#3973

PERFORMING HEAT LOSS CALCULATIONS

FACTSHEET

WASHINGTON ENERGY EXTENSION SERVICE

August 1988

Rising energy costs over the last few years have prompted many homeowners to look for ways to reduce the cost of heating their homes. Fortunately, there are many investments which will result in energy savings. The variable costs and savings of these techniques, however, often make it difficult to choose the most appropriate measure. The purpose of this pamphlet is to simplify the selection of cost effective conservation investments. This will be achieved in the following ways:

1. Familiarize the reader with heat loss theory and formulas.
2. Estimate the heat lost through various components of the building shell by applying the formulas.
3. Prioritize conservation investments for existing homes by comparing estimates of heat loss from the building components.

HEAT LOSS THEORY AND FORMULAS

While heat moves in three ways (radiation, convection, and conduction), most heat escapes from a home by convection and conduction. The examples used to illustrate the concepts will all refer to the house diagramed in Figure 1.

Characteristics of Sample House

-Windows: single glazed; 440 sq. ft.

-Doors: solid core wood; no storm; 42 sq. ft.

-Walls: 2 x 4 framed 16" O.C. 2118 sq.ft.; uninsulated

-Ceiling: 2 x 4 truss; framed 24" O.C. 1000 sq. ft.; uninsulated

-Floor: 2 x 8; framed 24" O.C. 1000 sq. ft.; uninsulated

-Volume: 16,000 ft^3 (assuming 8' ceilings and two floors at 1000 sq. ft. each)

-Infiltration: 1.5 ACH

-Inside Temperature: 70^0F

-Outside Temperature: 24^0F

-Heating Degree Days: 4800

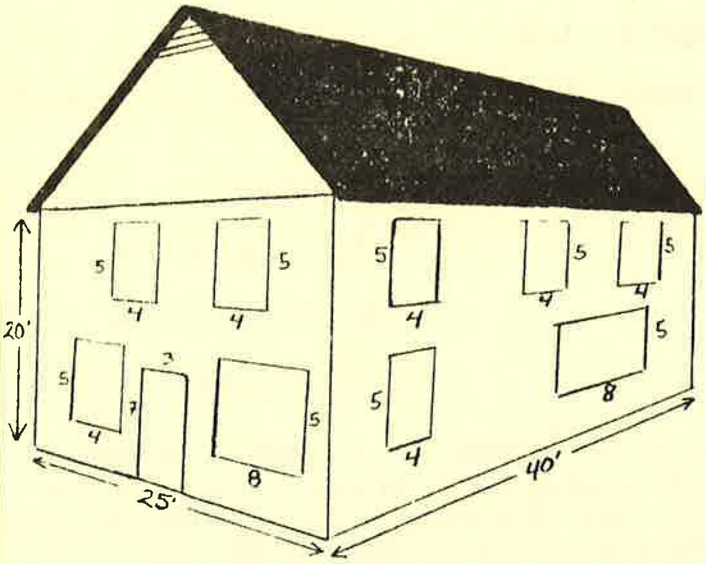

Figure 1.

WISE USE OF RESOURCES THROUGH EDUCATION

914 E. JEFFERSON, #300
SEATTLE, WA 98122
(206) 296-5640

W. 808 SPOKANE FALLS BLVD., RM. 627
SPOKANE, WA 99201
(509) 624-4180

HEAT LOSS THROUGH AIR LEAKS

A major form of convective heat loss in residences is called infiltration. Typically, infiltration occurs when cold, outside air leaks into a house (usually in the lower part) and forces out heated, inside air (usually through cracks in the upper part of the house). Wind blowing against the walls of the house will accelerate such heat loss. Through air leaks around doors and windows, vents, chimneys, and holes or cracks in the building shell, cold outside air displaces the total volume of warm air in the house anywhere from .1 to 5 or more times in an hour. The rate at which this occurs is called air changes per hour, denoted by ACH or sometimes AC. Since energy must be used to heat up the cold incoming air to comfort level, the greater the difference in temperature between the inside and outside level, the greater the heat loss. At any given moment, the rate of heat loss is directly related to the difference in temperature. The formula to compute hourly infiltration heat loss is:

$$Q_i = .018 \times V \times \Delta T \times ACH$$

where:

Q_i = the heat lost by infiltration, expressed in BTUs per hour. (One BTU is roughly equal to a single kitchen match in heat content.)

.018 = a constant that represents the heat needed to raise one cubic foot of air one degree Fahrenheit

V = the volume of air contained in the house, in cubic feet

ΔT = the difference between inside and outside temperatures; usually an average difference

ACH = the number of air changes per hour

Using the specifics from the example house, one finds the total heat lost through infiltration, Q_i, is:

Example 1: if V = 8 ft. x 2(25ft. x 40ft.) = 16,000 cubic feet

$\Delta T = 70^o - 24^o = 46^o$

ACH = 1.5

$$Q_i = .018 \times V \times \Delta T \times ACH$$

$$= .018 \times 16{,}000\text{cf} \times 46^o \times 1.5\text{ACH}$$

$$= \underline{19{,}872 \text{ BTU/hour}}$$ or about 20,000 BTU/hr.

The difficulty here is not the formula or the mathematics, but how to determine the figure to use for ACH. Formerly, one used an ASHRAE procedure which had the homeowner rank the windows, doors, walls, and floors from 1 to 3. If the component was tight, say a weatherstripped window with a storm window, it had 1 ACH; if it was loose, as in large cracks between floor boards and in the foundation wall, it had 3 ACH. The rankings were then added and the total divided by the number of components, four, to obtain an average ACH rate. The obvious problem here is that the oversimplified procedure can only result in a broad estimate. Furthermore, studies have indicated that the number of air changes occurring in homes most likely is not as high as this procedure would suggest. Instead of 1 to 3 ACH, the typical home in the U.S. seems to range from 0.3 to 1.5 ACH. Utility audits, building departments, and heating and ventilating contractors currently use figures that are comparable to the following ranges:

newer homes (1-5 years old):	
with electric baseboard:	0.3 ACH
with a central heating system:	0.6-0.8 ACH
older homes (5-30 years old):	0.8-1.5 ACH

A blower door test is one way to test air leakage that is becoming increasingly popular. The house is pressurized and/or depressurized by a special fan-door mounted in an exterior door opening, and the leaks are detected by smoke sticks. A computer calculates out the number of air changes at the high pressure. Similar leaks can be found with a stick of incense on a windy day. Unfortunately, while both techniques will identify leaks, neither will yield a dependably accurate ACH number at natural air pressure.

HEAT LOSS THROUGH SOLID MATERIALS

Conductive heat loss happens as heat flows directly through the solid building materials. How quickly the heat is lost depends again on the difference in temperature, but also on the resistance of the building materials to heat flow and the area involved. The ability to resist heat flow, called R value, varies from one material to another. The higher the R value, the better an insulator the material is. The separate R values of the materials, including R values for the surface air films, must be added together to get a total R for a building component (see Figure 2). Books about home heating or insulation often list tables which state the R values for different materials. Some books list the conductance or U value, rather than the resistance, for some materials, particularly windows. U values must be converted to R values before they can be added together. To do so, use the formula R = 1/U (or U = 1/R). The U value for a building component is the inverse of the sum of all the separate R values; that is

$$U = \frac{1}{R_1 + R_2 + R_3}$$
(including air films)

The formula to derive heat lost through conduction is:

$$Q_c = \frac{A \times \Delta T}{R}$$

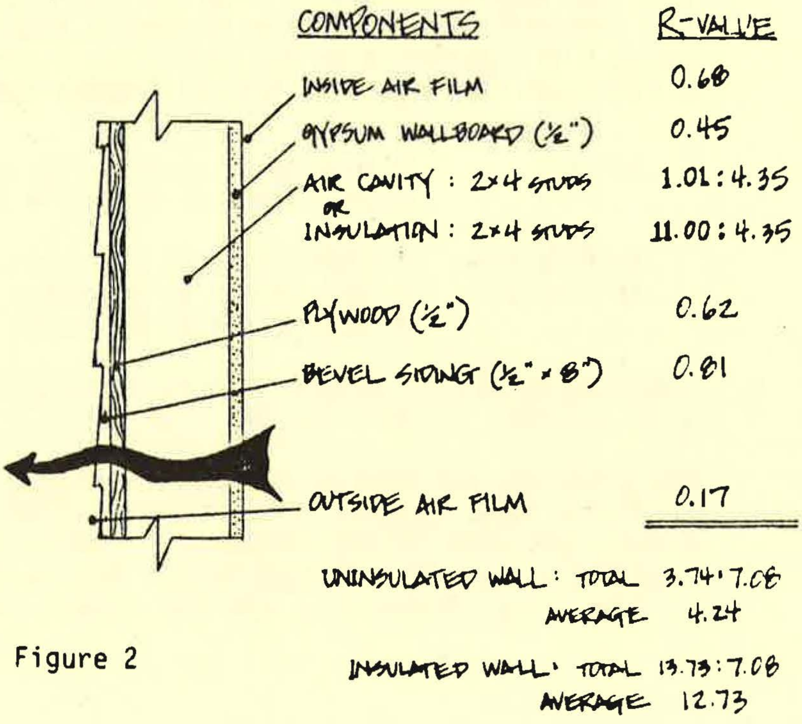

Figure 2

($Q_c = A \times \Delta T \times U$ can also be used, if appropriate.) In this case,

Q_c = the total heat loss by conduction, expressed in BTUs/hr.

A = the total area of the component in square feet.

ΔT = the difference in temperature; inside temperature - outside average temperature.

R = the average R value of the component (sq. ft.-hr.-F$^{\circ}$/BTU)

Using the conditions of the example house, the heat lost by conduction through the wall area can be computed as follows:

Example 2: $$Q_w = \frac{A \times \Delta T}{R} = \frac{2118 \text{ s.f. } \times 46^{\circ}}{4.24} = 22{,}978 \text{ BTU/hr.}$$

OR $$Q_w = A \times \Delta T \times U = 2118 \text{ s.f. } \times 46^{\circ} \times 0.235849 = 22{,}978 \text{ BTU/hr}$$

Roughly, 23,00 BTU/hr are lost through conduction.

The example here and that used for infiltration are both hourly heat loss figures on a cold winter day in Seattle. By computing the heat loss for every component in the home, that is, windows, doors, walls, ceilings or attics, floors, and infiltration, one can derive a total hourly heat loss for the home. Comparing each component with the total will yield the percentage of the total heat load lost by that component. Multiplying the annual heating bill by the percentage results in a dollar cost for the heat lost through the component. This is described in more detail in the following section.

PRIORITIZING CONSERVATION INVESTMENTS IN EXISTING HOMES

In order to simplify the mathematics, Chart 1 on page 5 uses constants which can be multiplied by the area of the appropriate building component. The constant has been derived by figuring the average R value of the building component and then determining the U value (1 ÷ average R). Since the framing members in the component have an R value different from the insulation, the area they make up must be averaged with the insulation-filled area to derive an accurate average R (as shown in Figure 2). Typical framing factors are:

Walls:	2-inch studs at 16 inches on center	15%
	2-inch studs at 24 inches on center	12%
Roof/Ceiling or floors:	2-inch joists at 12 inches on center	13%
	2-inch joists at 16 inches on center	10%
	2-inch joists at 24 inches on center	6%

The example wall in Figure 2, when insulated, has an average R value of $(.15 \times 7.08R) + (.85 \times 13.73R) = 12.73R$

The procedure outlined by the chart will work for any home regardless of climate or degree days. By using a UA factor (U value times the area of the component), a heat loss rate for any component -- walls, floors, doors, whatever--can be computed independent of temperature. The UA is actually per degree Fahrenheit, so if a heat loss figure at a specific temperature is desired, the ΔT can be multiplied

CHART 1.

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	BUILDING COMPONENT	U	AREA SQ.FT.	HEAT LOSS RATE (UA)	FRACTION (D)÷TOTAL	$ COST (E) X BILL	CHANGES: NEW U	NEW HEAT LOSS(GxC)	SAVINGS FRACTION (D-H)÷(D)	$ SAVED (F) x (I)
WINDOWS AND SKYLIGHTS	Single glazed	1.1								
	With storm	.54								
	Insulated (1/2")	.58								
	Other*									
DOORS	Solid core	.46								
	With storm	.31								
	Other*									
WALLS	No insulation	.24								
	R 11 (2 x 4)	.08								
	R 19 (2 x 6)24"OC	.05								
	Other*									
	Below grade*									
ROOFS vented attic ceiling	Uninsulated	.403								
	R 11 (2 x 4)	.084								
	R 19 (2 x 6)	.051								
	R 30 (2 x 4)	.034								
	R 38 (2 x 4)	.026								
	Other*									
FLOORS (2 x 8)	No insulation*	.193								
	R 11	.063								
	R 19	.044								
	R 30 (2 x 10)	.031								
SLAB ON GRADE	Existing*									
	Improved*									
INFILTRATION (cubic ft.)		ACH	V x (.018)				NEW ACH			
	Elec. baseboard	.3	cf.							
	Conv. newer home	.6-.8	cf.							
	Conv. older home	.8-1.5	cf.							

TOTAL HEAT LOSS ____________

* See chart #2 for alternate figures

AVERAGE YEARLY HEATING BILL ____________

CHART 2 ALTERNATE FACTORS FOR COLUMN B OR G

WINDOWS	Wood	Metal	Thermal Break Metal
Single glazed	.96	1.10	1.01
Plus storm	.48	.66	.57
Double-insulated			
1/4"	.55	.71	.66
1/2"	.47	.61	.54
Triple-insulated			
1/4"	.37	.57	.47
1/2"	.30	.45	.37
Heat Reflective			
3/8" triple	.25		
1/2" triple	.23		

DOORS	R7	R14
Foam core	.14	.08

WALLS-ABOVE GRADE*

	Foam board plus: R4	R5	R6.5	R7.2	R10	R14
D R11 2x4 16 O.C.	.06	.056	.049	.048	.042	.036
D R19 2x6 24 O.C.	.041	.040	.037	.036	.033	.029

	R0	R4	R5	R6.5	R7.2	R10	R14
8" concrete block;unfilled	.53	.17	.15	.12	.11	.08	.06
filled	.36	.15	.13	.11	.10	.08	.06
8" poured concrete	.58	.17	.15	.12	.11	.09	.06

* note - all walls assumed to have sheathing beneath siding

WALLS-BELOW GRADE

Multiply constant by perimeter length not area (includes floor losses)

Wall depth	R0	R4	R7	R11	R19
1'	.84	.58	.54	.51	.48
2'	.97	.61	.54	.48	.43
3'	1.06	.65	.56	.48	.41
4'	1.14	.70	.70	.50	.41
5'	1.22	.76	.76	.54	.43
6'	1.28	.82	.82	.58	.45
7'	1.34	.87	.87	.61	.48

CEILING

Flat roof		Add: R4	R5	R8	R10	R14.4
2x8 - uninsulated cavity with built up roof	.266	.129	.114	.085	.073	.055
above +R1.39 deck insulation	.194	.109	.099	.076	.066	.051
w/R19 between joists	.048	.039	.039	.035	.033	.028
Cathedral						
2x8; 24 O.C. closed in	.255	.126	.112	.084	.072	.055
+ R19 batts	.048	.040	.039	.035	.032	.028

FLOORS

Floors assume carpeting; 2x8s at 16" O.C.

Slab on grade floors - factor times perimeter length

			Unheated slab			Heated slab	
18" above grade			2'	4'		2'	4'
	R0	1.18			1.42		
	R5		.40	.28		.49	.34
	R10		.32	.18		.40	.23
4" above grade	R0	.56					
	R5		.18	.15			

times the chart results to yield a temperature specific heat loss rate. Using the UA figure is preferable for several reasons. First, it makes the calculations easier with some components like windows, because they are rated by U values rather than R values. Second, the UA factor is becoming increasingly more popular for describing building components. In fact, an average heat loss factor, U_oA, is often used to describe the overall efficiency of a house. Finally, using just the UA characterizes the building independently from the climate (F°). Since it is desireable to make this chart work in a variety of climates, the temperature factor is removed. Since the ΔT would be the same for all the components in a heat loss calculation, it is a constant and can be removed without affecting the accuracy of the chart. Since the chart uses percentages and the heating bill specific to the house being examined, it can be accurate for a variety of homes. It is important that the UA for each component is computed; these are then totaled for the house. Next the percentage of the total that each component represents is figured. The average heating fuel usage is the indication of the building's real energy efficiency. This is equivalent to the total UA at the bottom of the chart. When the heating bill is multiplied by the percentage of each component, a dollar figure for the heat lost through that component is achieved. This is explained in more detail in the chart instructions.

(A) BUILDING COMPONENT		(B) U	(C) AREA SQ.FT.	(D) HEAT LOSS RATE (UA)	(E) FRACTION (D)÷TOTAL	(F) $ COST (E) x BILL	(G) CHANGES: NEW U	(H) NEW HEAT LOSS(GxC)	(I) SAVINGS FRACTION (D-H)÷(D)	(J) $ SAVED (F)x(I)
ROOFS vented attic ceiling	Uninsulated	.403	1000	403	.198	$198				
	R 11 (2 x 4)									
	R 19 (2 x 6)									
	R 30 (2 x 4)						.034	34	.916	$172.14
	R 38 (2 x 4)									
	Other*									
		TOTAL HEAT LOSS 2040								

AVERAGE YEARLY HEATING BILL $1000

Example 3: SAMPLE HOUSE

Step 1: To fill in column C, find the areas of each component. The area of a square or rectangle is length x width (1 x w). The area of a right triangle, one with a 90° angle, is 1/2 (1 x w). Some areas may have to be broken into rectangles and right triangles to determine the area easily. The window and door areas should be subtracted from the total wall area before wall heat loss is figured. Skylights should be subtracted from ceilings. Note also that the factors for slab-on-grade floors are multiplied by the length of the perimeter not the area of the slab. Write the net area of perimeter length for each component in column C next to the appropriate description. For infiltration, the volume of the house is multiplied by the constant .018 before it is written in column C.

SAMPLE HOUSE ATTIC AREA = 1000 sq.ft.

Step 2: As in Example 3 above, multiply the constant in column B times the area in column C. This is the component's UA. Write this figure, the BTUs/hour -F^0 heat loss, in column D for each component.

$$\begin{array}{ll} & \quad U \qquad\quad A \\ UA & .403 \times 1000 = 403 \text{ BTU/hr-F}^0 \end{array}$$

Add up all the figures in column D and write the total at the bottom.

Step 3: To determine the fraction of the total each component contributes, divide each figure in column D by the total at the bottom of the column. This will be a fraction. This figure should be written in column E.

$$\frac{\text{component}}{\text{total column C}} = \frac{403}{2040} = .198 \text{ or } 19.8\%$$

Step 4: Find last year's heating bill or get it from your energy supplier. If possible, it is a good idea to get several year's heating bills. Instead of using the dollar figure, average the amount of fuel consumed per year over several years. This should yield a more accurate average consumption. If the house was not lived in for any major part of the heating season, that year should probably not be averaged in. Once the average fuel consumption is known, multiply that by the current fuel price to get the average yearly heating bill. For all electric homes, which have heating and appliances all billed together, 60% of the annual electric bill is a good estimate for space heat. Multiply the bill by the fraction representing each component's part of the total heat loss. This will yield a dollar figure for the heat lost through the component which will be written in column F.

$$.198 \times \$1000 = \$198.00$$

Now all the background work is finished, it is time to figure out how much a particular energy conservation investment will save. The wisest move is to compute the savings for a variety of measures and compare them for cost effectiveness.

Step 5: Choose an investment, say increasing the uninsulated attic to R30; find the appropriate constant (.034) and write it in column G. Then compute the new heat loss figure by multiplying the new constant by the area in column B. Write the new figure in column H. If Chart 1 does not list the proper constant, check Chart 2 and use the row titled "other".

$$1000 \times .034 = 34 \text{ BTU/hr-F}^0$$

Step 6: To determine the savings, subtract the new heat loss from the old heat loss (D-H). Then divide this savings by the old heat loss for that component. (D-H) - D. This shows what fraction or percent of the old heat loss is saved. Write this in column I.

$$\frac{403 - 34}{403} = .9156 = .916$$

Step 7: Multiply the savings fraction times the old heat loss dollar cost for each component being upgraded (column I x column F). This yields the dollar savings that can be expected in the first year. Write this in column J. By comparing the cost and savings from each investment, the homeowner can determine which conservation measure will bring the most return. It is important to look at cost, because dollar savings alone (column J) is not the whole picture. If an investment is especially expensive, it may take some time to achieve overall savings even if the dollar savings per year is high. It is also essential to note that the savings are not additive since they are related. When one conservation measure is taken it reduces the total heat loss and how much can be saved by other measures.

.916 x \$198 = \$181.37

A more realistic example for homes in this area would include some attic insulation to begin with--say R11. In this case the computations would look like this: Remember there will be a new figure for the total UA (1721) as well, so percentages will change.

1. .084 x 1000 s.f. = 84
2. $\frac{84}{1721} = .049$
3. .049 x \$1000 = \$49.00
4. $\frac{84 - 34}{84} = .595$
5. .595 x \$49.00 = \$29.16

If there are only a couple of inches of insulation (R7), the savings by going to R30 would be about double (\$47.42). The extreme difference in possible savings between the home with no insulation and a home with only just a little insulation shows the remarkable service insulation has to offer.

For building components that are not described on the chart, the homeowner can derive his own constant using the formulas described previously above. For more detailed information, consult the ASHRAE Book of Fundamentals (see "Suggested Reading" at the end of the pamphlet).

SIZING A HEATING SYSTEM

The process described in this pamphlet is only valid for estimating heat loss. Because homes can have so many individual differences in actual construction, ventilation rates, crawl space differences, and so on, detailed examination has been sacrificed for the sake of a reasonably simple and brief process. The actual dollar figures are also only estimates because they are based on the heat loss estimates and because the tiered structure of electrical rates is not taken into account. This process has only limited usefulness in sizing a heating system or designing a new home, because two important factors are overlooked: heat gains from appliances and occupants (between 1000-3000 BTU/hr), and the solar heat gains. The proper placement of windows can contribute significantly to home heat through incidental solar gains. These contributions can make up sizable portions of the heat warming the home. If the chart is used to figure heat loss and that figure is used to size a heating system, the system could be unnecessarily oversized and inefficient.

Furthermore, the heating system size is based on the capacity needed on the coldest day likely to occur ninety-seven and one-half percent of the time. The chart dispenses with temperature differences and so does not directly apply. It is assumed that a home held at 70°F interior temperature will begin to need heat when the outside temperature drops below 65°. Yet many newer, better insulated homes do not actually call for heat until the outside temperature is in the upper 40°s. This means a much smaller heating system can be used. For these reasons, many people are turning to consultants familiar with a number of computer programs which can vary building details and compare effectiveness more quickly and with greater accuracy. Those ambitious souls who nevertheless wish to plunge ahead will find the 1981 ASHRAE Handbook of Fundamentals (sections 22-25), the 1982 ASHRAE Handbook of Application (section 58), and the Passive Solar Design Handbook: Volume II useful and interesting.

One last note of caution: the chart does not take into account the benefits of thermostat setbacks. Turning the thermostat back for an eight hour period can reduce the heating bill by about one percent for each degree the thermostat is turned down. If a thermostat setback is instituted at the same time as other conservation investments, the investments will take somewhat longer to pay for themselves through savings due to them alone. The thermostat setback, however, will augment those savings well.

Despite these limitations, the process described in this pamphlet can be very useful. Enough information is provided to enable the homeowner to run through the calculation easily, or adapt certain components if he/she really thinks it necessary. The net result will be a clearer look at investment options. This in turn leads to savings. Choosing the right conservation measure does not have to be a mystery or a hit-miss proposition. Working through the procedures outlined in this pamphlet will make the right investment easier to select.

SUGGESTED READING:

Recommended Outdoor Design Temperatures: Washington State. Puget Sound Chapter - American Society of Heating, Refrigeration, and Air Conditioning Engineers. 1200 Westlake N., Seattle.

ASHRAE Handbook of Fundamentals, 1981. American Society of Heating, Refrigeration, and Air Conditioning Engineers.

Basic calculations.

ASHRAE Handbook of Applications, 1982. American Society of Heating, Refrigeration, and Air Conditioning Engineers.

Handbook of Air Conditioning, Heating and Ventilating. Stamper and Koval, ed. Industrial Press, New York.

The Complete Book of Insulating. Larry Gay, ed. The Stephen Greene Press, Brattleboro, VT.

Lists materials.

Passive Solar Design Handbook: Volume II. 1980. J. Douglas Balcomb and Los Alamos Scientific Laboratory, California.

For figuring solar gains.

This factsheet was written by Chuck Eberdt.

Washington Energy Extension Service, a Washington State Energy Office program, is funded by the Bonneville Power Administration and the U.S. Department of Energy.

You can obtain free copies of this and other fact sheets by contacting a WEES office listed on page one of this document, or: Energy Librarian; Washington State Energy Office; 809 Legion Way S.E., FA-11; Olympia, WA 98504-1211

FS-1201 (Revised EY0050, 8/88)