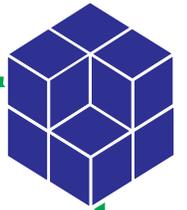




OFFICE OF ENERGY EFFICIENCY  
AND RENEWABLE ENERGY



# Lighting In the Library

## A Student Energy Audit



OFFICE OF BUILDING TECHNOLOGY,  
STATE AND COMMUNITY PROGRAMS



**Department of Energy**  
Washington, DC 20585

Dear Earth Day and Science Coordinators, Teachers and Administrators,

Tomorrow's decision-makers are sitting in your school today, and with your help, they will have the power to make the world a better place. The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy would like to provide you with the necessary tools to offer that assistance to your students. We know how difficult it is for educators to balance this responsibility with curriculum demands which is why we are pleased to offer you the free energy awareness activities enclosed with this letter. The lessons contained in this package will help your students learn how to reduce greenhouse gas and save money for your school simply by using less energy. The high school student energy audit materials contain grade-level appropriate student worksheets and teachers' guides designed to bring about the outcomes specified in the National Education Standards for Math and Science.

We invite you to use these materials when you plan your 1999-2000 school year lesson plans on topics like energy, electricity, greenhouse gas, Earth Day and real life applications of algebra and scientific analysis. We hope both you and your students find the activities enjoyable and informative, and we welcome and encourage your feedback. If you have questions, comments, or suggestions, or, if you would just like to let us know how you have used these activities in your class, please contact our Building Technology, State and Community Programs office by telephone at 202-586-9240 or find them on the World Wide Web at: [www.eren.doe.gov/buildings](http://www.eren.doe.gov/buildings).

Thanks again for your hard work and continued dedication to educating tomorrow's decision-makers.

Kindest Regards,

A handwritten signature in black ink, appearing to read "Dan W. Reicher".

Dan W. Reicher

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Glossary





## High School Energy Audit and Teachers' Guide

### Overview / School Energy Audit:

The U.S. Department of Energy's vision for Energy Smart Schools is to "form a national partnership to cut energy bills in schools and reinvest the savings in educating the nation's most valuable resource....our children". The plan is to invest in "books not BTUs". Some schools have taken the energy savings dollars and reinvested the funds into local education priorities. By reducing energy use, our schools could spend approximately \$1.5 billion more on books, computers, and teachers each year by the year 2010. That amounts to almost \$30 for each student, 40 million new textbooks, or 30,000 new teachers. In this activity, your students learn science and mathematical concepts in a hands-on, minds-on way. They become empowered to research their school environment and make recommendations for changes. They begin by focusing on the energy saving and pollution preventing opportunities that can be achieved by changing the light bulbs in your school library. They conclude their work by extending these findings to the opportunities in the entire school and preparing a presentation for the school board.

#### Level

Grades 8-12

#### Subject

Mathematics

#### Goals of the High School Energy Audit

- Provide students with tools and information they need to effectively monitor energy use within their school building
- Identify ways to save their schools 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 their 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 CO<sub>2</sub> emissions at smokestack to Greenhouse gas/global warming

#### Introduction

We spend most of our time in buildings—homes, schools, offices, and stores. But most people hardly notice details about the buildings, such as how they are designed, how they are built, and how well they are maintained. The details have a strong effect on how comfortable a building is and how much it costs to operate.

An "energy-efficient" building is more comfortable than a wasteful building. It needs less fuel for heat and less electricity for cooling. A building that is badly designed and poorly maintained wastes money. This is because the building components are trying to heat and air-condition the outdoors as well as the indoors.

In a 1995 report, *School Facilities: Condition of America's Schools*, the General Accounting Office (GAO) estimated that the cost of bringing the Nation's 110,000 K-12 schools into good overall conditions was \$112 billion.

The report revealed:

- 28,100 schools serving 15 million students have less-than-adequate heating, ventilation, and air-conditioning systems
- 23,100 schools serving 12 million students have less-than-adequate plumbing
- 21,100 schools serving 12 million students have less-than-adequate roofs

The National Center for Education Statistics projects that elementary and secondary enrollments will swell from 52.2 million in 1997 to 54.4 million in 2006. So as our nation grapples with modernizing older schools we will also need to build an additional 6,000 new schools to accommo-

date growing student enrollment over the next decade. We must take advantage of this building boom to introduce energy efficiency in the design, construction and operation of our nation's next generation of school buildings.

With the backlog for repairs and continued operation of older, inefficient, and often polluting equipment and school buses, our schools are wasting large amounts of energy and valuable taxpayer dollars that could be used to teach students. Our nation's schools spend over \$6 billion a year on energy. Significant opportunities exist to lower energy bills with equipment upgrades and the use of widely available energy-efficient technologies such as energy-efficient lights, motors, energy management systems and alternatively fueled school buses.

As an added benefit, these improvements can result in better lighting conditions, better indoor and outdoor air quality, and better controlled classroom temperature – all of which can improve the productivity and general well-being of students and teachers.

#### Impact of Inadequate School Facilities on Student Learning

Businesses have spent millions of dollars on understanding the link between work environment and productivity. Yet, we generally view schools as separate public institutions the same way we view correctional facilities. Current research has linked student achievement and behavior to the physical building conditions and overcrowding.



## High School Energy Audit

*The High School Energy Audit Guide is a tool for you to use with your students to take an active role in making changes in the school environment. Contact your administration and find out if your school is on the school construction or retrofit schedule for your school district. If it is, an opportunity exists for your students to complete the energy audit and make a formal presentation to the school board and administration on their energy saving recommendations. The audit is designed to use the library, and eventually the whole building as a working and living laboratory for the students to learn about energy efficiency and renewable energy. The U.S. Department of Energy will make additional school energy audit activities available before the end of the school year for those who would like to extend this project into a more comprehensive audit. For the most update activities and information, please continue to check the following web page address: <http://ww.eren.doe.gov/buildings/earthday/>.*

Decaying environmental conditions such as peeling paint, crumbling plaster, nonfunctioning toilets, poor lighting, inadequate ventilation, and inoperative heating and cooling systems can affect the learning as well as the health and the morale of staff and students. A school year is approximately 180 days. This is a lot of time to spend in an atmosphere that is not conducive to learning or teaching.

## National Science and Mathematics Content Standards and Benchmarks for Science Literacy

The content and associated activities are challenging and rigorous for high school students. The standards and benchmarks that are covered in these activities are noted in the individual teacher guides. The standards that are covered in the High School Energy Audit are as follows:

### National Science Education Standards

#### PHYSICAL SCIENCE Content Standard A Science as Inquiry

As a result of their activities in grades 9-12, all students should develop:

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

#### Content Standard B

As a result of their activities in grades 9-12, all students should develop an understanding of:

- Conservation of energy and increase of disorder
- Interactions of energy and matter

#### SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

##### Content Standard F

As a result of activities in grades 9-12, all students should develop understanding of:

- Natural resources
- Environmental quality
- Science and technology in local, national, and global challenges

## Benchmarks for Science Literacy

### Benchmark 4 – The Physical Setting

4B – The Earth - Students will understand physical concepts and principles as energy, gravitation, conservation, and radiation.

### Benchmark 5 – The Living Environment

5E – Flow of Matter and Energy - Students will understand the conservation of matter with the flow of energy in living systems.

### Benchmark 8 – The Designed World

8C – Energy Sources and Use - Students can examine the consequences of the world's dependence on fossil fuels, explore a wide range of alternative energy resources and technologies, and consider trade-offs in each. They can propose policies for conserving and managing energy resources.

## National Math Standards

### Standard 1: Mathematics as Problem Solving

In grades 9-12, the mathematics curriculum should include the refinement and extension of methods of mathematical problem solving so that all students can:

- use, with increasing confidence, problem-solving approaches to investigate and understand mathematical content;
- apply integrated mathematical problem-solving strategies to solve problems from within and outside mathematics;
- recognize and formulate problems from situations within and outside mathematics;
- apply the process of mathematical modeling to real-world problem situations

### Standard 2: Mathematics as Communication

In grades 9-12, the mathematics curriculum should include the continued development of language and symbolism to communicate mathematical ideas so that all students can:

- reflect upon and clarify their thinking about mathematical ideas and relationships;



## Assessment/Rubric

*An assessment is just one method of evaluating each student's grasp of the major concepts presented in the activities. Teachers are encouraged to use the assessments as-is or to develop their own assessments that meets the individual needs of the students. The assessments are used at the end of each activity. However, these assessments are provided as guidelines for the teacher to use in developing appropriate measurement packages. Many assessment techniques are available, including multiple-choice, short-answer, discussion, or open-ended questions; structured or open-ended interviews; homework; projects; journals; essays; dramatizations; and class presentations. Among these techniques are those appropriate for students working in whole-class settings, in small groups, or individually. The mode of assessment can be written, oral, or computer oriented. Please use these ideas and add or delete according to your needs. The tasks in this audit usually involve open-ended, problem-solving activities but some will require recall of content knowledge.*

*Included with the assessment is a standard, generic rubric. The rubric is established as guideline for performance. It is also a useful form of self-evaluation because it lets the student know what is expected for high quality work.*

- formulate mathematical definitions and express generalizations discovered through investigations;
- express mathematical ideas orally and in writing;
- read written presentations of mathematics with understanding;
- ask clarifying and extending questions related to mathematics they have read or heard about;
- appreciate the economy, power, and elegance of mathematical notation and its role in the development of mathematical ideas.

### Standard 3: Mathematics as Reasoning

In grades 9-12, the mathematics curriculum should include numerous and varied experiences that reinforce and extend logical reasoning skills so that all students can:

- make and test conjectures;
- formulate counterexamples;
- follow logical arguments;
- construct simple valid arguments;

and so that, in addition, college-intending students can:

- construct proofs for mathematical assertions, including indirect proofs and proofs by mathematical induction.

### Standard 5: Algebra

In grades 9-12, the mathematics curriculum should include the continued study of algebraic concepts and methods so that all students can:

- represent situations that involve variable quantities with expression, equations, inequalities, and matrices;
- use tables and graphs as tools to interpret expressions, equations, and inequalities;
- operate on expressions and matrices, and solve equations and inequalities;
- appreciate the power of mathematical abstractions and symbolism— and so that, in addition, college-intending students can:
  - use matrices to solve linear systems;
  - demonstrate technical facility with algebraic transformations, including techniques based on the theory of equations.

### Standard 6: Functions

In grades 9-12, the mathematics curriculum should include the continued study of functions so that all students can:

- model real-world phenomena with a variety of functions;
- represent and analyze relationships using tables, verbal rules, equations, and graphs;
- translate among tabular, symbolic, and graphical representations of functions;
- recognize that a variety of problem situations can be modeled by the same type of function;
- analyze the effects of parameter changes on the graphs of functions; and so that, in addition, college-intending students can understand operations on, and the general properties and behavior of, classes of functions.

### Standard 10: Statistics

In grades 9-12, the mathematics curriculum should include the continued study of data analysis and statistics so that all students can:

- construct and draw inferences from charts, tables, and graphs that summarize data from real-world situations;
- use curve fitting to predict from data;
- understand and apply measures of central tendency, variability, and correlation;
- understand sampling and recognize its role in statistical claims;
- design a statistical experiment to study a problem, conduct the experiment, and interpret and communicate the outcomes;
- analyze the effects of data transformations on measures of central tendency and variability; and so that, in addition, college-intending students can:
  - transform data to aid in data interpretation and prediction;
  - test hypotheses using appropriate statistics.



### Credits

The National Renewable Energy Laboratory would like to give credit to the following agencies for supplying information that used to prepare the *High School Energy Audit*:

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National Laboratory  
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U.S. Department of Energy  
**Making Cents of Your Energy Dollar: A Guide to Identifying Energy and Cost Saving Opportunities in Institutional Buildings, Volume 1 - Energy Audit**

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**In the Bank or Up the Chimney? A Dollars and Cents Guide to Energy-Saving Home Improvements**

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### Student Rubric

	Exceeds Expectations	Meets Expectations	Meets Some Expectations	Does Not Meet Expectations
Points Earned	6	4	2	0
<b>Calculations of the activities and observations that were conducted</b>	Calculations are complete, include clear writing, relevant examples, and contain very few errors	Calculations are complete, written clearly and have few errors	Calculations are incomplete, unclear, or contain several errors	No calculations of activities are included
<b>Data showing potential sources of energy savings</b>	Data is well done and includes useful information. Graphs and symbols are used	Data complete and includes a useful graph	Data is not clear or incomplete	No data is supplied
<b>Description of how the team will validate the findings</b>	Multiple validation techniques are used that produce accurate and conclusive results	Validation techniques are effective and produce conclusive results	Efforts are made to validate the information but is incomplete, irrelevant, or	There is no validation of the findings
<b>Explanation of the potential relevance or importance of the findings</b>	The relevance is clearly articulated and the explanation makes a compelling statement	The relevance of the findings is clearly articulated	The explanation or relevance is illogical or fails to communicate clearly	No explanation or relevance is offered
<b>Use of the internet to research relevant information concerning building components and energy</b>	Demonstrates the ability to research a topic without assistance using several tools	Demonstrates the ability to research a topic without assistance	Research topics with minimal assistance	Does not demonstrate the ability to research a topic
<b>Cooperative group behavior</b>	Team worked in a consistently positive mode; clear evidence of shared work and responsibility	Team worked mostly in a positive mode; effort made to include all members	Team members required careful monitoring; presentation component	Team members did not work as a team
<b>Presentation delivery</b>	Clear evidence of participation in some form by every team member; all parts well planned; strong portrayal of the teams' special suggestions	Evidence of participation by the majority of the team; good planning and execution; special interest of the team is evident	Participation by only 1 or 2 members; little evidence of group planning; special interest of team is not clearly presented	No participation by the team to prepare a presentation
<b>Technology based presentation</b>	Final project is enhanced through use of technology	Final project is partially technology based	Final project not technology based	No final project completed



## Lighting in the Library

### Overview

The purpose of the Lighting in the Library Activity is to calculate the electricity used to provide lighting in the school library and determine the feasibility of saving energy and money by using energy efficient lighting fixtures.

Your students will assume the role of an energy auditor assigned the task of assessing the current situation and making a recommendation for energy-efficient improvements. This activity requires a trip to the library, an examination of the school's energy bill, and a basic understanding of algebraic concepts as a problem solving strategy.

#### Level

Grades 8 - 12

#### Subject

Mathematics, Economics

#### Concepts

- Efficiency: getting a desired outcome lighting with the least effort and cost
- 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 of the library
- Critical thinking
- Problem solving
- Creating and giving presentations

#### Objective

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

(continued next page)

### Getting Ready

The exercise is designed in two parts. The first part consists of determining the energy consumption, operating costs, and amount of "greenhouse gases" resulting from the existing lighting fixtures. The second part entails determining the economic feasibility of retrofitting the existing fixtures with three types of energy-efficient lights.

Two primers have been prepared to help you and your students ramp up your energy, environment, and lighting knowledge relatively quickly (see appendix). In addition, helpful hints and some examples specific to each step have also been provided. Before meeting as a class about this subject, download a copy of the energy and environment primer located on the web page ([www.eren.doe.gov/buildings/earthday/](http://www.eren.doe.gov/buildings/earthday/)) chalkboard. Each student in the class should have a copy of the following:

- energy and environment primer
- student pages 1-10
- Lighting technology primer
- glossary

### Choosing the Room in the School for the Exercise

The exercise is designed for the school library; however it will work for almost any room in the school. If the school library is not available, choose a different common room, preferably one with different kinds of light fixtures with different on/off schedules. Ask the librarian or custodian to help the students determine the on/off schedule for the lights in the library. For example, there is typically one schedule for when school is in session and another for when it is out of session.

### Additional Exercises for Advanced Students

Ask the students to see if there are any rooms in the area to be studied where lights are left on for long periods of time and are not occupied. Advanced students might determine the feasibility of installing motion detectors for those rooms as an extra credit exercise. Motion detectors will automatically turn lights on and off. Costs of motion sensors could be determined by calling a local electrical wholesale house and calculating labor at 1/2 hour per switch at a cost of \$50 to \$75 per hour for an electrician's time. The savings accrue from the number of hours the lights can be turned off. The payback period for the investment in motion detectors can be calculated in the same way as the **Lighting in the Library** exercise.

### Background

Lighting typically accounts for 15 percent of the total energy bill of educational institutions nationwide. The majority of buildings were built before the 1970s and have high levels of illumination according to the design standards at the time. Most use older fluorescent fixtures with four tubes, the standard fixture used in schools and office buildings for many years. As a result, most schools spend too much on lighting bills.

Since the late 1980s, many modern fluorescent fixtures have come equipped with the more efficient T8 lamp operated by an electronic ballast. Depending on the task being performed, there are situations where the old four light fixture can be converted to a two light fixture and still provide the required amount of light. The electronic ballasts were developed to operate fluorescent tubes more efficiently



(continued)

### Materials

- Pencil, paper, and a ruler
- Tape measure
- One copy per student of the *Student Guide Primers:*
  - *All About Energy*
  - *High School Energy Inventory: Lighting Technology Overview*
- Student pages 1-10
- Glossary

### Time

Two 55-minute classroom periods.

and consume less energy when the lights are on. Older, standard ballasts consume up to 20 percent of the total amount of electricity required to operate the lamp. Therefore, a 1.2 multiplier was added to the last equation in Step 5.

Light fixtures in this exercise are typical of those installed in schools built from the 1950s to the 1980s. During this period, the standard light fixture was the 4-tube fluorescent located in the ceiling. Incandescent lighting remains the standard fixture for task lighting. The majority of exit signs use incandescent bulbs. As students will see in this exercise, these fixtures can often be replaced with newer, more efficient types of lighting that cost much less to operate.

At the same time, there are a large variety of light fixtures in schools used across the country. Some schools have been designed to use natural lighting so effectively in common rooms, such as the library, that it will be extremely difficult to reduce their lighting bills. The best way to tell if there is an opportunity to improve the lighting efficiency of a room is to calculate the "lighting index" for the room as done in Steps 9, 14, and 19. If the index is above 1.3 ( $W/ft^2$ ), there is likely an opportunity to economically reduce lighting energy consumption in the library. If the index is below 1.3, it will be more difficult to do so within a 3-year payback period but there are still many opportunities for savings and enhancing the visual environment that warrant serious consideration. Retrofitting the lighting system in older buildings, especially in institutional buildings that are illuminated above the current lighting design levels, has proven to be one of the most cost-effective energy conservation measures. The savings from lighting retrofits depend on the amount of time the lights are used during the year. For lights that are on a large percentage of the time, simple payback on the cost of replacing them is from one to three years.

### Doing the Activity

Ideally, the students would read the primers first (perhaps as homework the night before beginning the activity), and then complete the exercises in subsequent classes. Steps 1-9 should be completed in the first class period. Steps 10-22 can be completed as a combination of in-class time and homework. When the students are done, they will have enough material to prepare a presentation for the school board about their energy-efficient proposal.