Sustainability in Undergraduate Civil and Mechanical Engineering Instruction

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Dr. Issa is an associate professor of Mechanical Engineering at West Texas A&M University. He joined the College of Engineering and Computer Science in 2004, a year after it started. Since joining the department, he has been in charge of the enhancement of the Thermal Sciences Laboratory. His background is in the area of heat transfer and fluid dynamics. He received his B.S. and M.S. degrees in Mechanical Engineering from University of Tennessee, Knoxville, and Ph.D. degree in Mechanical Engineering from University of Pittsburgh. Dr. Issa has worked for 4 years in the aerospace industry and 8 years in the steel rolling industry. While working in industry, he has conducted extensive experimental and numerical studies on the cooling of rolls and flat products in the hot mill. He is a co-inventor on a US patent on the rolling of flat products. His academic research activities focus on numerical modeling and experimental studies of air-mist cooling in the metal production, power generation, and food process industries. Recently, he conducted experimental studies on the chilling of beef carcasses using spray atomizers and has experience in designing spray cooling systems. Other research activities include energy sustainability studies, such as utilization of a multi-stage wind tower for indoor cooling, and design of a passive solar heating system for the distillation of industrial wastewater using solar vacuum tubes. Dr. Issa is an author of over 20 journal and conference papers in the area of heat transfer and fluid dynamics.
Abstract

Teaching sustainability in engineering curricula fulfills ABET 2000 Outcome 3c as well as the codes of ethics of, ASCE, ASME, and NSPE. The authors have investigated the use of sustainability concepts of the Leadership in Energy and Environmental Design (LEED) criteria and have applied principles to several undergraduate research projects and in coursework. LEED is an optional sustainability guideline in private construction and is mandated or encouraged by many federal, state, and local governments for public construction projects. Learning about sustainability will help engineers understand how their creations will interact with and operate in a more complementary manner with the natural world as well as to reduce water, energy, and material usage.

Sustainability has been implemented in the engineering curriculum, particularly in courses such as capstone senior design, thermal-fluid system design, and engineering research. The projects implemented in those courses were selected in such a way to establish an in-depth understanding of sustainability through analytical and experimental studies, and to build environmentally friendly and energy efficient systems. Some of these projects include: design of an active solar distillation system for purification of wastewater produced in rural agricultural processing facilities, experimental studies on prototype green roofs to investigate the effects that soil type and soil moisture level have on the thermal performance of a roof, design and construction of a three-stage wind tower with a bypass system for indoor cooling in rural dry and hot climates, and design of an outdoor civil engineering instructional laboratory.

These projects will be discussed in brief in this paper and future guidance on applications of sustainability in the undergraduate civil and mechanical engineering curriculum is discussed.

Introduction

Engineering technical societies recognize the importance of the incorporation of sustainability concepts into engineering curriculum. Many current faculty and instructors are not fully informed on what sustainability entails. One definition used by the authors for curriculum relates sustainability to maintaining a high quality of life for not only people of the present but also for those people that will follow in the future by ensuring access to natural and constructed resources to maintain that high quality of life. Engineers must determine how to allocate scarce resources effectively while also thinking of the operation and eventual dismantling or rehabilitation of their creations. As such, getting buy-in and agreement from all involved parties is crucial, including engineers, architects, scientists, contractors, owners, users, and other concerned parties.

While computer science and engineering technology have been well established at West Texas A&M University (WTAMU), the mechanical (2003) and civil (2010) engineering programs are more recent. Curricula for the newer engineering degree programs are similar to other ABET-
accredited programs which are constrained in the number of credits that can be allotted to many worthy topics, including sustainability.

The School of Engineering and Computer Science (ECS) at WTAMU recognizes the importance of sustainability concepts in the engineering curriculum. Drs. Leitch and Issa (civil and mechanical engineering, respectively) recognize a common need for sustainability as well as other topics such as technical writing and experimentation skills in the engineering curriculum and have committed to incorporation of these worthy concepts into their respective engineering courses as well as through independent undergraduate research projects.

Many universities have successfully dealt with the constraint of a limited number of credit hours specifically devoted to sustainability by implementing improvement to curricula, with a few examples described in the following Review section. These examples fall into two broad approaches: 1) a multi-departmental approach involving engineering programs with technical communication experts or 2) as an engineering program or engineering college only approach.

**Review**

Many engineering programs are incorporating elements of sustainability across their coursework. Ahn, et. al (2008) and Cottrell and Cho (2009) provided a list of universities incorporating elements of sustainability into engineering curricula such as at the University of Colorado, the University of Florida, Pennsylvania State, Texas A&M, Texas Tech, and Virginia Tech. Lamar University reports using Shangri La Botanical Gardens and Nature Center in Orange, Texas (LEED Platinum certified) as a teaching tool. Beginning in 2000, the Oregon Institute of Technology has implemented a three-term sequence in senior civil engineering design that emphasizes sustainability by using the LEED criteria. George Mason University uses the LEED Neighborhood Development criteria for its senior design project to address all major subareas of civil engineering. In 2012, Sattler et. al at the University of Texas at Arlington addressed integrating sustainability across the civil, mechanical, and industrial engineering curriculum including a multi-disciplinary senior design experience to design a biodiesel production facility.

**Example Projects**

Students in the civil and mechanical engineering curriculum are exposed to sustainability in a wide variety of required courses including the final senior capstone design experience. A few recent examples of sustainability in the curricula are presented in the following sections.

**Project I - Thermal Performance of an Active Solar Distillation System**

In the fall semester of 2012, senior mechanical engineering students in Thermal-Fluid System Design were assigned a project to design a solar collector system that can be coupled to an existing solar still. The purpose of the project was to convert an existing passive solar distillation system into an active system. The students had to evaluate the effectiveness of using such a system in the distillation of wastewater produced in agricultural processing facilities in west Texas. They conducted a research on some of solar still designs available in the open...
The solar distillation system they built is shown in Fig. 1a, and a schematics diagram for its operation is shown in Fig. 1b. The system consisted of a steel basin coupled to a solar collector panel. The steel basin was 0.85m x 0.85m with a Plexiglas cover inclined at 30° with respect to the horizontal surface. The inclination of the solar still cover causes the condensing distillate to slide down the glass surface and collect into a tray that drains into a holding tank where distilled water is collected. The solar collector panel was constructed of two arrays of nine solar vacuum tubes paired with parabolic mirrors. Each array had nine tubes running in series and the two arrays ran in parallel. The purpose of the solar collector panel was to preheat the water before it entered the basin of the solar still using a circulator pump. Since limited research has been conducted on solar vacuum tubes, the students were interested in examining the feasibility of the tubes in such a design.

Thermocouples were installed at various locations in the system to monitor the temperature. Tests were conducted for periods ranging from three to four days. The first series of tests were conducted on a passive system by decoupling the basin from the solar collector panel. The second series of tests were conducted on an active system that had the basin coupled to the solar collector. For all tests, water was poured into the still to a depth of 5 cm for a total volume of 36 liters. The students learned from the tests results that active solar distillation can outperform passive solar distillation by several factors as reflected in Fig. 2. The maximum production rate reached in the passive system was 1.35 L/m²/day, while that reached in the active system was 3.6 L/m²/day. Figure 3 shows typical results of the temperature time history at various locations in the distillation system. Due to having low investment and operation cost, students learned that solar distillation is the most economic method for use in the rural dry and hot climate of West Texas where solar energy is abundantly available. Throughout the world, the availability of clean water is always on continuous decline, while the demand of clean water is on a continuous increase. This design project provided a sustainable approach for water distillation.

**Project II - Thermal Performance of a Green Roof in Arid to Semi-Arid Climates**

In each of the spring, summer, and fall semesters of 2013, three undergraduate research students (nine in total) from the mechanical and civil engineering programs at WTAMU conducted pilot studies on the feasibility of using a green roof in the semi-arid climate of West Texas. The
spring recruits were given the task to design and construct the roof and perform thermal property evaluation of two types of soils. The summer recruits were given the task to conduct a parametric study on the thermal performance of the roof under different climatic and roof conditions. The fall recruits conducted extensive tests on the thermal properties of additional types of soils. In their literature review, students discovered that extensive amount of research is currently being done on green roofs, but no research has been done yet on green roofs under arid to semi-arid climates. A test model of a green roof was built on WTAMU campus as shown in Fig. 4. The system consisted of a six-wall enclosure having a base of dimensions 1.22 m x 1.22 m. The top and bottom surfaces of the enclosure were constructed of 1.9 cm thick OSB (Oriented Strand Board) wood panels, while the sides were constructed of 5 cm thick polystyrene foam panels. Soil was poured to a height of 10 cm. In some of the performed tests sand was used, while in others a local clay loam was used. Also, in some tests a layer of grass, 2 cm thick, was added to the top soil surface. Thermocouples were installed at various locations in the roof to monitor the temperature. Students estimated the soil moisture content by taking a soil sample twice a day and measuring its weight before and after holding it to dry for 24 hours in an oven.
The student summer group conducted a series of tests. The first series of tests used bare sand and bare clay loam soil, while the second series used sand and clay loam soil with a layer of grass on top. The grass was watered twice a day for a water depth of 10 mm at each watering. The third series of tests used sand and clay loam soil with a layer of grass on top. In this case, the grass was watered once a day for a water depth of 10 mm. Figures 5(a)-(c) show the roof inner temperature. Temperature results for three different roofs were compared: Roof with clay loam soil, roof with sand, and a control roof with no soil. The roof with clay loam soil had the lowest fluctuation in temperature between daytime and nighttime, and the lowest temperature during daytime. The roof with sand had a slightly higher temperature during daytime, while the control roof had the highest temperature during daytime. The largest temperature fluctuation between daytime and nighttime was seen in the control roof, which also had the lowest temperature during nighttime. The results show the inner temperature of the vegetated roofs (with clay loam or sand) dropped considerably during daytime compared to non-vegetated soils. Also, doubling the amount of grass watering from 10 to 20 mm per day reduced the inner roof temperature by several degrees.

Fig. 5(a) Roof Inner Temperature (July 21-Aug 1, 2013)

Fig. 5(b) Roof Inner Temperature (Aug 2-Aug 10, 2013)

Fig. 5(c) Roof Inner Temperature (Aug 11-Aug 22, 2013)
The goal of this project was for the students to learn about the thermal benefits of converting a conventional roof into a green roof. The results of the study affirmed that the presence of a layer of vegetation protects the roof from extreme temperatures and high temperature fluctuations. Students discovered that clay loam soil, the local soil in Canyon, Texas retains considerable moisture which results in better cooling during daytime due to evaporation heat transfer, while soils that dry very quickly or do not hold enough moisture are less effective for thermal comfort. At the end, the research students learned that not only green roofs provide a sustainable solution for energy savings, but they are easy to install on conventional roofs and offer plenty of LEED credits (refer to Project IV).

**Project III - Thermal Performance of a Multi-Stage Wind Tower for Indoor Cooling**

A three-stage wind tower was designed in fall 2010 by a group of three mechanical engineering students for their capstone senior design project. The idea of using wind towers for indoor cooling in hot and dry climates is not new, and its use in residential dwellings in the Middle East dates back to several centuries ago. For their project, the students had to analyze existing designs of wind towers\(^ {19-22}\) and propose a new design that outperforms the others. Their optimal design was a wind tower built in the shape of two venturi tubes connected together. Their analysis showed that such a system not only outperforms conventional straight-sections wind towers, but is also attractive to use in climates where the wind is not very strong. They constructed an 8 m high wind tower made of wood material and performed experimental tests on it. A sketch of the system is shown in Fig. 6. As the hot dry air from outside enters the tower, it vaporizes the mist droplets sprayed at the different locations inside the tower; therefore, producing a cool moist air capable in displacing the room’s hot and stagnant air.

![Fig. 6 Design of a 3-stage wind tower for the cooling of a dwelling facility](image)

Spray nozzles that disperse water droplets with different sizes were installed in the wind tower at different locations. The wind catcher at the top of the tower was designed such that it allowed air to enter from any direction into the tower. Openings near the constriction of the venturi tube section allowed auxiliary air to enter the tower through the constriction due to the effect of suction. Their study investigated the effect of the inlet air relative humidity on the wind tower exit temperature, exit relative humidity, water flow rate and cooling power (Fig. 7). Figure 8
shows the inlet and exit conditions for the wind tower on a Psychometric chart. Based on the variation in wind speed, inlet temperature and relative humidity, the tests provided an insight into the desirable spray water flow rate for comfortable air temperature and relative humidity level entering the room. Given the increasing urgency for energy conservation, the goal of this project was to introduce the students to sustainable energy solutions that are environmentally friendly and energy efficient for cooling buildings in hot and dry climates. The study asserted the feasibility of relying on renewable forms of energy such as wind energy to achieve this.

**Fig. 7** Effect of inlet relative humidity on exit temperature, exit relative humidity, water flow rate and cooling power

**Fig. 8** Adiabatic-cooling process inside a 3-stage wind tower presented on a Psychometric chart
Project IV – LEED Principles and Building Scorecards

In fall 2012, a team of three senior level civil engineering students in undergraduate research conducted a LEED (Leadership in Energy and Environmental Design) study of two WTAMU campus buildings (Fig. 9 and 10). One building is a newly constructed dormitory (Centennial Hall, 2011) and the other was a major renovation (Engineering and Computer Science Building, 2012). In the process, the students had to learn about the LEED criteria, read and interpret engineering drawings, and evaluate the sustainable features of each building.

![Fig. 9: Engineering and Computer Science Building](image1)
![Fig. 10: Centennial Hall Dormitory](image2)

The LEED\textsuperscript{23-24} criteria require the assessment of five key areas: sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor air quality. In addition, two bonus categories are used in LEED: innovation in design and regional priority. The sum of the five key areas can be up to 100 points and up to 10 points can be awarded as a bonus. Buildings and developments are awarded a level of achievement affixed to a plaque on the building as follows: certified 40-49 points, silver 50-59 points, gold 60-79 points, and platinum for 80-110 points.

Based on the students’ assessment of the LEED criteria and the building plans, they determined that the Engineering and Computer Science (ECS) Building would be awarded 32 points, (Fig. 11) not enough for certification. While the ECS building gains considerable points for reuse of an existing building, use of recycled content materials, and low volatile organic compound (VOC) materials and furnishings, it does not do much beyond meeting prerequisite levels for water and energy usage. However, the Centennial Hall dormitory would be rated at 45 points (Certified, Fig. 12) due to its reuse of a previously developed parcel of land, use of recycled content materials, use of low VOC materials and furnishings, as well as the use of a greywater recycling system that uses shower rinse water to flush toilets in the facility.
Assessment and Student Feedback

A total of 37 students were recruited for these four projects. Eight students (22%) graduated with honors and two students (5%) were McNair Scholars, an honors program at WTAMU. Seven of those recruits (19%) were employed as student workers, and four (11%) received university scholarships. Three of the students (8%) decided to pursue a graduate degree and all of the remaining students were offered employment upon graduation.

The following are quotes from some of the students for their feedback evaluation of the projects:

- “The research this summer was a great experience that allowed us as students to work independently.”
- “It was really great how much data we could collect using the data logger.”
- “Because it was a joint effort between mechanical and civil engineering, it allowed me (a mechanical engineering major) the chance to learn about civil engineering, specifically about different types of soils and their effects on water and energy storage.”
- “I found the project to be interesting and it was exciting to finally work on something that was not simply theoretical.”
Conclusions and Recommendations

The authors have incorporated concepts of sustainability into the civil and mechanical engineering curriculum at West Texas A&M University without altering the number of credits in the degree programs. Concepts of sustainability are now being incorporated into curricula from the first introductory engineering course through the senior design capstone experience.

Getting buy in from the teaching faculty is key for incorporation of sustainability into engineering classes and laboratories. Many current faculty have not be educated in sustainability concepts and may need additional reference material and training to bring these ideas into their respective courses. The concept of sustainability and being ‘green’ has reached critical mass and will be essential for the engineers of the present and future.

Bibliography