ESA21
Environmental Science Activities for the 21st Century

Energy: Home Energy Audit

Introduction

Energy Transfers and the First Law of Thermodynamics

In the 1800's, scientists found, empirically, that rules exist that determine how energy can be transferred. The first of these rules is called the First Law of Thermodynamics. This law is usually stated as, "Energy can neither be created nor destroyed; it can only be transferred from one form to another." This often leads to the re-titling of this law as the Conservation of Energy Principle since it says that energy must be conserved.

This statement of the First Law does not say anything about how energy can be transferred, though. It turns out that there are only two ways. This was discovered in 1850 by the English scientist James Joule, who found that heat and work are equivalent methods for changing the energy of an object. In his experimental work, Joule was able to show that he could increase the thermal energy of a pot of water by either placing it over a flame (adding heat), or by stirring it with a paddle (doing work). For this and other important work in this area, the SI unit of energy is called a joule ($1 J = 1 kg\ m^2 /sec^2$). Using this, we can re-write the First Law mathematically as

$$\Delta E = W + Q$$

where ΔE is the change in the energy of an object, W is the work done on the object, and Q is the heat added to an object. In laymen's terms, this means that the only way to change the energy of an object is to exchange either work or heat with it.

Energy History

The discovery of the laws of thermodynamics was extremely important, as our need to understand energy is fueled by the overwhelming use of energy in human society. From the earliest days, humankind has recognized the need to use energy to condition the environment around it. Wood was needed to heat homes and to cook food. Beasts of burden were needed to plow fields and to provide transportation. When either of these commodities became scarce, hardship prevailed, and solutions were sought. In ancient Rome, for example, the lack of available firewood led to the passing of laws that made it illegal to build a house or structure that would block another person's home from getting sunlight, as this was the primary method of heating homes without fire.

In the 20th century, fossil fuels (oil in particular) reigned supreme as the energy of choice. Their ubiquitous nature created historically low prices for energy. This led to a substantial increase in the number of mechanized tools used by the average citizen. By the year 2000, the U.S. had a population of about 283 million people that were driving over 200 million passenger vehicles. Almost every home in America has a television, some type of range or stove, and a refrigerator. About 3/4 of all households have their own washer, dryer, and air conditioner. Of course, this cheap price does not come without some political and economic consequences. Energy, and oil in particular, have

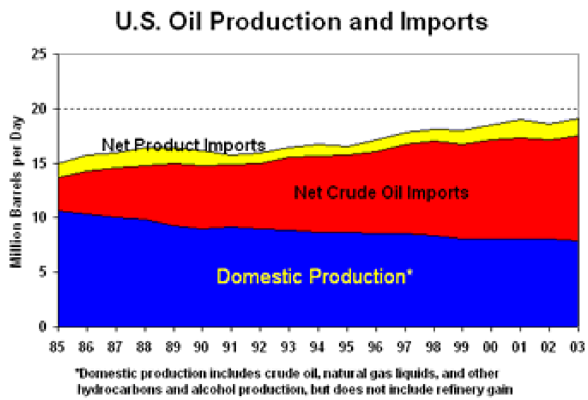


Fig. 1: U.S. Oil Consumption (Source: DOE)

played a very important role in the economy and politics throughout the last 150 years, affecting everything from the entry of U.S. into World War II to the rampant inflation of the 1970's to the current de-stabilized situation in the Middle East.

Energy Use in the U.S.

This modern dependence on many appliances of convenience requires a lot of energy. Our current energy per capita use is over 330 million BTU's of energy. Put another way, this means that the average U.S. citizen would be responsible for using almost 60 barrels of crude oil each year, if all of the energy used in America came from oil. The only other country in the Western World that was even close to this is Canada, which has almost the same amount of usage. Most of the Western world uses 200 million BTU's of energy or less. Although we make up only about 5% of the world's population, we account for almost 25% of all of its energy consumption. In comparison, many Third World countries such as Ethiopia use less than 1 million BTU's per person.

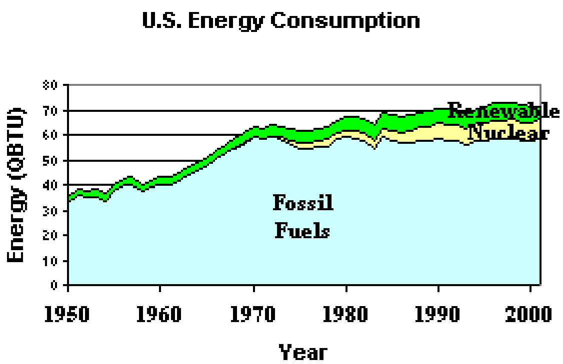


Fig. 2: U.S. Energy Consumption (DOE)

The majority of this energy (82%) is supplied by fossil fuels. Crude oil accounts for the largest share of this (38%), followed quickly by coal (22%) and natural gas (22%). The remaining energy comes mostly from nuclear (8%) and renewable sources like hydroelectric, solar, and wind (7%). Contrary to common belief, most of this energy is produced domestically. The only energy source that we are forced to import is crude oil, of which we can currently supply only about 45% of our need.

Of the energy used in the U.S., about 38% of it is used for industrial processes (mining, milling, etc.), 36% of it is used to power homes and offices, and 28% of it is used for transportation. While most of us cannot directly affect the amount of energy used for industrial processes, we can do something about our residential and transportation energy use. The figures above mean that about 101 million Btu's are used each year just to run our households (this does not include the energy that was lost in producing and transporting this energy, which accounts for an additional 71 million Btu's). The majority of this energy use is to heat and cool our homes (55%). In this week's lab, we are going to begin to study ways to reduce our home energy usage, primarily through reducing our demand for heating and cooling.

Measuring your home

In this week's lab, we are going to prepare for the energy analysis that we are going to perform in two weeks by measuring the surface areas of our homes that are exposed to outside temperatures. We are also going to note what materials were used in the construction of our dwelling. This will allow us in week three of this module to estimate the amount of energy that is being lost in our homes due to conduction. This type of heat transfer depends upon the type of materials used for construction, the amount of surface area through which heat is transferred, and the temperature difference across the material. As we will see in next week's lab, the type of material can drastically change the amount of heat that is conducted from a hot to a cold region. Plywood, by itself, provides little resistance to the flow of heat; plywood, combined with fiberglass and polystyrene insulation, can provide a significant barrier to conduction and allow large temperature differences to be maintained between hot and cold regions. While we are making these measurements of the exterior surfaces of our home, we will also be gathering some basic information about some energy-using devices in our home, such as the refrigeration, cooking, and water heating systems. These systems are responsible for most of the energy used in the home outside of the heating and air-conditioning systems. These are also systems for there can be a wide range of energy efficiency between various makes and models.

Instructions

1. Prepare a drawing of your dwelling. This does not need to be an intricate blueprint of your dwelling (although it helps if you already have one), but a simple illustration of it that will allow for all external surface measurements to be shown. Indicate north on the illustration.
2. On your drawing, please signify the measurements of all exterior, heat-dissipating surfaces. These will be surfaces that lead from an air-conditioned and heated room to either the exterior of the house or to rooms (ex garage) that are not heated or air-conditioned. **NOTE: These measurements do not need to be made from the outside of the home; measurements made from the inside of the house will be sufficient)**
3. While you are measuring the exterior components of your home, note the materials from which they are constructed. For instance, is your exterior door constructed of 1 1/2 inch solid wood, or is it 1 3/4 steel with foam insulation? Enter this information on your Data Sheet (Exterior Surface Type section) as to type of material of each exterior surface (Interior surfaces are irrelevant for calculating heat transfer since internal heat transfers do not affect the amount of energy lost or gained to your home). Some homes will have more than one surface type for each exterior surface. For instance, a house might have single and double paned windows. If so, make sure that both types of surfaces are entered onto the sheet.
4. Using the measurements from your drawing, calculate the area of each exterior surface in your home and enter the data on the Data Sheet provided. Round off all dimensions to the square foot and enter the data into the appropriate slot for each surface type. If you have more than one surface type for each component, remember to the different areas for each type (ex. if you have 10 square feet of single paned windows and 20 square feet of double paned windows, be sure to put the appropriate amount in each slot). If you are unsure of how to calculate areas of external surfaces, look at the example audit.
5. For each surface type, check the list of surface types and fill in the value for the appropriate R factor (Ex. single pane window, R: .9).
6. From your drawing, calculate the square footage of the livable space and write this value in the appropriate slot on your Data Sheet. If you have not done so already, measure/estimate the average height of the ceilings in that living space, and place the value in the slot below this.
7. Check the accuracy of thermostats on your heating and air conditioning unit. While you might think that you have it set at 70 degrees, it might actually be maintaining a temperature of 72. This can be checking by placing an accurate thermometer near the thermostat and noting any differences between the readings. Noting any differences, record the temperature settings for both the air conditioner and heater during the year.
8. The final audit will require certain information about the appliances in your home. You will need to know what type of heating and cooling system your home has, as well as the types of major appliances. For heaters and air conditioners, describe the energy source (electrical, natural gas, wood, etc.) and tell whether the system is centralized (ductwork takes the air to all parts of the home) or not. For the other appliances, check the line next to the type if you have it. For electrical stoves and dryers, we are also going to need to know the wattage of the appliances. If you cannot find this information on the inside door of the appliance, please note this on your data sheet.
9. From your utility company(ies), find out the cost per unit energy for your energy source(s). For some companies, this information will be printed on their bill (Ex. $.75/therm on a natural gas bill or $.08/kWhr on an electric bill). For other companies, this information can be

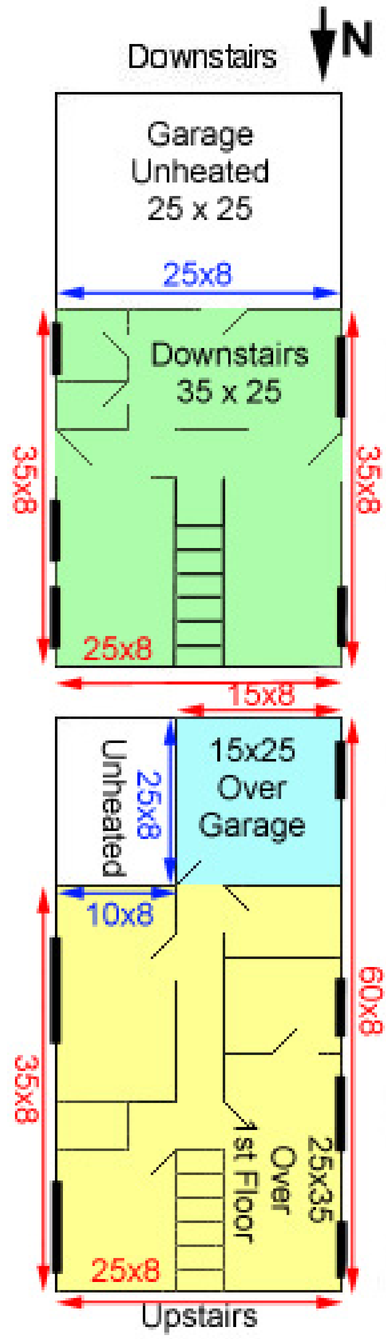
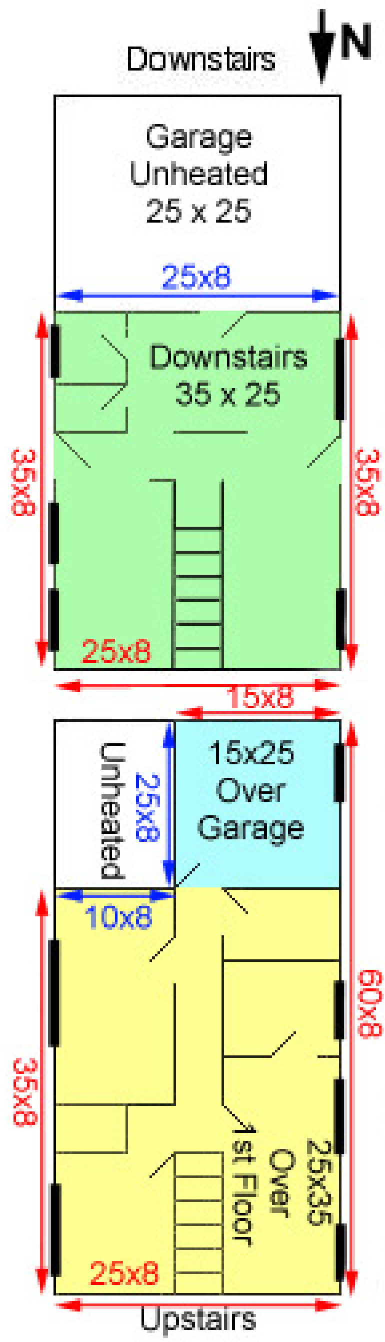


Fig. 3: Sample house drawing

extracted from the bill by dividing the total cost of the energy by the amount of energy that was used. If this information is not on your bill, or if you do not have a bill to check, call the companies that supply you with energy and ask the rate that they are billing you.

Example



The floor plan at the left is of a wood-sided house built upon a cement slab. It is two stories tall with insulated walls and twelve inches of blown fiberglass insulation in the attic. The house is 5 years old, and has been well maintained. The garage, while sealed with doors, is not heated or cooled. The main living space occupies a 25'x35' space both upstairs and downstairs (yellow and green areas), with an additional 15'x25' room (blue area) on the second floor that is over the garage. Windows are as marked on the floor plan and are all 1/4" double pane. The three exterior doors are standard 3'x7' insulated-core steel doors.

The Data Sheet for this house looks like the following:

Type of structure: _X_ House ______ Apartment/Duplex ______Mobile Home
Number of stories _2__

Exterior Surface Types

	First Type	Second Type (if needed)
Windows	1/4" double paned	
Walls	Wood with 3 1/2" fiberglass and 1" foam	Sheetrock with 3 1/2" fiberglass
Doors	1 3/4" Pella	
Roof/Ceiling	12" fiberglass (blown)	
Ground Floor	Concrete slab	6" fiberglass over closed unheated space

Exterior Surface Types	Area	R-factor	Area	R-Factor
Windows	210	1.7		
Walls	1588	20	459	12
Doors	63	13		
Roof/Ceiling	1250	43		
Ground Floor	875	11	375	43

For instructions on how to calculate the areas in the above table, click here.

Total area of heated and air conditioned space: _2125__ sq. ft.
Average height of ceilings: _8__ ft.
Average indoor winter temperature (^{o}F): _69____
Average indoor summer temperature (^{o}F): __74____
Number of air exchanges per hour: __1___

Appliances

Heater Type: Central Natural Gas with insulated ducts
Air Conditioning Type: Central Electric with insulated ducts
Refrigerator/Freezer Combo: 1
Gas Hot Water Heaters: 1
Gas Stove/Oven: 1
Electric Clothes Dryer: 1 If yes: 2000 Watts

R-Factors for Common Materials

After you have finished making the drawing of your dwelling with the measurements of the exterior surfaces, it is time to determine what is the R-factor of all of the exterior surfaces. The R-factor of a surface determines how quickly heat is conducted across it. The values below are some of the more common R-factors for surfaces found on homes in the U.S. **NOTE:** If your exterior surface leads into an enclosed area that is sealed, but is not heated or air-conditioned (ex. a door that leads to a closed garage), then multiply the R-factors below by 1.5 in order to get a better estimate of the factor. If the enclosed area happens to be earth-sheltered (ex. a basement that is not heat or cooled), then multiply the R-factors by 2.0.

Exterior Doors (Excluding sliding glass doors)
Calculate glass area of door as window

Wood Door	Factor
1 1/4" no storm door	2.4
1 1/4" with 1" storm door	3.8
1 1/2" no storm door	2.7
1 1/2" with 1" storm door	4.3
1 2/3" solid core door	3.1
Steel with Foam Core Door	
1 3/4" Pella	13
1 3/4" Therma-Tru	16

Roof / Ceiling

Material	Factor
No insulation	3.3
3 1/2" fiberglass	13
6" fiberglass	20
6" cellulose	23
12" fiberglass	43
12" cellulose	46
14" cellulose	54

Exterior Walls with Siding

Concrete block (8")	Factor
(a.) Concrete block (8")	2.0
with Vermiculite insulated cores	13
with foam insulated cores	20
with 4" on un-insulated stud wall	4.3
with 4" insulated stud wall	14
with 1" air space and 1/2" drywall	2.7
Brick (4")	
with 4" un-insulated stud wall	4
with 4" insulated stud wall	14
Wooden Logs	
Logs (6")	8.3

Floor

Over unheated basement or crawl space vented to outside	Factor
Un-insulated floor	4.3
6" fiberglass floor insulation	25
Over sealed, unheated, completely underground basement	
Un-insulated floor	8
with 1" foam on basement walls	19
with 3 1/2 fiberglass on basement walls	20
Insulated floor, 6" fiberglass	43
Concrete Slab	
No insulation	11
1" foam perimeter insulation	46

Logs (8")	11
Wooden Frame	
Un-insulated with 2" x 4" construction	4.6
with 1 1/2" fiberglass	9
with 3 1/2" fiberglass; studs 16" o.c.	12
with 3 1/2" fiberglass and 1" foam	20
with 6" fiberglass; studs 24" o.c.	19
with 6" fiberglass and 1" foam	26
with 6" cellulose	22
with 6" cellulose and 1" foam	28

2" foam perimeter insulation	65

Windows and Sliding Glass Doors:

Glass	Factor	Low Emissivity	Drapes	Quilts
Single pane	0.9	1.1	1.4	3.2
Single w/storm window	2.0		2.5	4.2
Double pane, 1/4" air space	1.7		2.2	4.0
1/2" air space	2.0	2.99	2.5	4.3
Triple pane, 1/4" air space	2.6		3.0	4.8
Triple pane, 1/2" air space	3.2	3.7	3.7	5.5

Home Audit Tips

1. Unless you live in a very unusual structure, the walls of your dwelling should be 3 1/2 inch studded walls. The biggest question you should have is whether your walls are insulated. If you do not know, there are a few ways to find out. If you dwelling was built since 1980, the odds are that it is insulated with fiberglass insulation. If your home was built before this, then the answer is not so easy. You could determine if there is insulation in the walls by cutting or smashing a hole in the wall to see. However, this is not recommended. There are probably holes in your exterior wall already. Remove the faceplate from either an outlet or a light switch that are on an exterior wall. Be very careful NOT to stick anything into the socket or switch. Once the plate is off (make sure that it does not rip the paint or paper off of the wall), you should be able to see around the side of the outlet box to see if there is any insulation in the wall.
2. If the ceilings in your home are horizontal, then the area of the ceiling is the same as the area of the floor. Therefore, there is no need to get on a ladder to measure the area of your ceiling. If you have vaulted ceilings, the task of measuring the area of your ceiling is slightly more difficult. You can try to measure the distance along the vault if your tape measurer is rigid enough to allow this. If you cannot measure the distance this way, you will need to use a little geometry to aid you. Measure the height (vertical distance) of the ceiling at its highest and lowest points. Then measure the horizontal distance from the highest to the lowest points. You can now use the Pythagorean Theorem to calculate the distance. Square the difference in the vertical distance between the highest and lowest points. Square the horizontal distance between the two points. Now, add the squares together and take the square root of the sum. This will give you the distance along the vault.
3. If your ceiling is neither horizontal nor vaulted (ex. bi-level or tri-level), then you will need to measure or estimate all horizontal and vertical surface areas and sum them together.

4. The wattage information for your electric stove, oven, or dryer should be found on tags somewhere on the device. On these devices, this is usually on a metal tag either on the side of the door or in the door opening. If it is not, then it is probably on the backside of the device. If it possible to easily get to the backside of the device, please do so. If it is not easy, then write "Could not find" on your sheet. When we get to the calculator section of the audit in two weeks, you should just use the average values that the calculator gives you as a default.

Name: **Professor:**

Structure Data

Type of structure: _____ House ______ Apartment/Duplex ______Mobile Home
Number of stories _____

Exterior Surface Types

	First Type	Second Type (if needed)	Third Type (if needed)
Windows:	______________	______________	______________
Walls:	______________	______________	______________
Doors:	______________	______________	______________
Roof/Ceiling:	______________	______________	______________
Ground Floor:	______________	______________	______________

Ext. Surface Type	**Area**	**R-Factor**	**Area**	**R-Factor**	**Area**	**R-Factor**
Windows						
Doors						
Walls						
Roof/Ceiling						
Ground Floor						

Total area of heated and air conditioned space: ___________ sq. ft.
Average height of ceilings: ____________ ft.
Average indoor winter temperature (^{o}F): _________
Average indoor summer temperature (^{o}F): _________
Number of air exchanges per hour: _________

Appliances

Heater Type: ___________________________ Air Conditioning Type: _____________________
Refrigerators:____ Freezers:____ Refrigerator/Freezer Combo:_____
Electric Hot Water Heaters:____ Gas Hot Water Heaters:____
Electric Stove/Oven:____ If yes:______ Watts Gas Stove/Oven:____
Electric Clothes Dryer:____ If yes:______ Watts Gas Clothes Dryer:____

Energy Cost

Energy Source	**Cost**
Electricity	$___/kwh
Natural Gas	$___/therm
LP gas	$___/gal
Wood (cord = 128 ft^3)	$___/cord