effort in which over 100 engineering and architecture students designed and built a solar-powered house. The sunshine falling on the house supplies all the energy needs of a normal family, as the design incorporates photovoltaic generation of electricity and solar water heating for domestic hot water and space heating using a radiant floor. There is also a stone-lined sunroom for collecting and storing solar energy, and adjustable louvers over the extensive south-facing glazing to regulate incoming solar radiation. Data logging, control and user interface are integrated by a LabVIEW-based automation system. The house continues to serve as a laboratory for multidisciplinary capstone design team projects.

The project, which allows students to learn energy concepts in an integrated realistic setting, provides numerous benefits for engineering students that are often lacking in standard engineering instruction, and that are being emphasized by the new ABET EC 2000 criteria. It introduces them to holistic systems thinking—that the system is not necessarily optimized by optimizing the subsystems individually. It connects with the real world experiences of students. It provides an ideal vehicle for "incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political". [ABET EC2000, criterion 4] It demands initiative and provides leadership opportunities in project management, cost estimation and budgeting, marketing and fund-raising. It develops manual skills, communication skills, and teamwork skills. It values and develops aesthetic judgment and creativity.

This paper will describe the Solar Decathlon, the UVA house design, the educational value of the project, and how it contributes to the goals of ABET EC 2000.

Introduction: ABET EC 2000

The Accreditation Board for Engineering and Technology (ABET) has issued a call for rethinking engineering education with its Engineering Criteria (EC) 2000. No longer is it sufficient for programs to demonstrate that they provide students with the appropriate inputs: a specified minimum number of credits in fundamental math and science, engineering science, engineering design, and humanities and social science. Now programs must demonstrate the attainment of specified outputs: capabilities achieved by students in eleven different skill areas specified by ABET, as well as additional areas selected by the programs themselves.

The eleven skills specified by ABET in criterion three, together with the design requirement of criterion four, emphasize the interdisciplinary nature of 21st century engineering. Not only must engineering graduates engineers be able to demonstrate competence in traditional engineering-related tasks: a) apply knowledge of mathematics, science and engineering, b) design and conduct experiments as well as analyze and interpret data, c) design a system, component or process to meet desired needs, d) identify, formulate, and solve engineering problems, and k) use the techniques, skills and modern engineering tools necessary for engineering practice. Engineering graduates must also d) be able to function on multidisciplinary teams, f) understand "professional and ethical responsibility", g) "communicate effectively", i) "engage in life-long learning", j) have "a knowledge of contemporary issues", and h) have "the broad education necessary to understand the impact of engineering solutions in a global and societal context."

The professional component of criterion 4 moreover, requires that "Students must be prepared for the engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political."

Opportunities and Challenges for ECC Instruction

Few areas of engineering offer such great opportunities to embrace the new EC 2000 approach as Energy Conversion and Conservation (ECC). The subject is inherently interdisciplinary, engaging electrical, mechanical, chemical, and nuclear engineers. It is rife with contemporary issues involving the environment, the economy, and sustainability, thereby confronting students and practitioners with ethical, social, health and safety, and political questions, and " the impact of engineering solutions in a global and societal context."

The development of EC 2000 comes at a time when ECC education is in serious need of reinvigoration. In both electrical and mechanical engineering, energy is increasingly regarded as a "mature discipline", which fails to attract and inspire the brightest young minds entering the engineering profession. It hardly matters that deregulation of the electricity industry and our nation's increasing reliance on imported petroleum have created ever more pressing challenges for energy engineers, or that breakthroughs in computers, semiconductors, and chemical separation technologies have created heretofore unattainable options for the creation, delivery and utilization of power. As is so often the case, perception trumps reality, and energy engineering remains in the backwater of most schools engineering curricula.

The thesis of this paper is that EC 2000 can reinvigorate ECC education, but only if energy engineers broaden their perspectives, loosen their disciplinary allegiances, and embrace the opportunities presented by this new paradigm. This will not be easy in an academic environment in which students' curricular requirements are largely determined by fossilized faculty groupings built around archaic "disciplines". Electric power engineers view the mechanical precursors and consequences of the phenomena they study as "prime movers" or "loads" that exist in some mystery sphere that hardly warrant further investigation. Much less do any energy courses, whether electrical, mechanical, or chemical, venture into the alien worlds of economics, government, or ethics which provide the motivating forces behind much of their work.

The Power of Projects

Although much more can be done to integrate context into normal engineering lecture classes, the full realization of the EC 2000 revolution in ECC instruction can best be achieved in multidisciplinary student design projects. Important as each is in its own right, if the skills of criterion three are only pursued in isolation, in separate courses, taught by faculty with little or no communication with one another, little will have been achieved. It is only by integrating these aspects of a larger whole in concrete open-ended problems, through which instructors patiently but not too directly guide students, that we can claim to be developing such qualities as initiative, resourcefulness, creativity, and leadership desired in an engineering graduate. The remainder of this paper will be devoted to a description of the University of Virginia (UVA) Solar House project and its success in accomplishing the objectives of ABET EC 2000.

The Department of Energy (DoE) Solar Decathlon

The Department of Energy (DoE) Solar Decathlon is an event where students from different colleges compete in an effort to design and build an energy-efficient dwelling powered by the sun. The main focus of the competition is to convert and store enough solar energy to permit an entire household to maintain normal everyday lifestyles. The competition is divided into the following categories: design & livability, design presentation & stimulation, graphics & communication, comfort zone, refrigeration, hot water, energy balance, lighting, home business, and mobility.

The multidisciplinary requirements of the Solar Decathlon places a premium on collaborative teams of engineering and architectural students. The engineering and architectural students work together to decide on material selection and construction, modeling and design, testing and system monitoring for the house. The Solar Decathlon gives students the opportunity to explore a realm of life outside of their academic curriculum. It also gives students the opportunity to interact with corporate sponsors, opening the doors for numerous career opportunities.

Figure 1: The public views UVA's entry into the 2002 Solar Decathlon.

Fourteen colleges and universities competed in the first Solar Decathlon competition on the National Mall in Washington, D.C. in fall 2002. The UVA team placed second overall and first in the design and livability and energy balance categories. Participating in the Decathlon gives students the opportunity to interact with DOE professionals and other students across the country, developing technologies that can improve the quality of life by supplying society's energy requirements with non-polluting, abundant solar energy.

The Design/Build process

The most exciting aspect of the project was that the months of design work would yield not only reports (as in a typical undergraduate project), but also a very real, 750-square-foot house. That we would be constructing a house that would produce all the energy it required made it even more exciting. The design/build process was a unique experience for most, if not all, students involved with the UVA Solar House project.

Six engineering students began work on the project in Fall 2000. They commenced research concerning each of the major systems of the house—heating, ventilation, and cooling (HVAC), electricity production, storage, and distribution, control system design, and energy-efficient building strategies. Through weekly meetings, the team focused their research efforts and learned a great deal about each system. During this semester, several architecture students became interested, and in the spring twelve students enrolled in a studio class. Together, engineers and architects completed the prototype house design in April 2001 (McGowan, 6).

The architecture studio, similar to an engineering laboratory course in the practical, hands-on experience it provides, but more open-ended and design oriented most labs, provides a favorable environment for approaching large design/build projects. The studio class was very time-consuming for everyone involved. The class formally met twelve hours a week, with a weekly review in which industry experts helped students choose the best designs and ideas, thereby polishing what would become the final design. Five nights a week, the lead engineering students worked with the architecture students, trading ideas and sometimes heatedly discussing the compromises inherent in such a large project. These student leads organized their fellow engineers into teams to continue researching technologies, and all gained experience in talking to companies on a professional level, asking for advice on system design and sizing so that the architects knew how much space to allow for the engineering systems as the design progressed (Click, 11-12).

Figure 2: Louvers on the south side control the amount of sunlight entering the house.

The 2001-2002 school year was a surprise for the project leadership. A Fall 2001 course was held for both architects and engineers, therefore students from both disciplines had at least three hours a week for discussion. At this point, we had completed the preliminary design for the house, and so this school year was intended to finish detailing and begin construction. The team was confronted with the details of practical reality. How much thermal mass should be in the house, and how would it best be incorporated? How can the mechanical systems be integrated into the living space? How can we have large windows yet create an energy efficient building? Should the roof be sloped or flat? These questions required a great deal of thought and creativity from all participants. By working together with students, advisors, and professionals from myriad disciplines, engineering students gained invaluable experience that will aid them in their future careers (Marshall, 11-12).

<u>Energy Systems Design</u>

Most engineering effort focused on managing the house's energy production and consumption. An important feature of an energy-efficient home is an effective HVAC system to adequately heat, cool, and ventilate the house with a minimum amount of electricity. The HVAC team worked for almost two years on their design. We knew we wanted to make our house the most efficient one at the competition. The first goal was an effective design to utilize the free energy available in the environment. Extensive south facing windows covered by adjustable louvers, shown in Figure 2, would admit the warming rays of the sun when heating was needed, but block them when it was not (Dorrier, 10). A stone-lined sunroom (shown in Figure 3) would store surplus solar heat during the day, allowing it to be vented into the house at night when it was needed. Fanless vents in the floor and ceiling would utilize buoyancy ventilation to exhaust hot air through the ceiling and draw in cooler air through the floor. Most importantly, a solar thermal system would store solar heated water in insulated tanks to not only supply the hot water needs of the house to provide heating through the radiant floor. The team worked with architects, sizing and placing the thermal collectors so that they would be of adequate size to perform well, but not be so large as to overwhelm the structure.

To supplement these natural energy systems when additional heating or cooling was needed, we chose a ¾-ton geothermal heat pump that operated a hydronic heating and cooling system. By pumping water through pipes, we could warm the house through the radiant floor and cool the house through a valance cooling unit. By avoiding a forced-air system like that found in most new construction, the

Figure 3: UVA Solar House Sunspace

Figure 4: UVA Solar House photovoltaics.

Figure 5: Two of the house's 16 batteries

team ensured a more comfortable living space and a more efficient design. A geothermal heat pump operates more efficiently than a standard model because it utilizes the energy stored in the ground as a source of heat for the house.

On the electrical side, the photovoltaic modules (shown in Figure 4) would naturally be a focal point of a solar-powered house, and much work went into their selection. Engineers and architects collaborated in communicating with manufacturers, negotiating prices and verifying specifications, to ensure that the array of modules would fit both into the budget and the assigned area on the roof of the house. In the end, we chose 16 large-area modules that generate 5.1 kW peak. The modules are mounted on aluminum frames that can tilt to allow for better power production depending on the season. For storage, 16 deep-cycle valve-regulated lead-acid batteries (see Figure 5) store enough power for the house to last through several days of little sunlight. Power is converted from DC to AC power in the electrical closet, shown in Figure 6. An important issue regarding the batteries was the structural design of their support. The mechanical space of the house is located at the top of the north wall of the house, and is accessible only from the outside. The batteries themselves are located above the office space and the entertainment center. Once the batteries were selected, the structural team could size the framing necessary to support them. Again, students had to look beyond their own subsystem to see how their work interfaced with the others involved on the project.

Figure 6: AC/DC Power equipment

<u>Automation--the integrating factor</u>.

The solar house seeks to optimize use of the natural energy resources available in the sunshine that strikes the house, the air that surrounds it, and earth beneath it. Effective use of these resources requires continuous monitoring of the energy needs of the house and the energy availability of the environment. As it is unrealistic to expect the residents to continuously monitor these factors, the team has designed and implemented a data logging and automation system.

To optimize an energy system it is necessary to monitor the factors that effect performance. The UVA Solar House uses National Instrument's (NI) LabVIEW, a graphical programming language, to monitor, control, and analyze different components within the house. Sensors are installed throughout the house. Sensor data are collected, converted to digital form, and transmitted to the LabVIEW computer by NI's FieldPoint modules. LabVIEW is used in the solar house to log temperature and humidity, current, voltage, and power production and consumption, and the status of controllable elements in the house. The data from the log is written to a text file or an excel spreadsheet ready to be accessed by the user.

LabVIEW has two main panels to help the user design the code and observe the results: a block diagram and a graphical user interface known as the front panel. When a user wants to check the status at the solar house, he or she will interact with the front panel.

LabVIEW is being programmed by the team to automate the solar house. When the temperature is higher or lower than desired, a normal system turns on an energy source (e.g. furnace, heat pump) to correct the problem. Our LabVIEW program will first determine what resources are available, then adjust the louver angles, open or close vents, or pump solar heated water through the radiant floor etc. to assure a comfortable living environment. It will also provide warnings to residents when energy supplies get low, and disable electrical loads to protect the batteries from excessive discharge (Podhajny, 37-46).

Assessment of Student Outcomes

The Solar Decathlon consists of ten events, scored by a combination of objective measures (e.g. temperature, humidity, electrical production and consumption) and panels of experts. The following two tables map the Decathlon events to ABET Criterion 3 outcomes a-k, and ABET criterion 4 constraints respectively. An entry in a cell indicates that the scoring for that event addresses the corresponding outcome or constraint. A composite score for each outcome and constraint is derived by averaging the ranks of the UVA team in the Decathlon events that contribute to that outcome or constraint.

Mapping of Solar Decathlon events to ABET Criterion 3 Outcomes a-k

Decathlon Event/ABET Outcome	a	b	c	d	e	f	g	h	i	j	k	Rank of 14
Design & Livability			xx	xx	xx	xx	xx	xx		xx	xx	1
Design Presentation & Simulation				xx		xx	xx	xx		xx	xx	7
Graphics and Communication				xx		xx	xx	xx		xx	xx	4
The Comfort Zone	xx	xx	xx	xx	xx				xx	xx	xx	9
Refrigeration	xx				xx							4
Hot Water	xx		xx		xx						xx	9
Energy Balance	xx	xx	xx	xx	xx	xx		xx	xx	xx	xx	1
Lighting	xx		xx	xx	xx					xx	xx	4
Home Business				xx			xx	xx		xx		6
Getting Around				xx								7
Composite assessment	5.4	5	4.8	4.9	4.7	3.3	4.5	3.8	5	4.6	5	

ABET Criteria 3 outcomes:

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs

(d) an ability to function on multi-disciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively

(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Mapping of Solar Decathlon events to ABET Criterion 4 Constraints

Decathlon Event/ABET Outcome	economic	environmental/ sustainability	manufacturability	ethical	health & safety	social	Rank
Design & Livability	xx	xx	xx	xx	xx	xx	1
Design Presentation & Simulation							7
Graphics and Communication				xx			4
The Comfort Zone	xx	xx	xx	xx	xx	xx	9
Refrigeration	xx	xx			xx	xx	4
Hot Water	xx	xx	xx	xx	xx	xx	9
Energy Balance	xx	xx		xx			1
Lighting	xx	xx	xx		xx	xx	4
Home Business	xx					xx	6
Getting Around	xx	xx					7
Composite assessment	5.125	5	5.75	4.8	5.4	5.5	

Clearly, most of the ABET outcomes and constraints are addressed and assessed by several of the decathlon events. This assessment falls short of a full assessment in two respects. The decathlon event scores do not individually assess each ABET category to which they contribute. Further, the competence of individual students is not assessed, but only the team as a whole, or that part of the team that worked on that aspect of the project. Nevertheless, these results are indicative of the success of the project in meeting the ABET criteria. On each outcome and constraint, the UVA team was ranked above the majority of its competitors.

Ongoing Work

The solar house is still generating challenging student projects almost a year and a half after the competition was completed. Inevitably, as designs get built and used, unanticipated problems and new possibilities for improvement emerge. Current projects focus on optimizing the utilization of the sunroom and the solar thermal/radiant floor heating systems, investigating the potential of maximum power point trackers for the photovoltaic arrays, monitoring the consumption of electrical loads, automating the vents, reprogramming the LabVIEW controls, and developing a better user interface.

Engineering in Context

To date, more than 30 engineering students have completed capstone design projects on the UVA solar house. They have developed their analytical and technical skills in a context that has related theory to practice, stimulated enthusiasm, and improved learning by requiring students to address the consequences of their work.

In addition, participation in the project has helped students develop their so-called "soft skills " and forced them to address the contextual issues that constrain any real-world engineering project. The project was inherently interdisciplinary and team-based. Students could only accomplish their own goals through negotiations, compromise, and brainstorming for win-win solutions with team members from other disciplines working on different problems. Operating on a limited budget, team members had to consider cost in their designs, and approach vendors for contributions in kind. The competition developed communication skills by requiring that teams develop a web site and produce newsletters describing their work to the public, and effective communication within the team was vital to the success of the project. Project management and scheduling challenges were ubiquitous and daunting. The team had to comply with local building codes, as well as the competition regulations. House construction placed a premium on safety procedures. The selection of environmentally responsible materials raised issues of ethics and professional responsibility, and engaged students in trade offs between performance and risk. The project and the competition immersed students in contemporary issues of energy policy and politics, and forced them to address the " impact of engineering solutions in a global and societal context." The integration of these issues was facilitated by the UVA engineering school's senior thesis requirement, directed by its division of Science, Technology, and Society (Marshall 11-12).

Conclusion: the Solar House Project and ABET EC 2000

ABET EC 2000 is meant to be more than a checklist of competencies that are required of engineering students before they graduate. It seeks to assure that graduates are prepared to employ their knowledge and skills for the improvement of society and the welfare of its citizens. Chief among the attributes needed are leadership, creativity, judgment, ethical integrity, and the ability to function productively on teams. The development of these attributes receives little emphasis in traditional engineering instruction. The incorporation of multidisciplinary team design/build projects into students' curricula can accomplish much to reenergize ECC education and accomplish the goals of ABET EC 2000.

Works Cited

Click, David Karlsson. Photovoltaic And Hot Water Systems Design For A Solar-Powered, Energy-Efficient House. May 2001.

Dorrier, Benjamin Blake. Automatic Shading System for Solar House Applications. December 2002.

Marshall, P. Paxton, Daniel Pearce, and David Karlsson Click. Bridging the Engineering/ Architecture Divide: The UVA Solar Decathlon Team. March 2003.

McGowan, Jessica Elyce. The Race to Save Energy: Passive Solar Technology for an Energy-Efficient Home. May 2001.

Podhajny, Daniel. Solar Home Control System. March 2003.

Authors' Biographies

Paxton Marshall is Professor of Electrical and Computer Engineering and Associate Dean for Undergraduate programs in the School of Engineering and Applied Science at the University of Virginia. A former chair of the Energy Conversion and Conservation Division of ASEE, Marshall was the engineering faculty advisor of the UVA Solar House team that finished second in the 2002 Department of Energy Solar Decathlon.

David K. Click is a graduate student in the Department of Electrical and Computer Engineering at the University of Virginia. He received his Bachelor of Science degree in Electrical Engineering from the University of Virginia in May 2001, and has been involved with the solar house project since September 2000. After graduating with a Master of Science degree in Electrical Engineering in May 2004, he plans to work in the field of solar and wind energy.

Shana C. Craft is a graduate student in the Department of Computer and Electrical Engineering at the University of Virginia. She received her Bachelor of Science degree in Physics/Pre-Engineering with a minor in Mathematics from Longwood College in May 2002. Her present work is based on her M.S. thesis, "Automation of the Solar Home using LabVIEW—A User's Manual." Shana has received numerous honors and recognitions including the Gates Millenium Scholarship funded by the Bill and Melinda Gates Foundation and administered by the United Negro College Fund (UNCF).