AC 2009-1656: SUSTAINABLE CONSTRUCTION: ACTIVE LEARNING OF SUSTAINABILITY THROUGH DESIGN AND EVALUATION OF GREEN BUILDINGS

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Sustainable Construction: Active Learning of Sustainability through Design and Evaluation of Green Buildings

Abstract

A sustainable future is not possible without innovative engineering solutions. New technologies must be developed and implemented to address emerging challenges in energy and natural resources. In parallel, engineering education must equip students with the knowledge and skills necessary for designing sustainable engineering systems, i.e. with optimum economical, environmental, and societal impact. This paper describes the experience of developing and teaching a senior-level civil engineering course titled "Sustainable Construction". A result of collaboration between two faculty members at University of Hawaii and Villanova University, the course provides students with an opportunity to apply sustainability principles in analyzing and evaluating the life-cycle performance of green buildings. This course was designed to emphasize active learning through hands-on, problem-based and project-based methods. Students worked in diverse teams and examined campus buildings according to LEED standards, to offer strategies for improving building's energy efficiency and environmental footprint. Through interactive classroom discussions and hands-on computer simulations, students gained a broad knowledge of sustainability, recycled and green materials, energy and water efficiency, and life-cycle assessment, and applied this knowledge towards real-life examples. This paper presents different components of this course with examples of students work and their progress throughout the semester.

1.0 Introduction

Education is an essential component of sustainability. As engineers are greatly responsible for development of infrastructure and technologies necessary for a sustainable world, engineering curricula must address sustainability and prepare students for designing engineering systems with long term social, economical, and environmental benefits. The need for the 21st century engineers to incorporate sustainability in their design process has been emphasized by recent reports by the National Academy of Engineering[1] and the Carnegie Foundation for Advancement of Teaching[2]. The Civil Engineering Body of Knowledge document[3] identifies sustainability as one of the main technical outcomes of CE programs and emphasizes that graduating students must demonstrate an ability to analyze and design sustainable engineered systems.

Traditionally, civil engineers have been trained to develop structural systems primarily based on safety and economical considerations. For example, buildings are designed to ensure the safety of occupants while minimizing the initial cost of construction. These buildings are often built using cheap and readily available materials that are extracted from nature and processed in a wasteful and polluting manner[4]. Additionally, the design phase rarely considers the building's life-cycle costs (i.e., cost of utilities, maintenance, and repair), nor does it consider the building's durability and ability to be disassembled and recycled at the end of its service life[4]. Similar problems can be seen in various forms of engineering design, including infrastructure, transportation systems, and manufacturing. An implicit design assumption has been that energy is cheap, natural resources are abundant, and the environment has a large capacity for absorbing our wastes. This assumption, however, is no longer valid.

With the goal of addressing some of these problems in the civil engineering curricula, we (the authors) have developed a senior level civil engineering course titled "Sustainable Construction". The objective of this course was to meet students' vivid interest in sustainability and to provide them with an opportunity to learn, practice, and develop creative building design strategies that also satisfy the requirements of LEED (Leadership in Energy and Environmental Design) standard system[5]. This course has been successfully taught during Fall 2008 at University of Hawaii and will be offered again during Fall 2009 at University of Hawaii and Fall 2010 at Villanova University. This paper describes the process of course development and presents the individual course components together with lessons learned based on students' performance during the semester.

2.0 Objectives and Design of Course Activities

Before developing detailed components of the class, it was essential to establish some principles regarding the course objectives, instructional strategy, and methods for assessing student performance[6]. In doing so, we asked ourselves the following questions:

1) What is our approach in teaching sustainability: breadth or depth?
2) What do we want students to be able to do at the end of semester?
3) What active learning methodologies can we employ in this class?
4) How should we assess student performance?

Answering the first two questions would determine which subjects should be covered in this course. Sustainability is a broad topic that includes many areas of engineering, natural sciences, architecture, economics, and public policy. A variety of topics are closely associated with sustainability, including climate change, energy, water resources, and robust infrastructure, to name a few. As such, the first question was: "Should a sustainability class for civil engineers be broad or focused on a particular subject?" The goal was to help students develop a broad understanding of sustainability; meanwhile, it was crucial to offer students some tangible and transferable skills and an opportunity to practice sustainable design in real-world problems. Additionally, it was important to keep in mind that engineering students often feel more comfortable with solving numerical problems and finding the 'correct' answer, rather than dealing with more general and conceptual ideas.

We also sought opinion from the industry advisory boards (IABs) on what new skills would benefit the civil engineering graduates the most in their career. Their common answer was that while CE graduates are good in numerical solution of traditional engineering problems, they often lack creativity in defining new problems and in offering innovative solutions. In the IABs' opinion, two areas of particular importance in near future will be (a) design and construction of green buildings, especially as outlined by LEED, and (b) development and rehabilitation of robust civil infrastructure[7]. In addition, CE graduates need to improve their communication and writing skills and should be able to work in interdisciplinary teams (with architects and other engineers) to better respond to clients' needs.

This feedback was also in line with students' interest. At the time of registration for the class at University of Hawaii (4 months before the first lecture), students were asked to fill out a survey which revealed that many of them were looking for a class that covers LEED and green construction topics. Based on this input, the class was designed to cover the breadth of sustainability (for the first 8 lectures) while focusing on the practice of design and construction of green buildings and LEED standards (for the remaining 22 lectures). The following performance objectives (not listed in the order of significance) were defined for this course as a list of skills that students are expected to gain during a semester:

1. To identify major challenges caused by environmental degradation and depletion of natural resources
2. To develop a simplified plan for design and evaluation of green building systems
3. To perform detail performance assessment of a building based on LEED standards
4. To demonstrate knowledge of methods to conserve energy in buildings and to use computer simulations to evaluate a building's energy performance
5. To demonstrate knowledge of methods to conserve and recycle water in buildings
6. To describe the production, application, and recycling of green construction materials
7. To evaluate the economical and ecological feasibility of alternative products and solutions based on life-cycle analysis (LCA)

In addition, our instructional strategy was to promote active learning as much as possible. It has been suggested that when students are actively engaged in the learning process (e.g. through group discussions and problem-based learning methods), they are much more likely to retain the obtained information[8]. Active learning was pursued through creating an interactive classroom environment, using actual LEED case studies for homeworks, use of hands-on computer simulations for improving energy conservation in buildings, and through a term project in which student teams examined campus buildings according to LEED and offered economical solutions to improve the energy and water conservation and environmental impact of each building.

3.0 Assessment Plan

To evaluate the progress of students during a semester and towards the 7 performance objectives listed above, an assessment plan was developed based on 4 homeworks, a mid-term and a final-term project, and a final examination. Details of each assignment and the assessment of students' performance in that assignment are provided in the following sections. The final course grades were determined based on a student's participation in classroom discussions (6%), quality of homeworks including the LEED assignments (6% per assignment – 24% total), quality of midterm and final projects (20% each), and performance in one final examination (30%).

4.0 Syllabus

The course was designed to have two 75-minute lectures per week over a 16-week semester. As presented in Table 1, the course covered five main subjects: Principles of Sustainability, Energy Conservation, Water Conservation, Green Materials, and Economics of Green Construction. The first subject covered a broad discussion on sustainability including topics such as growth versus carrying capacity, causes of environmental degradation, and basics of sustainable development. Next, the course focused on energy conservation in buildings through methods such as efficient heating, ventilation, and air conditioning (HVAC), renewable energy devices, smart building envelopes, and waste energy harvesting. During these lectures, students practiced with computer simulations related to energy-use and learned about performing energy audits. The next subject, water conservation, covered topics such as efficient water fixtures, rain/grey-water harvesting, sustainable landscaping, and storm-water management. The subject of green construction materials included reducing embodied energy and carbon print of materials, recycling and remanufacturing, life-cycle assessment, and design of materials for a healthy indoor air quality. Finally, during section 5, students practiced with economical concepts of green buildings including the important subject of life-cycle cost assessment.

Table 1: Course Syllabus

Subject		Lecture Number	Lecture Title
Principles of Sustainability	Week 1:	1	Introduction to Course
		2	Sustainability 101
	Week 2:	3	Major Environmental Challenges
		4	Global Warming (movie)
	Week 3:	5	Introduction to Green Buildings; LEED
		6	Greening Our Campus (2 guest speakers)
	Week 4:	7	Sustainable Urban Development
		8	Sustainable Sites - LEED Credits
Energy Conservation	Week 5:	9	Energy Conservation in Buildings
		10	HVAC Systems
	Week 6:	11	Energy and Atmosphere - LEED Credits
		12	eQuest Energy Simulations
	Week 7:	13	Conducting an Energy Audit (guest speaker)
		14	Fossil Fuels vs. Renewable Energy (movie)
	Week 8:	15	Midterm Presentations
		16	Midterm Presentations
Water Conservation	Week 9:	17	Water Conservation in Buildings
		18	Storm Water Harvesting and Management
Green Materials	Week 10:	19	Green Construction Materials
		20	Materials and Resources - LEED Credits
	Week 11:	21	Building Deconstruction, C&D Recycling
		22	Indoor Environmental Quality - Basic
	Week 12:	23	IEQ - LEED Credits
		24	Building Commissioning (guest speaker)
Economics of Green Construction	Week 13:	25	Economics of Green Buildings
		26	LCC/LCA
	Week 15:	27	Green Home Construction (guest speaker)
		28	LEED Exam Review
	Week 16:	29	Final Presentations
		30	Final Presentations
	Week 17		Final Exam

The main textbook for the course was "Sustainable Construction: Green Building Design and Delivery" by Kibert[4], while additional information was collected from various texts and provided to students in the form of handouts. The LEED Reference Guide[5] was used as a reference text; two copies were reserved by the instructor at the campus library and were available for the use of students. During the semester, a course website was maintained (powered by Sakai), through which students had access to lecture notes, project descriptions, and homework solutions. In addition, students could use the website to post questions or participate in online discussions. Other useful documents such as various LEED, ASTM and ASHRAE standards, as well as links to relevant websites, were available on the course website.

5.0 Interactive Classroom Environment

To promote active classroom discussions, classes often began with an open-ended question to allow in-depth consideration of a problem and to give students time to develop their own ideas and solutions. For example, the class on green materials started with the question "What criteria do you think we should consider in selection of green construction materials?" or the class on environmental life cycle assessment (LCA) started with "Paper or plastic? Which one do you ask for in a supermarket?" Students were arranged in groups and were asked to discuss the question(s) among themselves and contribute to discussions in groups. This would allow the instructor to better moderate the discussion while it would also help the shy students to speak up and represent their groups.

This initial discussion period would continue for approximately 15 minutes and would be followed by a more traditional power point lecture format for the remaining 60 minutes. However, the instructor would maintain the interactive class environment by asking follow up questions, or by introducing short numerical problems for students to solve in class. Initially, it took few lectures to establish the interactive discussions as a routine; but overall, this was a positive experience with students eager to participate and offer or debate ideas.

In addition to regular lectures, five guest speakers were invited during the semester to help students in gaining a diverse perspective of sustainability and an understanding of the current state of practice in the industry. These guests included two on-campus speakers presenting the topics of green roofs and efforts on greening the campus, two speakers from local consulting companies presenting on performing building commissioning and energy audits, and one speaker from a local construction company in charge of building green homes for military housing. The presentations were very informative and provided a valuable opportunity for students to interact with the industry. In addition, there was a plan for visiting a LEED certified building which unfortunately did not happen due to schedule conflicts.

6.0 Homeworks

There were four homework assignments in this class. The first homework was an essay on global warming. The students were asked to perform a literature review and prepare a short report on causes and consequences of global warming, the effect of warming on climate change and sea level rise, and the impact on water and food resources. The students were also asked to formulate general engineering strategies to control the consequences of global warming. In addition, students were asked to use the interactive website: www.myfootprint.org, and calculate their own ecological footprint based on the individual life style and consumption habits. The website allows a user to quantitatively determine how life style changes (for example using public transportation) can reduce the user's environmental impact. This assignment was design to evaluate students' mastery of the performance objective #1 and to evaluate the ability of students to perform an independent research and write a short report. The submitted reports were of higher than expected quality reflecting that students have a good understanding of the challenges caused by global warming and climate change. The homework grades were in the range 90-100 with an average of 94.0. It should be noted, however, that since no beginning-of-the-semester pre-test was administered in this class, it was not possible to determine the extent of students' familiarity with these subjects prior to start of the course. The importance of including a pre-test in future offerings of this course is discussed in later sections of the paper.

Homeworks 2 and 4 were based on LEED case studies (an example is provided in Appendix A). In these homeworks, actual construction projects were studied and students were asked to propose particular measures to be taken for the project to earn LEED credits. These homeworks were aimed at evaluating students' mastery towards performance objectives #3, #4, #5, and #6. To perform the assignment, students needed to consult the LEED reference manual[5] and to research alternative options. This type of homework was especially popular among students as it would allow them to practice for the LEED Accredited Professional exam that many of them were interested in taking in future. The overall experience was very positive as the submitted assignments showed the students' ability to come up with creative solutions to improve the building performance. The average grades were 86.7 (out of 100) for the first homework and 85.3 for the second homework (again out of 100). It should be mentioned here that preparing this type of homeworks would not be challenging for civil engineering instructors, as there are a number of useful books that include LEED case studies and practice examples[9].

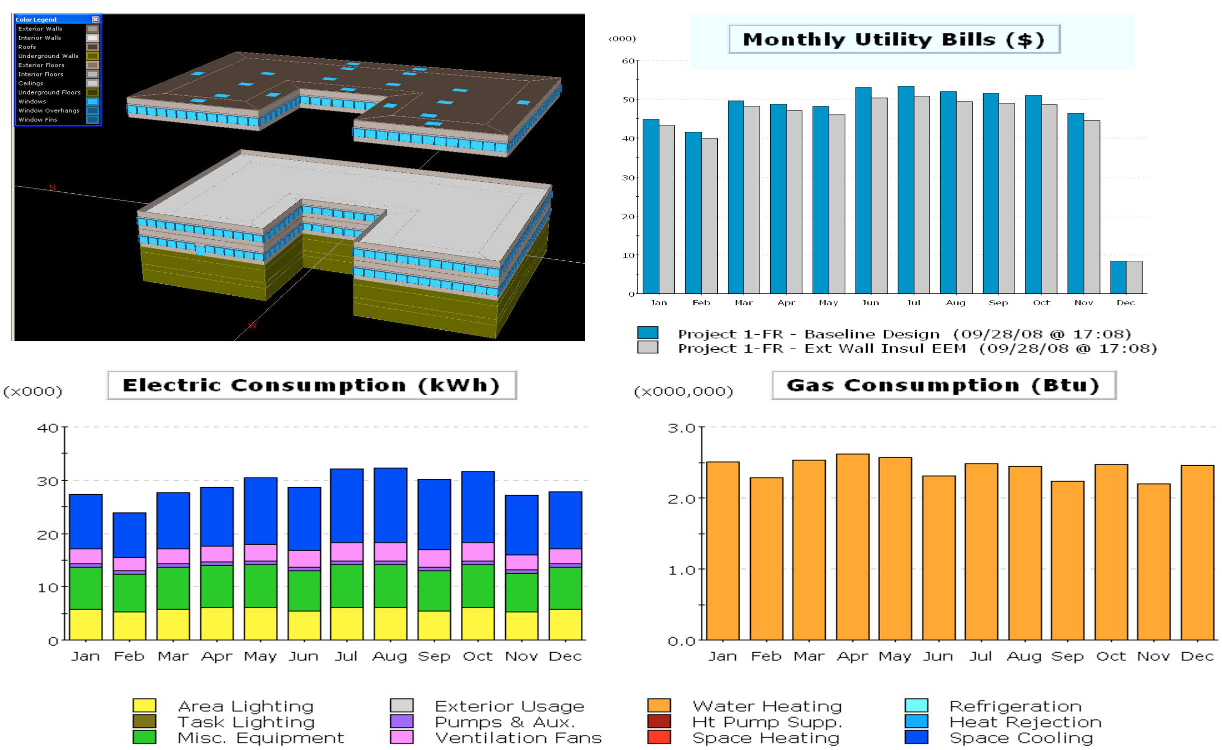


Figure 1 – Sample building energy simulations using eQUEST

Homework 3 was a practice with two computer simulation software: eQUEST and BEES. eQUEST is an interactive and user-friendly simulation tool that allows a user to easily assess the energy consumption of a building and predict the monthly utility bills (Figure 1). The user inputs parameters such as building geometry, composition of exterior walls, type of doors and windows, location and type of building (e.g., office, residential, etc.), hours of operation, type of HVAC and lighting systems, and desired internal temperatures. The software then calculates energy consumption by individual building components and predicts the monthly electricity and gas bills based on local utility rates. The software also allows for comparison of alternative design options (for example, concrete versus wood framing exterior walls) and provides a life-cycle cost analysis to aid in decision making. eQUEST has been developed through funding from USDOE and is available free of charge at www.doe2.com.

BEES is a computer software that allows comparing the life-cycle performance of alternative construction materials based on economic and environmental criteria. For example, the user can compare the use of asphalt versus concrete for construction of a parking lot. The software estimates the life-cycle cost of each material based on local availability and predicted maintenance needs. The software also evaluates the environmental impact of the material in 12 separate categories (global warming, fossil fuel depletion, indoor air quality, etc.). BEES has been developed by NIST and is available free of charge at www.bfrl.nist.gov/oae/software/bees.

Homework 3 was designed to target performance objectives #4 and #7. The students were excited about this homework as it would allow them to easily realize the impact of building design and choice of construction materials on saving energy costs and improving the eco-footprint of the building. The quality of submissions showed that students acquired adequate skills in using the two computer programs. The average homework grade was 87.8 out of 100.

7.0 Course Projects

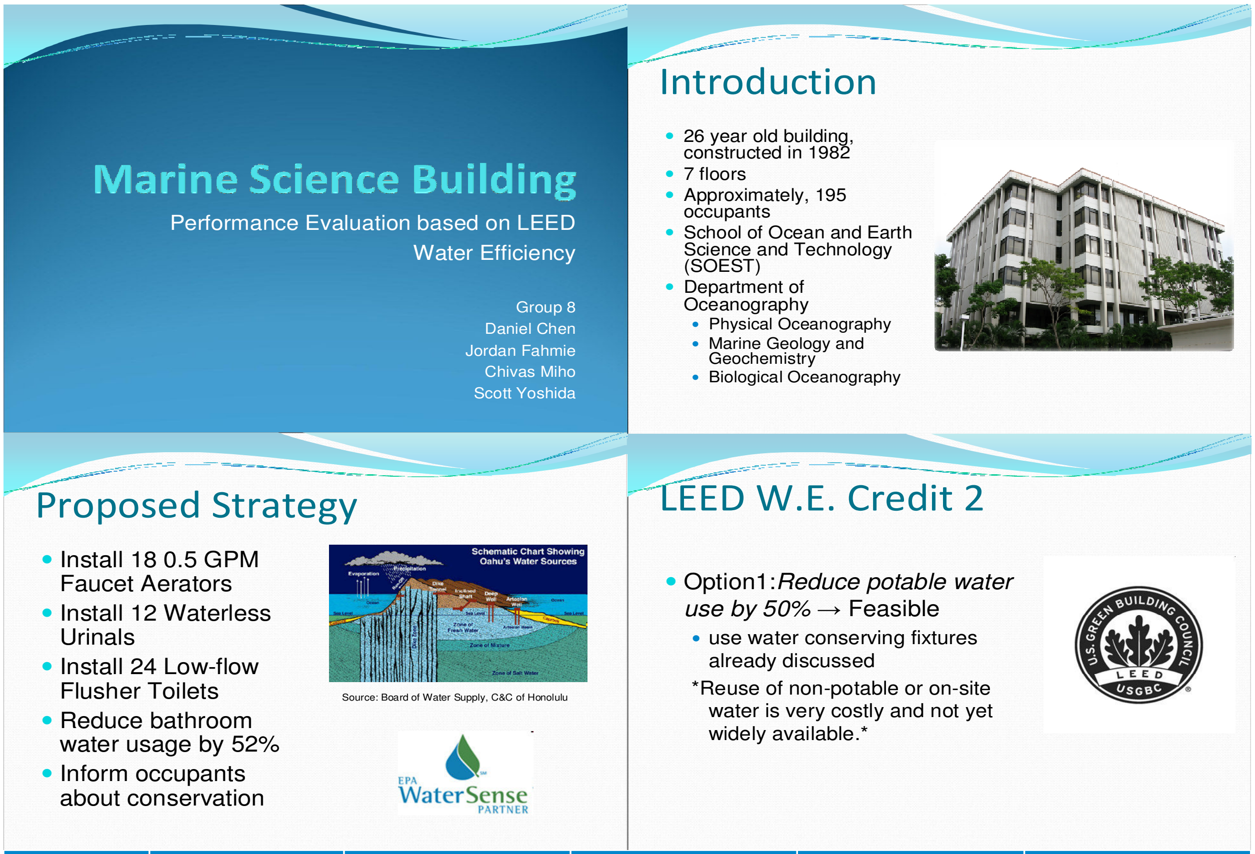
This course included a mid-term project and a final project. Both projects were done in teams with 3 to 4 students per team. There were a total of 9 teams in this class. The teams were assembled by the instructor at the beginning of semester based on the results of a biographical survey of students. The survey included information such as a student's GPA, class standing, age, and birthplace (i.e., Hawaii, US mainland or international) as well as questions reflecting the student's personality. Diverse teams were assembled as groups of individuals with different backgrounds and different working styles. At the time of submission of both projects, each student was asked to also submit a team performance survey to evaluate the contribution of all team members towards completion of the project and to comment on the overall team dynamics.

For the midterm project, the student teams were asked to perform a literature search on a topic of their choice related to sustainability. This assignment was designed to evaluate students' performance towards objectives #1 and #7 and to provide an opportunity for students to work in diverse teams, perform independent research, prepare a report, and present their results. Each team was asked to submit a 10-12 page report of their findings and to prepare a 15-minute presentation (including Q&A) to be delivered in the class.

The following topics were chosen by the 9 student teams: ocean/wave energy, water resources and pollution, sustainable cities, solar energy, trash incinerator power plant, sustainable transportation, fuel cells, wind power, and hybrid electric vehicles. Internet was the main source of information used by the students and various websites were cited in each report. The students satisfactorily followed project descriptions requiring them to research multiple sources of information. The quality of reports was generally good and the students made a good use of figures, charts, and tables. The power point presentations were informative with all team members delivering a part of the presentation. It was interesting to notice, however, that while the majority of students had good writing skills (owing to their practice with writing lab reports), they were clearly not as skilled in delivering presentations. They had difficulty in managing time (on average, each team went 3.5 minutes over time) and maintaining the flow of presentation. In one case, the presentation had to be stopped after 20 minutes with 7 slides still remaining. To correct this deficiency, after each presentation, the instructor briefly discussed the strength and weaknesses of the presenting team and made suggestions on how to improve the quality of the independent research and its presentation.

In the final project, student teams conducted a performance evaluation of an existing campus building based on LEED criteria in one of these five categories: sustainable sites, energy and atmosphere, water efficiency, materials and resources, and indoor environmental quality. Each team was assigned a campus building and would select one of the five LEED categories to perform its evaluations. The teams were also asked to propose an alternative strategy to improve the building's performance in the selected category and to evaluate the costs, benefits, and payback period associated with their proposed strategy. This project was designed to help students practice their learning and apply it in solving a real-world problem. The project was designed in consultation with the campus facilities so the collected information can be used in future to improve the efficiency of campus buildings. Detail instructions were provided at the time of project assignment to clarify the expected project deliverables. For example, in the water efficiency category, students were asked to evaluate water consumption in the building's restrooms, propose strategies to conserve the use of potable water, and elaborate on the benefits, costs, and payback period of their proposed solution. Alternatively, students could choose to estimate the volume of water used for landscaping irrigation and to design an alternative system (e.g., rain-water catchment, drip irrigation, etc.) to reduce potable water use.

This project targeted all of the 7 areas of performance objectives. To fulfill the project's requirements, students needed to utilize their acquired skills during the entire course to perform a comprehensive analysis of the building performance, to propose solutions, and to evaluate the life-cycle cost and ecological impact of their proposed strategy. Each team was asked to summarize its work in a 10-12 page report and to deliver a 15-minute presentation. Overall, the quality of the submitted projects was very good and the presentations were of much higher quality than the mid-term presentations. Figure 2 shows selected slides from the presentation of a student group that worked on improving the water efficiency of a building. The students' final project grades showed a considerable improvement comparing to the mid-term assignment. The average project grades improved from 91.2 to 96.9.



MSB Bathroom Cost Analysis	Baseline		Alternative 1 - Waterless Urinal		Alternative 2 - Low Flow Toilet 1.4 GPF		Alternative 3 - Low Flow Faucet Aerator		Combination of all Alternatives	
Description	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Toilet Usage										
Flushes per hour per floor*	12	12	12	12	12	12	12	12	12	12
Flushes per day for MSB	576	576	202	576	576	576	576	576	202	576
Water Usage per month (gallons) **	62208	62208	21816	62208	24192	24192	62208	62208	8484	24192
Monthly Cost of Usage ***	$171.69	$171.69	$60.21	$171.69	$66.77	$66.77	$171.69	$171.69	$23.42	$66.77
Sink Usage										
Amount of users per day	576	576	576	576	576	576	576	576	576	576
Estimated Sink Water Flow (GPM)	2.17	2.17	2.17	2.17	2.17	2.17	0.5	0.5	0.5	0.5
Water Usage per month (gallons) **	74995.2	74995.2	74995.2	74995.2	74995.2	74995.2	17280	17280	17280	17280
Monthly Cost of Usage ***	$206.99	$206.99	$206.99	$206.99	$206.99	$206.99	$47.69	$47.69	$47.69	$47.69
Total Cost for Alternative******	**$762.51**		**$651.03**		**$552.66**		**$443.92**		**$190.72**	
Savings from Baseline	-		**$111.48**		**$209.85**		**$318.59**		**$571.79**	

Figure 2 – Selected slides from final project presentation on water conservation measures in a campus building

In their team performance surveys, students expressed satisfaction in working with one another. Several students mentioned that they enjoyed working on the final project more than the mid-term project as it was more practical and hands-on and gave them an opportunity to practice with LEED. The main problem mentioned in the surveys was that team members could seldom meet in person due to their conflicting schedules. As such, many groups decided to break the project into smaller tasks that can be accomplished individually. This was clearly not the instructor's intention and in future, alternative approaches should be taken to encourage students to work more efficiently as a team. One solution can be to schedule a lab component (e.g., 2 hours per week) for the course during which student teams work on their project. Other course components that require a longer than 75-minute class time (for example computer software tutorials, or performing physical experiments) can be moved to the lab section as well.

8.0 Final Examination

The final exam was open book/notes with 22 multiple choice questions, 8 short answer questions, 5 numerical questions, and 5 extra credit questions (2 hours total). Figure 3 shows a breakdown of the exam questions based on the 7 performance objectives discussed in section 2.0. The pie chart shows the number of exam points (out of 90 points total) in each of the 7 performance objectives. The bar chart shows the average students grade in each performance objective. For example, based on the questions targeted at assessing the performance objective #1, students had an average score of 77.8%. The bar chart shows a satisfactory performance of students for objectives #2, #3, #4, and #6. The students showed a less than satisfactory performance for objective #7 and to some extent for objectives #1 and #5. These deficiencies must be addressed and improved in future offerings of this course. The average exam grade based on all questions (excluding the extra credits) was 83.4%.

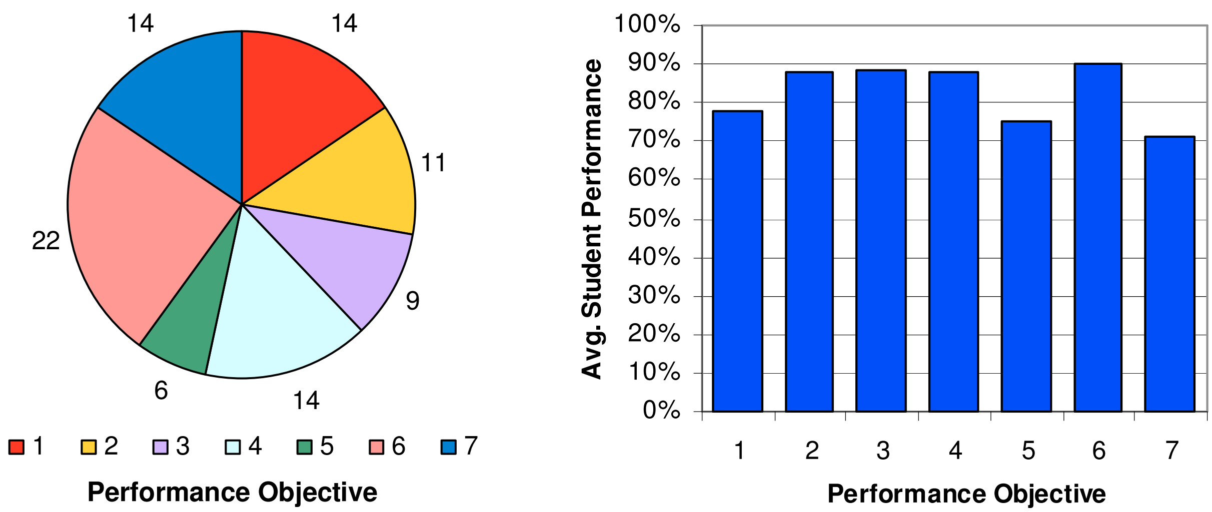


Figure 3 –Assessment of student performance based on the final examination

9.0 End-of-Semester Student Evaluations

In an anonymous end-of-semester course evaluation, students were asked to name the most important and useful subjects that they have learned in this course. They were also asked to indicate what they liked and disliked about the course, provide suggestions to improve the course, and assign an overall grade to the quality of the course.

Based on the responses from 27 students who completed the survey, the most important and frequently cited subject learned in this course was evaluating building performance according to LEED criteria (cited by 22 students). Other frequently cited subjects were eQUEST (11 citations), recycling and green materials (7 citations), and renewable energy (7 citations). The citation of renewable energy as a major course outcome is of significance and shows the effectiveness of students' learning from peers. While this topic was only briefly covered by the instructor, it was extensively covered by students themselves during their mid-term presentations.

The survey results also showed that students were the most interested in learning about LEED and working on case studies and the final project (12 citations). Many students liked that the course enabled them to learn about and use engineering solutions to achieve sustainability (7 citations) and believed that the learned skills will be valuable in their future careers (9 citations). Students also enjoyed the open classroom discussions and referred to it as an interesting and effective alternative to traditional lecture-format classes. Guest speakers were also popular.

Among the negative comments, the most cited (7 citations) was that some of the information (e.g., global warming) is common knowledge for most students and need not be covered in the class. Also, some of the topics had been covered in other civil engineering courses and as such they were just a review. To address this comment, a two-fold strategy could be adopted for future offerings of this course. First is to determine the course pre-requisites and design instructions to minimize overlap with other civil engineering classes. This would ensure that the sustainability course fits well into the rest of curriculum, utilizes information from pre-requisite courses, and covers materials that can be used in follow on classes. Second is to have a pre-test at the beginning of semester to evaluate the students' background knowledge in several subjects and to modify instructions accordingly. The other benefit of the pre-test is that it assists in a better assessment of student learning and progress during the course. A valuable assessment metrics can be in the form of bar charts similar to that of Figure 3 to represent the mastery of students in several performance objectives both before and after the completion of this course.

Finally, in their surveys, the students suggested that the course cover even more LEED materials in future to prepare them for the LEED Accredited Professional (AP) exam. They also suggested a site visit to a LEED certified building and inviting a LEEP AP architect as a guest speaker. Overall, the students graded this course as 4.52 out of 5.00.

10.0 Recommendations for Future and Similar Courses

Although the pilot Sustainable Construction course was generally very successful, for future and similar courses, we recommend the following modifications to improve the course efficiency and students learning: (1) Designing instructions by considering information already learned in pre-requisite courses, (2) Administering a pre-test at the beginning of semester to evaluate the students' background knowledge in several subjects related to sustainability, (3) Scheduling a lab component during which student teams can work on projects, practice with computer simulations, and perform physical experiments, (4) Arranging a site visit to a LEED certified building.

11.0 Summary and Conclusions

Developing and teaching the senior-level "Sustainable Construction" class was a very positive experience. The students were very satisfied with learning and practicing LEED performance criteria. The interactive classroom discussions created a stimulating learning environment, especially that the class included both conceptual and numerical problems. The computer simulations allowed students to link the building design and choice of construction materials to the energy consumption and eco-efficiency of the building. The final projects provided students with an opportunity to work in diverse teams on a real-world problem of evaluating and improving the efficiency of buildings, and to prepare engineering reports and presentations of their findings. The assessment of students' performance using homeworks, projects, and final examination showed that students acquired an adequate level of mastery in most areas of the 7 performance objectives. Recommendations for improving the students learning experience for future and similar courses were provided.

References

1. 'Educating the Engineer of 2020: Adapting Engineering Education to the New Century', National Academy of Engineering, 2005
2. S. D. Sheppard, K. Macatangay, A. Colby, and W. M. Sullivan (2008) 'Educating Engineers: Designing for the Future of the Field', San Francisco: Jossey-Bass
3. 'Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future', 2nd ed., American Society of Civil Engineers, Reston, VA, 2008
4. C.J. Kibert (2008) 'Sustainable Construction: Green Building Design and Delivery', 2nd ed., John Wiley, Hoboken, New Jersey
5. 'Leadership in Energy and Environmental Design: LEED-NC v2.2 Reference Guide', 3rd ed., U.S. Green Building Council, 2007
6. R. M. Gagné, L. J. Briggs, and W. W. Wager (1992) 'Principles of Instructional Design', 4th ed., Harcourt Brace Jovanovich College Publishers
7. P. Ooi 'Minutes of the Industry Advisory Board Meeting, Department of Civil and Environmental Engineering, University of Hawaii', February 22, 2008.
8. C. Bonwell, and J. Eison (1991) 'Active Learning: Creating Excitement in the Classroom', AEHE-ERIC Higher Education Report No.1. Washington, D.C.: Jossey-Bass
9. M. Peot, and B. Schumacher (2007) 'LEED NC Practice Problems: New Construction', Professional Publications, Inc.

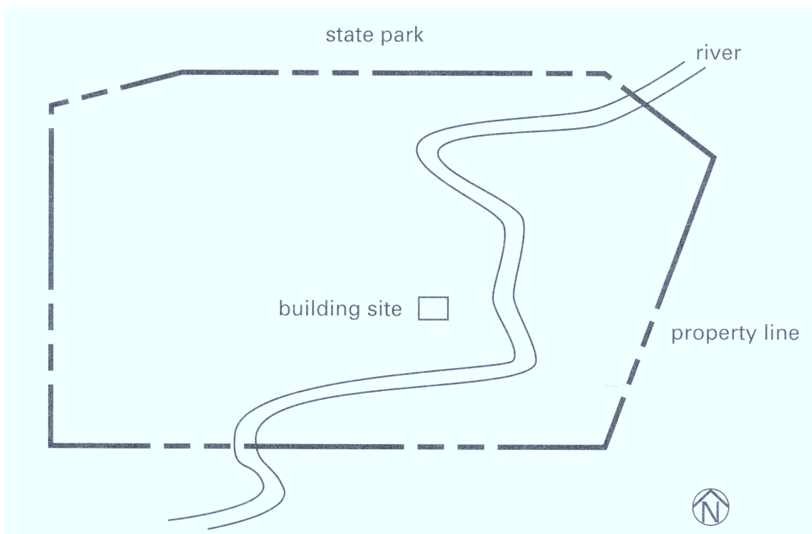
Appendix A: Sample Homework for CEE 491 Sustainable Construction Course

Homework #2 – LEED Exercise

Assigned: Tuesday, 09/29/08 Due: Tuesday, 10/07/08 (3:00pm – in class)

Scenario

Good View is a rural community in central Colorado at 9000ft above sea level. A nonprofit institute plans to construct a new environmental learning center on a previously impacted site in Good View. The site is adjacent to a state park, and the learning center will be maintained and operated by a full-time staff. The facility will serve as an educational center for the general public and local schools. It will also cater to the professional needs of geologists, wildlife biologists, botanists, and astronomers. The facility will serve as the headquarters for a research team studying the decreasing local lynx population, which is federally threatened and state endangered. Biologists will study the facility's fully functional Living Machine® (a bio-remediation wastewater treatment system) to see its performance at high altitudes. Local astronomers will use the facility's new high-power telescope for research and educational classes.



General Information	
project building footprint	55,000 ft^2
gross building square footage	80,000 ft^2
project site area	200 ac
occupant hours (at peak period)	344 occupant-hr
transient occupants (at peak period)	25
quantity of parking spaces (non-preferred)	65
overall construction cost	$24,000,000
ventilation type (natural or mechanical)	natural
regularly occupied spaces	68,540 ft^2
non-regularly occupied spaces	11,460 ft^2

The facility will be naturally ventilated and will be constructed using fire-retardant, high performance insulated concrete forms (ICF) that are manufactured locally. It will also be off-grid and powered by photovoltaics (PVs) and three on-site wind turbines. The building project team will work with a daylighting lab to effectively use natural light to decrease the need for electric lighting in the building. Additionally, this project team will take great care not to disturb the natural areas surrounding the facility. The team will extensively restore the site's vegetation with native plants, as the ecosystem is a habitat for a diverse selection of flora and fauna. Furthermore, there will be no irrigation systems installed.

Questions

1- The design team will use soil stabilization and structural control measures to comply with the requirements of SS-Pr1: Construction Activity Pollution Prevention. Specify two soil stabilization and two structural control technologies that are suited for this project.

2- Will this project meet the requirements of SS-Cr1: Site Selection? If yes, what must be submitted? If no, explain why not.

3- The design team has sized the facility's parking capacity to meet the requirements of SS-Cr 4.4: Alternative Transportation: Parking Capacity. How many preferred parking spaces for carpools or vanpools must be provided?

4- The project team is committed to the preservation of the lynx habitat and has minimized the development footprint as much as possible. They expect to receive one point for SS-Cr5.2: Site Development: Maximize Open Space. The vegetated open space required by zoning in Good View for this type of project is 25% of the site excluding the building footprint. What is the total amount of vegetated open space required for the project to receive one point for SS-Cr 5.2?

5- Using the following measurements, determine whether the project is eligible for SS-Cr7.2: Heat Island Effect: Roof.

- Roof surface area: 55,000 ft^2
- PV panels: 10,000 ft^2
- White EPDM (ethylene, propylene, diene monomer) material (SRI = 84): 40,000 ft^2
- Red clay tile (SRI = 36): 5,000 ft^2
- Low-sloped roof

6- What systems must be commissioned according to EA-Pr1: Fundamental Commissioning of the Building Energy Systems?

7- The project scenario discusses two methods for creating renewable energy through photovoltaics (PVs) and wind turbines. What other renewable energy systems might be efficient in this project to provide energy to the building?