OFFICE OF ENERGY EFFICIENCY
AND RENEWABLE ENERGY

Lighting In the Library
A Student Energy Audit

OFFICE OF BUILDING TECHNOLOGY,
STATE AND COMMUNITY PROGRAMS

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BUILDING TECHNOLOGY, STATE AND COMMUNITY PROGRAMS

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_2 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 accommodate 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 alot 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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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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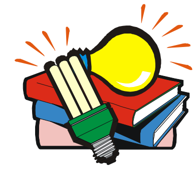
Student Rubric

	Exceeds Expectations	Meets Expectations	Meets Some Expectations	Does Not Meet Expectations
Points Earned	6	4	2	0
Calculations of the activities and observations that were conducted	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
Data showing potential sources of energy savings	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
Description of how the team will validate the findings	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
Explanation of the potential relevance or importance of the findings	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
Use of the internet to research relevant information concerning building components and energy	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
Cooperative group behavior	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
Presentation delivery	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
Technology based presentation	Final project is enhanced through use of technology	Final project is partially technology based	Final project not technology based	No final project completed

Glossary



Annual Energy Index. The ratio of the total annual energy consumption of a building or plant in millions of Btu divided by the total building area in thousands of square feet. The AEI is computed in thousands of Btu per square foot of building per annum as a way of characterizing energy usage in the building.

Air Changes per Hour. A measure of how rapidly air is replaced in a room over a period of time, usually referring to that replaced by outside air.

Air Conditioning. The process of treating air to meet the requirements of the conditioned space by controlling simultaneously its temperature, humidity, cleanliness and distribution.

Air Conditioners. Systems that control the temperature and humidity of air using electricity to power fans and pumps called compressors. Air conditioners use a refrigeration cycle to extract heat from indoor air and expel the heat outside.

Air Handler. Mechanical ventilation systems contained inside large sheet metal boxes. Air handlers have fans inside that supply air to rooms through ducts connected to them. Air handlers recirculate air inside buildings and provide fresh air from outside. They usually contain coils of copper tubing with hot or cold water inside the tubing. When fans blow air across the tubes containing hot water, heat is transferred to the air blown through the ducts for heating. When fans blow air across the tubes containing cold water, heat is removed from the air blown through the ducts for cooling.

Air Infiltration. The process by which outdoor air leaks into a building by natural forces (pressure driven) through cracks in walls and around doors and windows.

Ballast. Devices for starting and controlling the electricity used by a lamp. Ballasts also protect electrical circuits in lighting systems. A ballast typically consumes 10 percent to 20 percent of the total energy used by a light fixture and lamp.

Boilers. Heating systems that burn natural gas, oil, coal, or sometimes wood or waste paper as fuel to heat water or produce steam. The heated water or steam is then circulated in pipes to devices called radiators and convectors. Radiators are made of a series of large iron grids or coils, while convectors are usually made of networks of non-iron metal tubes with steel fins surrounding the tubes. Hot water or steam can be circulated in a boiler system by pressure and gravity, but pumps are typically used to control the circulation more efficiently. Boilers sometimes also provide hot water for showers, cleaning, or other uses in schools.

British Thermal Unit (Btu). The amount of energy required to raise one pound of water one degree Fahrenheit.

British Units. A unit of measure of energy and other scientific phenomena based on the British Engineering System. For example, temperature is measured in degrees Fahrenheit in British units.

Caulking. A flexible material made of latex or silicone rubber used to seal up cracks in a wall or between window frames and door frames and walls. Caulking reduces the infiltration of outside air into a building and makes it more energy efficient and reduces maintenance due to wear from rain, sun, and other weather related stress on a building.

Celsius or Centigrade. The SI temperature scale on which the freezing point of water is zero degrees and the boiling point is 100 degrees at sea level.

Chillers. Refrigeration machines used in some schools to provide cool air. They use a refrigeration cycle that extracts heat from water and rejects it to outdoor water. Chillers produce cold water that is fed through coils of copper tubing contained in *air handlers*. Air handlers contain fans that blow air across the copper tubes containing cold water. This cools the air, which is then delivered to rooms through ducts.

Controls. Devices, usually consisting of electronic components, used for regulating machines; for example, a thermostat is a control that regulates the heating and cooling equipment in a building.

Cooling Load. Calculated on a monthly, yearly or seasonal basis by multiplying the overall thermal transmittance (U-value) of a building (in Btu per hour per degree F per square foot) times total building surface area times 24 hours/day times the number of cooling degree days per time period desired.

Degree Days, Cooling. A method of estimating the cost of cooling a residential home based on the local climate, and is usually expressed in the average number for an entire year. The degree day value for any given day is the difference between the mean daily temperature and 65 F when the temperature is greater than 65 F. The total for the year is the sum of the average daily value for 365 days a year.

Degree Days, Heating. A method of estimating the cost of heating a residential home based on local climate. Like cooling degree days, heating degree days are usually expressed in an average number for a year. The degree day value for any given day is the difference between 65°F and the mean daily temperature when the temperature is less than 65 F. Degree days are a measure of the severity of the heating season and are directly proportional to fuel consumption.

Ducts. An enclosed tube or channel, usually made of sheet metal or flexible plastic, for delivering air to rooms in a building. Supply ducts bring treated air from air handlers, consisting of warm air in the winter to warm the rooms and cool air in the summer for air conditioning. Old ducts that lie in unconditioned areas of a building often leak significant quantities of air and can result in large energy losses in a building.

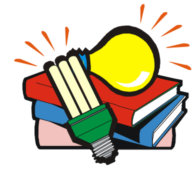
Efficiency. The ratio of the energy used for a desirable purpose, such as heating or lighting, compared with the total energy input, usually expressed in percent.

Electricity, or Electric Energy. A basic form of energy measure as kilowatt-hours (kWh). For conversion, one kWh of electricity is 3413 Btu's. Electricity is generated in electric power plants, most of which burn fossil fuels to produce heat, which is converted to electricity in a generator. The process is not 100% efficient, and it takes, on average, about 11,600 Btu of heat energy from fossil fuels to generate 1 kWh of electricity.

Envelope, or Building Envelope. The external surfaces of a building, including as walls, doors, windows, roof and floors in contact with the ground.

Fahrenheit: The temperature scale in "English" units used in the United States and England on which the freezing point of

Glossary



water is 32 degrees and the boiling point of water is 212 degrees at sea level.

Foot-candle. A unit of measure of the intensity of light. A foot-candle is a lumen of light distributed over a 1-square-foot (0.09-square-meter) area.

Fossil Fuels. Fuels consisting of coal, oil, natural gas, propane, and those derived from petroleum such as gasoline that are derived from prehistoric plants having been "fossilized" by remaining for eons under pressure underground. These fuels are called hydrocarbons because the hydrogen and carbon in the fuels combines with oxygen in the air to release heat energy.

Global Warming: Possible accelerated increase in the Earth's temperature caused by excess production of greenhouse gases due, in large part, to the depletion of forests, air pollution from automobiles, making electricity via fossil fuels and burning fossils fuels for other needs.

Greenhouse Effect: The trapping of the sun's heat. In houses and cars it can be caused by glass. In the Earth's atmosphere it is a naturally occurring phenomenon resulting from the interaction of sunlight with greenhouse gases (such as CO_2 and CFCs). This interaction helps maintain the delicate balance of temperature and breathable air necessary for life as we know it.

Heat Capacity (rc_p) per unit volume of air. As used in this document, heat capacity is the amount of heat energy it takes to increase the temperature of one cubic foot of air by one degree Fahrenheit.

Heat Pumps. Energy-efficient heating and cooling systems that use the refrigeration cycle to move heat from one source (air, water, or the Earth) to another.

Heat Transfer. The movement of heat energy always flowing in the direction from hotter to colder through materials such as walls or windows in a building. The flow of heat energy is usually measured in terms of Btu/h, and is equal to the area times the temperature difference divided by the thermal resistance (R-value).

Heating, Ventilating, and Air-Conditioning (HVAC). Systems that provide heating, ventilation and/or air-conditioning within with buildings.

Humidity. The amount of water vapor in the air, and usually expressed in terms of percent relative humidity. This figure represents the amount of moisture the air actually contains divided by the total amount of moisture that it is physically possible for the air to hold at a particular temperature. In other words, at 100% relative humidity condensation will occur, and if outdoors, it will start raining.

Insulation. Material used to increase the resistance to heat flow. In buildings, three types of insulations are most common: batts usually made from fiberglass that fit between wall studs or roof joists; loose-fill usually made from shredded newspaper (treated cellulose) that is blow into wall cavities or attics; and rigid foam boards usually made from petrochemicals (polyisocyanurate) that are nailed into walls, under roofs, or just below outside wall coverings like siding or sheathing.

Kilowatt (kW). A unit of electric power equal to one thousand watts.

Kilowatt Hour (kWh). A unit of electric energy equal to one thousand watts over a period of one hour.

Lamp. A generic term for a non-natural source of light. In fluorescent fixtures, lamps also refer to the part of the glass tubes that light up when electricity is turned on.

Lumen. An SI unit of light output from a source such as a lamp or light fixture. Commonly, the efficacy of electrical lighting is gauged by the number of "lumens per watt" of light output per unit of electric power input listed on the lamp manufacturers' label.

Occupied Hours. The time when a building such as a school is normally occupied with people working or attending classes.

Power. The time rate of doing work, which in SI units is measured in Watts, and in British units, is measured in British thermal units per hour (Btu/h). In the United States, we usually refer to electric power in terms of Watts and heat flow in terms of Btu/h.

Simple Payback Period. The length of time required for an investment to pay for itself in energy savings.

SI Units. Units of measuring energy and other scientific phenomena based on the International System (or SI for Systme Internationale d'Unites). For example, temperature is measured in degrees Celsius in SI units.

Therm. A unit of gas fuel containing 100,000 Btu's. Most natural gas bills are charged according to the number of therms consumed.

Thermal Resistance (R-value). A term used to measure an insulating material's resistance to the flow of heat, and usually measured in units of square feet x hour x degrees F per Btu. Thermal resistance is the reciprocal of thermal conductance (U-value). R-values can be added together to obtain an overall value for an insulated wall or ceiling.

Thermostats. Heating and cooling systems' controls that monitor the temperatures of buildings and allow temperatures to be maintained or changed automatically or manually.

U-value (Thermal Transmittance): Overall coefficient of heat expressed in British units as Btu's per square foot per hour per degree F. The lower the U-value, the less heat is transferred. Numerically, it is equivalent to the reciprocal of the sum of the thermal resistance of materials measured in their R-values.

Unoccupied Hours. The time when a commercial, industrial, or institutional building is normally empty of people, except maintenance people such as janitors.

Ventilation. Air supplied to buildings from outdoors plus air recirculated from indoors that has been filtered and treated by heating, cooling, and/or air handling equipment.

Watt. An SI unit of measurement for power. In the United States, a watt almost always refers to electric power, and is equal to the amount of power (energy per second) supplied when one ampere of electric current flows at a potential difference of one volt. For conversion to British units, 1,000 watts equals 3,413 Btu's.

Weatherstripping. Materials such as metal, plastic, or felt strips designed to seal spaces between windows and doorframes to prevent infiltration of outside air into a building.