Remotely Accessed Photovoltaic Power Project

by

William J. Hutzel
Mechanical Engineering Technology Department
Purdue University
West Lafayette, IN 47906

and

William M. Healy
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899 USA

Reprinted from Journal of Engineering Technology, Vol. 23, No. 1, Spring 2006

NOTE: **This paper is a contribution of the National Institute of Standards and Technology and is not subject to copyright.**

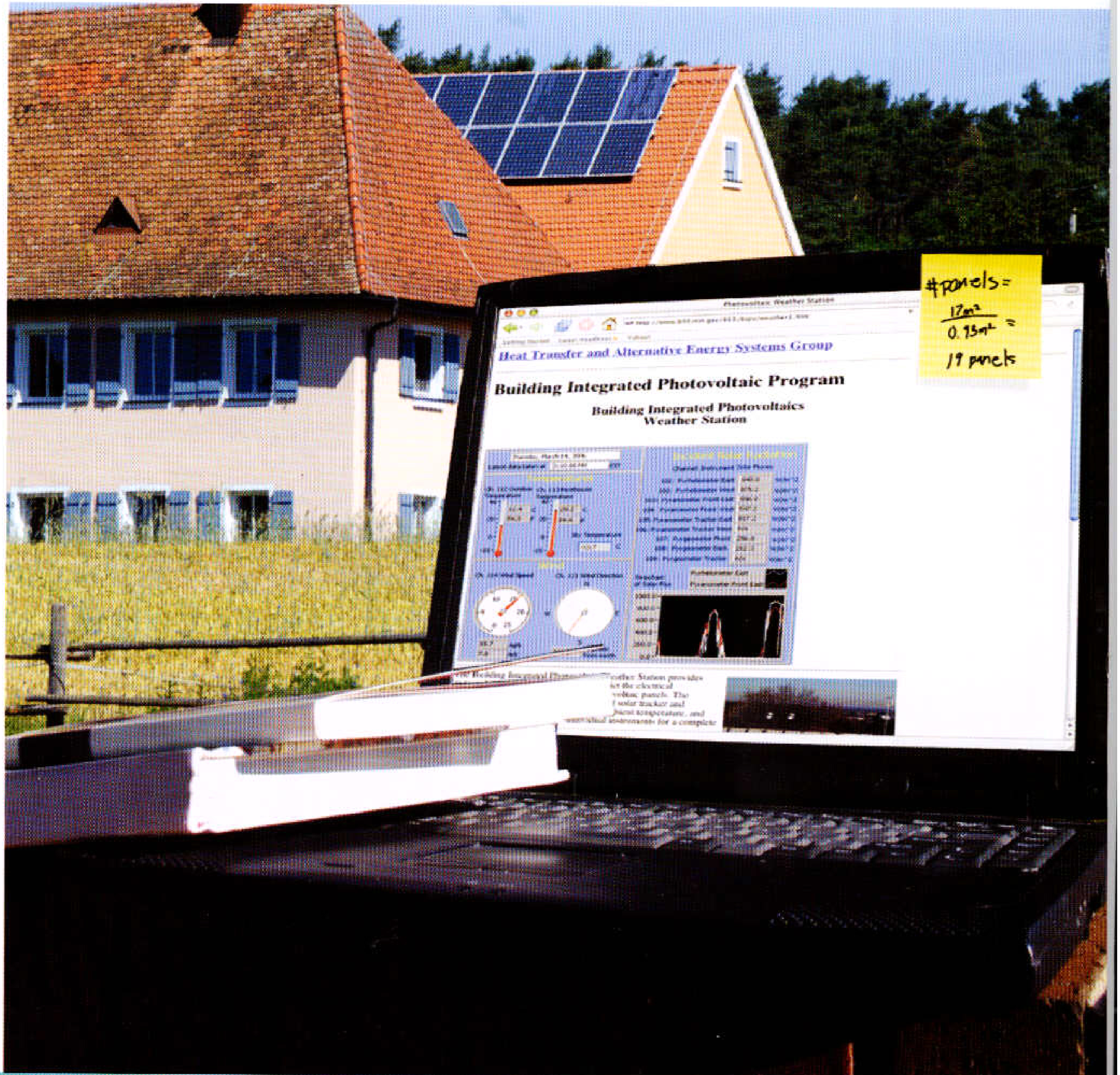
NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Journal of

ENGINEERING TECHNOLOGY

Spring 2006

A Publication of the Engineering Technology Division • American Society for Engineering Education



ETD

Remotely Accessed Photovoltaic Power Project

William J. Hutzel and William M. Healy

Abstract

Sharp increases in the price of fossil fuels have helped generate new interest in solar and other alternative energy technologies. Despite its resurgence, solar energy receives sporadic coverage in undergraduate programs. Part of the problem is the cost of constructing and maintaining solar energy equipment. This paper describes a laboratory experiment that uses freely available online resources for estimating the number of photovoltaic panels needed to provide supplemental power for a typical residence. Students use the Internet to 1) estimate residential power usage, 2) gather real solar energy data from the National Institute of Standards and Technology, and 3) look up specifications for photovoltaic panels. An evaluation of student achievement and a student survey suggest that this project is a reasonable replacement for a traditional in-person laboratory, particularly for undergraduate programs that lack access to real solar energy equipment.

Increasing Importance of Alternative Energy

It is not surprising that an article in the *Journal of Engineering Technology* identified "alternative energy" as one of the key disciplines that will influence the future careers of engineering technology students.[1] Solar energy is one of several promising technologies with the potential to reduce the demand for fossil fuels. It is abundant, renewable, and non-polluting. Due to sharp increases in the price of fossil fuels, the Energy Information Administration of the U.S. Department of Energy is projecting a 4% increase in the demand for solar energy in 2006.

Despite the promise of solar energy, it is not widely understood or deployed. Solar energy currently contributes only about 0.1% of the energy annually used in the U.S.[2] The overall cost with respect to traditional energy sources has been the major holdup. For a typical homeowner, installing a solar heating or photovoltaic system is more expensive than relying on existing energy networks. It has been suggested that a more sophisticated accounting mechanism, which would take into account energy quality, grid independence, and environmental benefits, could make solar energy more econonomically attractive.[3]

Adopting a broader view of the true cost of energy is unlikely without steady long-term support from the U.S. government. The importance of governmental sponsorship for advancing renewable energy is reflected in the sporadic coverage that solar energy receives in college classrooms. Around 1980, when financial incentives from the federal government for renewable energy were in place, solar energy courses were taught at about 150 universities in the U.S. At present, fewer than ten universities in the U.S. are regularly offering solar energy electives.[3] Not coincidentally, federal subsidies of renewable energy technologies have fallen off dramatically in the last 20 years.[4]

Solar energy has been featured in the Mechanical Engineering Technology (MET) Department at Purdue University in West Lafayette for many years. Figure 1 illustrates a 3kW photovoltaic array and a 9kW solar heating system that have been constructed on the roof of the Knoy Hall of Technology. One experiment in an undergraduate thermodynamics course computes the efficiency of the solar heating system.[5] Another related experiment has students determine the efficiency of the photovoltaic power system.[6] These solar energy experiments demonstrate energy conversion and power computations that are important in any introductory thermodynamics course, but also introduce students to one possible source of alternative energy.

Remotely Accessed Laboratories Are Becoming More Common

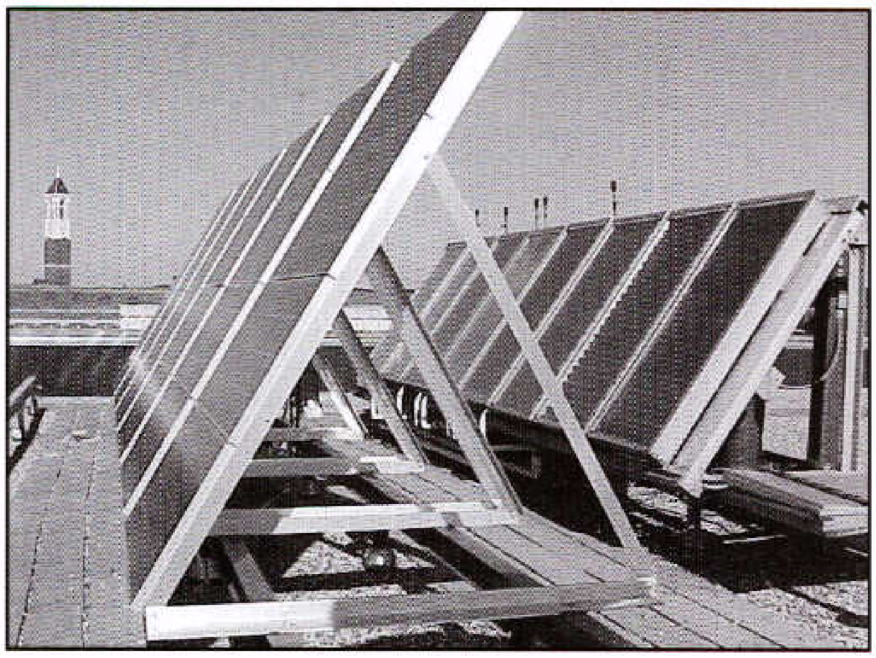


Figure 1. Photovoltaic (left) and solar heating (right) systems are used in undergraduate courses.

Figure 1 illustrates one of the drawbacks to solar energy education. Solar laboratory equipment tends to be large, cumbersome, and located in inaccessible places such as the rooftop shown here. These one-of-a-kind installations are fine for demonstrations, but are not easily adapted for hands-on use by large groups of students because there is simply not enough physical equipment. It is difficult to deliver an active learning experience while sharing one set of measurements among large numbers of students. To address the overcrowding issue, the MET Department added network-based controllers to the existing solar energy equipment. Rather than making measurements as a group, individual students access sensor data over the Internet.[7]

Despite the beneficial features of a remotely accessed laboratory, the cost can be prohibitive. Internet-based monitoring and control of the solar energy equipment in Figure 2 cost at least $20,000. Because of the expense, funding from the National Science Foundation has played a significant role in developing remotely accessed laboratories. The Division for Undergraduate Education has contributed to networked laboratories dealing with controls,[8,9] laser positioning,[10] mechatronics,[11] and dynamical systems.[12] To further speed up the deployment, NSF has also sponsored a project that expedites the development of any networked laboratory. The Web-based Educational framework for Analysis, Visualization, and Experimentation (WEAVE) project at Duke University is developing a generic platform to help other institutions develop inquiry-based remote-access modules.[13]

Since the hardware and software for remotely accessible laboratories have become common, current educational research is beginning to shift toward formal assessments of student learning. An investigation at the University of Illinois split a class of Mechanical Engineering students into two arbitrary groups. Group one completed a compressible fluid mechanics laboratory experiment using the traditional hands-on format. Group two completed the same experiment using remote access. Researchers noted that the laboratory report grades for the two groups were essentially the same. Within the remote-access group, students who completed an in-person pre-laboratory with the assistance of a teaching assistant performed slightly better than students who completed the entire project on their own.[14]

Overview of Remotely Accessed Solar Experiment

The remainder of this paper describes a practical solar energy project that illustrates how remote laboratories can be used for distance learning. Students use a variety of freely available Internet resources to estimate the number of photovoltaic panels needed to provide supplemental power for a typical residence. The project can be used by educators to begin assessing the strengths and weaknesses of Internet-based laboratory experiments—without committing financial resources to develop a remotely accessible laboratory. Students use the Internet to:

- estimate residential power usage using Web-based calculators available from most utilities
- gather solar energy data from the National Institutes of Standards and Technology (NIST)
- look up specifications for photovoltaic panels at a manufacturer's Web site.

This solar energy project uses two equations to estimate the size of a photovoltaic array located in Gaithersburg, MD. Equation 1 (at bottom of page) estimates the

Equation 1.

$$\text{total array surface area } (m^2) = \frac{\text{daily residential energy consumption (kW·h)}}{\text{daily available energy (kW·h/m}^2\text{) * panel conversion efficiency (\%)}}$$

total array surface area in square meters. Daily residential energy consumption in kW·h is divided by the daily radiant energy available for a specific location and season in kW·h/m. Equation 1 also takes into account the panel conversion efficiency (sunlight to electricity).

Equation 2 determines the number of panels to meet the needs of a particular building. The total array surface area calculated from Equation 1 is divided by the surface area of an actual panel to give a realistic estimate of the total number of panels needed.

Equation 2.

$$\text{number of panels} = \frac{\text{total array surface area (m}^2\text{)}}{\text{surface area of manufacturer's panel (m}^2\text{)}}$$

Estimating Residential Energy Consumption

The numerator of Equation 1 estimates energy usage in a typical residence. An energy audit that accounts for the kilowatt rating of typical household appliances and the number of hours the appliances are operated in a typical day can provide this value. The daily energy requirement for a typical appliance is expressed in kW·h. Adding up these requirements for all appliances (e.g., lights, computers, and TV sets) gives an estimate of the overall energy usage for a residence in kW·h.

Estimating residential energy consumption is not difficult, but can be problematic while working in a laboratory setting. A physical visit to a home or an appliance store to estimate power ratings is not always practical. Fortunately, many power utilities have online tools for surveying residential energy consumption. These Web-based tools are available so that homeowners can make informed decisions about domestic use of electricity.

An Internet search with key words like "energy calculator," "residential," and "kW·h" will identify numerous online energy calculators. Table 1 lists a few of the free and non-proprietary energy calculator Web sites sponsored by electric utilities. Commercial Web sites are named to thoroughly describe the project, but these references do not imply a recommendation by NIST.

Table 1. Utility Web sites evaluate power use.

Mid-Carolina Electric Cooperative: http://www.mcecoop.com/calculator/
New Hampshire Electric Cooperative: http://www.nhec.com/energycalculator.html
Tampa Electric Utility: http://www.tampaelectric.com/TEHMEnergySaversCalc.html

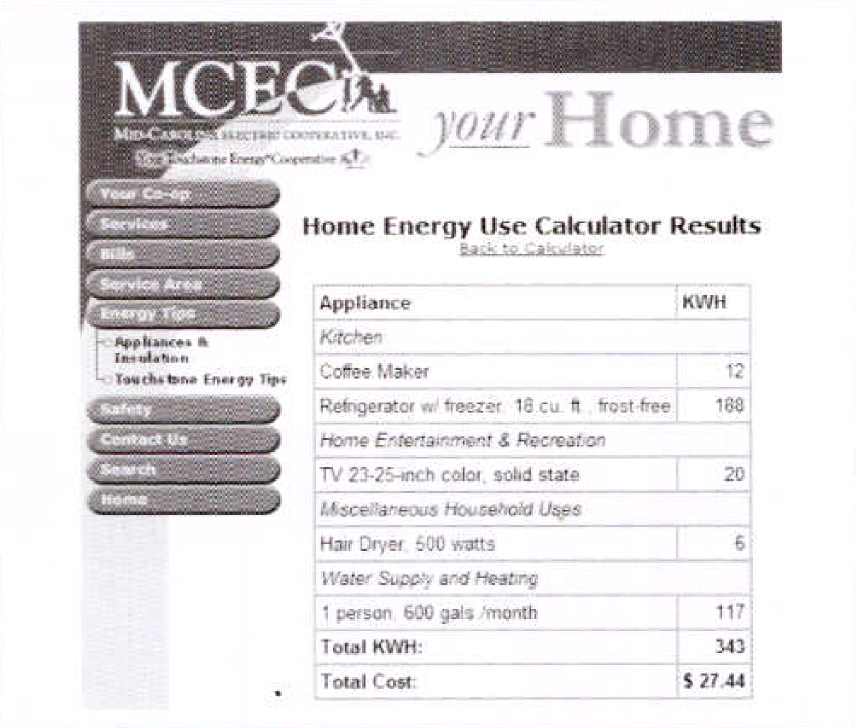


Figure 2. On-line energy calculators simplify estimates of residential power use.

As an example, Figure 2 shows the results of a power calculation using the Mid-Carolina Electric Cooperative Web site. It estimates that routine use of a coffee maker, a refrigerator, a TV set, a hair dryer, and a hot water heater will require 343 kW·h per month. Assuming 30 days per month, the daily energy consumption is 11.4 kW·h. The 11.4 kW·h value is the "daily residential energy consumption" referenced in Equation 1.

Undergraduate students must exercise engineering judgment while estimating residential energy consumption, the first step of sizing a photovoltaic array. On the first iteration, students typically include all the mechanical systems (e.g., central air conditioning) and appliances (e.g., dishwasher) found in a typical U.S. home. Subsequent calculations will quickly show that a huge number of photovoltaic panels would be needed to power this home.

To make the overall design more feasible, students should consider scaling back residential energy consumption until a photovoltaic array that fits on the south-facing (sunlit) rooftop of a typical home is achieved. A smaller roof-mounted photovoltaic array would be unobtrusive, convenient to install, and deliver about one-third of typical daily power requirements. The home would remain tied to the power grid for electrical capacity beyond what is supplied by solar energy. The computation for residential energy consumption is interesting for students because it illustrates the large energy demand by a typical U.S. residence.

Estimating Daily Energy Available

The denominator of Equation 1 estimates the daily energy available from the sun. This measurement is strongly dependent on geographic location, season, and daily weather patterns. The data could be obtained from standardized tables of solar radiation, like those published by the American Society of Heating, Refrigerating, and Air Conditioning Engineers,[15] but this remote laboratory experiment takes a more direct approach. Students access real Web-based data collected at the National Institute of Standards and Technology (NIST) in Gaithersburg, MD. The Building Integrated Photovoltaic Weather Station at NIST, shown in Figure 3, provides meteorological data used in assessing the performance of building integrated photovoltaic panels.

Figure 3. The NIST weather station.

The weather station features instruments to measure the solar flux, ambient temperature, wind speed, and wind direction on top of a building at the Gaithersburg campus. For this laboratory experiment, the important measurements are those related to the solar flux. As can be seen in Figure 3, there are several instruments that provide data regarding solar insolation. Two pyranometers are positioned on a level surface to measure the total (beam plus diffuse) solar radiation. A third pyranometer is shaded from the sun's direct rays and yields a measurement of the diffuse solar radiation. This instrument is mounted on a mechanism that tracks the sun's movement during the day to ensure that the pyranometer's sensing surface is shaded from the sun's direct rays at all times. The tracking instrument also holds two pyrheliometers that provide a measure of the direct radiation from the sun. One other instrument, a pyrgeometer, is placed on the level surface to provide measurements of long-wave radiation beyond 3 mm. Further descriptions of these instruments can be found at the Web site where the data are accessed.

Data from the instruments are gathered at five-minute intervals and are available from a Web site maintained at NIST (http://www.bfrl.nist.gov/863/bipv/weather1.htm).

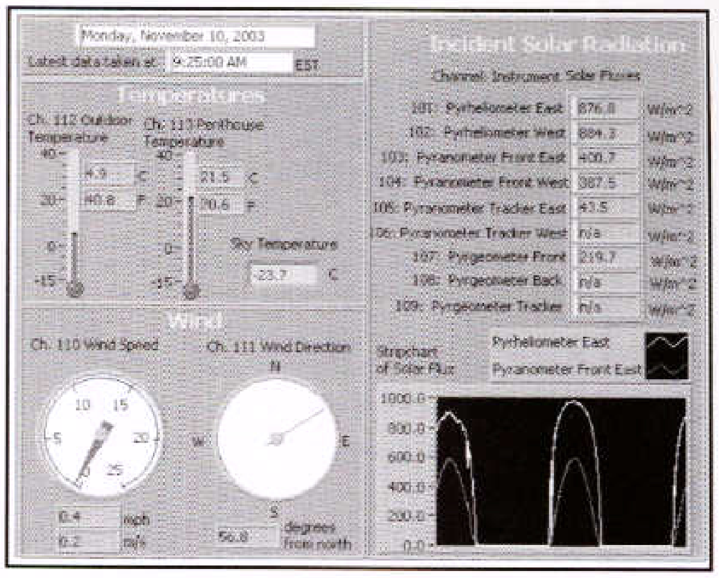


Figure 4. Weather data at the NIST Web site.

The front page of this Web site, part of which is shown in Figure 4, provides the current conditions from the instruments, displays a plot of total and beam radiation over the last 48 hours, and gives the user a form to find and download archived data.

Figure 5 (*next page*) summarizes student computations using data from a NIST pyranometer positioned on a level surface to measure the total (beam plus diffuse) solar radiation. After downloading one day's worth of data and putting it into a spreadsheet, students apply the trapezoidal rule to integrate the solar power curve. The area under the pyranometer power curve for one day represents the energy available from the sun. Figure 5 shows that on September 29, 2003 approximately 4.79 $kW \cdot h/m^2$ was available for powering a photovoltaic array. The 4.79 $kW \cdot h/m^2$ value is the "daily energy available" term referenced in Equation 1.

The pyranometer data displayed in Figure 5 also helps illustrate the challenges that confront any solar energy application. On an ideal sunny day the power curve for solar radiation is close to a symmetric "dome" shape. However, the erratic curve in Figure 5 clearly illustrates that solar energy is strongly influenced by local atmospheric conditions. Occasional cloud cover on September 29, 2003 reduced the total energy available by a significant amount.

Students need to exercise engineering judgment to select a daily energy available term ($kW \cdot h/m^2$) that considers seasonal variations in solar energy. Even on clear days, NIST data for a sunny day in June will show significant differences as compared to a sunny day in December. Students should use NIST data to compute the power integral for several combinations of summer/winter and sunny/cloudy days. This extension encourages students to consider the implications of over- or undersizing a photovoltaic system.

Computing Array Area and Panel Number

To finish sizing the photovoltaic array, students must review the specifications for a commercially available photovoltaic panel. There are numerous photovoltaic manufacturers, so this information is not difficult to find on the Web. The key specifications for this Web-based photovolta-

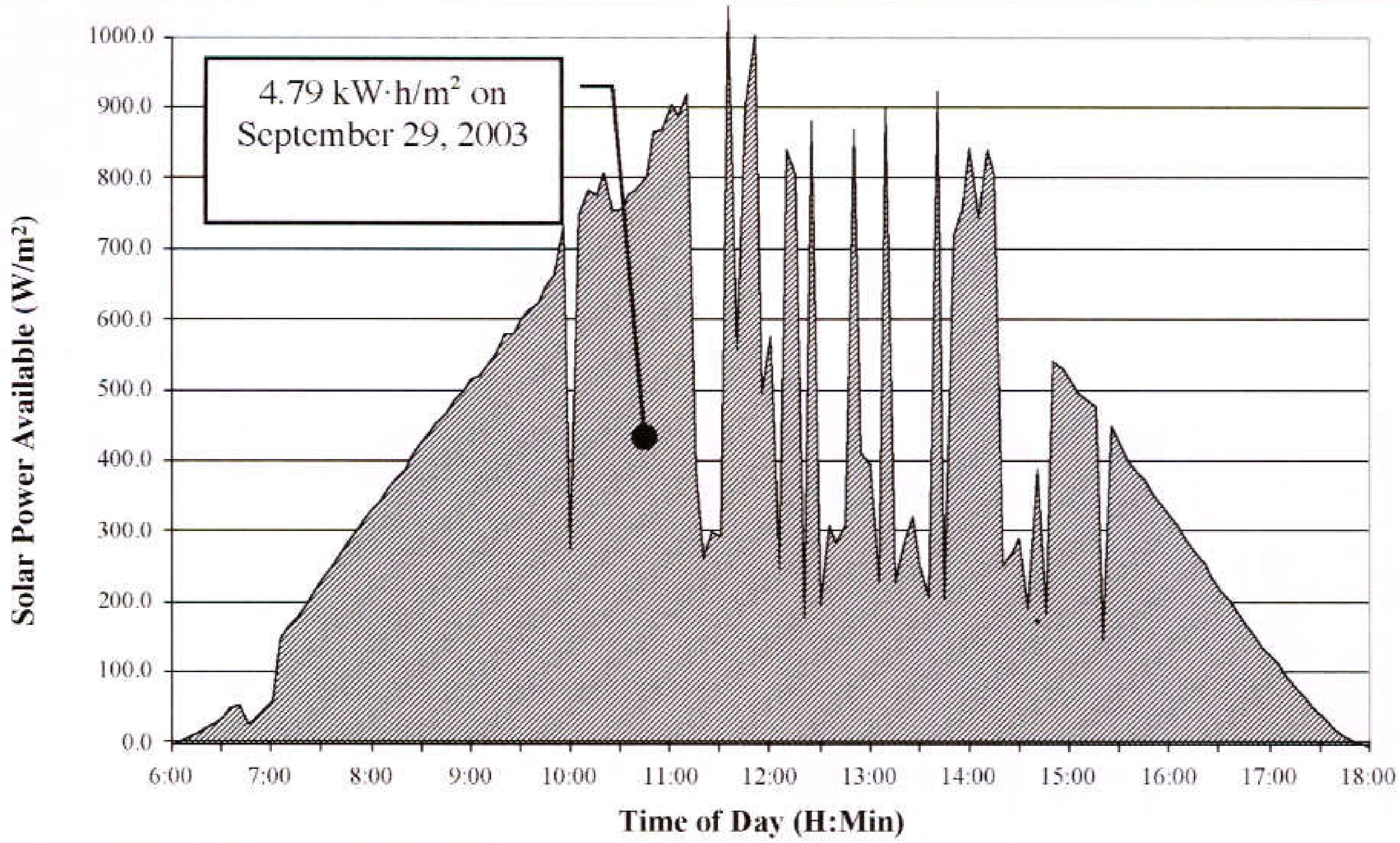


Figure 5. The area under the solar power curve represents energy available.

ic power experiment are the panel conversion efficiency (radiant to electrical power) for Equation 1 and the panel surface area (m^2) for Equation 2.

To complete the discussion, this paper uses the specifications for a Kyocera KC120 photovoltaic panel (http://www.kyocerasolar.com/pdf/specsheets/kc120_1.pdf). Commercial vendors are mentioned by name to thoroughly describe the laboratory experiment, but these references do not imply a recommendation by NIST. The Web-based data for a KC120 panel specifies at least 14% conversion efficiency and a surface area equal to 0.93 m^2.

An example using Equation 1 to compute the overall array area is shown below. The values for residential energy consumed, radiant energy available, and panel efficiency were all discussed earlier. The computation estimates that 17 m^2 of array surface area is needed.

$$\text{total array surface area } (m^2) = \frac{11.4 \text{ kW}\cdot\text{h}}{4.79 \text{ kW}\cdot\text{h/m}^2 * 0.14} = 17 \text{ m}^2$$

Example of Equation 1.

An example using Equation 2 to quantify the number of panels is shown below. Dividing 17 m^2 by the 0.93 m^2 area of one panel yields 18.3. Once students recognize that a fractional number is not possible, they will round up to a 19-panel system.

$$\text{number of panels} = \frac{17 \text{ m}^2}{0.93 \text{ m}^2} = 19 \text{ panels}$$

Example of Equation 2.

Before completing the experiment, students should consider the overall feasibility of the panel sizing computations. In this case, a 19-panel system is probably realistic in terms of the surface area that is usually available on the south-facing roof of a typical residence. In terms of installation and operation, a 20-panel system is probably better than 19. Twenty panels allow for parallel wiring combinations so the system can operate at higher voltages with lower transmissions loss. It also adds a small factor of safety to account for transmission losses in the power wiring.

Student Achievement on Remote-Access Photovoltaic Experiment

The photovoltaic project described in this paper appears in a course called Air Conditioning and Refrigeration (MET 421). Prior to 2003, students in MET 421 completed a "hands-on" version of the photovoltaic power project described in this paper. The data collection for this experiment was very structured, with very little opportunity for critical thinking about the numeric information being recorded. The energy consumption (numerator of Equation 1) was from power measurements for two electrical loads in the laboratory. The energy available (denominator of Equation 1) was computed from one day of solar pyranometer readings on the roof of the Knoy Hall of Technology, which means there was little opportunity to account for the impact of varying weather conditions.

In the Spring of 2003, the same photovoltaic project was delivered to students in a new remote-access laboratory format. Although the data reduction followed the same basic procedure, students used personal computers to help find a Web-based energy calculator, access pyra-

Table 2. Summary of student achievement on photovoltaic project.

Academic Year	Laboratory Delivery	Number of Students	Average Score on Laboratory Report (%)	Standard Deviation of Laboratory Report Scores (%)
2003	Remote Access	18	89	7
2002	Hands On	17	92	5
2001	Hands On	18	92	6

nometer data at the NIST Web site, and look up the specifications for a real photovoltaic panel. In contrast to the earlier experiment, students had much more flexibility in selecting electrical loads (e.g., different types of household equipment). Students were also encouraged to review several days' worth of NIST solar data in order to compute an "energy available" term that had a reasonable amount of cloud cover.

Table 2 compares student achievement on the remote-access laboratory by showing the average course grade on the same photovoltaic power laboratory across several academic years. The population of hands-on students (18 students in 2001 and 17 students in 2002) provides a baseline for comparing student achievement with the remote access photovoltaic power laboratory. This comparison is reasonable because of strong similarities in the course from one year to the next. The same instructor has taught the solar energy material for more than five years and uses a standardized grading rubric for evaluating laboratory reports. The enrollment in MET 421 is always limited to approximately 20 MET students who are nearing graduation.

Table 2 suggests a small difference in student achievement for "remote-access" and "hands-on" versions of the same laboratory experiment. The average student grade for the laboratory-based photovoltaic power experiment in 2001 and 2002 was 92%. In contrast, the average student grades on the remote-access experiment dropped to 89% in 2003. The reduction in laboratory scores is relatively small, but statistically significant. A hypothesis test comparing the two groups of learners confirms that the difference in laboratory scores is something more than an anomaly. A two-tailed hypothesis test with a t distribution, 17 degrees of freedom, and a 10% level of significance was used for this analysis.

The most likely cause of the slight decrease in laboratory scores is the increased complexity of the remote-access version of the project. In the original hands-on version, students made direct measurements of electric power and solar radiation. There was little opportunity to question or interpret the data. In the remote-access version, students had more variables to consider. A higher level of engineering judgment was needed to identify reasonable values for daily residential energy consumption and daily energy available. It is not surprising that student scores are slightly lower on an open-ended project. The author believes that a small decrease in student scores is an acceptable trade-off while delivering a more sophisticated experiment.

Topic	#	Student Survey Question	Average Response
Integrity of Web Data	1.	The kW·h data obtained from the energy utility was reliable and accurate.	3.7
	2.	The solar data obtained from the National Institute of Standards and Technology was reliable and accurate.	4.3
Viability of Remote Laboratories	3.	Remote access (Internet only) is good for some laboratory experiments.	3.9
	4.	I would have learned more if I had made the solar energy measurements in person.	2.7
	5.	Remote access laboratories are more boring than traditional laboratory experiments.	2.5
	6.	I could have completed this laboratory project on my own, without a laboratory instructor.	3.1
Real World Applicability	7.	This laboratory taught me how to use a spreadsheet for numeric integration (computing the area under a curve).	3.2
	8.	After completing this lab, I could work on my own to size another photovoltaic installation for a different part of the U.S.	4.1
The average responses are a continuum, where a "1" indicates strong disagreement and a "5" indicates strong agreement with the corresponding statement.			

Table 3. Summary of responses to student survey.

Student Perceptions of Remote-Access Photovoltaic Experiment

A post-laboratory survey completed by all students who worked on the remote-access photovoltaic power laboratory experiment in 2003 was helpful for assessing student reactions to the project. Table 3 summarizes the responses from the eight-question survey. The average response for the entire class is a continuum, with a "5" indicating strong agreement and a "1" indicating strong disagreement with the corresponding statement. For purposes of discussion, the column on the far left breaks the survey down into three target areas.

Survey questions 1 and 2 targeted student perceptions about the integrity of various types of Web data. This is an important topic for remote-access laboratories, where students must accept the information presented on a computer screen at face value. Students trusted data from the NIST Web site (4.3 on a scale of 1 to 5) more than the data from an energy utility that was located using a generic Web search engine (3.7 on a scale of 1 to 5). The statistical significance of the difference between the two survey responses was validated using a two-tailed t-test with 17 degrees of freedom and a 10% level of significance.

Survey questions 3 through 6 were designed to assess the student's overall reaction to completing laboratory experiments over the Internet. The responses to questions 3 and 4 provided some encouraging feedback about the photovoltaic laboratory experiment and remote-access laboratories in general. For example, students generally agreed (3.9 on a scale of 1 to 5) that the Internet is useful for interfacing with expensive or one-of-a-kind equipment. Survey question 5 alleviated some of the initial concerns about whether remote-access laboratories capture the imagination of student learners. Students generally disagreed (2.5 on a scale of 1 to 5) with the statement that remote-access laboratories are boring, but the score leaves room for future improvements in Internet-based laboratory delivery. The result from survey question 6 is an important reminder that students still value the presence of a qualified laboratory instructor to guide experimental work.

Survey questions 7 and 8 did not target the remote-access issue directly. These two questions assessed whether students had developed enough confidence and familiarity with the laboratory computations to tackle problems beyond the scope of this introductory photovoltaic project. The results from these survey questions are a little ambiguous. On one hand, students felt that they could apply the techniques discussed in laboratory to size a different photovoltaic installation on their own (4.1 on a scale of 1 to 5). On the other hand, students were not particularly confident about completing problems that require numeric integration (3.2 on a scale of 1 to 5). Unfortunately for the students, numeric integration is a key component of the array-sizing technique presented in this experiment.

Conclusions

Solar energy is an important topic that is frequently omitted from undergraduate coursework. This paper presents a Web-based photovoltaic power experiment that uses freely available online resources as a low-cost alternative to operating a solar energy laboratory. Educators are encouraged to use this project in their classroom for introducing solar energy, but also for assessing the strengths and weaknesses of Internet-based laboratory experiments.

The remote-access version of the photovoltaic power design project is an improvement over the original hands-on version. Web-based data for estimating 1) residential energy consumption and 2) daily solar energy available creates many more design options, and forces students to apply engineering judgment to complete the open-ended project. A modest decrease in laboratory grades is a small price to pay for the improved educational experience. In addition, a survey showed that most students liked using remote access for some laboratory experiments.

References

1. Mott, R.L., Neff, G.P, Stratton, M.J., and Summers, D.C., (2002), Future Directions for Mechanical, Manufacturing, and Industrial Engineering Technology Programs, *Journal of Engineering Technology*, Vol 19, No 1, page 9.
2. Short Term Energy Outlook (2006), Energy Information Administration, U.S. Department of Energy, Retrieved January 9, 2006 from http://www.eia.doe.gov/emeu/steo/pub/11tab.html
3. Goswami, D.Y, (2001), Present Status of Solar Energy Education, *Proceedings of the 2001 American Society of Engineering Education Annual Conference*, [CD-ROM].
4. *Federal Financial Interventions and Subsidies in Energy Markets 1999: Primary Energy* (2000), Energy Information Administration. U. S. Department of Energy, Retrieved November 4, 2003 from http://www.eia.doe.gov/oiaf/servicerpt/subsidy/research.html
5. Hutzel, W. J. (2001). Energy conservation in thermal power courses, *Proceedings of the 2001 Annual Conference and Exposition*, [CD-ROM], American Society for Engineering Education.
6. Hutzel, W. J., and Webber, P. L. (2003). Evaluating the efficiency of a photovoltaic power system, *Engineering the Future: Proceedings of the 2003 ASEE IL/IN Regional Conference*, American Society for Engineering Education, pp. 39-40.
7. Hutzel, W. J. (1999). Digital controls for an active solar collector loop, *Proceedings of the 1999 ASME International Mechanical Engineering Congress and Exposition*, Paper No 99-WA/MET-1.
8. Henry, J., (1998) Running Laboratory Experiments via the World Wide Web, *Proceedings of the 1998 American Society of Engineering Education Annual Conference*, [CD-ROM].

9. Gillet, D., Latchman, H.A., Salzmann, Ch., and Crisalle, O.D., (2001), Hands-on Laboratory Experiments in Flexible and Distance Learning, *Journal of Engineering Education*, Vol 9, No 2, pp 187-191.
10. Skormin, V. and Nikulin, V., (2001), Engineering Laboratory Accessible Via the Internet, *Proceedings of the 2001 American Society of Engineering Education Annual Conference*, [CD-ROM].
11. Wong, H., Kapila, V., and Tzes, A., (2001), Mechatronics/Process Control Remote Laboratory, *Proceedings of the 2001 American Society of Engineering Education Annual Conference*, [CD-ROM].
12. Esche, S.K., Prasad, M., and Chassapis, C., (2000), Remotely Accessible Laboratory Approach for Undergraduate Education, *Proceedings of the 2000 American Society of Engineering Education Annual Conference*, [CD-ROM].
13. Web-based Educational framework for Analysis, Visualization, and Experimentation, Retrieved January 6, 2006, from http://weave.duke.edu/.
14. Ogot, M., Elliott, G., and Glumac, N. (2003), An Assessment of In-Person and Remotely Operated Laboratories, *Journal of Engineering Education*, Vol 92, No 1, pp 57-64.
15. ASHRAE Fundamentals Handbook 2001, American Society of Heating, Refrigerating, and Air Conditioning Engineers.

William J. Hutzel

William J. Hutzel is an Associate Professor of Mechanical Engineering Technology at the West Lafayette campus of Purdue University. He teaches undergraduate courses in thermodynamics, fluid dynamics, and applied controls. His specific areas of expertise include building automation and solar energy systems. Professor Hutzel has led several projects to evaluate student learning from remotely accessible laboratories.

William M. Healy

William M. Healy is a member of the Heat Transfer and Alternative Energy Systems Group of the Building and Fire Research Laboratory at the National Institute of Standards and Technology in Gaithersburg, MD. He is currently leading a project to find improved sensors for detecting moisture in building envelopes, and oversees residential water heater testing as part of the DOE Appliance Program. He has also helped develop a Web-based data acquisition system for weather data that is used in photovoltaic research.

Consider Submitting Your Paper to the *Journal of Engineering Technology...*

Papers submitted to the *Journal of Engineering Technology* are reviewed for their contribution to the advancement of the field of engineering technology. To submit a manuscript for consideration for publication, contact Carlos Ortiz, Manuscript Editor, by mail, phone or e-mail at:

Carlos Ortiz
Southern Polytechnic State U.
1100 S. Marietta Parkway
Marietta, GA 30060-2896

(678) 915-5496
cortiz@spsu.edu

NORTHERN ILLINOIS UNIVERSITY

Department of Technology

www.ceet.niu.edu/tech

Undergraduate Programs:

- **Industrial Technology** (NAIT Acc.)
- **Electrical Engineering Technology** (ABET Acc.)
- **Manufacturing Engineering Technology** (ABET Acc)

Graduate Program:

- **Industrial Management** - concentration areas in Environmental Health and Safety, Manufacturing, and Project Management

Please contact:
Department of Technology, Northern Illinois University, Still Gym 204, DeKalb, Ill 60115