Santa Cruz-Watsonville
Inquiry-Based Learning
in Environmental Sciences
An NSF GK-12 Project

Energy for Change

Green Energy Audit

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Field-tested with: 11th-12th grade students in the Green Careers Course, ESNR Academy, Watsonville High School, Watsonville, CA (Fall, 2010)

Concepts: Energy conservation and efficiency, power, Laws of Thermodynamics, light measurements, watts, watt-hours, retrofits

Skills: Scientific investigation, use of appropriate technology, mathematical calculations and conversions, environmental problem solving, writing.

Module Type: Interactive worksheets for conceptual engagement; data collection; analysis and write-up

Duration: Three 110-minute class sessions, or one 60-minute session per week for 2 months)

Key materials:
- Workbooks
- Flicker Checkers
- Light Meters
- Incandescent light bulb and Compact Fluorescent Lamp
- Kill-a-Watt meters (optional)

Science Education Standards:
National: B. Physical Science; F. Science in Personal and Social Perspectives
California: Physics: 3. Heat and Thermodynamics; Investigation and Experimentation

Overview: In this 3-day module, students strengthen their understanding of concepts in physics such as **power** and **energy** by making real-world connections, and develop the skills and knowledge needed to conduct an **energy audit** so that they can consider this as a potential career path. The students assess energy consumption (particularly of lighting systems) using the appropriate technological tools and calculate potential energy savings from both behavioral (e.g., turning lights off) and operational (e.g., retrofits) measures. Finally, students synthesize their data and develop specific recommendations for improvements in **energy conservation** and **efficiency** in the form of a final product (e.g., a report presented to the administration).

This project is an opportunity for students to learn:

- How to calculate energy consumption and potential savings from light energy conservation
- How to use appropriate tools, data recording methods, and small group resources to conduct scientific inquiries

SCWIBLES is an NSF-GK-12 project, #DGE-0947923, a partnership between the University of California, Santa Cruz, and the Pájaro Valley Unified School District.
For more information, see: http://scwibles.ucsc.edu

Background for Teachers

Green Energy Audit

The goal of this module is to strengthen students' understanding of concepts in physics such as **power** and **energy** by making real-world connections, and to develop the skills and knowledge needed to conduct an **energy audit** so that they can consider this as a potential career path. In addition, the students learn how to use tools effectively (e.g., **light meter, flicker checkers**) to measure energy consumption. Finally, students synthesize their data and develop specific recommendations for both behavioral and operational measures (e.g., retrofits) to improve **energy efficiency** and **conservation** at their high school.

Science Education Standards Addressed:

Science Content Standards for California Public Schools Grades 9-12

Physics

3. *Heat and Thermodynamics*. Energy cannot be created or destroyed, although in many processes energy is transferred to the environment as heat. As a basis for understanding this concept:

   d. Students know that most processes tend to decrease the order of a system over time and that energy levels are eventually distributed uniformly (p42)

   f. Students know the statement "Entropy tends to increase" is a law of statistical probability that governs all closed systems (second law of thermodynamics; p42).

Investigation and Experimentation

1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:

   a. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.

   c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.

   d. Formulate explanations by using logic and evidence.

SCSCPS (http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf)

National Science Education Content Standards A-G: Grades 9-12

B. Physical Science (pp 176-181)

Conservation of Energy and the Increase in Disorder (p 180)

- The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.

- Everything tends to become less organized and less orderly over time. Thus, in all energy transfers, the overall effect is that the energy is spread out uniformly. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection and the warming of our surroundings when we burn fuels.

Students learn about the First and Second Laws of Thermodynamics. They know that energy is always conserved (the First Law of Thermodynamics), but can be converted from one form into another. They also know that as energy is converted, the overall energy can become dispersed as heat and the entropy of the system increases (The Second Law of Thermodynamics).

F. Science in Personal and Social Perspectives (pp 193-199)

Natural Resources (p 198)

- The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed Environmental Quality

Environmental Quality (p 198)

- Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth.

Students know that resource consumption can lead to environmental degradation and consider how to reduce their resource use by both focusing on energy efficiency (improvements in technology), as well as energy conservation (considering changes in institutional and behavioral actions that can reduce energy use).

NSES (http://www.nap.edu/catalog/4962.html)

Common Student Misconceptions and Advice to Teachers:

It will be important for the teacher to be prepared to spend time defining and illustrating the concepts of power, energy, and entropy as these concepts are often difficult to grasp. The 2nd Law of Thermodynamics and entropy, in particular, are often taught in ways that are misleading for students (e.g., with analogies of messy rooms).

The 2nd Law of Thermodynamics and entropy is not about everything tending towards disorder, chaos or decay. While complex formulas are associated with the 2nd Law, to teach high school students it is best to simply explain it in terms of energy changes, namely that energy becomes dispersed or less concentrated. Heat, for example, will always flow to regions of lower temperature, not higher, unless there is external work being performed on the system. In a refrigerator, heat will flow from a cold to a hot region only because work is being done by a compressor.

The first day of the module is best spent going over handouts, discussing examples as a class, and doing calculations (both on the board and on worksheets).

Project Description

Materials:

- **Energy Audit workbooks** for each student (including introduction to exercises, datasheets for calculations and observations and questions that test understanding)
- **Flicker checkers.** Flicker checkers are tops with a radial pattern that show the frequency of modulation of light (see Handout 4) and will help students see if their classroom lighting systems use inefficient electromagnetic ballasts or more efficient electronic ballasts. Teachers can contact the NEED Project (need.org) for curriculum-kits (www.need.org/curriculum-guides) that contain flicker checkers. Prices vary based on kit, but a teacher can contact them about buying the inexpensive flicker checkers separately.
- **Light meters.** Light meters can be purchased online or at some home improvement stores for approximately $30.
- **Incandescent light bulb and compact fluorescent lamp** for demonstration purposes
- **Kill-a-Watt meters (optional)** for measuring energy use of appliances. Available at home improvement stores for approximately $20.

Preparation:

Some supplies may have to be ordered online several weeks in advance (see materials section). The teacher can also do the calculations for **Part 4 and/or Part 6** in advance, to facilitate assistance of students' work in the classroom.

Timeline:

Day 1

5 minutes	Introductory presentation to Energy Audit (**Part 1 of workbook**).
20 minutes	Read over Understanding Energy Units section in workbook as a class and do examples on board (**Part 2**).
60 minutes	Read over Introduction to Energy Conservation and Efficiency section in workbook as a class (**Part 3**). Students answer follow-up questions individually.
25 minutes	Students form groups and brainstorm on what parts of the school they will visit and what they can measure during their Energy Audit (**Part 4**).

Day 2

5 minutes	Recap from last class and introduction to second part of module.
40 minutes	Overhead lighting audit for linear fluorescent lamps done for classroom. Read Introduction to Overhead Lighting Audit for Fluorescent Lamps (**Part 5a**), and conduct audit (**Part 5b**): use flicker checkers, fill out Chart 1, and begin calculations for Chart 2 and Retrofit Savings Analysis.
20 minutes	Introduction to Lighting Level Audit section in workbook **(Part 6a);** read over introduction as class and demonstrate use of light meter and how to draw an illumination map (**Part 6 demo**).
30 minutes	Students conduct self-designed audit, collecting site data (light levels and observational data) for their chosen part of the school, using data sheets from **Parts 7 & 8**, and/or their own datasheets.
15 minutes	Group reflections on data collected.

Day 3

30 minutes	Extra time to work on mathematical calculations from previous handouts. Review answers. Report back from group work.
80 minutes	Create a final product with recommendations for improving energy consumption (e.g., poster, report, or website blurb).

Applying Science and Math to Reducing Energy Consumption: Detailed Procedure

The goal of this module is to review fundamental concepts in physics, such as **energy** and **power**, and then apply those concepts to assessing energy consumption and opportunities to improve **energy conservation** and **efficiency**.

This module uses a workbook to guide students through discussions of these concepts, calculations to practice applying concepts and unit conversions to everyday consumption and conservation problems, and then through a four-part audit using similar calculations.

On <u>Day 1</u> of the module, students use **Parts 1-4** of the workbook, reading together and discussing concepts of energy conservation and efficiency, doing exercises to understand energy units, and working in small groups to choose where they will conduct their part of the school audit.

85 minutes total. Students learn about the **Laws of Thermodynamics**—that during energy conversions (e.g., from electrical energy into light energy), while energy is conserved, much of that energy is lost as heat to the surrounding atmosphere. They learn how **energy efficiency** emphasizes improving conversion devices to result in more useful energy. A discussion of incandescent light bulbs versus compact fluorescent light bulbs (CFLs) is used to illustrate this point. While reading the teacher should stop after each paragraph to ask the students to clarify the new concepts and vocabulary they just learned, as well as allow for student discussion on any relevant issues. It would also be useful if the teacher could bring in an incandescent light bulb and a CFL for demonstration.

Students do calculations to find how much energy is used by a device based on how power-hungry it is. They practice converting between **watts** and **kilowatts** and calculating **kilowatt-hours**. Questions are included in Parts 2 and 3 of the workbook, and can either be done individually or in groups by students, and/or by having students write their answers on the board with the assistance of the rest of the class. Some of the questions are calculations, and some are idea-generators about efficiency and conservation (See Teachers' Answer Key Appendix). After reading the text in these sections, the teacher can give students time to complete the follow-up questions and should go around the room offering assistance. If students do not finish the questions, they can be assigned as homework (extra time is allocated on Day 3 as well for students who still need in-class time or assistance).

25 minutes. At the end of this class session, students work in small groups to begin planning their own energy audit of one room or space in their school. It is recommended that students look over the introductory sections of Parts 5 and 6, and the checklist of Part 7 in order to get a sense of what their audit may include, but the real purpose of this activity is to decide where the groups will go on Day 2. In this version of the module, students were instructed to begin with the Lighting Level Audit (Part 6) and to complete at least some items from the General Observations checklist (Part 7), which includes a question about Linear Fluorescent Lamps (testable with flicker checkers, covered in Part 5). If the students have ideas that are not incorporated in these handouts the teacher can help them create their own datasheets.

The teacher should also verify that the students can indeed visit the areas of the school that they stated. For example, sometimes students will want to visit another classroom and that might be disruptive. Also, students might want to visit an area that might be locked during class time (e.g., a cafeteria or computer lab) and the teacher will want to ensure that the students can gain access to the area during Day 2 of the module.

When they are working in small groups, the teacher can ask them the following questions to stimulate discussion:

- Where do they want to look (classroom, gym, cafeteria, office, workroom, library, computer lab)?
- What do you want to look at when assessing possibilities for reducing energy consumption? (New or older lighting system? Light levels? Unnecessary electric devices? Electronic equipment or lights on when not needed?)
- How are you going to measure and record your data?

Day 2 of the module is the audit.

60 minutes total. The teacher might begin with a review of previous concepts, including how to calculate kilowatt-hours; then open **Part 5a: introduction to overhead linear fluorescent lighting**. Students will learn the basic parts of the lamps, and how to determine whether lamps are more or less energy-efficient. Draw on the board what the flicker checker looks like beneath the magnetic ballasts versus the electronic ballasts (see instructions that come with flicker checker). Then the teacher should distribute flicker checkers around the room, read **5b: methods** together as a class, and have students fill out at least the first columns on Chart 1 together, figuring out if the light fixtures have the newer electronic ballasts or the less efficient magnetic ones.

Depending on time available in class, students will use the charts and worksheets in **Part 5** of the workbook to calculate the annual energy consumption and operating cost for existing lighting, and to do calculations for another two sets of data analysis: 1) energy, emissions, and cost savings if the school switched to more efficient T8 lamps (or conversely, how much energy and money their school is saving by having installed these lamps already).

The teacher then opens **Part 6a: introduction to lighting level audit**. Because students will be conducting their own lighting level audits in independent groups, demonstrate the primary steps of **6b:** show how to use a light meter, and draw an illumination map (or to save time, use a prepared transparency or Powerpoint slide) showing one or two meter readings.

30 minutes. Students are then divided into their audit groups from Day 1 to carry out their planned audit activities in different parts of the school, using light meteres and completing worksheets in **Part 6**, and completing chosen items in **Part 7** of the workbook, a checklist of general observations on opportunities to improve energy efficiency.

15 minutes. The groups return to report findings before adjourning.

Day 3 is for analysis and presentation.

30 minutes. The teacher should provide extra time to work on mathematical calculations from previous handouts, and review answers. Groups finish reporting their findings from site audits.

80 minutes. Create a final product with recommendations for improving energy consumption (e.g., poster, report, or website blurb).

If students do a report, this could be presented to the school administration.

Starting Points For Inquiry:

The overall starting point for inquiry is the question, How energy-efficient is your school? Is there anything we could be doing differently?

During Day 1, students break down this task, by learning what efficiency means, how to calculate it, and how to understand the broader implications of efficient energy use. They practice by investigating the real cost of different types of light bulbs (buying and operating them). At the end of Day 1, students begin to implement the overall inquiry project, by thinking about where they would go during their energy audit, what they would measure, and how. If appropriate, students can make their own data sheets (or modify those included here) for their room audits.

Day 2 combines structured quantitative analysis with a more open-ended creative design process during the mapping activity, by asking students to imagine how the school could adjust space and/or conditions to reduce energy consumption.

Assessment Methods:

Recommended approaches to assessment include:

- Asking questions of groups and individuals while they carry out activities.
- Class discussions.

- Grading of datasheets and follow up questions included in worksheets.
- Assessing final product (e.g., report to administration, website blurb, poster) for student engagement, comprehensiveness of project, and presentation.

Appendices

Glossary

Ballast- regulates the flow of electrical current going through a fluorescent lamp

De-lamping- removes one or more lamps from a light fixture

Energy- the capacity of a physical system to perform work. You must have energy to accomplish work. Energy can exist in several forms such as heat, kinetic or mechanical energy, light, potential energy, or electrical.

Energy Conservation- a reduction in the amount of energy consumed by a process or system, usually referring to a change in social behavior (e.g., making sure electronics are turned off when not being used or avoiding unnecessary purchases).

Energy efficiency- using less energy to provide the same level of energy service. Energy efficiency, for example, could be changing to a more efficient lighting system in which the amount of light delivered is the same, but the amount of energy consumed is reduced.

Entropy- a measure of how much energy spreads out in a process. According to the concept of entropy, in any transformation of energy from one form to another, useful energy is lost irreversibly as it becomes dispersed in the system.

Foot-candles- a measure of the amount of light output. One foot-candle equals one lumen hitting one square foot of surface area.

Illuminance- the amount of light that covers a surface

Light meter- a device to measure illuminance

Linear Fluorescent Lamps- the standard light tube in interior overhead lighting

Lumens- a measure of light output.

Power- the rate at which energy is transferred

Retrofit- the addition of new or upgraded parts to an old, outdated assembly that does not require a change of an entire system.

Work - refers to an activity involving a force and movement in the direction of the force.

Workbook

Energy for Change: A Green Energy Audit Workbook, by Jennie Liss.

Download the PDF here:
http://scwibles.ucsc.edu/modules/fulltext/Energy%20for%20Change%20Workbook.pdf

Teachers' Answer Key

For Conversions, Cost Calculations, and Conservation Measures, Parts 2 and 3 in the Workbook

PART 2, page 4. Watts, Watt-hours; Kilowatts and Kilowatt Hours

⇨ How many watt hours (WH) does a 15W compact fluorescent light bulb use if it is turned on for 5 hours? 75 WH

Instead of watts or watt-hours, you will often see kilowatts (**kW**), or kilowatt-hours (**kWh**), as the unit of measurement. Kilo means 1000, so you just need to divide watts or watt hours by 1000 to get kW or kWh.

⇨ What is a 60W light bulb in kilowatts? How many kilowatt-hours (kWh) are used if it is left on for 2 hours? a) 0.06 kW b) 0.12 kWh

⇨ What about that 60W light bulb left on for 100 hours? 60 kWh

PART 3, Follow-Up Questions:

1. If you find energy waste at your school, what are some examples of **conservation measures** that might be taken?

   turning lights and computers off when not needed, opening the blinds and turning off a circuit of lights, unplugging appliances when not in use.

2. What are some examples of actions your school could take that could improve **energy efficiency?**

   changing incandescent light bulbs with CFLs, retrofitting the overhead lighting system to newer fluorescent lamps, changing the exit signs to LEDs.

PART 3, page 8. Calculating Real Costs.

a) Real Cost of a 60-watt Incandescent Bulb:

First figure out the Energy cost: energy use multiplied by energy rate.

1) How many kilowatt-hours are used if you leave the bulb on for 1 hour? .06 kWh
(multiply 60 by 1 hour to get watt-hours, then divide by 1000)

2) Multiply by 10,000 hours of use: 600 kWh

3) Multiply total kWh by the rate you will be charged: 600 kWh x $0.057/kWh (rate) = $ 34.20 (energy cost)

4) Multiply the price of one bulb by the number of bulbs you need to last 10,000 hours:

$ 0.63 (price of one bulb) x 10 (number needed) = $ 6.30 (total bulb costs)

5) Add energy costs to bulb costs: $34.20 + $6.30 **= Total Real Cost: $40.50**

b) Real Cost of a 15-watt CFL (quicker this time!) First calculate the energy cost, and begin by figuring out how many kW the bulb is.

1) Energy cost: 0.015 kW x 10,000 hours x $ 0.057/kWh (rate) = $8.55 (energy cost)

Bulb costs needed to last 10,000 hours: $ 9.55 (total bulb costs)

Energy costs: + bulb costs: **= Total Real Cost: $18.10**

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