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Modernized Teaching Methods for Solar Energy Projects

Prof. William Hutzel, Purdue University, West Lafayette

William (Bill) Hutzel is a Professor of Mechanical Engineering Technology at Purdue University in West Lafayette, IN. He teaches and conducts research on high performance buildings.

Dr. Jan T. Lugowski, Purdue University, West Lafayette

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Abstract

Employers want college graduates who have technical knowledge, but are also inquisitive and have good technical judgement. Achieving these skills requires modernized teaching methods that engage students in open-ended assignments where students encounter uncertain data that forces them to question the results of technical computations. These are some of the key reasons for a large energy transformation project underway in an Engineering Technology program. The transformation project crosses traditional course boundaries by highlighting similar energy conversion processes that occur in many different disciplines. As one example of the progress so far, undergraduate students in a thermodynamics course assisted with the installation of an 8 kW solar photovoltaic array on the roof of a campus building. More importantly, a web-based graphic interface was created so that future students access live solar energy data from their laptop or smart phone. A preliminary evaluation of the educational impact shows that students not only gained an appreciation for solar energy, but they had confidence in their ability to develop innovative ideas for improving solar panel performance.

Energy Transformation

Engineers should have technical expertise, but also the ability to work with new and "uncertain" information, collaborate, and solve open-ended problems [1]. In order to make it a reality, an institutional transformation of university teaching is essential [2] – [5]. That is the motivation behind an energy transformation project underway in an undergraduate Engineering Technology program. The goal is a new energy systems curriculum that crosses traditional course boundaries to teach students that similar energy conversion processes occur in many different disciplines. Figure 1 shows that the courses appear in a progression, from introductory first year courses to career-related courses taken by graduating seniors (4th year). The unifying and integrating theme, whether 1st year materials or 3rd year thermodynamics, is basic energy conversion processes, which could be showing the conversion from electricity to work in an electric motor or the conversion from heat to work in a turbine.

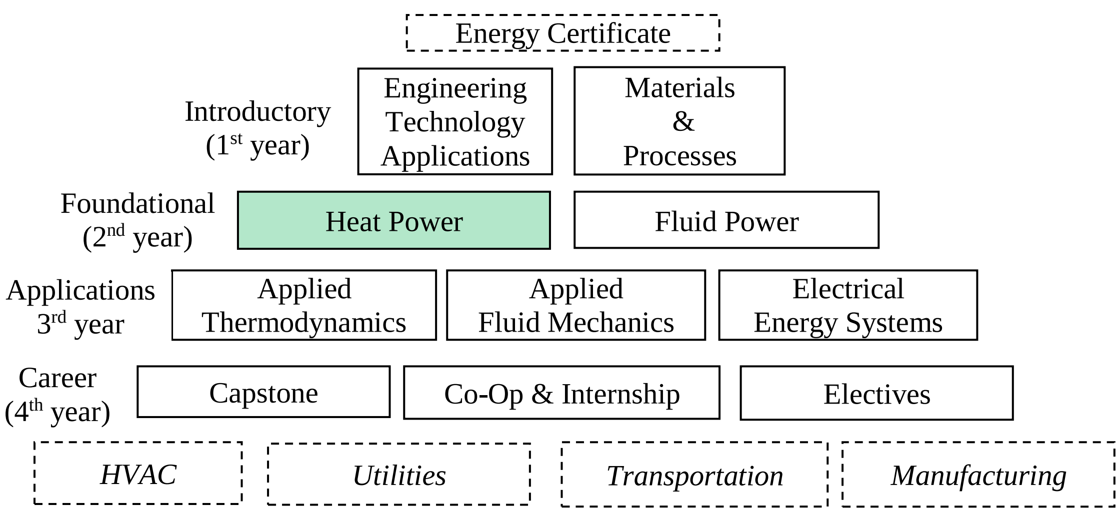


Figure 1. Energy conversion modules are being integrated into the 4-year plan of study.

Another aspect of Figure 1 is an effort to maintain continuity between the energy conversion modules in different courses by creating an Energy Certificate. This is intended as an entry-level credential that could help launch a student's professional career in one of the targeted industries. Students will earn a badge for successfully completing each course-based energy conversion module. By completing a number of badges, plus an energy-related professional experience in HVAC, Utilities, Transportation, or Manufacturing, students can also earn an Energy Certificate that will appear on their transcript.

The green highlighted box in Figure 1 identifies a sophomore-level lab-based thermodynamics course that has been re-designed so that students work in small groups on open-ended projects that span multiple weeks and multiple technical topics. The goal is to give students opportunities to explore and work on their own, helping them gain a deeper understanding of the technical material. Beyond basic thermodynamics, students are getting experience with real world equipment, data acquisition, and interpreting unexpected results. This paper describes the implementation of an 8 kW solar photovoltaic array and a web-based graphic interface that allows students to access and interpret solar energy data as an open-ended homework assignment. The assignment supports Energy Transformation by highlighting the basic energy conversion process that transforms sunlight into useable electricity.

Modernized Teaching Methods

Achieving skills expected from a college graduate [1] requires modernized teaching methods that go beyond a traditional classroom [5]. Engaging students in open-ended assignments will ultimately require students to apply their technical skills in innovative ways. One important aspect is that the practical implications of the technical assignment must be readily apparent.

Learners have higher levels of motivation if they know *"Why"* they need to learn the new information in the first place. That seems obvious, but thermodynamics students frequently cannot explain the 1st Law of Thermodynamics or how it is used. To remedy this, a photovoltaic system [6] – [7] was built to train students in real-life applications of energy systems.

The 8 kW solar photovoltaic array that is shown in Figure 2 was designed and constructed to provide students with a clear context from which to learn and apply the fundamental principles of energy. This is a timely topic as the solar energy industry in enjoying rapid growth due decreasing costs of equipment and installations. In some cases the cost of solar energy has become competitive with more traditional forms of energy. [8] Students seem to recognize this because in a student survey more than 1/3 of the students agreed with the statement "I expect to use solar energy during my career."

Figure 2.   8 kW solar photovoltaic array constructed in 2017.

Figure 3 is a simplified schematic that illustrates the basic electrical wiring from the individual panels to the connection point inside the building. The array consists of 28 panels rated at 285 watts apiece.   The 28 panels are subdivided into two strings of 14 panels. The 14 panels are wired in the series/parallel configuration shown in Figure 3 to stay below the current and voltage limits of the disconnects and the inverter. The inverter provides its own DC and AC disconnects and then the wire is routed to a distribution panel within the building.

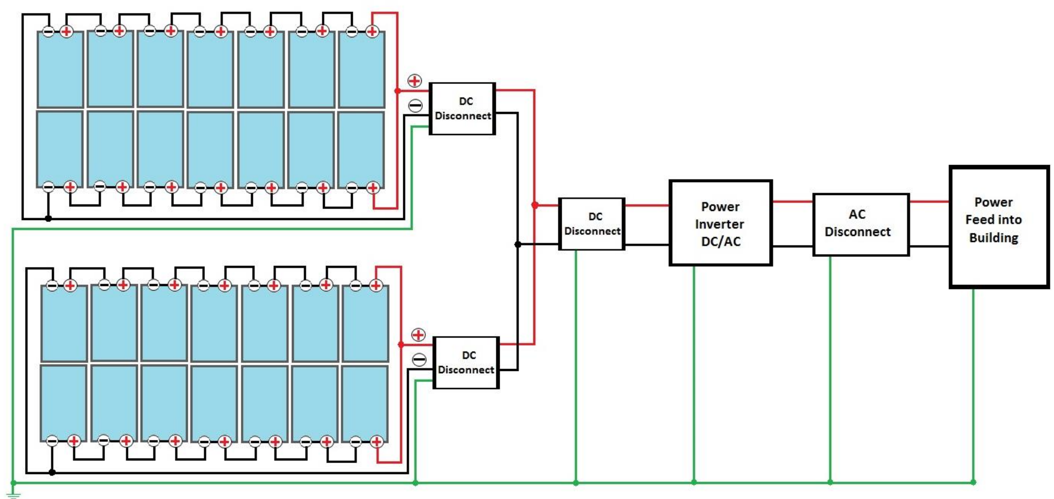


Figure 3. Schematic of solar photovoltaic array.

The basic construction of the photovoltaic array was relatively easy.   A pre-fabricated truss system was mounted to a steel frame on the roof of the building.   The panels were then attached to the truss.   As shown in Figure 4, much of this work was accomplished by students who volunteered to assist. This do-it-yourself installation was a great learning experience but it did take a substantial amount of time. The 8 kW array was completed over one month in April of 2017. Weather-related delays were a regular occurrence that added to the project schedule.

Figure 4. Installation of solar photovoltaic array by students, faculty, and staff.

Safety was a key aspect of this project from inception to design to completion. Article 690 of the National Electrical Code [9] provided detailed guidance for grounding, wire sizing, and other topics. A safety officer was present to monitor for physical safety of personnel during construction. The Physical Facilities staff of the university provided additional assistance during design and also inspections prior to energizing the solar photovoltaic array.

The big pay-off occurred in May of 2017 when the solar photovoltaic array was energized for the first time. It has performed flawlessly ever since and provides approximately 9,000 kWh of renewable electricity annually, which is enough to provide all of the electricity for a small home. The value of the electricity is approximately $1,000 annually based on residential rates. These contributions seem substantial, but it is almost inconsequential in the context of the large commercial building where the solar photovoltaic array is actually located. The 8 kW solar photovoltaic array offsets approximately 0.5% of the large building’s annual electricity use.

Web-Based Interface

Another aspect of modernized teaching methods is allowing students to learn at their own pace while working on open ended assignments. For an instructor that means giving students time for discovery and exploration. This conflicts with the highly structured nature of traditional homework assignments that are taken from problems at the end of a textbook chapter. Figure 5 is the web-based interface to the solar photovoltaic array that is one opportunity for improvement. The graphic shows the DC volts, amps, and watts being produced by the solar array. It also shows the AC volts, amps, and watts being delivered to the building. The "Current OA Conditions" in the lower right of Figure 5 is particularly important because it gives users insight into the temperature (°F), relative humidity (%), and solar intensity in watts/m^2.

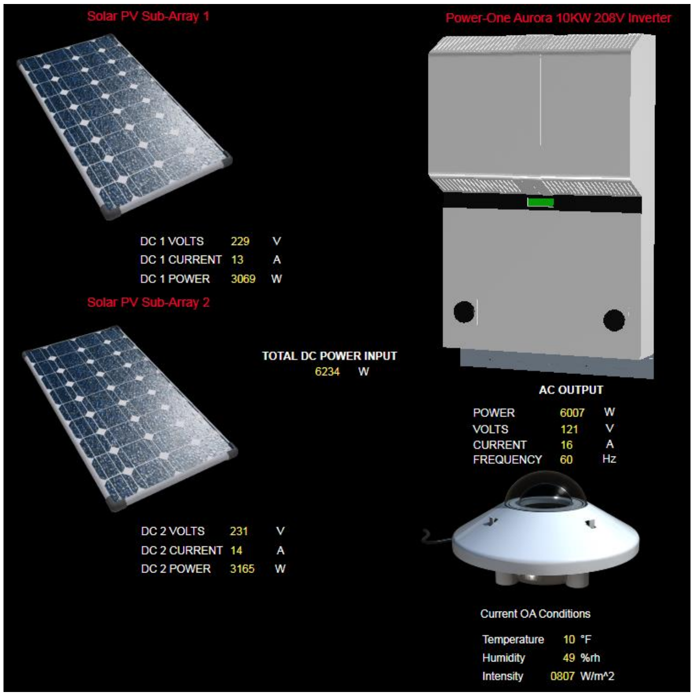


Figure 5. Web interface to solar photovoltaic array.

Even though the solar energy equipment is physically located on a remote roof-top, the web-based interface removes this potential bottleneck. Large numbers of students can individually access solar energy data from this system in real time, and at their own pace, to complete a variety of energy-based homework assignments. Students navigate to a website and use a password to login to this system. The live data is far better than a textbook problem because, like it or not, the data has uncertainties due to changing climatic conditions. Students learn to question the raw data and repeat the computations when a questionable result is found. It is helpful for students to encounter the web-based systems and questionable data that they will surely encounter during their professional career.

Solar Photovoltaic Analysis

Students compute a number of homework assignments using data from the 8 kW solar photovoltaic array. One important computation introduces the concept of energy conversion by showing how well solar photovoltaic array converts sunlight into electricity. The efficiency of a photovoltaic array is a strong determining factor of cost and economic payback, but it is tricky to measure accurately [10]. Equation 1 shows the basic computation. The numerator is the instantaneous AC or DC power output of the solar photovoltaic array in watts, which is recorded directly from the web-based graphic interface. The denominator is the amount of sunlight striking the array in that moment of time, also measured in watts.

$$\eta = \frac{power\ produced}{power\ available} = \frac{electricity}{sunlight} \qquad (1)$$

Equation 2 shows the sunlight computation from the denominator of Equation 1 in more detail. Sunlight is determined from the instantaneous solar intensity reading in $\frac{watts}{m^2}$ taken from the web-based graphic interface. Students compute the total solar panel area by multiplying the number of solar panels by the length (m) and width (m) of one solar photovoltaic panel.

$$sunight = solar\ intensity\ \left(\frac{watts}{m^2}\right) x\ \#\ of\ solar\ panels\ x\ length\ (m)\ x\ width\ (m) \quad (2)$$

The red dashed box in Figure 3 is a snapshot of the solar panel specifications that shows where the length and width dimensions of one solar panel are found. The green dashed box in Figure 3 shows the rated conversion efficiency of the solar photovoltaic panels that students uses as a basis of comparison for their energy conversion efficiency computation.

Students who make this energy conversion computation as part of a homework assignment generally find that the energy conversion efficiency is close to the rated efficiency of 17.34%. Students are encouraged not to show too many significant digits, maybe 3 or 4 at the most, because this computation has significant uncertainty due to weather fluctuations and sensor error.

ELECTRICAL DATA (NOMINAL)

The rated power may only vary by -0/+3% and all other electrical parameters by ± 5%

Model Number	OPT275-60-4-100	OPT280-60-4-100	OPT285-60-4-100
Power Classification (Pmax)	275 W	280 W	285 W
Module Efficiency (%)	16.73%	17.04%	17.34%
Voltage at Max. Power Point (Vmp)	31.7 V	31.8 V	31.9 V
Current at Max. Power Point (Imp)	8.68 A	8.81 A	8.93 A
Open Circuit Voltage (Voc)	38.7 V	38.8 V	38.9 V
Short Circuit Current (Isc)	9.43 A	9.57 A	9.71 A

The electrical data apply to standard test conditions (STC): Irradiance of 1000 W/m² with AM 1.5 spectra at 25°C.

CHARACTERISTIC DATA

Type of Solar Cell	High-efficiency ARTisun Select cells, 3 and 5 busbar options available
Frame	Anodized or powder coated aluminum alloy
Glass	Tempered (low-iron), anti-reflective coating
Junction Box	NEMA IP67 rated; 3 internal bypass diodes
Cable & Connectors	12 AWG (4 mm²) PV Wire with multiple connector options available; cable length 1000 mm

MECHANICALS

Cells / Module	60 (6 x 10)
Module Dimensions	1660 x 990 mm (65.35 x 38.98 in.)
Module Thickness (Depth)	35 mm (1.37 in.)
Approximate Weight	17.9 +/- 0.25 kg. (39.5 +/- 0.5 lb.)

Figure 3. Solar panel specifications.

An example of the solar photovoltaic conversion efficiency computation, using data from Figure 3, is shown in equation 3. The results shows a 16.8 % conversion efficiency, which is fairly typical for this system.

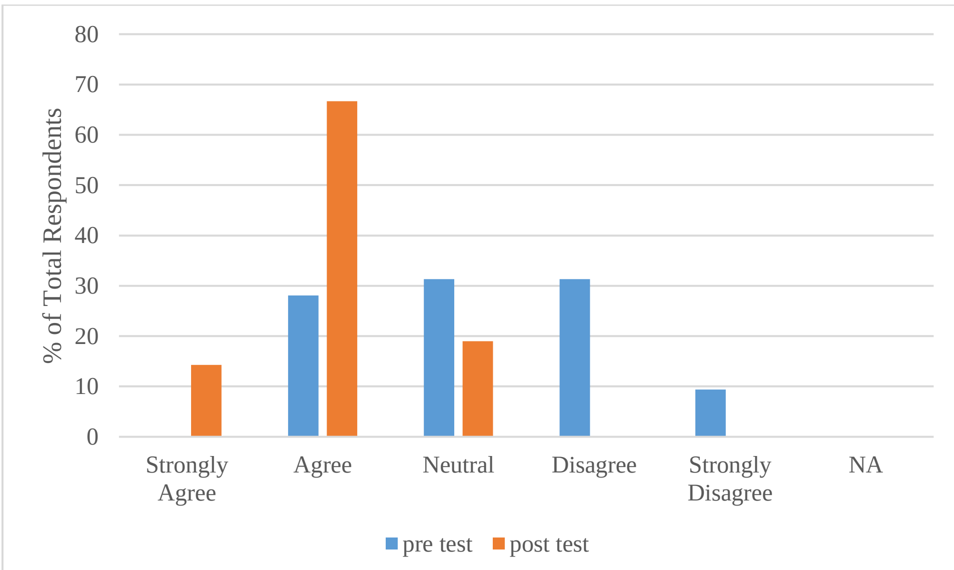
$$\eta = \frac{power\ produced}{power\ available} = \frac{electricity}{sunlight} = \frac{6234\ watts\ DC}{807\ \frac{watts}{m^2}\ x\ 28\ panels\ x\ 1.66\ m\ x\ 0.99\ m} = 0.168\ or\ 16.8\% \quad (3)$$

Evaluation of Student Learning

A pre and post survey using Likert scale questions was used to assess student perceptions of solar energy and web-based data acquisition. The surveys were not specific to the one energy conversion assignment described in this paper, but were conducted before and after a two week module that included data collection and computations for both solar thermal and solar photovoltaic equipment.

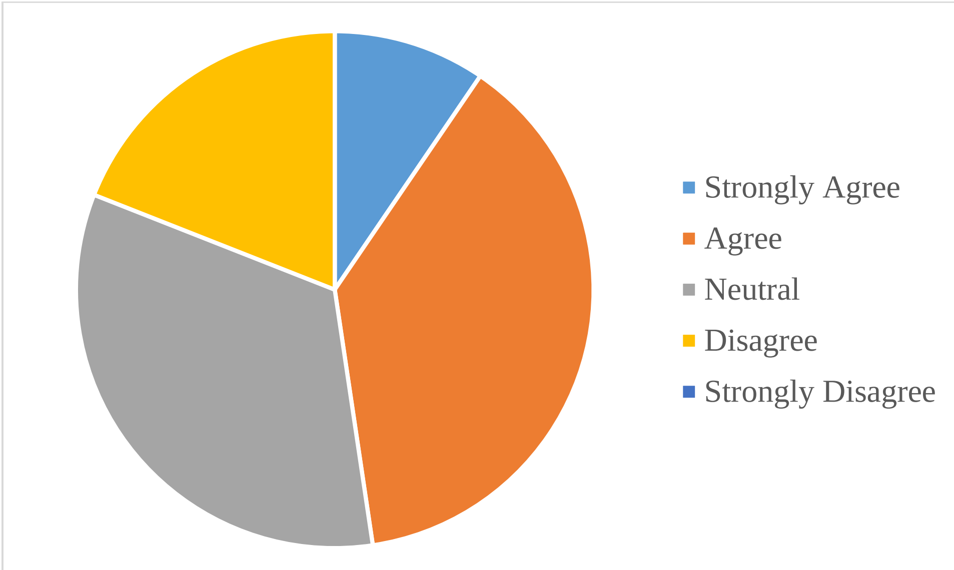
The question summarized in Graph 1 is in response to a Likert Scale pre and post prompt "I am knowledgeable about solar energy". The results are striking. Less than 30% of students either "strongly agreed" or "agreed" that they were knowledgeable about solar energy before conducting the on-line experiments. That number increased to 85% afterward. This survey point, along with assessments of student learning based on assignments, confirms that students achieved some level of mastery of this technical topic.

Graph 1. Responses to "I am knowledgeable about solar energy".



Graph 2 is another result of the survey that assessed whether students gained any insight to improving the performance of solar panels. Nearly 1/2 of the respondents either "strongly agreed" or "agreed" with the assertion "I have ideas on how to improve the performance of solar panels". While this single response is not definitive, it does suggest that students not only achieved some level of mastery of the technical topic, but were also comfortable and confident in applying their technical knowledge to achieve further performance improvements.

Graph 2. Responses to “I have ideas on how to improve the performance of solar panels”.



Conclusions

This paper describes modernized teaching methods being used to improve student learning in an undergraduate thermodynamics course. Students were allowed to work collaboratively and at their own pace by accessing web-based data from a solar photovoltaic array that was constructed on the roof of the building. A homework assignment that illustrates energy conversion from sunlight to electricity is just one example of the open-ended instruction that has been created. A preliminary evaluation of the educational impact shows that students not only gained an appreciation for solar energy, but they had confidence in their ability to develop innovative ideas for improving solar panel performance. Students also enjoyed working with real data outside the confines of a traditional laboratory.

Acknowledgements

This design and construction of the 8 kW solar photovoltaic array could not have been accomplished without Physical Facilities staff who provided technical support during design, construction, and commissioning of this system.

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