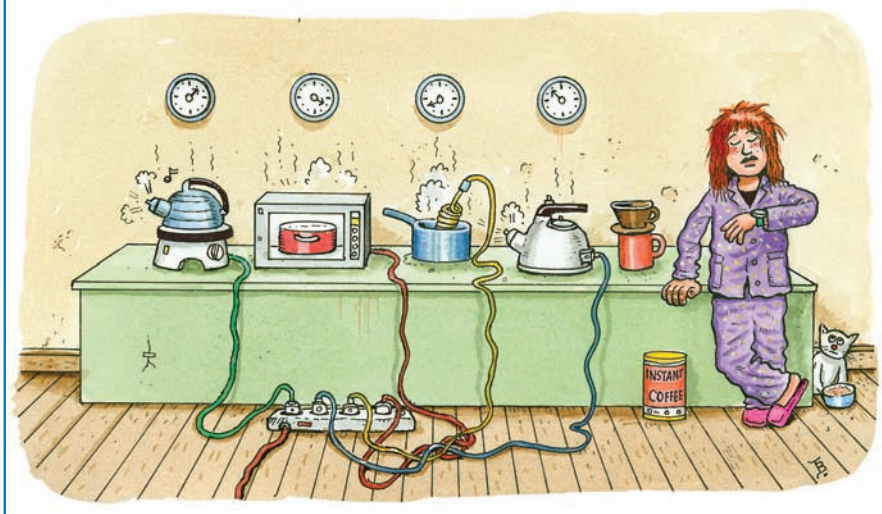
Section 9

Comparing Energy Consumption: More for Your Money

What Do You See?



Learning Outcomes

In this section, you will

- **Measure** and compare the energy consumed by appliances.
- **Compare** the costs of operating a variety of electrical appliances in terms of power ratings, amount of time each appliance is used, and billing rate.
- **Distinguish** among the three ways of heat transfer.

What Do You Think?

Some hot-water heaters and furnaces for homes are more than 90% efficient.

- **If high-efficiency appliances cost more, are they worth the added cost?**

Record your ideas about this question in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

Investigate

You will be heating up water three different ways in this section and comparing the energy, time, and costs for each.

1. Place 250 mL of cold tap water in a beaker made of heat-resistant glass. Make sure the outside of the beaker is dry so it does not slip from your grasp. Measure the temperature of the water.

a) Record the temperature of the water in your log.

b) Record the quantity of water in milliliters and grams. (1 mL of water has a mass of 1 g.)

2. Place the beaker of water in a microwave oven of known power, in watts. Mark the time at which the oven is turned on at its highest power level. After two minutes, stop the time measurement. Carefully check that the beaker is not too hot to grasp and remove the beaker from the oven, stir the water, and check the water temperature, all as quickly as possible.

a) Record the power rating of the microwave, the amount of time it was on, and the final temperature of the water in your log.

b) Why is it important to complete the temperature measurement as quickly as possible?

3. Prepare an identical heat-resistant beaker containing the same amount of cold tap water, preferably at the same original temperature as the water used above.

a) Record the mass and temperature of the water in your log.

4. Have ready a hot plate that has not been turned on (a "cold" hot plate) and that has a known power rating, in watts. Also have ready a clock or stopwatch capable of measuring time, in seconds, for an interval of several minutes. Place the beaker of cold water on the hot plate, and mark the time at which the hot plate is turned on at its highest setting. Gently stir the water while it is heating and monitor the temperature of the water. When the temperature of the water has increased to the value of the water from the microwave, mark the time and shut the hot plate off.

a) Record the power of the hot plate, the time required to heat the water, and its final temperature in your log.

5. Repeat the process a third time with an immersion heating coil.

a) Record all your observations in your log.

6. Calculate the energy used by each appliance to cause equal temperature increases in equal amounts of water. Recall:

Energy (in joules) = power (in watts) × time (in seconds)

$$E = Pt$$

a) Show your calculations in your log.

b) Which appliance is the "winner"?

7. Choose a way to express a comparison of the performance of the three appliances.

a) Was the method used to compare the three appliances fair? How could the fairness be improved?

b) The beaker that served as the container for the water also was heated by the three appliances. How did the method you used affect the outcome of the comparison? Might another kind of container be more or less effective to use with either appliance; for example, might using a metal pan as the container on a hot plate make the hot plate perform more efficiently? Explain your answer.

8. You measured the time that each appliance was used and calculated the energy used. You can also calculate the expense of that energy. To calculate the expense of running an electrical appliance you can use the following equation.

   Cost = energy × price per unit of energy

   Energy can be expressed in joules, which are equivalent to watt-seconds. However, electricity is usually priced by the kilowatt-hour. Converting from watt-seconds to kilowatt-hours (kW • h) will require you to convert the time to hours and the watts to kilowatts.

   $kW \bullet h = 1000\ W \times 3600\ s = 3{,}600{,}000\ W \bullet s$

   a) Calculate the cost of using each appliance to heat the water. Assume that the cost of electricity is 10.40 cents per kilowatt-hour.

   b) Does the cost difference seem significant? Explain your answer.

9. In a previous section, you estimated the time that an appliance is used, and the amount of energy required to use it for one month. Now you will calculate the expense of that energy. Combine the lists from the group members and calculate the expense of running the electrical appliances.

   a) Record your calculations in your log.

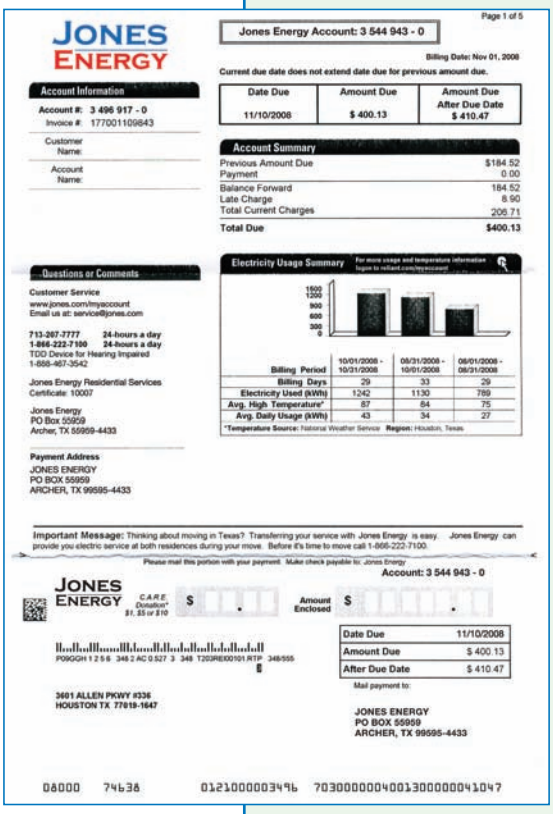
   b) Does the cost of running the appliances seem significant? Explain your answer.

Physics Talk

DETERMINING ENERGY CONSUMPTION

The electrical energy consumed by appliances can be determined in different ways. If the power rating of an appliance is known, and if the power remains at a steady value while the appliance is in use (for example, a light bulb will use electricity at a constant rate), the energy, in kW • h, can be calculated by multiplying the power of the appliance, in kilowatts, by the time, in hours, for which the appliance is used.

Determining the energy consumed by some appliances, however, is tricky, because the appliances vary in power while they are in use. For example, a refrigerator may cycle on and off under the control of a thermostat. Therefore, it is not operating during all of the time it is "plugged in" and the calculation described above would lead to a misleadingly high value for the refrigerator's energy consumption. For such appliances whose power varies throughout time, a kilowatt-hour meter is used to measure the total energy consumed, with variations in power throughout time taken into account. The same kind of meter, a kilowatt-hour meter, is used by the power company to measure the total electrical energy used in your home. The meter is mounted somewhere at your home (usually on an outside wall) so that it can be read by the power company's "meter reader," or electronically.



JONES ENERGY

Jones Energy Account: 3 544 943 - 0

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Billing Date: Nov 01, 2008

Current due date does not extend date due for previous amount due.

Date Due	Amount Due	Amount Due After Due Date
11/10/2008	$ 400.13	$ 410.47

Account Information

Account #: 3 496 917 - 0
Invoice #: 177001109843

Customer Name:

Account Name:

Account Summary

Previous Amount Due	$184.52
Payment	0.00
Balance Forward	184.52
Late Charge	8.90
Total Current Charges	206.71
Total Due	$400.13

Questions or Comments

Customer Service
www.jones.com/myaccount
Email us at: service@jones.com

713-267-7777 24-hours a day
1-866-222-7100 24-hours a day
TDD Device for Hearing Impaired
1-888-467-3542

Jones Energy Residential Services
Certificate: 10007

Jones Energy
PO Box 55959
Archer, TX 55959-4433

Electricity Usage Summary

Billing Period	10/01/2008 - 10/31/2008	08/31/2008 - 10/01/2008	08/01/2008 - 08/31/2008
Billing Days	29	33	29
Electricity Used (kWh)	1242	1130	789
Avg. High Temperature*	87	84	75
Avg. Daily Usage (kWh)	43	34	27

*Temperature Source: National Weather Service Region: Houston, Texas

Payment Address
JONES ENERGY
PO BOX 55959
ARCHER, TX 99595-4433

Important Message: Thinking about moving in Texas? Transferring your service with Jones Energy is easy. Jones Energy can provide you electric service at both residences during your move. Before it's time to move call 1-866-222-7100.

Please mail this portion with your payment. Make check payable to: Jones Energy

Account: 3 544 943 - 0

JONES ENERGY CARE Donation* $1, $5 or $10 $. Amount Enclosed $.

Date Due	11/10/2008
Amount Due	$ 400.13
After Due Date	$ 410.47

Mail payment to:

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PO BOX 55959
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3601 ALLEN PKWY #336
HOUSTON TX 77019-1647

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Another way to determine the energy used by electrical appliances is to use the experience of power companies or corporations that sell electrical supplies. Extensive lists of appliances, their power ratings, and each appliance's average energy use per month by a typical family are available free from such sources.

The cost of operating an electrical appliance can be calculated using the following equation:

$$\text{Cost} = \text{energy} \times \text{price per unit of energy}$$

where energy is in kilowatt-hours ($1000\ \text{W} \cdot \text{h} = 1\ \text{kW} \cdot \text{h}$).

Sample Problem

An electric coffee maker uses an average of 22.5 kW • h of energy each month. If the family is charged $0.12/kW • h for electricity, what is the average monthly cost of operating the coffee maker?

Strategy: Use the equation for cost.

Given:

$$\text{Energy} = 22.5\ \text{kW} \cdot \text{h}$$
$$\text{Price} = \$0.12 / \text{kW} \cdot \text{h}$$

Solution:

$$\text{Cost} = \text{energy} \times \text{price per unit of energy}$$
$$= 22.5\ \text{kW} \cdot \text{h} \times \$0.12/\text{kW} \cdot \text{h}$$
$$= \$2.70$$

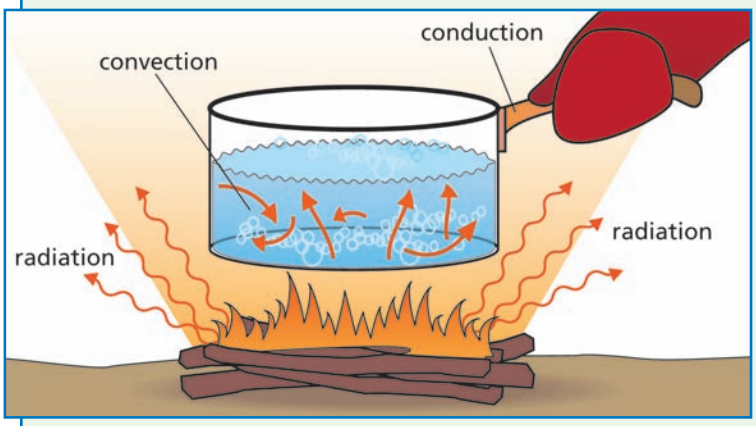
In this *Investigate*, you heated the same amount of water using an immersion heating coil, a microwave oven, and a hot plate. Although the water gained the same amount of energy in all three methods, the amount of electrical energy was different, as was the time required and the cost. The cost difference for the time you heated the water in the *Investigate* may have appeared insignificant. However, over long periods of time the differences in the energy used and the cost becomes evident.

Heat Transfer

In this chapter, you have been looking at **heat transfer**. You saw that when there is a difference in temperature between two substances that are in contact, heat is always transferred between them. You also read that the second law of thermodynamics states that the transfer will always take place from the warmer body to the cooler one.

Physics Words

heat transfer: the transmission of heat energy from a warmer substance to a cooler substance.



You may have studied in previous science classes the three ways that heat can be transferred: **conduction**, **convection**, and **radiation**.

In the case of conduction, the thermal energy of a material is transferred to another material by direct contact of the materials with one another. In your investigation, the rapidly moving (and hence high energy) atoms in the heating coil came in direct contact with the cold water. The thermal energy of the coil's atoms was conducted by physical contact directly to the water molecules. In turn, energy from these molecules was transferred to adjacent molecules, and so on. In this way, the heat was dissipated throughout the water, warming it in the process. Conduction always requires direct contact.

Once the water near the coil became hotter than the other water, the water began circulating. The hot water moved up and away from the coil and cold water came in contact with the coil. These are convection currents in the water. Convection is another means of transmitting thermal energy. In convection, the molecules or atoms of a fluid (a liquid or a gas) that have more thermal energy will move faster than the surrounding molecules of that material. As a result, they will move farther apart and, therefore, become pushed by the colder, more closely packed molecules or atoms. As the hotter molecules spread out through the colder surrounding material, they carry their thermal energy (motion) with them, losing it along their path to other colder molecules by conduction. Convection then, is the transmission of heat from one place to another due to physical movement of a warmer fluid through a colder fluid.

When heating the water in the microwave oven, microwaves moved through the oven and were absorbed by the water molecules. This increase in kinetic energy of the water molecules resulted in an increased temperature of the water. Some people make sun-tea by placing cold water in a glass jar with tea bags. Placing the jar in direct sunlight for a few hours will make the tea. The radiation from the Sun is used to heat the water. Radiation is the third form of energy transmission. In radiation, the electromagnetic radiation given off by high-energy (hot) materials can be transmitted through objects, or even a vacuum, at the speed of light. When this energy strikes a material that can absorb it, the radiant energy causes the atoms or molecules of the material it strikes to move faster and the molecules now have more heat.

Physics Words

conduction: the transfer of heat energy from particle to particle between substances through contact or within a substance.

convection: the transfer of heat energy through the movement of air or liquid currents.

radiation: the transfer of heat energy by emission of electromagnetic radiation in all directions.

Checking Up

1. What unit does the power company use to charge consumers for energy?
2. If a student leaves a 100-W light bulb on in his room for 1 h, how many kilowatt-hours of electricity does the bulb use? If the power company charges $0.18 per kilowatt-hour, how much will it cost to leave the light bulb on for this amount of time?
3. List two places where you could look to see how much electrical energy your family has used in the previous month.
4. What is the name given to heat transfer when objects are heated by direct contact? By currents flowing through a fluid? By electromagnetic waves?
5. When objects are heated by contact, what happens to the kinetic energy of the cold molecules in contact with the hot heating coil?
6. What happens to the distance between molecules in a fluid as their temperature increases?

Active Physics Plus

+Math	+Depth	+Concepts	+Exploration
◆	◆		◆

Finding the "Best" Method of Cooking

What is the best way to cook a hot dog? Do you fry it in a pan? Cook it in the microwave? Boil it in water? What do you think "the best way to cook a hot dog" means? Does "best" mean the least energy, the least cost, the least time, the least cleanup? Or does "best" mean the best tasting or the best appearance? Or is "best" a combination of these?

Design an experiment that can compare all of these factors for cooking hot dogs. Once you get all the data, you will then have to weigh each criterion. For example, what is the most important factor to you – cost, taste, appearance, or clean-up? Once you place a weighting on each criterion (0 = don't care, 10 = extremely important), you can then multiply the relative values for each method (3 = highest, 1 = lowest) by the weightings to have a better sense of how you will arrive at "best."

The following table may help you in your analysis. You do not need to limit yourself to these criteria. You may have other criteria that you consider important.

The "Best" Way to Cook a Hot Dog

	Fry	Boil	Microwave
Cost (cents)			
Energy (joules)			
Time (seconds)			
Appearance			
Taste			
Ease of cleanup			

What Do You Think Now?

At the beginning of this section, you were asked:

- **If high-efficiency appliances cost more, are they worth the added cost?**

Now that you have completed this section, how would you figure out if an energy-efficient appliance is really worth the added cost? Looking back to your initial ideas recorded in your log, how did your thinking about this question change? Is there anything besides the physics you learned that you would consider when answering this question?

Physics

Essential Questions

What does it mean?

What is a kilowatt-hour and how is it related to the unit of energy used more commonly in physics—the joule?

How do you know?

How does the electric company compute your monthly electric bill?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Electricity and magnetism	* Interaction of matter, energy, and fields	Good, clear, explanation, no more complex than necessary.

* How are electric energy, thermal energy, and mechanical energy related?

Why should you care?

Physics allows you to calculate energy use, but does not limit the amount of energy you use. The wind generator supplying electricity limits you to 2400 W and 3 kW • h per day. How will this impact your choice of appliances?

Reflecting on the Section and the Challenge

You know that the electrical appliances used in the universal dwelling cannot exceed 90 kW • h per month of energy consumption. In this section, you discovered that some appliances are more efficient than others. That is, a highly efficient appliance can accomplish a task while using less electrical energy than a low-efficiency appliance for the same task. Obviously you will want to make a careful selection for each kind of appliance based on efficiency so that Homes For Everyone (HFE) inhabitants can have the greatest possible benefit from the electrical system.

The *Chapter Challenge* requires that you need to be thinking about two things at the same time as you select appliances for the universal dwelling: the power consumed by each appliance and the amount of time for which each appliance is used. Both need to be taken into account to stay within the power and energy limits of the HFE electrical system.

Physics to Go

1. Calculate the energy used, in joules, by each of the following:
   a) a 1500-W hair dryer operating for 3 min
   b) a 1200-W hair dryer operating for 4 min
2. If both situations described in *Question 1* result in the same dryness of hair, which hair dryer is more efficient?
3. A 1200-W hair dryer is used by several members of a family for a total of 30 min per day during a 30-day month. How much electrical energy is consumed by the hair dryer during the month? Give your answer in:
   a) watt-hours
   b) kilowatt-hours
4. If the power company charges \$0.15 per kW • h for electrical energy, what is the cost of using the hair dryer in *Question 3* during the month? What is the cost for a year?
5. Not enough heat from the furnace reaches one bedroom in a home. The homeowner uses a portable 1350-W electric heater 24 h per day to keep the bedroom warm during four cold winter months. At \$0.12 per kilowatt-hour, how much does it cost to operate the heater for the four months? (Assume two 30-day and two 31-day months.)
6. A portable CD player is rated at approximately 20 W and uses 4 AA batteries.
   a) Estimate the number of hours that you can listen to the music on a CD player before the batteries need replacing.
   b) Calculate the energy requirements of the CD player.
   c) Estimate the cost of 4 AA batteries.
   d) Calculate the cost per kilowatt-hour of a battery.
   e) Compare battery costs with the cost of electricity from the utilities (use approximately \$0.10 per kilowatt-hour).
7. Are some cooking utensils (pots, pans, etc.) better than others for certain purposes? Write what you think about the effectiveness of different cooking utensils, and what you could do to find out about their comparative effects on efficiency.
8. Does either the hot plate or the microwave oven seem to be a good choice to include in the HFE appliance package? Why, or why not?
9. You probably have concluded that the most efficient appliance of the three tested is the one that used the least energy. Explain how you could calculate the actual efficiencies.

10. *Preparing for the Chapter Challenge*

Prepare your personal list of electrical appliances to recommend to your group to be included in the HFE appliance package. Remember that you will have to justify why you chose a certain appliance. Be prepared to contribute your ideas to your group's decision-making process when completing the challenge.

Inquiring Further

Your electric bill

If possible, also obtain a copy of the monthly electric bill for your home or that of an acquaintance. Compare the electric bill to the ones from the homes of individuals in your group. What factors might account for differences among electric bills within your group? Identify as many factors as you can and explain what you think is the effect of each factor on the bill. What is the average monthly amount of electrical energy used in the homes represented in your group, and how does it compare to the 90 kW•h per month available to Homes For Everyone (HFE) dwellings? How might your consumption of electricity change if you had to pay for your own electrical bills? Be prepared to share your findings with the class.