Watts On Your Mind?

Solar energy educational activities for schools

Calculating the Efficiency of a Solar Electric System

Activity Overview

Grade Level: 9-12
Activity: WOS-5

Description

Students will use data from their school's solar electric system to learn how to calculate system efficiency.

Learning Outcome

Students will learn how to calculate the instantaneous energy conversion efficiency of a solar electric system and compare the energy conversion efficiency to that of other energy conversions

Subjects

Computer science, math

Process Skills Used

Discussion, application, research, and computer literacy

Duration

1 class period

Key Vocabulary

Efficiency, instantaneous efficiency

Curriculum Standards

Texas (TEKS): 112.42.c.6, 11248.b.3
Louisiana (LSCS): PS-M-C6, PS-H-F1
Arkansas (ASCF): 3.1.34, 4.1.28, 5.1.29
National (AAAS Project 2061):
The Designed World – 12^{th}
The Physical Setting – 12^{th}

Materials

- Computer (with internet access or connected to solar electric system)
- Computer spreadsheet application

Method

1. Review the information presented below and in the Sample Calculation
2. Based on the sample calculation, calculate the efficiency of the system for a day with very low temperatures and for a day with high temperatures, compare and discuss.

Background

Solar electric energy systems, like those we use in the Watts On Schools program, convert the sun's radiant energy directly into electricity. But how well does the solar electric system do its job? Or, more precisely: How much of the sun's energy is actually converted into usable electricity by the PV system?

The answer to this question is best expressed by calculating the "efficiency" of the solar electric system. The efficiency reveals the percentage of sunlight that is converted into usable electricity by the solar electric system.

Sounds Easy, What Makes it Hard?

Efficiency is expressed as a percentage. To calculate efficiency, we need to divide the amount of energy actually produced by the amount of energy that could have been produced, then multiply the result by 100.

As an example, if you ate only one hamburger for every two hamburgers you were given, your eating efficiency would be calculated like this:

(1 hamburger actually eaten / 2 hamburgers that you could have eaten) x 100
= (1/2) x 100
= 0.5 x 100
= 50%

So your eating efficiency in this example is 50%. You are only making use of 50% of the hamburgers that are available to you.

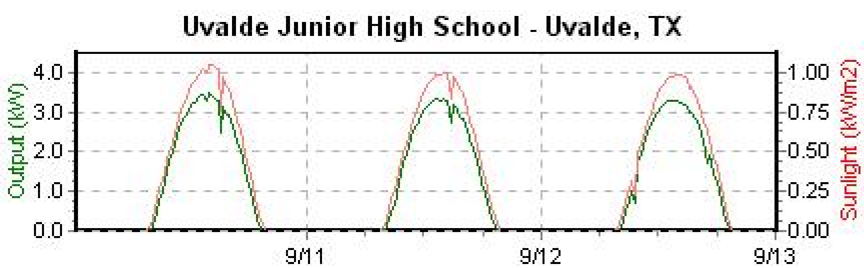
Calculating solar electric system efficiency is a little harder, because we have to figure out:

- How much energy the system actually produced at a certain time, and
- How much energy the system could have produced during that time.

Sample Efficiency Calculation

Data for use in this activity can be derived from the daily graphs of system performance available on the schools pages or from the raw historical data files available on the data page. We'll use examples of both in this activity.

For the graph data, we'll use the following graph from our system at Uvalde Junior High School that was made on September 13, 2000. At the peak hour on September 12, the graph shows that energy output from the Uvalde system was about 3.25 kW while the solar irradiance was about 1000 watts per square meter.



For the raw historical data, we'll use data from our system at Fayetteville High School. We'll look at the data at 1:00 pm on January 1, 2000. You can find and download this record and lots of other data on our data page. Here is the actual data record we will use:

```
1,1,2000,1,1300,19.25,861,2.356,3.279,2205,9.81
```

We are interested in the data on time, solar irradiance, and energy output. According to the data file description we provide on the data page, the time is given in the 5th field (1300, or 1:00 p.m.), the solar irradiance data is given in the 7th field (861 watts per square meter), and the energy output is given in the 9th field (3.279 kW).

To summarize, here are the data points we will use:

Location	System Output (kW)	Solar Irradiance (w/m2)
Uvalde	3.25	1000
Fayetteville	3.729	861

You can use any data from any system for this activity.

Since we are using just one data point or measurement for our calculation of efficiency, the efficiency value that we derive is called the "instantaneous energy conversion efficiency" of the system. The conversion efficiency may change over time or with different weather conditions, so the value we calculate will be valid instantaneously, or just for the time period from which our data is derived.

To calculate the efficiency at each school, we need to know two things:

- The amount of energy actually produced by the system, and
- The amount of energy that could have been produced by the system.

Step 1. Calculating the Amount of Energy Actually Produced by the System

The first part is easy, since we already know the amount of energy produced by the system just by looking at the graph or by reading the raw data. For Uvalde, the amount of energy actually produced is 3.25 kW; for Fayetteville, it is 3.279 kW.

Step 2. Calculating the Amount of Energy that Could Have Been Produced by the System

The second part, calculating the amount of energy that could have been produced by the system, is harder. How do we know how much energy could have been produced? Well, let's start with what we know.

We know that in Uvalde, the amount of solar radiation available to the system was 1000 watts per square meter. If we knew how many square meters of solar panels the solar electric system contained, we could calculate exactly how much sunlight energy was available to the panels. This would be the amount of energy that could have been produced by the system!

So all we need to know is how many square meters of solar panels are on the system at Uvalde. Every Watts On Schools system is the same and consists of 16 photovoltaic (PV) modules. According to the module specifications, each of these modules measures 1.892 meters in length by 1.282 meters in height. Let's multiply these dimensions to obtain the area of each module:

$$1.892 \text{ m} \times 1.282 \text{ m} = 2.4255 \text{ m}^2$$

But there are 16 modules, so the area of all the modules is:

$$2.4255 \times 16 = 38.8087 \text{ m}^2$$

Now, if we multiply the area of the modules by the amount of sunlight available for each system, we get the amount of energy that could have been produced:

For Uvalde,

$$38.8087 \text{ m}^2 \times 1000 \text{ w/m}^2 = 38{,}808 \text{ watts, or } 38.808 \text{ kW}$$

For Fayetteville,

$$38.8087 \text{ m}^2 \times 861 \text{ w/m}^2 = 33{,}414 \text{ watts, or } 33.414 \text{ kW}$$

Step 3. Calculating the Efficiency

Now we go back to our equation for calculating efficiency. We need to divide the amount of energy actually produced by the amount of energy that could have been produced, then multiply the result by 100.

So, for Uvalde, we have:

$$(3.25 \text{ kW} / 38.808 \text{ kW}) \times 100$$
$$= 0.0837 \times 100$$
$$= 8.37\% \text{ Efficiency}$$

For Fayetteville, we have:

$$(3.279 \text{ kW} / 33.414 \text{ kW}) \times 100$$
$$= 0.0981 \times 100$$
$$= 9.81\% \text{ Efficiency}$$

Activity

1. Using the data file for your school, select 2 days to analyze:

   1 – Low average temperature (winter)
   2 – High average temperature (summer)

2. Calculate the efficiency for each day by using the sample calculation above as guidance.

3. Which day had a higher efficiency? Why do you think this occurred?

Review

If we lived in a perfect world, we would expect our solar energy systems to convert every bit of available solar energy into usable electricity. This would be 100% energy conversion efficiency. But we don't live in a perfect world, and it turns out that no conversions of energy from one form to another form can be done with such perfect efficiency.

As our experiment showed, the Watts On Schools systems at Uvalde and Fayetteville converted just 8.37% and 9.81% of the available solar energy into usable electricity. This doesn't sound like much - even our hamburger example was more efficient (and we threw away half a hamburger every time we ate one!). Let's compare the efficiency of the solar energy system with the efficiency of some other energy conversions.

Energy Conversion	**Efficiency**
Human Beings - Chemical energy stored in food into mechanical energy (running, walking, etc.)	3-5%
Automobile - Chemical energy stored in gasoline into mechanical energy (forward motion)	25%
Fireplace - Chemical energy stored in wood into thermal energy (heat)	14%

Solar energy has a lower conversion efficiency than many other energy conversions, but one advantage of solar energy is that it converts the source energy into usable energy in only one step. Other forms of energy, like fossil fuel power plants, first convert chemical energy stored in coal into thermal energy (heat), then convert the thermal energy into mechanical energy (turning a turbine), then convert the mechanical energy into electrical energy. This process of several steps can make the overall conversion efficiency much lower for these forms of energy. Another advantage of solar energy systems is that they produce electricity without any pollution.

Discussion

1. What does it mean to say that we calculated the "instantaneous" energy conversion efficiency for our solar energy systems?
2. What kinds of factors do you think might increase or decrease the energy conversion efficiency of a solar electric system? Why do you think each factor would have an effect on efficiency?
3. How could you make a solar electric system more efficient at converting sunlight into electricity?