

01 Heat and Energy: The Basics

Time

5 sessions, 1–2 hours each.

Note: Each part of this lesson can be used as a stand-alone lesson for teachers with time constraints.

Materials

Wattmeter, thermometers, hot plate, stopwatch, pot for boiling water, rubber bands, calculators.

Resources

Telephone, fax machine, utility bills, *Conventional Storage Hot Water Heaters* sheets, BTUs data sheet (http://tonto.eia.doe.gov/kids/energy.cfm?page=about_energy_conversion_calculator-basics#unitsexplained), Spec sheets and Energy Guides on conventional water heaters, Fuel Cost Spreadsheet, *Shades of Green*, chapter 11, page 95 (this and related publications available at www.ybshadesofgreen.org)

Brief description

■ Nationally, families who live significantly below the poverty line spend as much as 19 percent of their total income on utility bills. In some areas of the United States, as many as 25 percent of evictions of low-income renters were due to inability to pay utility bills. ■ How do we make recommendations to our community, family, friends, and neighbors on saving energy without our understanding how energy works?

■ We need the skills to understand how our major costs, such as home heating and cooling, are measured. We are going to conduct some experiments to learn the facts about the heat and energy so we can differentiate between the hype of slick advertisements and the reality of calculating and measuring energy costs. ■ If we were put in charge of purchasing a new hot water heater, how would we choose the best type for a low-income family? The salesman at the appliance store has informed us that the electric-powered, domestic hot water tank is the most efficient. The question we are going to ask is: Is that really the best one for us?

Framing question

Can we prevent homelessness in our community by better understanding energy usage and cost?

Know, understand, be able to do

Know	Understand	Be able to do
First law of thermodynamics	Energy is neither created nor destroyed.	Describe how energy moves from place to place and can change forms
Kinetic energy	Kinetic energy is the energy of motion. The faster the molecules within a material vibrate, the higher the temperature of the material.	Use a thermometer and describe its readings as a measure of kinetic energy
Delta T (ΔT)	ΔT as the temperature difference between two zones. Where there's a temperature difference, heat transfer will occur.	Measure ΔT with a thermometer and describe how it is the value used in many heating- and cooling-load calculations in buildings.
Thermal efficiency	The quantity of energy put into an appliance, depending on the fuel type can differ from the useful energy the appliance delivers.	Describe the efficiency of an appliance in terms of a percentage: what energy is lost in the exhaust versus what is usable.
British thermal unit (Btu)	Btu defines the amount of heat it takes to raise 1 pound of water 1°F at sea level. This is the unit used to describe the heat value of fuels as well as heating equipment.	Describe the power of fuels in terms of Btu (i.e., kilowatt hour of electricity, therms of natural gas, gallon of propane or #2 fuel oil.)
Conventional water heaters	How they work, peak hour demand, energy factors, purchase price vs. annual operating costs, first hour rating (FHR).	Size, compare costs, and determine payback on different types of conventional water heaters

Standards and competencies

Standards*	Other Competencies**
<i>Example: CA Department of Education, 1998 Science Content Standards, Physics Grades 9-12, Part 3. Heat and Thermodynamics</i>	<i>Example: NCCER Your Role in the Green Environment, Chapter 1.3.2 Reducing Energy Use</i>
<p>* Education World's Web site contains links to some voluntary national and to all required state standards: http://www.educationworld.com/standards/index.shtml</p> <p>** Don't forget to map your lessons to the U.S. Department of Labor Employment and Training Administration's SCANS competencies, occupational ones such as HBI's Pre-Apprenticeship Certificate Training (PACT), and your program's civic and leadership development standards.</p>	

Final product, presentation, or demonstration

Students will learn about conventional storage hot water heaters through their reading and discussion of the supplementary data sheet. They will complete math work in their journals to practice the techniques used to predict energy costs and will use critical thinking skills to compare domestic hot water heating appliances and make predictions of their comparative operating costs. Students will conduct an experiment that demonstrates the first law of thermodynamics using an electrical kilowatt meter, hot plate, measuring cup, thermometers, and calculators. They will describe in an oral presentation the step-by-step process of how the experiment was conducted, how it works, and how it demonstrates the intended concept. Students will orally present their findings and a best case of providing a conventional backup hot water heater (in *Shades of Green*, chapter 11, page 95) for a low-income family. Students will complete and turn in a lab report.

Tasks and activities: The teaching and learning

Session 1 2 hours

20 minutes

- Introduce framing question and brief description of module 1. Ask students to write for five minutes in their journals to get their juices flowing. Ask them to reflect on how people become homeless, what Americans' average monthly utility costs are, and what their initial thoughts on the framing question are. Ask students to generate questions; write these down on the board and address them throughout the week.

10 minutes

- Discuss the first law of thermodynamics, how energy can neither be created nor destroyed, and ask students to challenge the theory. Introduce common energy concerns, like gasoline for automobiles, and discuss where the energy goes, e.g., energy from gasoline goes into the heat and motion of the vehicle.

>> Session 1, continued

20 minutes

- Introduce Btu, the energy required to raise a pound of water 1° at sea level.
- Discuss the Btu quantities found in different types of fuels and their costs:
 - 1 gallon of heating oil = 139,000 Btu
 - 1 cubic foot (.01 therms) of natural gas = 1,028 Btu
 - 1 gallon of propane = 91,000 Btu
 - 1 kWh of electricity = 3,412 Btu
- Compare costs of units of fuel using Fuel Cost Spreadsheet (at the end of this module) as an example. Ask students: Based on values found in spreadsheet example, ask students which one is the most expensive/least fuel used to run hot water heaters.

10 minutes

- Introduce the concept of delta T.

50 minutes

- Distribute Conventional Storage Water Heater teacher resource sheets (pages 9–14 of this module). Read them as a class, complete the math problems included, and go over any questions students have along the way.

10 minutes

- Review. Answer questions.

Session 2 (2 hours)**20 minutes**

- Distribute sample copies of utility bills and discuss the units of measurement used for billing (i.e., natural gas therms, kilowatt-hours of electricity, and gallons of fuel) and their costs.
- Ask students to guess how their family's utility bills compare to these samples.

60 minutes

- Ask students to research spec sheets and energy guides from manufacturers on the rated efficiency of conventional storage water heaters by consulting the Web sites of Bradford White¹, Rheem², and State Industries³ and downloading spec sheets and information that provide efficiency (EF) ratings for specific products. Have students call these manufacturers and request this information if it is not available on the manufacturer's Web site.

1 www.bradfordwhite.com

2 www.rheem.com

3 www.statewaterheaters.com

>> Session 2, continued

30 minutes

- Demonstrate the critical thinking involved in comparing domestic hot water heating appliances and making predictions of their comparative operating costs. Model this for the class, and then have students work in their journals independently. Refer to Conventional Storage Water Heater data sheets.

10 minutes

- Review. Answer questions.

Session 3 (1 hour, 50 minutes)**10 minutes**

- Ask students to hand in their journal exercises (the comparisons of water heating appliances) from previous session. Go over the math problems as a class.

10 minutes

- Introduce scientific method and hand out lab report sheets.
- Introduce wattmeter, thermometers, and hot plate.

60 minutes

- Conduct an experiment to prove the first law of thermodynamics. Using a wattmeter, measure the consumption and kilowatt-hours (kWh) the hot plate consumes to raise water temperature and cross-compare that consumption into Btu.
- Place a pot of water equaling 1 pound (16 ounces or 2 cups or 1 pint) to hot plate. Measure the temperature of the pound of water and start a stopwatch. Record how long it takes to raise the water temperature 10° and cross-compare the consumption data of the wattmeter.
- Discuss the difference between the data found and the students' expectations and the possible reasons for any discrepancies (e.g., loss of heat around the pot or wire resistance in the cord).

10 minutes

- Discuss any discrepancies and relate them thermal efficiency and the first law of thermodynamics. As an example, revisit thermal efficiency of combustion and the heat lost up smokestacks.

10 minutes

- Clean up.

10 minutes

- Review expectations for the oral presentations the students will prepare for session 4 (see session 4 for details). Answer questions.

Session 4 (1 hour, 40 minutes)**60 minutes**

- Students describe in an oral presentation the step-by-step process of the experiment and how it demonstrates the intended concept.

30 minutes

- Reflect on presentations. Discuss the relationship between lab findings and the practical recommendations for replacement hot water heating appliances in your community.

10 minutes

- Review. Answer questions.

Session 5 (60 minutes)**60 minutes**

- Students hand in lab reports.
- Students complete Reflection and End-of-Project Self-Assessment (page 7).
- Group reflection. What worked? What didn't work? Discuss findings and community building possibilities.
- Review bonus exercise: Ask students to write a letter to their housing partner recommending the installation of a new hot water heater of their choosing. The logic behind their selection will include the calculations and research from this module, and will reflect what they have learned about energy usage and costs.

Final product / Performance assessment

Criteria	Does not meet expectations (substandard performance)	Meets expectations (standard performance)	Exceeds expectations (exceptional performance)
<p>Comprehension</p> <p>The student selects math, measurement, data sources, and record-keeping techniques that meet the requirements of the project.</p>	<p>Student does not demonstrate selection of effective measurement tools, record-keeping technique, or data sources to achieve the goal as defined in the project guideline.</p>	<p>Student selects effective measurement tools, record-keeping technique, or data sources to achieve the goal as defined in the project guideline.</p>	<p><i>In addition:</i> Student has an in-depth understanding of the concepts and has selected tools, techniques and materials that enhance their understanding.</p>
<p>Application</p> <p>The student can apply new understanding to new situations.</p>	<p>Student does not demonstrate ability to apply theories, principles, and skills to new problems.</p> <p>Student is unable to modify technique to fit new challenges.</p>	<p>Student demonstrates an ability to apply theories, principles, or skills to new situations and problems.</p>	<p><i>In addition:</i> Student actively seeks new situations to apply knowledge. Student provides multiple examples of how principles can be applied.</p>
<p>Oral presentation</p> <p>Student has a firm grasp of the content and can present and deliver that knowledge.</p>	<p>Student disregards important details and presents very little supporting content.</p>	<p>Student's presentation increases audience's knowledge of the experiment through complete information and basic details with supporting content.</p>	<p><i>In addition:</i> Student's presentation significantly increases audience's knowledge of the experiment through complete information well supported with details. Oral presentation is compelling and fluently delivered.</p>
<p>Analysis</p> <p>Student can organize knowledge into components and articulate this in their lab report and in the oral presentation so that its structure can be applied to new situations. Student has used scientific method in experimentation and can clearly communicate, in formal language, observations, hypothesis, and problems encountered.</p>	<p>Student does not demonstrate a clear understanding of the concepts, theories, and math of this module.</p> <p>Student's analysis does not include step-by-step progression of problem under study.</p> <p>Student's report lacks components or is not clearly articulated.</p>	<p>Student demonstrates a clear understanding of the concepts, theories, and math of this module.</p> <p>Student's analysis includes step-by-step progression of problem under study. The student can identify relationships between concepts. Lab report is clear and thorough.</p>	<p><i>In addition:</i> Student uses the analysis to teach the definitions, laws, and principals under study and is able to differentiate between similar definitions, laws, and principles.</p> <p>Student demonstrates additional effort in lab report or oral presentation to advance the applicability of the findings.</p>
<p>Community building</p> <p>Student can use the knowledge gained in this module to create an independent community action, event, or educational material that works to positively effect change.</p> <p>Suggested additional community-based activities include canvassing neighbors; educating family members; arranging presentations or discussions with community groups; sending letters to elected officials; arranging meetings with school committees, city counselors, or mayor; taking a poll in a public place; making a petition and gathering support, and meeting with homeowners of YouthBuild homes.</p>	<p>Student does not complete any project of any kind.</p>	<p>Student's project reflects a broader awareness of issues that affect the community. Student collaborates effectively with community members and institutions to implement the project.</p>	<p>Student's project demonstrates a commitment to addressing the issue at hand. Student follows through with ongoing work and empowers others to join in and contribute to the process of working towards change.</p>

Reflection and End-of-Project Self-Assessment

I saw:

I learned:

I thought about:

I heard:

I completed the following tasks during the project:

I used the following mathematic principles and formulas on this project:

As a result, I learned the following about heat:

As a result, I learned the following about building and remodeling techniques:

As a result, I learned the following about conducting an experiment:

As a result, I learned the following about presenting to an audience:

I can explain the relationship between thermodynamics and energy efficiency techniques in this way:

Student lab report

Title

- The title should be brief and concise, yet descriptive.

Statement of the problem

- What question(s) are you trying to answer?
- Include any preliminary observations or background information about the subject.

Hypothesis

- Write a possible solution for the problem.
- Make sure this possible solution is a complete sentence.
- Make sure the statement is testable.

Materials

- Make a list of ALL items used in the lab.

Procedure

- Write a paragraph (using complete sentences) that explains what you did in the lab.
- Your procedure should be written so that anyone else could repeat the experiment.

Results (data)

- This section should include any data tables, observations, or additional notes you make during the lab.
- You may attach separate sheets as necessary.
- All tables, graphs, and charts should be labeled appropriately.

Conclusions

- Accept or reject your hypothesis.
- Explain why you accepted or rejected your hypothesis using data from the lab.
- Include a summary of the data—averages, highest, lowest, etc.— to help the reader understand your results.
- List one thing you learned and describe how it applies to a real-life situation.
- Discuss possible errors that could have occurred in the collection of the data (experimental errors).

Teacher Resource Sheet

Conventional Storage Water Heaters

Conventional storage water heaters are the most popular type of water heating system for the home. Here you'll find basic information about how storage water heaters work and what criteria to use when selecting the right model.

When we think about how much of our money is spent on energy, we think of the things we see around the house, such as the television, lights, air conditioning, and mobile phone chargers, but . . .

Q: What about the expense of heating water?

The answer: 25 percent of each energy dollar goes toward heating water.

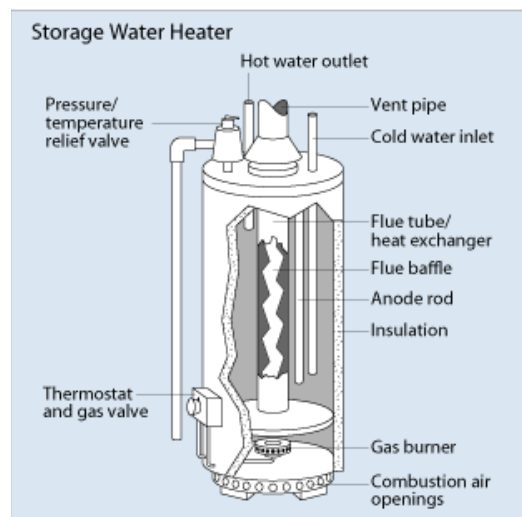
If you wanted to replace your family's existing water heater with the same exact model you probably couldn't - and you probably wouldn't want to.

If you were able to purchase a more efficient water heater that will save money spent on energy each month, would it be worth it? Or should you just buy the least expensive one? You shouldn't just consider the initial purchase price—think about how much it costs to operate. You could save hundreds of dollars in the long run.

Look at it this way: Some cars get 12 miles to a gallon, while more efficient vehicles can go 30 miles or more on a gallon of gas. In the same way, some water heaters use energy more efficiently. Buy one of those and you'll spend less money each month to get the same amount of hot water.

How conventional storage water heaters work

A single-family storage water heater offers a ready reservoir—from 20 to 80 gallons—of hot water. It operates by releasing hot water from the top of the tank when you turn on the hot water tap. To replace that hot water, cold water enters the bottom of the tank, ensuring that the tank is always full.



Source: www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12980

Conventional storage water heater energy sources include natural gas, propane, fuel oil, and electricity. Natural gas and propane water heaters basically operate the same. A gas burner at the bottom of the tank heats the water. A thermostat, like a light switch, opens the gas valve as the water temperature falls. The valve closes when the temperature rises to the thermostat's set point. Oil-fired water heaters work the same way, but they have power burners that mix oil and air in a vaporizing mist, ignited by an electric spark. Electric water heaters have one or two electric elements, like a toaster, each with its own thermostat. With two electric elements, a standby element at the bottom of the tank maintains the minimum

thermostat setting while the upper demand element provides hot water recovery when we are using a lot of hot water (a long shower, for example).

Selecting a storage water heater

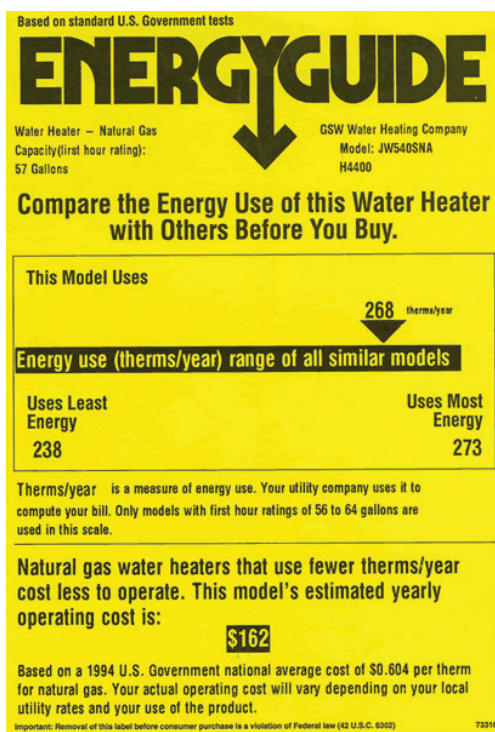
Price. The lowest-priced storage water heater may be the most expensive to operate and maintain over its lifetime.

Size. While an oversized unit may seem better, it carries a higher purchase price and increased energy costs because water is constantly heated in the tank, energy can be wasted even when a hot water tap isn't running. This is called *standby heat loss*.

Tank or no tank. Only tankless water heaters—such as demand water heaters¹ and tankless coil water heaters—avoid standby heat losses. However, you can find some storage water heater models with heavily insulated tanks, which significantly reduce standby heat losses, lowering annual operating costs. Look for models with tanks that have a thermal resistance (R-value) of R-12 to R-25.

Sizing storage and heat pump (with tank) water heaters

To properly size a storage water heater for your home, look at the water heater's first hour rating (FHR). The first hour rating is the amount of hot water in gallons the heater can supply per hour (starting with a tank full of hot water). FHR depends on the tank capacity, source of heat (burner or element), and the size of the burner or element.



The EnergyGuide Label lists the FHR in the top left corner as “Capacity (first hour rating).” The Federal Trade Commission requires an EnergyGuide Label on all new conventional storage water heaters². Product literature from a manufacturer may also provide the first hour rating. Look for water heater models with a first hour rating within 1 or 2 gallons of your peak hour demand—the daily peak 1-hour hot water demand for your home.

To estimate your peak hour demand:

1. Determine during which hour of the day you use the most hot water in your home. Keep in mind the number of people living in your home.
2. Use the worksheet below to estimate your maximum usage of hot water during this one hour of the day—this is your peak hour demand. (Note that the worksheet does not estimate total daily hot water usage.)

1 http://energysavers.gov/your_home/water_heating/index.cfm/mytopic=12820

2 http://energysavers.gov/your_home/water_heating/index.cfm/mytopic=12980

>> *Teacher Resource Sheet: Conventional Storage Water Heaters, continued*

The worksheet example shows a total peak hour demand of 46 gallons. Therefore, this household would need a water heater model with a first hour rating of 44 to 48 gallons.

Worksheet ▶ **Estimating peak power demand — First hour rating**

Use	Average gallons of hot water per usage		Times used during peak hour		Gallons used during peak hour
Shower	12	×	_____	=	_____
Bath	9	×	_____	=	_____
Shaving	2	×	_____	=	_____
Hands and face washing	4	×	_____	=	_____
Hair shampoo	4	×	_____	=	_____
Hand dishwashing	4	×	_____	=	_____
Automatic dishwasher	14	×	_____	=	_____
Food preparation	5	×	_____	=	_____
Wringer clothes washer	26	×	_____	=	_____
Automatic clothes washer	32	×	_____	=	_____
Peak hour demand				=	_____

Example: Estimating peak hour demand

3 showers	$12 \times 3 = 36$
1 shave	$2 \times 1 = 2$
1 shampoo	$4 \times 1 = 4$
1 hand dishwashing	$4 \times 1 = 4$
Peak hour demand	= 46

This worksheet assumes no water conservation measures.

Adapted from information from the Air Conditioning, Heating, and Refrigeration Institute

Now that we have established the first hour demand of our conventional water heater, we can start to estimate the annual operating costs of different models based on our fuel options by calculating the total Btu your home requires annually by completing the worksheet below to estimate the weight of the water we need to heat.

Worksheet ► Estimating Btu demand per day

Use	Average gallons of hot water per usage	Times used during one hour	Gallons used in one hour	Pounds per gallon	Total weight of gallons used in one day	ΔT
Shower	12	×	_____ = _____	×	8.33 = _____	64
Bath	9	×	_____ = _____	×	8.33 = _____	64
Shaving	2	×	_____ = _____	×	8.33 = _____	64
Hands and face washing	4	×	_____ = _____	×	8.33 = _____	64
Hair shampoo	4	×	_____ = _____	×	8.33 = _____	64
Hand dishwashing	4	×	_____ = _____	×	8.33 = _____	64
Automatic dishwasher	14	×	_____ = _____	×	8.33 = _____	64
Food preparation	5	×	_____ = _____	×	8.33 = _____	64
Wringer clothes washer	26	×	_____ = _____	×	8.33 = _____	64
Automatic clothes washer	32	×	_____ = _____	×	8.33 = _____	64
Total daily demand = _____				Total weight per day = _____		

Because the earth's temperature is fairly constant and most of our drinking water comes from underground sources (e.g., a well or water main), we can estimate that the average incoming water temperature in our homes is 56°F. Furthermore, we are going to average the temperature of the hot water we are heating in our water heater's thermostat at 120°F. This will leave us with a ΔT of 64°. To estimate Btu, use the following equation:

$$\Delta T \times (\text{total pounds per day}) = \text{Btu per day}$$

For example:

$$64 (\Delta T) \times 100 (\text{lbs.}) = 6400 \text{ Btu per day}$$

The energy factor

The energy factor (EF) indicates a water heater's overall energy efficiency based on the amount of hot water produced per unit of fuel consumed over a typical day. This includes the following:

- Recovery efficiency—the efficiency of heat transfer from the energy source to the water (i.e., the exhaust pipe—or flue pipe—carrying some of the heat (Btu) of the fuel up the chimney).
- Standby loss—the percentage of heat loss per hour from the stored water compared to the heat content of the water (water heaters with storage tanks)
- Cycling loss—the loss of heat as the water circulates through a water heater tank or inlet and outlet pipes.

The higher the EF, the more efficient the water heater. However, a higher EF values doesn't always mean lower annual operating costs, especially when you compare different fuel sources, as demonstrated in the example below.

Example ► Calculating annual costs

For gas and oil water heaters

You need to know the unit cost of fuel by Btu (British thermal unit) or therm. (1 therm = 100,000 Btu)

$$\frac{365 \times 41045 \text{ (Btu)}}{\text{EF} \times \text{Fuel Cost (Btu)}} = \text{estimated annual cost of operation}$$

OR

$$\frac{365 \times 0.4105}{\text{EF} \times \text{Fuel Cost (Therm)}} = \text{estimated annual cost of operation}$$

Example: A natural gas water heater with an EF of .57 and a fuel cost of \$0.00000619/Btu

$$\frac{365 \times 41045}{.57 \times \$0.00000619} = \$163$$

For electric water heaters, including heat pump units

You need to know or convert the unit cost of electricity by kilowatt-hour (kWh).

$$\frac{365 \times 12.03 \text{ (Btu)}}{\text{EF} \times \text{Electricity Cost by kWh}} = \text{estimated annual cost of operation}$$

Example: A heat pump water heater with an EF of 2.0 and a electricity cost of \$0.0842/kWh

$$\frac{365 \times 12.03}{2.0 \times \$0.0842} = \$185$$

Comparing costs and determining payback

Once you know the purchase and annual operating costs of the water heater models you want to compare, you can use the table below to determine the cost savings and payback of the more energy-efficient model(s).

Models	Price of Water Heater	EF	Estimated Annual Operating Cost
Model A			
Model B (higher EF)			
Additional cost of more efficient model (Model B)			Price of Model B – Price of Model A = \$Additional Cost of Model B
Estimated annual operating cost savings (Model B)			Model B Annual Operating Cost – Model A Annual Operating Cost = \$Model B's Cost Savings Per Year
Payback period for Model B			\$Additional Cost of Model B/\$Model B's Cost Savings Per Year = Payback period/years

Example ► Comparing costs

Models	Price of water heater	EF	Estimated annual operating cost
Model A	\$165	.54	\$166
Model B (higher EF)	\$210	.58	\$155
Additional cost of more efficient model (Model B)			$\$210 - \$165 = \$45$
Estimated annual operating cost savings (Model B)			$\$166 - \$155 = \$11$ per year
Payback period for Model B			$\$45 / \11 per year = 4.1 years

Fuel cost spreadsheet

Fueltype	Fuel unit	Fuel price per unit (dollars)	Fuel heat content per unit (Btu)	Fuel price per million Btu (dollars)	Fuel price per 100 thousand Btu (dollars)
Fuel oil (#2)	Gallon	\$4.71	138690	\$33.96	\$3.34
Electricity	Kilowatt-hour	\$0.15	3412	\$43.96	\$4.40
Natural gas 1	Therm	\$1.77	100000	\$17.7	\$1.77
Propane	Gallon	\$3.00	91333	\$32.85	\$3.29