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Sustaining Sustainable Engineering Design Projects*

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Experiential learning has been emphasized in the School of Engineering at the University of Dayton for over 25 years. The evolution has gone from individual projects to team projects and from single discipline to multidisciplinary teams. In the last 5 years the percentage of projects related to design for the environment, design of thermal systems and renewable energy systems reached about one-third of the capstone design projects. The purpose of this paper is to share the experiences over these last 5 years. Thus, this submission covers the applied aspects of sustainability in design education. In doing so this paper concentrates on three areas. First, there must be a venue, or a sustainable design landscape, in which sustainable design and development projects can be implemented. Second, it is important that the appropriate resources be available in order to facilitate sustainable design. Finally, there will be a review of the types and scope of these projects and the lessons learned over this time.

Keywords: sustainable design; product realization process; renewable and clean energy; innovation; entrepreneurship

1. BACKGROUND

IT IS WELL KNOWN that over the past 25 years there has been a significant emphasis on sustainable engineering and design. In its publication 'Guiding Principles of Sustainable Design' [1] the U.S. Department of the Interior and the National Parks Service define sustainable design as 'a concept that recognizes that human civilization is an integral part of the natural world and that nature must be preserved and perpetuated if the human community itself is to survive. Sustainable design articulates this idea through developments that exemplify the principles of conservation and encourage the application of those principles in our daily lives.' (http://www.nps.gov/dsc)

Over the past 13 years the School of Engineering at the University of Dayton has emphasized experiential learning in its capstone design experience where projects were implemented through the Design and Manufacturing Clinic. [2] Using the Product Realization Process over 500 projects have been implemented and have been sponsored by nearly 90 companies, or entrepreneurs. Initial projects involved the design of components, machines or processes. Over the last 5 years there has been a growing interest on the part of companies and individuals to sponsor projects related to sustainable design as it relates to alternate sources of energy as well as renewable and clean energy.

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2. THE SUSTAINABLE DESIGN LANDSCAPE

The phrase 'Sustainable Design Landscape' is defined here as the environment within which the design projects and in particular the sustainable design projects are implemented. In this category there are several topics. First there is the course sequence. For a number of years the main course was a single capstone design course. As explained in section 2.1, more courses from the first year on have been added to the design sequence. The product realization process continues to be the sequence by which the projects are initiated and brought to completion. Finally, the newly renovated Innovation Center facility has been a location that is the focal point for nearly all design related activities associated with sponsored projects.

2.1 Course sequence

The course sequence (Fig. 1) can best be visualized by a flow diagram that shows the interrelationship between the stages of design process at various levels. In this figure there are four courses that span the four year engineering curriculum.

2.2 Engineering innovation (EGR103)

The Engineering Innovation course (EGR 103) is an introductory class to Innovation and Design. This class incorporates a number of important aspects that will be of benefit to the student throughout their engineering curriculum. *Engineering Design* by Dym and Little [3] is the focal point for the course activities. Early in the course

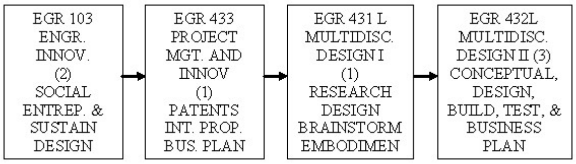

Fig. 1. Design and innovation course sequence.

the students take the Myers-Briggs Test to determine not only their own personal traits but how to deal with others. A psychologist spends one class period going over the different characteristics of each type and how differences can enhance a team. This is followed by a 'fun' team building exercise.

The first attempt was for a team to build a 'marble maze' with materials that can be recycled. The envelope dimensions are stipulated and the team must come up with a design that will maximize the amount of time for the marble to go from the highest elevation to the lowest. An activity that appeared to be more successful was one presented by Sheri Sheppard at MDWII, called the Gummy Bear Project. This has been modified to include a Gummy Bear Boat or a Gummy Bear Car. In these design and fabrication challenges each team is provided with a deck of playing cards, a roll of celephane tape, a scissors and 10 gummy bears. The bears must remain in the towers, cars or boats throughout the event. In each of the designs a hair (blow) dryer is used to try to topple the tower, or propel the car or boat. The tower that withstands the highest flow wins. The car or boat that moves four feet on the top of a table in the shortest time wins.

Another competition that has worked well is for the student teams to design, build and test a cardboard chair. The students are provided with a 4×5 ft. sheet of cardboard. Also provided are 10 glue sticks. A box cutter, a yard stick and a glue gun are used as construction tools. The chair must be at least 20 inches high, have a flat top surface and be able to withstand a weight of 320 pounds (8 salt bags). All of the chairs that meet or exceed this are entered in a course-wide challenge.

These 'fun projects' are used to stress the product realization process and foster team building. The students are asked to write a letter report describing their experiences. How did you arrive at a design? Was everyone involved? Did you experience all of the design phases? What would you do differently if you were to start over?

The Product Realization Process continues to be analyzed in a more detailed project after this initial 'small' project. In this case a series of projects is generated by the faculty that exemplifies the intent of the course to be socially responsible and to be environmentally friendly. The designs developed in this segment result in the building of models but short of being prototypes. Projects have included a self sustaining cabin, the use of photovoltaics for pumping water for irrigation in Togo and a solar collector that would follow the sun. This last concept will be discussed in more detail in the projects section of this paper. The conclusion of the project requires oral presentations and a written technical report. As in previous studies [4] the outcome of this class is that students believe they have a better appreciation of the design process and the engineering profession. This prepares them for other courses in the curriculum and being a practicing engineer where team projects are the norm.

2.3 Project management and innovation (EGR 433)

As part of the design sequence a new course has been implemented to emphasize innovation and entrepreneurship. Topics include project management, time value of money, cost estimating, business plans, and intellectual property. This course does not emphasize sustainability but has been an asset to sustainability projects because of the large number of sustainability entrepreneurs that need business plan support.

2.4 Product realization process

The Product Realization Process (PRP) [2, 5] or the Design Process [3] is the approach used in all of the design project courses. Nearly all of the projects have an external client, especially those that are later in the curriculum. The major areas are:

1. Establishing the need—with the client
2. Developing the specifications and writing a proposal—This includes the functional requirements, the design requirements and design criteria.
3. Based on these guidelines the individuals generate concepts and bring their ideas to the team for consideration. The top candidates undergo a decision analysis.
4. The decision analysis establishes the embodiment design. This is where a feasibility analysis and feasibility tests are performed. In Fig. 1 above this is the end result in the one credit hour class. It is here that the project may be continued in EGR 432L where the final design, build and prototype testing occurs.
5. This embodiment design is followed by the final design, analysis and testing.
6. The final step is the implementation of the design into the system or perhaps will result in the design being combined with a business plan to provide a new product through entrepreneurship.

The above process has been enhanced in the curriculum with the partnership with the individuals in the School of Business Administration and the Entrepreneurship Program. With the strong foundation that has been built with over a decade of industry sponsored projects in engineering and an Entrepreneurship program that is ranked 4th in the country by *'The Princeton Review',* a strong collaboration has been established. We are continuing to strengthen this alliance through multidisciplinary teams that design and build products that along with a strong business plan can be the basis for an entrepreneurial enterprise.

2.5 The innovation center

Five years ago it was decided that an Innovation Center would be built on the already successful Design and Manufacturing Clinic. Since its inception the clinic and center have implemented over 500 projects with nearly 100 clients. This was not only an administrative effort but also involved a substantial investment in the renovation of a part of the first floor of the engineering building. There are a number of major areas that include:

1. The design studio. This is the heart of the facility where students come to collaborate with other members of their teams. Several views of this are shown in Fig. 2. The studio includes computer equipment and projection equipment.
2. Adjacent to the design studio is the Emerson Climate Technologies, Product Development Lab. In this lab students can build models and small prototypes using hand tools, bench top tools, electronic equipment including sensors, transducers, power supplies and recording equipment. An overview of this lab is shown in Fig. 3.
3. In proximity to this are the team meeting rooms. These rooms are used when teams need to have more space than in the studio, or when they need to meet outside of class. They are frequently used when clients visit and the teams need to be away from the movement and noise of the studio. This is shown in Fig. 4.
4. There is a large conference room in the complex that can comfortably hold 25 people. This is the

Fig. 2. Innovation center design studio.

Fig. 3. Emerson climate technologies product development lab.

Fig. 4. Individual team meeting rooms.

main room used for formal presentations and distance communication.

5. The team projects room is the location where project hardware can be stored before, during and after assembly takes place. Frequently materials are stored in this room from one semester to another when a project starts in the one credit hour class and is finished by the same team of individuals in the next semester.
6. Adjacent to the large conference room is the office area. This houses the offices for the Administrative Assistant, Director, Coordinator and Adjunct Faculty.

3. PROJECTS

Over the past 13 years the number of projects has grown from 11 projects per year to 80. This is because of the increase in the number of students in mechanical engineering and the number of departments participating in the Innovation Center and the Design and Manufacturing Clinic. The number of students in one year has grown from 65 in 1996-97 to 350 this past academic year.

3.1 Customer feedback and continuous improvement

At the conclusion of each project the industry mentors are asked to evaluate the projects and the student performance. Over the past 6 years 76 percent of the clients/mentors have said that the results have been significant for them. Twenty three (23) percent thought the results would be moderately helpful. A major area of interest has been for the question that asks at what level the goals have been met. Twenty four (24) percent said the goals were exceeded while sixty two (62) percent said the goals had been met. Thus, 86 percent felt that the goals were either exceeded or attained. Thirteen percent thought that they were nearly met while one percent said that they failed to meet the goals.

3.2 First-year engineering innovation project.

As described earlier, the first-year engineering innovation class emphasizes the product realization process, teamwork and written and oral communication. The 'major project' covers about 6 weeks and most of the projects are centered on social entrepreneurship and sustainable design. One project involved the design of an assistive device for stocking shelves by an individual that was paralyzed on one side of his body. Another concentrated on the design of a cabin that could come close to being energy independent. Because of the total number of first-year students there are about 7 sections of the class with about 24 students in each class. This means that there would be 6 teams with four or five students on each team. One class that had a successful project was a section that designed a device to move a flat plate that would remain nearly perpendicular with the direction of the light from the sun. This flat plate could be considered a photovoltaic panel although this was not included with the apparatus. Examples from two successful teams are shown in Fig. 5.

These designs typically incorporated a device that was powered by the transfer of a mass from one point to another by means of gravity. This motion in turn produced motion of the mechanism that moves the solar panel. One device used a suspended mass with a controlled rate of decent and the other used a bucket of sand that was used to drain into a 'water wheel' that rotated a shaft and produced linear motion to a cable.

At the conclusion of these projects the multidisciplinary student teams write a report that described the design process, the unique features

Fig. 5. Solar plate panels from engineering innovation, EGR 103.

of the device and the principles of science and engineering that were used to achieve their goals.

3.3 Multidisciplinary design I, EGR 431L, solar thermal panel

The one credit hour junior/senior level design class, Multidisciplinary Design I, introduces the product realization process in detail and requires that student teams identify needs and specifications, develop conceptual and embodiment designs, conduct a decision analysis and perform feasibility analyses and testing. If these designs show significant potential they are carried over to the 3 credit hour class, EGR 432L. In recent semesters about forty percent have been related to sustainability and renewable energy. This has included wind turbine location, solar thermal for heating water, photovoltaics and the implementation of ground source heat pumps.

An entrepreneur has sponsored a project to design solar thermal panels to heat water for home use. These panels could be a part of a wall panel or could be installed on a roof. One criteria is that it should be easily transportable so that it could be sold at a hardware store and installed by a semi-skilled homeowner. A sketch of this device is shown in Fig. 6. The pump could be powered by normal electricity from the grid but the student team [6] decided to use of photovoltaic panel. In this design, the water would move through the panel, be heated by the sun and drain into a tank similar to a hot-water heater. This tank would become a heat exchanger in which the primary flow would be from the solar thermal panel and the secondary coil would transport the normal household incoming water from approximately 55 degrees F to a higher temperature. This water would be introduced to the hot water heater at a temperature nearly that of the normal hot water tank. Thus, this would reduce energy consumption because of the reduced need from the utility grid.

The test arrangement is shown in Fig.7. All of the elements of the system are shown in the figure including the photovoltaic and the solar panel. The system has been proven to be feasible in the lab but now we are waiting for a few days of sunshine to test the entire system.

3.4 Multidisciplinary design I, EGR 431L (continued), geothermal aquifer

Another EGR 431L project was sponsored by a real estate entrepreneur working with numerous architects to revitalize downtown Dayton. There are 10 buildings under consideration for renovation, eight of which are within a two block area of a large open lot and a park. This block is approximately 2000 feet from the banks of the Miami River. Since the city sits on the top of this aquifer the water level in the aquifer is approximately the same as that of the river. Thus, one only needs to drill down a 20 feet to reach the water level of the aquifer. The aquifer location is shown in Fig. 8.

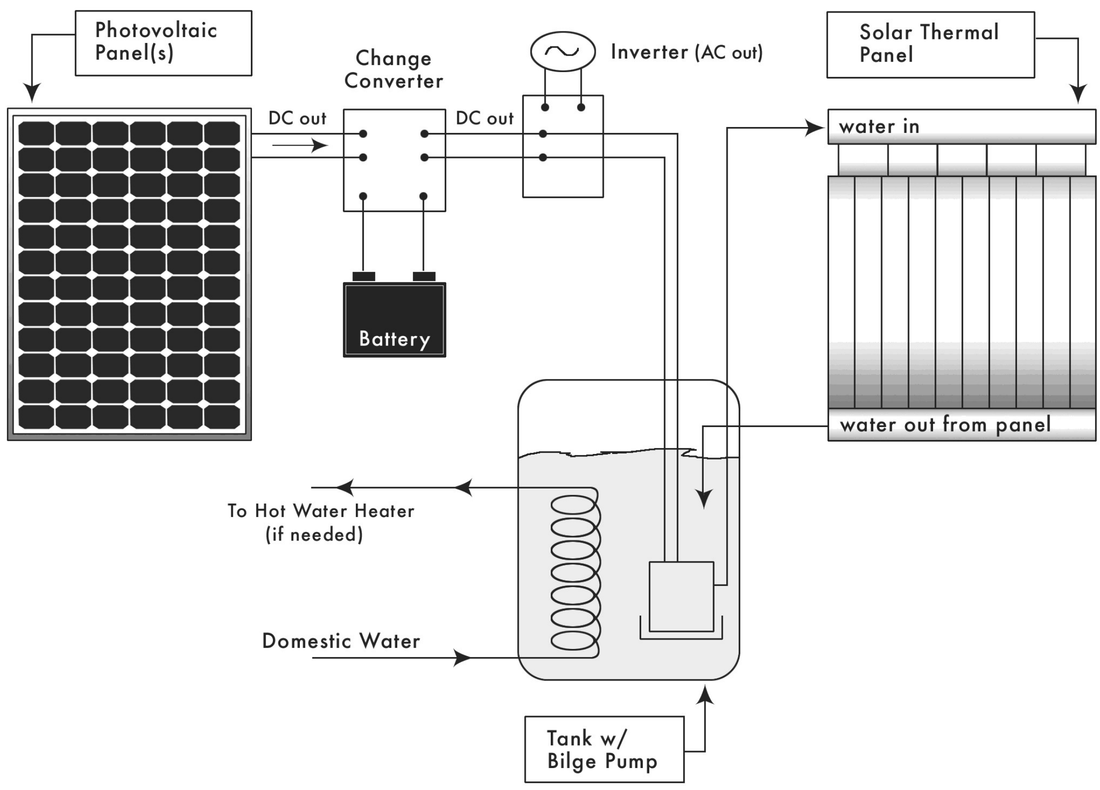

Fig. 6. Schematic diagram of a solar thermal system.

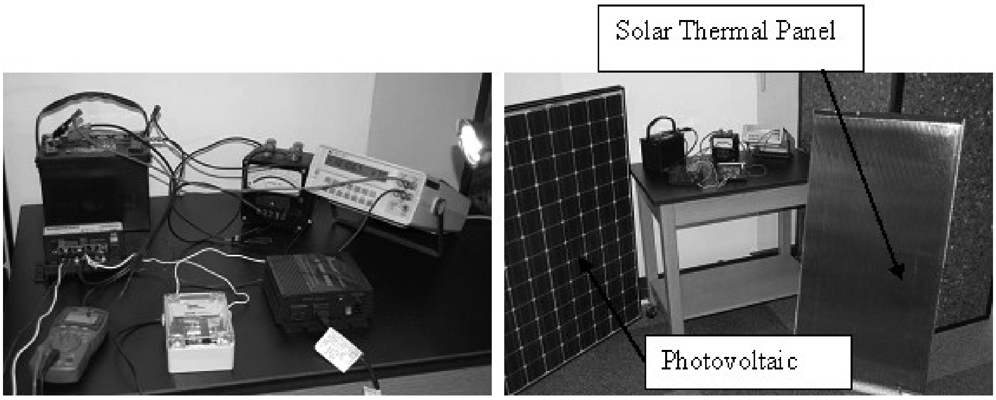

Fig. 7. Components of the thermal solar—photovaltaic system in the lab.

The developer approached the Innovation Center with the idea of using the water supply from the aquifer to provide a constant flow of water to a plate style heat exchanger. This flow of water from the aquifer is defined as the primary flow. The secondary flow is the flow that is heated or cooled in the heat exchanger and is the supply to the heat pumps. The primary side water cannot be used for this because of the high acid content of the flow water. The student team developed a system similar to that shown in the schematic diagram of Fig. 9 [7].

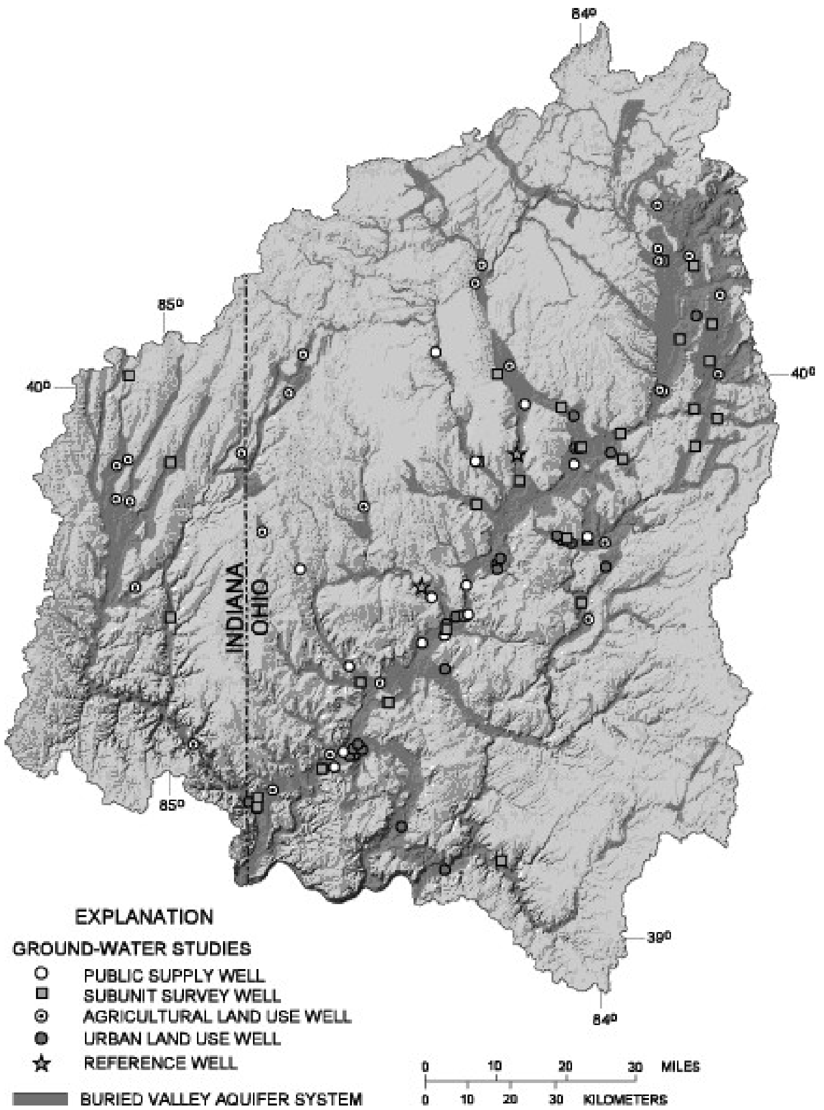

Fig. 8. Southeast Ohio aquifer [8].

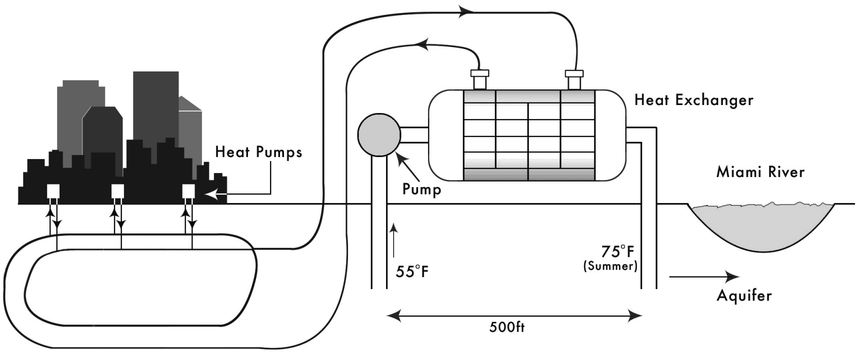

Fig. 9. Schematic for the geothermal source for heat pumps.

Since this project was initiated in the one credit hour course the student team developed conceptual designs and moved to the embodiment design phase. The team has been communicating with many constituencies within the city to do research and make estimates regarding the cost for such a system. It is estimated that it will require 4 wells to be drilled, three of which will be used at any one time. The wells plus the cost of the pumps will range from $100,000 to $200,000 for each system. Based on an earlier venture of this type with a condominium complex it was found that water must be returned to the aquifer at a point greater than 100 feet or the inlet ground water will be compromised in temperature. It is estimated that for this venture the water could and should be returned 500 feet from the inlet. This project will carry on to the fall term in the 3 credit hour class (EGR 432L) at which time the size and cost of the flat plate heat exchangers will be determined.

3.5 Multidisciplinary design II, EGR 432L, Industrial energy assessment

A major corporation requested that a student team evaluate the energy conservation and sustainability aspects of one of its major manufacturing facilities. The managers within the company realized that improvements needed to be made and asked that the team evaluate their practices and make recommendations for an approach to address more efficient energy practices. The student team [9] addressed this over two semesters and developed the following:

1. Researched and evaluated tools for environmental management systems (EMS) and made recommendations for packages to use.
2. The team made detailed recommendations within their final report that evaluated environmental policy. This included an evaluation of recent policies of the new national political administration. The team addressed energy policies, carbon trading markets, tax credits, and renewable energy certificates.
3. The team evaluated energy assessment organizations and made recommendations based on the needs of the company and their criteria. A great deal of assistance was provided by the head of the Industrial Assessment Center at the University of Dayton.

3.6 Multidisciplinary design II, EGR 432L, transportable solar PV system.

A major supplier of efficient energy systems requested that a student team design a transportable photovoltaic system. This system could be moved to remote sites that may have experienced power outages or in a region that does not have existing power from the grid. This involved the design of a trailer and a grouping of photovoltaic panels, electronics and batteries that could be transported to remote sites. This was a two semester project culminating in a system that can be put on a trailer. The first semester (EGR 432) evaluated conceptual designs and the resulting embodiment design. The second semester addressed the final design and building the electrical and structural systems. The system was assembled in the lab the results of which were compared to the design criteria. The team researched [10] the needs for such sites, like the power required to recharge tools, the power to operate machines and to provide power to appliances. Figure 10 shows the components that were assembled and developed in the lab prior to installation on the structural frame.

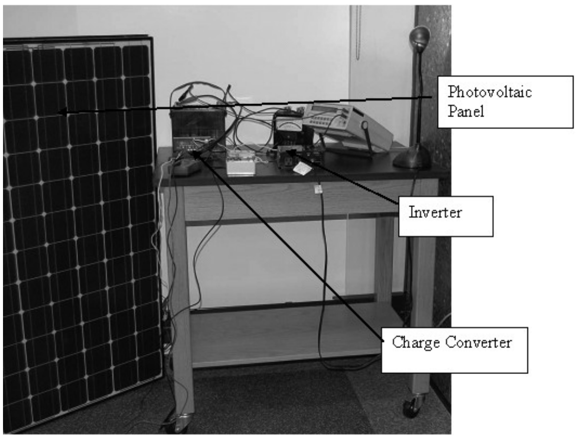

Fig. 10. Components for a transportable photovoltaic system

4. RESOURCES

The key ingredients for all of the project teams include the resources available. Some of these resources are:

- Availability to faculty mentors, some of whom are a part of the Industrial Assessment Center that provides no-charge energy and waste reduction assistance. These faculty members also have a vision that has sought and expanded our programs to include an MS in Renewable and Clean Energy.
- A design studio, team meeting rooms and a large conference room for teams to meet to discuss and brainstorm ideas.
- A prototyping lab that includes facilities for building models and developing experiments. From a sustainability standpoint this is equipped with photovoltaic panels, solar collectors, and the electronics necessary to build energy efficient systems. We have been fortunate to have clients/sponsors that have contributed to the special equipment required for designing renewable energy systems. These have formed the building blocks for students of all levels to explore alternatives for renewable energy.
- Industry mentors that are experienced in all forms of renewable energy and sustainability initiatives.
- As the result of having a World-Class Industrial Assessment Center there is a high level of interest in energy systems not only among the faculty but also among the student body. Courses in design for the environment, energy-efficient manufacturing and design thermal systems prepare the students for these capstone level projects.

5. STUDENT INTEREST—RESULTS

Students are matched to the projects by having the students prioritize the projects based on the project description. This is supplemented with a survey of their technical and professional interests. A summary of the survey from last semester is shown in Table 1.

This type of interest was examined at the MUDD VII Workshop. The data in this table is organized by topic according to gender and discipline. MEE is mechanical engineering and ECE is electrical and computer engineering. There were 12 women, 63 men with MEE majors and 14 men in ECE. Women had their highest interest in sustainability, leadership and management. Mechanical engineering men had the highest interest in mechanical design, leadership and sustainability in that order. Electrical and computer engineering men (no women in ECE capstone projects last semester) preferred the more technical area of electrical systems, then leadership and energy systems. It is interesting to note that mechanicals were the only majors to place sustainability high. Why? Because a major focus in mechanical is on renewable energy and sustainability. This has been shown in enrollment figures. Also, women tend (in this major) to gravitate to the environmental/sustainability area for minors in their field of study.

6. LESSONS LEARNED AND RECOMMENDATIONS

1. The EGR 103 class was implemented for the first time in the 2008–2009 academic year. Several projects were attempted for the major project. It was found that those involving sustainability we the most liked and easiest to implement. Photovoltaics, thermal solar and other projects of this neture were easy to implement because of the simplicity of the systems. They are at a level that first year students can understand.
2. The sequence of the smaller project followed by a larger project was a plus.
3. The two semester sequence of MEE 431L and 432L were good for sustainability projects. Research and conceptualization could be implemented in the first class followed by final design, build and test in the second project.
4. Sustainability projects are popular with small business (photovoltaics, solar thermal, etc) while larger companies are interested in energy savings. Faculty are also a good source of projects. Nearly 40 percent of our projects are related to sustainability.
5. Try not to implement projects that are submitted at the last minute. These tend to be poorly defined and frustrating to the students.

Table 1. Student interest survey

Topic of Interest	MEE—Female	MEE—Male	ECE—Male
Fluids/Heat Transfer	4.3	5.4	2.6
Thermodynamics	4.8	5.5	3.3
Energy Systems	6.3	6.5	5.3
Environmental/Sustainability	8.3	6.6	4.2
Mechanical Design	7	7.3	4.1
Electrical Systems	2.6	3.6	8.9
Leadership	7.3	6.9	6.2
Management	7	6.3	4.8

6. Having the resources, equipment and mentors, has provided the support needed for successful project. Faculty in the field are good during brainstorming sessions. The equipment is needed for feasibility testing and analysis. If it were ordered during a project there is a high probability it would not be available for a long enough period to help the student teams.
7. It is recommended that we continue to address the interest in mechanical and electrical engineering to determine the level of interest in sustainability so that this can be marketed to the potential clients. In addition this should be reported at future MUDD Workshops.

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