View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by DigitalCommons@CalPoly

Presented at the Air and Waste Management Association Annual Conference, June 2008, Portland, Oregon

Development of a Laboratory Based Sustainability Course for Environmental Engineers

Paper # 364

Samuel A. Vigil
Professor of Environmental Engineering, Civil and Environmental Engineering Department, California Polytechnic State University, San Luis Obispo, California 93407

ABSTRACT

An understanding of sustainability is important for all engineering students, but especially for Environmental Engineers who will be taking leadership roles on sustainability issues. This paper will discuss the development of a graduate and senior level course which provides the knowledge, computational, and experimental skills in sustainability for these future engineering leaders. The course includes both lecture and laboratory sections.

Lecture topics covered in the Spring 2007 course included:

1. Introduction to Sustainability, UN Agenda 21
2. Global Warming and Climate Change
3. Life Cycle Assessment
4. The LEED Green Building Rating System
5. Sustainable Energy Sources – Biofuels, Wind, and Solar
6. Sustainable Waste Management – Hurricane Katrina Disaster Debris Case Study
7. Sustainable Manufacturing – Automobile Manufacturing Case Study

Laboratory and Computational Assignments:

1. Analysis of EPA, FEMA, and State of Louisiana Hurricane Katrina Debris Recovery data. Development of alternative recycling and recovery scenarios.
2. Life Cycle Assessment – Use of the EPA WARM Life Cycle Assessment Model to analyze the scenarios developed in Assignment 1.

3. Sustainable Manufacturing – Field trip to New United Motors Manufacturing (GM-Toyota Joint Venture). Analysis of sustainable manufacturing practices.

4. LEED Green Building Rating System – Field trip to a local building undergoing LEED Certification, Preparation of LEED Checklists.

5. Sustainable Energy Sources – Solar energy experiments to measure optimum tilt and orientation angles for a solar panel. Measurement of solar panel efficiency using a solar pyranometer and variable electrical load. Development of the characteristic curve.

INTRODUCTION

Sustainability has become one of the principal themes of modern environmental engineering, yet many students have only a rudimentary knowledge of what sustainability really means to their future careers. Sustainability is much broader than the traditional fields of environmental engineering (water and wastewater, air pollution, solid and hazardous wastes). However these fields form the foundation of the emerging field of Sustainability Engineering.

At California Polytechnic State University we have taken a multidisciplinary approach to sustainability with a variety of courses available across the University including the physical and biological sciences, agriculture, architecture, and engineering. This paper discusses one of those courses, Sustainable Environmental Engineering, which has been taught by the author for several years. It includes both lecture and laboratory components.

LECTURES

The course is dynamic, with a mix of core topics on the science and engineering of sustainability, and special topics based on current events.

Core Lecture Topics

Core topics include an Introduction to Sustainability, Global Warming and Climate Change, Life Cycle Assessment, LEED Green Building Rating System and Sustainable Energy Sources.

Introduction to Sustainability

The introductory lecture defines the field and discusses the history and politics of sustainability. One of my favorite examples of a definition of sustainability is by Andy Duncan, of Oregon State University.[1]

"The definition of sustainability depends on who is speaking. Managing a two-year-old is like nailing Jello to a tree, goes an old saying. Maybe getting adults to agree on a definition of sustainability is like that, too. Individuals and groups keep trying, but no one has hammered out one that everybody accepts."

A random poll of students in the class shows that they also can't agree on a precise definition of sustainability either. To get the class over this conceptual hurdle, the first reading assignments are the seminal documents of the sustainability field, the writings of Gro Harlem Brundtland, Chair of the United Commission on Environment and Development, 1987[2] , and The Rio Declaration on Environment and Development – Agenda 21, 1992[3]. This is a difficult reading assignment for the typical engineering student, but the readings serve as an introduction to the broader political, social, and environmental justice implications of sustainability. Agenda 21 in particular, in the author's opinion, is the most accepted definition of sustainability. Other definitions of sustainability that have been developed since, are all subsets of Agenda 21. For example the definition of sustainability from the Code of Ethics of the American Society of Civil Engineers[4] is clearly based on the principles of Agenda 21:

"Sustainable Development is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management conserving and protecting environmental quality and the natural resource base essential for future development."

Global Warming and Climate Change

Global warming and climate change are core topics of the course because of their overwhelming effect on the environment. Both the scientific and political aspects are covered in the lectures and reading including the most recent IPCC Report[5], the original text of the Kyoto Protocol[6], and current readings in the literature of the politics of global warming. Students are required to read current articles on climate change in major newspapers such as the *New York Times* and *Los Angeles Times* as well as in leading multi-disciplinary journals such as *Science* and *Environmental Science and Technology*.

Life Cycle Assessment

Life Cycle Assessment (LCA) is the fundamental computational tool of sustainability engineering. It provides a rational method of evaluating the pros and cons of various environmental alternatives. It is of course not without controversy, but it remains nevertheless an accepted procedure.

The fundamentals of LCA as discussed by Bishop[7] and Graedel[8] are covered in the lectures. The EPA Waste Reduction Model (WARM)[9], a public domain LCA tool for analyzing the greenhouse gas emissions from various waste management alternatives, is discussed in lecture and used in a laboratory assignment.

The LEED Green Building Rating System

The LEED (Leadership in Energy and Environmental Design) Green Build Rating System is the most widely used sustainability evaluation system for buildings in the world. LEED addresses all building types and emphasizes state-of-the-art strategies in five areas: sustainable site development, water savings, energy efficiency, materials and resources selection, and indoor environmental quality.[10]

During the lectures the LEED audit system is explained and several case studies of exemplary building designs are studied. As a laboratory exercise, students travel to local building sites which are undergoing LEED Certification. The students use LEED Checklist sheets to evaluate the buildings (see Figure 1).

Figure 1 – Sample LEED Checklist

Project Checklist

Sustainable Sites

14 Possible Points

Y	Prereq 1	**Erosion & Sedimentation Control**	Required
Y ? N	Credit 1	**Site Selection**	1
Y ? N	Credit 2	**Urban Redevelopment**	1
Y ? N	Credit 3	**Brownfield Redevelopment**	1
Y ? N	Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
Y ? N	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
Y ? N	Credit 4.3	**Alternative Transportation**, Alternative Fuel Vehicles	1
Y ? N	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
Y ? N	Credit 5.1	**Reduced Site Disturbance**, Protect or Restore Open Space	1
Y ? N	Credit 5.2	**Reduced Site Disturbance**, Development Footprint	1
Y ? N	Credit 6.1	**Stormwater Management**, Rate and Quantity	1
Y ? N	Credit 6.2	**Stormwater Management**, Treatment	1
Y ? N	Credit 7.1	**Heat Island Effect**, Non-Roof	1
Y ? N	Credit 7.2	**Heat Island Effect**, Roof	1
Y ? N	Credit 8	**Light Pollution Reduction**	1

Water Efficiency

5 Possible Points

Y ? N	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
Y ? N	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
Y ? N	Credit 2	**Innovative Wastewater Technologies**	1
Y ? N	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
Y ? N	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Energy & Atmosphere

17 Possible Points

Y	Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y	Prereq 2	**Minimum Energy Performance**	Required
Y	Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
Y ? N	Credit 1	**Optimize Energy Performance**	1–10
Y ? N	Credit 2.1	**Renewable Energy**, 5%	1
Y ? N	Credit 2.2	**Renewable Energy**, 10%	1
Y ? N	Credit 2.3	**Renewable Energy**, 20%	1
Y ? N	Credit 3	**Additional Commissioning**	1
Y ? N	Credit 4	**Ozone Depletion**	1
Y ? N	Credit 5	**Measurement & Verification**	1
Y ? N	Credit 6	**Green Power**	1

Sustainable Energy Sources – Biofuels, Wind, and Solar

Because there are several other courses in the University that discuss energy issues, this course focuses on sustainable energy sources including biofuels, wind, and solar. The discussions of biofuels and wind are conducted during the lecture part of the course. Solar energy, especially photovoltaic systems , are discussed in more detail in three lectures and two laboratory exercises.

Photovoltaic systems are emphasized in the lecture and laboratory because they are applicable to a broad range of sustainable energy projects, particularly in California. Solar PV systems are scalable, and can be easily demonstrated at small scale with reasonably priced laboratory equipment.

The first of three solar energy lectures discusses the physics and astronomy of the solar sunpath, the solar spectrum, effects of latitude and season, the use of sunpath diagrams and the Solar Pathfinder instrument to estimate annual solar insolation at a site. The use of the National Renewable Energy Laboratory website to obtain solar insolation data is discussed and demonstrated.[11]

The second lecture discusses photovoltaic (PV) technology including : the invention of the silicon solar cell; the physics of PV cells; electrical characteristics of PV cells; off-grid PV systems; on-grid PV systems; and using the PV Watts on-line model for evaluating the economics of on-grid PV systems.[12]

The third lecture discusses the economics of grid connected residential and commercial PV systems. Topics include: estimating capital and installation costs of typical systems; California electric utility rate structures; Federal and California state incentive programs; and the use of simple payback, lifecycle cost, and internal rate of return procedures for evaluating the economics of solar PV systems.

Special Lecture Topics

Several special topics are covered each year based on current events and faculty and student interests. Recent Special Lecture Topics have included :

***Sustainable Waste Management* –** This topic is based on the author's professional practice and research.[13] Current practices in solid waste management are reviewed and critiqued in the context of sustainability principles. The economics and environmental impacts of current practices in recycling, composting, and energy recovery are emphasized.

***Sustainable Disaster Mitigation – Hurricane Katrina Disaster Debris Case Study* –** This topic is based on presentations and tours at the 99th AWMA Annual Conference in New Orleans. Much of the lecture materials were contributed by Professor Tim Townsend of the University of Florida[14] and are based on his work in Louisiana after Hurricane Katrina.

***Sustainable Manufacturing – Automobile Manufacturing Case Study* –** This topic is covered both in lecture and a field trip to the New United Motors Manufacturing Inc. plant in Fremont California. The plant, a joint venture of General Motors and Toyota is a superb example of sustainable manufacturing processes.

LABORATORY AND COMPUTATIONAL ASSIGNMENTS

Several laboratory assignments were part of the course including: Life Cycle Assessment of Hurricane Katrina Debris Recovery; LEED Green Building Rating System; and Sustainable

Energy Sources – Solar Energy Experiments. The latter two assignments are discussed in detail below.

LEED Green Building Rating System

The fundamentals of the LEED Green Building Rating System were discussed in several lectures. The laboratory portion of the topic consists of field trip to a local building which is undergoing LEED certification, the Education Center of the San Luis Obispo Botanical Garden. The Center is a passive solar heated and cooled design with straw bale insulation. The Center has a number of other sustainable design features which are also evaluated by the students on LEED Checklists.

Sustainable Energy Sources – Solar Energy Experiments

Three solar energy experiments are performed outdoors using a portable laboratory kit as described in Table 1. Six laboratory kits are available so that students can work together in small groups.

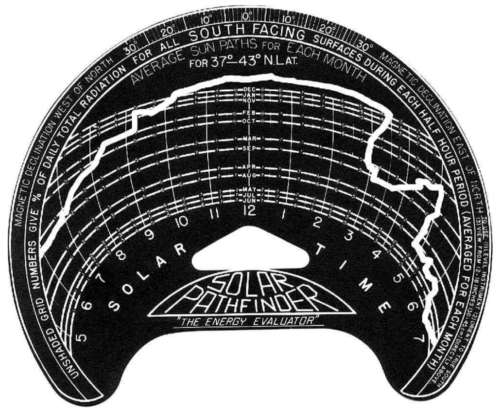
Table 1 – Solar Laboratory Kit

Fluke Digital Multimeter with Test Leads
ICS Sunsei 2 W solar panel with cables
Brunton Type 7 Orienteering Compass
Protractor
Adjustible Base Plate for Solar Panel
Screwdriver and Small Handtools
Apogee Model PYR-P Silicon Pyranometer
Decade Resistor Box
Solar Pathfinder

Solar Experiment 1 – The Solar Pathfinder

The Solar Pathfinder is a unique instrument that provides a diagram of potential obstructions at a particular site. It consists of a transparent Plexiglas dome which is mounted over a sunpath diagram. After aligning the instrument to face true south, a tracing can be made on the solarpath diagram of reflected obstructions (see Figure 2).

Figure 2 – Sunpath Diagram



The sunpath diagram is calibrated with a series of arcs for time of day and month of the year. This allows the user to calculate the number of hours per month that the solar panel would be unobstructed. This data, in conjunction with the NREL solar insolation data, can be used to calculate the annual average solar radiation in kWh/m2/day available at the site.[11]

Solar Experiment 2 – Effects of Effects of Solar Azimuth, Altitude, and Shading

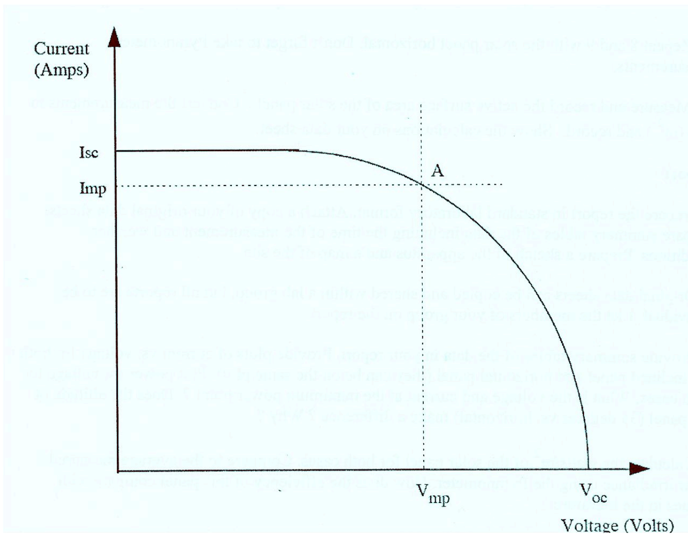
Solar panels are sensitive to orientation (solar azimuth and altitude) and shading. These effects are determined by measuring the I_{sc} (short circuit current) and V_{oc} (open circuit voltage) of the panel at different solar azimuths and altitudes. The digital multimeter is used to measure I_{sc} and V_{oc} at three different azimuths (true south, and 15 degrees + or minus true south) and two different altitudes, 35 degrees (the latitude of the University) and 0 degrees.

To determine the effects of shading, I_{sc} and V_{oc} are measured with the panel shaded in the crossways and lengthwise directions.

Solar Experiment 3 – Solar Panel Characteristic Curves and Efficiency

The characteristic curve of a solar panel is a plot of I (DC Current) versus E (DC voltage). The power output of the panel , P (watts), can be found by multiplying I (Amps) times E (volts) P = IE . The maximum efficiency of the solar panel occurs at one point. In this experiment, the characteristic curve will be measured at two altitudes, horizontal (altitude = 0) and altitude = latitude (35 degrees). The panel is loaded by a decade resistance box to operate the panel at different currents and voltages. The maximum efficiency is given at Point A on Figure 3 below. During the experiment, readings of solar insolation are also taken with a silicon pyranometer so that the potential solar energy available can be compared with the energy captured by the panel and an efficiency calculated.

Figure 3- Typical Solar Panel Characteristic Curve



During the Spring Quarter class, the students had to contend with an overcast day (see Figure 4). This was a good learning experience as the experiments showed that the solar panel would still produce useable power under adverse conditions.

Figure 4 – Solar Experiment on an Overcast Day

SUMMARY

This paper has discussed the author's approach to teaching Sustainable Environmental Engineering. The course includes both lectures and laboratories. The core topics taught in this course included: Introduction to Sustainability; Global Warming and Climate Change; Life Cycle Assessment; LEED Green Building Rating System; and Sustainable Energy Sources.

Several Special Topics based on current events were also covered. In the Spring 2007 class these topics included: Sustainable Waste Management; Sustainable Disaster Mitigation – Hurricane Katrina Disaster Debris Case Study; Sustainable Manufacturing – Automobile Manufacturing Case Study.

The laboratory experiments emphasized the LEED evaluation process and solar energy experiments. Many other approaches to a laboratory experience are possible, depending on the interests and skills of the faculty member.

The National Science Foundation has recognized the importance of this emerging discipline and has supported the establishment of the Center for Sustainable Engineering (CSE) at Carnegie-Mellon University, the University of Texas, and Arizona State University. The Center has sponsored several workshops for engineering faculty to exchange ideas, and discuss how to incorporate sustainability topics into existing and new courses and maintains an extensive website[16]. The next CSE Workshop is scheduled for Summer 2009. The author was a participant in the Summer 2007 Workshop.

ACKNOWLEDGEMENTS

The development of the Sustainable Environmental Engineering course was supported by a Sabbatical Leave funded by California Polytechnic State University. My attendance at the Summer 2007 Sustainable Engineering Workshop was supported by the Center for Sustainable Engineering.

REFERENCES

1. *Looking for Oregon's Future What is Sustainability?* ; Duncan, A., Editor. See http://oregonfuture.oregonstate.edu/index.html (accessed March 2008).

2. *Report of the World Commission on Environment and Development, Our Common Future*; Brundtland G. H., Chair; United Nations General Assembly, New York, 1987.

3. *Report of the United Nations Conference on Environment and Development, Annex I- Rio Declaration On Environment and Development*; United Nations General Assembly, Rio de Janiero, Brazil, 1992.

4. *Code of Ethics*; American Society of Civil Engineers. See http://www.asce.org/inside/codeofethics.cfm (accessed March 2008).

5. *Intergovernmental Panel on Climate Change Fourth Assessment Report Climate Change 2007: Synthesis Report*; Intergovernmental Panel on Climate Change. See http://www.ipcc.ch/index.htm (accessed March 2008).

6. *Kyoto Protocol*; United Nations Framework Convention on Climate Change. See http://unfccc.int/2860.php (accessed March 2008).

7. *Pollution Prevention Fundamentals and Practice*; Bishop, P.L.; Waveland Press, Inc. : Long Grove, IL, 2000.

8. *Streamlined Life-Cycle Assessment*; Graedel, T. E.; Prentice Hall: Upper Saddle River, NJ, 1998.

9. *Waste Reduction Model (WARM),* U.S. Environmental Protection Agency. See http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsWasteWARM.html (accessed March 2008).

10. *The LEED Green Building Rating System*; U.S. Green Building Council. See www.usgbc.org (accessed March 2008).

11. *U.S. Solar Radiation Resource Maps: Atlas for the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*; National Renewable Energy Laboratory. See http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/ (accessed March 2008).

12. *PV Watts- A Performance Calculator for Grid-Connected PV Systems*; National Renewable Energy Laboratory. See http://rredc.nrel.gov/solar/codes_algs/PVWATTS/ (accessed March 2008).

13. *Integrated Solid Waste Management: Engineering Principles and Management Issues*; Tchobanoglous, G, Theisen, H.M., and Vigil, S.A. ; McGraw Hill, New York, 1993.

14. *Photos of the 2005 Gulf Coast Disaster Debris Management – Overview Presentation*; Townsend, T., University of Florida, 2005. (Personal correspondence with the author).

15. *The Solar Pathfinder.* See http://www.solarpathfinder.com (accessed March 2008).

16. *The Center for Sustainable Engineering.* See http://www.csengin.org/index.html (accessed March 2008).