LEVELS
Grades 6 - 12

SUBJECT
Mathematics, Economics, Astronomy, Environmental Studies

CONCEPTS
• Energy-efficient lighting fixtures
• Energy conservation
• Cost of electricity

APPLICABLE NATIONAL STANDARDS
National Math Standards:
• Standard 1: Mathematics as Problem Solving
• Standard 2: Mathematics as Communication
• Standard 3: Mathematics as Reasoning
• Standard 5: Algebra
• Standard 6: Functions

SKILLS
• Addition, subtraction, multiplication, and division
• Compiling lighting energy and cost data
• Drawing a plan for the outdoor building lighting
• Critical thinking
• Problem solving
• Creating and giving presentations

OBJECTIVE
Calculate the feasibility of replacing older, less efficient outdoor lighting with new lamps and fixtures that are more efficient and cost less to operate.

MATERIALS (per student group or student)
• Pencil, paper, and a ruler
• Tape measure
• Student Guide Primers:
  -- All About Energy
  -- Lighting Technology Overview
• Worksheet
• Vocabulary
TIME
Two 55-minute classroom periods; one 1-hour night time session

GOALS
- Provide students with tools and information they need to effectively monitor energy use within their school building
- Identify ways to save their school’s money by using energy wisely
- Understand that the information that they learn may be used to help improve the environment
- Create in students and teachers an appreciation and passion for using energy efficiently and wisely
- Assist schools in using school buildings as working laboratories for learning about energy
- Encourage schools to consider managing or retrofitting their buildings so that energy is used as efficiently and wisely as possible
- Link between energy use like lighting and electricity productions at power plant to CO2 emissions at smokestack to Greenhouse gas/global warming

LEARNING OBJECTIVES
Each student is given the opportunity to

1. Define terms associated with an energy audit, e.g., incandescent, fluorescent, etc.
2. Identify the components (including the types of data) to include in a school outdoor lighting audit plan.
3. Prepare a school outdoor lighting audit plan.
4. Conduct a school outdoor lighting audit.
5. Analyze data from the school lighting audit.
6. Write recommendations/improvement options for more efficient lighting.
7. Write a school lighting audit action plan that includes recommendations derived from the analysis of data.
8. Develop the presentation materials (e.g. PowerPoint presentations, handouts, and other visual media) that show the data analysis results and recommendations using graphs, tables, etc.
9. Present the action plan to classmates and/or administrators.

VOCABULARY:
Fixtures, shielded fixtures, lamp, fluorescent lamp, incandescent lamp, etc.

HOOK: Tomorrow is coming soon. Tomorrow we will have far less energy resources than we have today. Today we can take steps to prevent depleting our energy more than is needed. To do that, we need your help.
SCHOOL OUTDOOR LIGHTING AUDIT

You will be auditing the types of outdoor lights on one building at your school to determine how much energy those lights are using. You will ultimately be making recommendations as to how your school might become more energy efficient by using a few different methods.

The project is in four parts: Data Gathering and Observation, Plan a New Approach, Compare the New Approach with the Current Situation, What’s the Bottom Line? Have fun as you start with Part 1...

Get Ready, Set, Go:

PART 1: DATA GATHERING & OBSERVATION: Current Situation

☐ Your teacher will place you into groups of three or four. Each group picks a different building at your school to use in the lighting audit. Make sure the building has more than a half dozen lights on the exterior.

☐ Measure the dimensions of the building and sketch it to scale on a piece of graph paper. Be sure to write the length and width on the sketch.

☐ On your schematic of the building, draw the location of the lights and where you think the light will fall (e.g., on the ground). You can figure out where the light will fall by looking at the shielding (if any) and where the light is pointed.

☐ Take a picture of the fixture, close enough to identify it later.

☐ Identify the kind of shielding. Match it to one of the pictures in the Figure 1. Identify the shape of the lamp. Match it to one of the pictures in the figures.

☐ Come back at night as a group and confirm where the light falls for each fixture. Describe whether the area being illuminated is too much or too little for the task. Describe if the light falls where needed or beyond where it is needed, or if it is blocked by vegetation or another structure. Also describe if there are overly bright or dark patches that hinder your ability to see what is around you.

☐ Record the color of the lamp (ex. yellow, orange-ish, greenish-white, bluish white...
For every light that you see, record the watts and lamp type by interviewing the buildings and grounds (facilities) staff. Ask about whether the lights are on timers or on light sensors (dusk to dawn) or motion sensors. If the lights are on timers, then ask the staff what the approximate hours of operation are.

Determine the number of hours per year that the outdoor building lights are on. (This is for all of the building lights on average.)

**Example:**
For the purposes of illustrating how such a schedule might work, take a hypothetical school week where the lights are on from 7 p.m. to 7 a.m., Monday through Friday. During school sessions, the lights are on 12 hours a day for five days a week totaling 60 hours a week.

If your school has 10 weeks off during the summer, a 2-week winter break, a week off for spring break, and a week off for holidays, this would amount to 15 weeks a year. The calculated “on times” for most of the lights in this case would be as follows:

\[(O \times I) + (F \times N) = Y\]

where
- \(O\) = the number of hours that the outdoor lights are on when school is in session
- \(I\) = the number of weeks that the school is in session
- \(F\) = the number of hours the outdoor lights are on when school is not in session
- \(N\) = the number of weeks that the school is not in session

**AUDIT WORKSHEET**

For every fixture with a particular lamp that has a particular wattage, calculate:

\[
\text{# of lamps} \times \text{wattage} \times \text{estimated hours of use in a year} = \text{power (W•h) used in a year}
\]

Add together the power used in a year for all the different lamps of different wattages.
Divide this yearly power in Watt-hours by 1000 to change the units to kilowatt-hours. You have determined how many kilowatt-hours or how much power has been consumed by the outdoor lights on your building.

Find out from the district main office what the dollars per kilowatt-hour is for the school. This number or ration can be found on the monthly bill.

Do the math to determine roughly the current annual cost of operating the outdoor lights around your building:

\[
\text{# of kilowatt-hours} \times \frac{\text{dollars per kilowatt-hour}}{\text{dollars spent on outdoor lights you calculated}} = \text{dollars spent on outdoor lights}
\]

The amount of carbon dioxide greenhouse gas generated during electricity production ranges from 1.4 lbs to 2.8 lbs. per kilowatt-hour, depending on whether or not the electricity is produced from coal, nuclear power or hydropower. Estimate the amount of greenhouse gas created when the electricity is made to power the outdoor lights around your building:

\[
\text{# of kilowatt-hours} \times 2 = \text{amount of greenhouse gas to power the outdoor lights you calculated}
\]

Congratulations! You have data that will help determine whether the lighting around your school building can be made more energy and cost effective. ... Saving the world one step at a time!
DISCUSSIONS and PRESENTATIONS by Students

Students discuss what they learned. Start them on a discussion of the types of lighting. For instance, the different groups can compare the results from the different buildings audited: the types of lamps and fixtures found, the range of wattages, how many out of all of the fixtures around the building were shielded, what angles or directions were the fixtures pointed (straight up, down, at an angle of 45 degrees from the ground), what were the colors of the lamps?

In particular, have the students describe the quality of lighting around the building. Does the lamp and fixture light where needed? How does your vision respond to a fixture that is unshielded versus shielded, even though the light might fall only where it is needed. (Talk about how it takes time for eyes to adjust.)

In terms of the calculations, did the student groups have differences in the total kilowatt-hours, or the cost per year, or the amount of greenhouse gas and why? What differences in the buildings might support the differences in the calculated results?

NEXT STEPS (Parts 2-4 to be written by C. Walker et al.)

The next step will be an investigation into the appropriate lighting to replace (possibly) the existing fixtures and lamps.

The International Dark-Sky Association has been asked to help with the next steps, which would include a lighting retrofit (or possibly a re-design). Lighting engineers first think about why you want to light an area, where you want to light, when you want to light, how much you want to light, and what kind of light you want to use (e.g., appropriate lamp for the task, what color needed). A redesign might even change the entire configuration of where lights are placed, etc.

Based upon the choices researched, the students will then calculate the new energy expenditure, similar to what was done in Part 1.

The difference between the current situation and the proposed plan is then explored. And a result, a recommended plan of action can be proposed to the school board.
BACKGROUND MATERIALS: Different Types of Fixtures and Lamps
(Recommendation: allow the students to explore without viewing the background materials first. Use the tables and figures with the students when you feel it is needed.)

<table>
<thead>
<tr>
<th>LAMP</th>
<th>COLOR OF BULB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Halide</td>
<td>bluish-white</td>
</tr>
<tr>
<td>Mercury Vapor</td>
<td>greenish-white</td>
</tr>
<tr>
<td>Low Pressure Sodium</td>
<td>yellowish</td>
</tr>
<tr>
<td>High Pressure Sodium</td>
<td>orange-ish</td>
</tr>
</tbody>
</table>

Figure 1. Pictures of different types of fixtures and their abbreviations. See also Table 2 which gives these lamps’ typical wattages and the fixtures these lamps commonly accompany that are frequently found near or on a school building.
**GOOD LIGHTING:**

- Lamp is on a motion sensor, so only on when needed.
- Lamp is on a timer so not operating from dusk to dawn.
- Lamp is fully shielded. Fully shielded lighting puts light where it’s needed & minimizes glare and energy waste. If your lamp is shielded, you can lower the wattage of your bulb and save energy and cost.

**NOT-SO-GOOD LIGHTING FIXTURES:**

- Fixtures that are unshielded are less desirable. Light from an unshielded fixture is directed upward never to be used where needed on the ground. Too much glare from the direct light of a lamp can create unsafe situations for drivers who do not see pedestrians, for instance.

### TABLE 2

<table>
<thead>
<tr>
<th>TYPE OF LAMP</th>
<th>Type of FIXTURE</th>
<th>Fixture Illustration</th>
<th>Typical WATTAGE (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure Sodium (HPS)</td>
<td>wallpack</td>
<td>USWPP USWPC</td>
<td>150</td>
</tr>
<tr>
<td>HPS</td>
<td>wallpack</td>
<td>USWPP USWPC</td>
<td>250</td>
</tr>
<tr>
<td>HPS</td>
<td>shoebox with or without a drop lens</td>
<td>FSSB USSL</td>
<td>250</td>
</tr>
<tr>
<td>Mercury Vapor</td>
<td>Cobra head with drop lens</td>
<td>FSCO USCO</td>
<td>175</td>
</tr>
<tr>
<td>Halogen</td>
<td>floodlight</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Incandescent</td>
<td>floodlight</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Incandescent</td>
<td>traditional light, sometimes hanging</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>Incandescent</td>
<td>globe</td>
<td>USFL USAG</td>
<td>60 to 150</td>
</tr>
<tr>
<td>Fluorescent (e.g., T12)</td>
<td>traditional lights</td>
<td>FSFLT</td>
<td>60</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>wallpack</td>
<td>USWPP USWPC</td>
<td>11</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>Area lighting (poles in parking area)</td>
<td>FSSB FSLPS</td>
<td>250</td>
</tr>
</tbody>
</table>
FIGURE 2: PICTURES OF TYPICAL DIFFERENT TYPES OF LAMPS:

<table>
<thead>
<tr>
<th>High Pressure Sodium:</th>
<th>Low Pressure Sodium:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fluorescent:</th>
<th>Compact Fluorescent</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mercury Vapor:</th>
<th>Incandescent:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>Metal Halide:</td>
<td>Halogen:</td>
</tr>
<tr>
<td>--------------</td>
<td>----------</td>
</tr>
<tr>
<td><img src="image1" alt="Metal Halide Lamp" /></td>
<td><img src="image2" alt="Halogen Lamp" /></td>
</tr>
</tbody>
</table>