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ESTIMATING ENERGY IMPACTS OF RESIDENTIAL AND
COMMERCIAL BUILDING DEVELOPMENT

A Manual for the Pacific Northwest and Alaska

February 22, 1979

Work Performed Under Contract No. EW-78-C-51-0261

Mathematical Sciences Northwest, Inc.
Bellevue, Washington

U. S. DEPARTMENT OF ENERGY

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OF RESIDENTIAL AND COMMERCIAL
BUILDING DEVELOPMENT

A Manual For The
Pacific Northwest And Alaska

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INTRODUCTION

This energy impact manual has been prepared in response to the growing need for a practicable procedure for estimating, in a non-engineering context, the energy implications of new building design and operation. It provides a simplified, yet reasonably accurate means of assessing the total energy impact of new construction in the commercial and residential sectors. While developed specifically for the States of Alaska, Idaho, Oregon and Washington, much of the data used are national averages; the procedures described in the text are applicable to other regions of the nation, with appropriate adjustments for climatic differences.

Although the text will specifically address the EIS writer/reviewer as the principal user of this manual, application can easily be extended to the more general audience of people familiar with only elementary energy concepts. By raising the general awareness of energy impacts, by providing some of the data necessary to estimate energy impacts, and by providing step-by-step procedures for estimating impacts, this manual attempts to focus the attention of the user on the potential for saving energy, and more specifically to provide a means by which EIS writers/reviewers, developers, planners and other energy conscious individuals can estimate the energy impacts of proposed developments and their alternatives.

The National Environmental Policy Act requires that federal actions be evaluated for their environmental impacts. Many states (e.g., Washington) have followed this lead by requiring similar evaluations for state and local public actions. The impact of a proposed action on energy use is only one facet of the environmental review, but is one that has taken on new meaning since the 1973 oil embargo, the water-short years in the Pacific Northwest, and the energy supply debates over the construction of new power plants and siting of new oil ports. Most frequently, the environmental assessment or impact statement has contained only a cursory treatment of energy impacts due to the following barriers:

1. Lack of knowledge of the types of impacts to look for,
2. Inadequate data with which to calculate impacts, and
3. Inadequate resources to do a thorough job.

While this manual cannot overcome the last barrier, it can and does address the first two.

The manual is organized into three parts, each covering one aspect of the energy impacts of building development. Part I addresses the energy impact of erecting the building(s). This includes the energy cost of grading and excavating and other site preparation. It also takes

into account the energy embodied in the fabrication of materials used in building construction, as well as the energy cost of transporting materials to the site and assembling them.

Part II focuses on the end use of energy during normal building operation, i.e. the energy consumed for space heating, cooling, lighting, water heating, etc. A simplified calculation sequence is provided which allows the user to estimate the consumption of most combinations of building orientation, characteristics and operating conditions. Through its repeated use the user can find the consumption sensitivity and energy savings associated with single or multiple configuration alternatives, and the use of renewable resources.

Part III examines the relationship of land use to energy consumption, principally the transportation energy impact of various land development patterns, the embodied energy impacts of infrastructure requirements, and the impacts of various orientation and siting schemes.

Each part can be prepared independently of the others and the sequence in which they are completed does not matter. A dual approach to calculating impacts is provided in Part I and Part II. In both cases, the direct approach will provide a more accurate estimate of the energy impacts than the indirect approach which relies on more general data and gross assumptions. (The direct method should be used whenever project-specific data is available, since it is clearly more accurate.)

The information and calculation techniques contained in each part are sufficiently detailed that the EIS writer/reviewer can construct alternatives that are less energy-intensive than the proposed action. For example, in Part I the embodied energy cost of glass versus the cost of wood framing, insulation, wall board, exterior siding, and paint might suggest energy saving substitutions. Whatever substitutions are made, however, must be evaluated for their impacts on building energy use in Part II. If there are definite energy advantages, we hope such substitutions will be made part of an alternative. In Part III it should become obvious to the EIS writer/reviewer that any alternative that requires shorter or fewer streets, a different orientation, or that locates the development close to shopping or employment opportunities, will result in energy savings. These factors should be considered in any alternatives evaluated.

There are several things this manual purposefully does not do:

- It does not try to show the writer how to prepare all sections of the impact statement - the requirements vary from state to state and for the federal guidelines. Its focus is narrowly on the estimation of energy impacts.

- It does not try to be comprehensive in suggesting ways to reduce the use of energy. Numerous other guides fulfill that function. Rather, it presents some energy-conserving action along with estimated percent savings, in an attempt to illustrate how the energy impact can be lessened.
- It does not weigh the associated economic, environmental or social costs and benefits of a proposed level of energy consumption or alternatives to that level of consumption. That is beyond the scope of a manual of this sort.

Finally, a word about the accuracy of the estimating procedures of this manual. The data in Part I showing the direct and indirect energy embodied in various materials represent national averages. Regional variations will of course occur, but the overall estimate of impacts is probably quite reliable. The accuracy in Part II relies on calculations which have been widely accepted by professional engineering groups. Some simplification has been made to reduce the number of calculations, and typical values for many variables are provided in an attempt to minimize the number of building characteristics and conditions required from building plans.

Part III will result in the least reliable estimates of energy consumption. The estimates for energy embodied in infrastructure are based on the same data as in Part I; but the estimates for transportation rely on many assumptions about average trip lengths and number of trips, which are based on a study for one city only. These assumptions may not result in accurate estimates, but they will support reasonably good comparative analyses for the project and its alternatives.

THE ENERGY COSTS OF CONSTRUCTION AND MATERIALS

PART 1

Energy in various forms is embodied in all materials used for building construction. This energy constitutes the initial "investment" and must be accounted as part of the energy impacts of a project. Embodied energy includes that used for extraction and processing of raw materials, for manufacture of construction materials and for related overhead and maintenance activities. Once materials are produced, further energy is consumed to transfer them from the point of manufacture to the job site and to perform the actual construction. The purpose of this section is to present two methods to account for the energy which is thus consumed in new or major renovation construction. This computation is the first step in the analysis of the overall energy impacts of the project.

Calculation of Energy Embodied in New Buildings

Three factors are involved in computing new construction energy impacts:

1. Energy embodied in manufacturing the building materials,
2. Energy used to transfer materials to the jobsite, and
3. Energy used at the jobsite during construction

The computation may be approached directly through a detailed analysis of each component, or indirectly using data for various types of buildings. The direct method is presented below as Method 2. In many instances, this detailed computation cannot be completed because required data is not available to the EIS writer. For example, many EISs are prepared well before details are known about the design characteristics of the building(s), and in such instances an indirect approach (Method 1) may be helpful. *In all cases where designs and engineering data are available, Method 2 should be used, since it is clearly more accurate and allows the EIS writer to take project-specific factors and their alternatives into account.*

Method 1: Construction Energy Costs of Buildings, by Type (The Indirect Method)

Description--Where only general information about a project is available, the EIS writer must make do with rather indirect estimates of the amount of energy which will be embodied in materials and used for transport and erection.

Method 1 utilizes data from a series of construction energy cost studies¹ which examined new construction and materials data for 1967² and developed unit (Btu/\$ and Btu/square foot)³ values for energy consumed in new construction. Values are available for 49 new construction and maintenance sectors. Of these, 20 sectors are representative of the types of buildings likely to be encountered by users of this manual. For activities not covered here, the reader may consult the referenced documents for unit energy cost data.

Procedure

To utilize Method 1 the EIS writer must know:

1. The type(s) of building(s) to be constructed, and
2. The total area or total cost to the contractor for each completed building type.

To estimate the construction and materials energy costs for a particular project, the EIS writer simply multiplies the appropriate unit values by the cost or area of the project. The resulting product includes site preparation, materials manufacture, delivery and assembly energy costs. The energy cost of streets and other infrastructure are covered in Part III of this manual.

Where both cost and area estimates are available, computations should be made and the more likely value, or an average of the two values, should be selected. All costs must be expressed as contractor's costs (not ultimate building owner's costs) and must be converted to 1967 dollars. See page 9 to convert to 1967 dollars for purposes of this computation.

Values for average energy embodied in new construction are given in Form 1. The EIS writer should complete the form as follows:

¹ Hannon, B., et al. Energy Use for Building Construction, CAC Doc. No. 228, February, 1977; and Energy Use for Building Construction Supplement, CAC Doc. No. 228A, October, 1977. Center for Advanced Computation, University of Illinois at Urbana-Champaign. Referred to below as Hannon, 1977. Hannon, B., et al. "Energy and Labor in the Construction Sector". Science, Vol. 202, November, 1978. Referred to below as Hannon, 1978.

² At the time these studies were performed, the most recent data available was from 1967.

³ A Btu is a British thermal unit: the amount of energy required to make one pound of water 1 °F warmer. One Btu equals 252 gram calories, or 1055 Joules.

Step 1: Using project data, fill in the appropriate rows in Columns 3 and/or 4. Use as many rows as necessary to include all project building types.

Step 2: Multiply Column 3 by Column 1 and/or multiply Column 4 by Column 2. Enter the result in Column 5 or 6. If both cost and area multiplications are used, select one of your answers (or average the two) and enter in Column 7.

Step 3: Sum Column 7. The result is an estimate of the energy used to manufacture and transport the building materials and erect the building(s).

Step 4: Repeat Steps 1-3 for any alternative building types or dimensions which are being considered for the project.

Example

A contractor wishes to build two single family residences. His total cost estimate is \$20,000 per house, and each residence will have 1,500 square feet. Using Form 1, the following calculations are made:

	Energy Costs		Project Data		Computation	
	Btu/\$	Btu/SF	Total \$	Total Area	Btu	Btu
	1	2	3	4	5	6
Single Family	55,500	702,000	40,000	3,000 SF	2.2×10^9	2.1×10^9

Because the values calculated by dollar and area coefficients differ, the EIS writer must either choose the more "likely" value or average the two values. In this example, it is assumed that area-based costs are most representative, so the value selected for invested energy costs is 2.1×10^9 Btu.

Limitations of Method 1

This method will give the average national energy values for typical buildings of the given type. It does not correct for design or other characteristics which significantly reduce or increase the energy costs of materials, their delivery to the jobsite, or construction. Average site preparation costs are assumed, and any particularly energy-intensive sitework will be underestimated. No correction is made for special materials, transportation, or construction energy costs which may be incurred in Alaska. Actually, because the dollar costs are higher in Alaska, the invested energy will be overstated if the Btu/\$ coefficients are used. For Alaska, the project's area data would yield more accurate results.

The estimate includes only average costs for building-related paving, utilities, and other features. Where streets and unusual amounts of peripheral features are contemplated, the writer should use Method 2 to compute energy costs for those elements. This cost should then be added to the costs estimated by Method 1.

FORM 1

ENERGY COSTS FOR NEW BUILDINGS, BY TYPE OF BUILDING
(see Appendix C)

TYPE OF BUILDING	Energy Costs		Project Data		Cost (1x3) Btu	Area (2x4) Btu	Value Selected Btu
	Total Project Coefficients		Total Cost ²	Total Area			
	Btu/\$ ^{1,2}	Btu/SF ¹	\$	SF			
	1	2	3	4	5	6	7
Residential							
Single family	55,500	702,000					
2-4 family	52,100	630,000					
Garden apartment	52,900	650,000					
High rise	60,000	740,000					
Alterations & Additions	51,600	(3)					
Hotel/Motel	69,200	1,230,000					
Dormitory	70,600	1,430,000					
Industrial building	70,900	970,000					
Office building	68,700	1,640,000					
Warehouse	77,600	560,000					
Garages/Service station	76,200	770,000					
Stores/Restaurant	73,200	940,000					
Religious building	65,600	1,260,000					
Educational building	67,900	1,390,000					
Hospital building	60,600	1,720,000					
Farm residence	53,800	560,000					
Farm service building	77,000	149,000					
Other non-farm	69,900	1,450,000					
Social/Recreational	69,900	1,380,000					
Laboratory	69,900	2,075,000					
Library/Museum	69,900	1,744,000					

¹ Hannon, 1977, Tables C1 and C2, Hannon, 1978, Table 2.

Project Total _____ Btu

² In 1967 contractor's dollars - see page 9 to adjust for current costs.³ Use new construction values.

FIGURE 1
PRODUCER PRICE INDEX

Because the Btu/\$ coefficients in Form 1 are expressed in terms of 1967 dollars, they must be adjusted to the current value of the dollar. A 1967 dollar that would "buy" 55,500 Btus will buy fewer Btus in 1979 due to inflation. For a given year, the producer price index relative to 1967 must be obtained. Indexes for the years 1967-1978 are shown in the above graph. Check the Bureau of Labor Statistics publication "Producer Prices and Price Indexes" in your local library for the most recent index. Use the "Producer Price Index for Finished Goods" (divided by 100) to find the factor by which to divide current project costs to convert into 1967 dollars. For example, \$50,000 in 1978 dollars is equal to $(\$50,000)/(2.025) = \$24,700$ 1967 dollars.

Method 2: Materials and Activity Analysis

In the case where more detailed information is available for a project, the EIS writer can produce a more accurate estimate of direct energy costs by using Method 2. This method utilizes energy cost factors for all of the materials used in constructing a project, and for certain other activities such as site preparation. Method 2 consists of two parts, and each part must be completed. However, each part offers a choice of procedures.

Part 1: Sitework

This procedure is used to estimate the energy invested in sitework. This computation may be done using very detailed techniques directly paralleling the cost estimation procedures used by contractors in preparing their bids. However, this calculation is dependent upon information not generally available to an EIS writer. If a very detailed estimate is required, the following procedure should be used:

- Step 1: Determine amount of each type of sitework (earthmoving, vegetative clearing, etc.).
- Step 2: Using engineering estimating or construction cost manuals ("Dodge," "Means," etc.), determine type of equipment to be used and hourly capacity.
- Step 3: Divide quantity of work by hourly capacity to determine the working time of each piece of equipment.
- Step 4: Contact equipment leasing/rental business to obtain hourly fuel consumption of each machine.
- Step 5: Multiply working time (Step 3) by hourly fuel consumption to determine total fuel usage for the project element.
- Step 6: Multiply total fuels usage (gallons) by energy content of the fuel (from Table 1) to obtain sitework energy costs.

Because of the complexities of this method, a simplified technique may be used for most projects. This simplified technique is similar to Method 1 above; it produces results which are not calibrated to the project, but which are close enough for most purposes.

TABLE 1
ENERGY CONVERSION FACTORS

1 British thermal unit (Btu)	=	the amount of energy required to make one pound of water 1° F warmer
1 kilowatt hour (kWh)	=	3,413 Btu (point of use ¹) 11,000 Btu (source ²)
1 therm of natural gas	=	100,000 Btu
1 gallon No. 2 home heating oil or diesel fuel	=	136,000 Btu
1 gallon automobile gasoline	=	125,000 Btu
1 gallon of liquified petroleum gas	=	95,500 Btu
1 short ton of coal	=	22,500,000 Btu

¹Considers usage only from building line

²Considers usage from generating facility. Includes transmission losses and generation inefficiencies. This value is a national average for all fuel sources.

FORM 2

SITWORK ENERGY COST ESTIMATION FOR NEW BUILDINGS
BY TYPE OF BUILDING
(see Appendix C)

	Direct Petroleum Products Usage (Btu/SF) ¹	Sitework Coefficient (Btu/SF) ²	Project Data (Total Area)	Sitework Energy (2x3)
	(1)	(2)	(3)	(4)
Residential				
Single family	29,917	28,421		
2-4 family	32,496	30,871		
Garden apartment	33,962	32,264		
High rise	54,336	51,619		
Hotel/Motel	96,569	91,741		
Dormitory	119,307	113,342		
Industrial building	51,165	48,607		
Office building	137,500	130,625		
Warehouse	33,333	31,666		
Garage/Service station	86,363	82,045		
Store/Restaurant	87,004	82,654		
Religious building	106,410	101,090		
Educational building	100,824	95,783		
Hospital	122,907	116,762		
Farm residence	13,578	12,899		
Farm service building	4,945	4,698		
Other non-farm building	125,596	119,316		
Social/Recreational				
Laboratory				
Library				
Project Total _____				Btu

¹Hannon, 1977, Table 43²Assumes sitework to be 95 percent of direct fuel usage value.

Procedure

Column 1 of Form 2 contains energy value multipliers for total direct fuel consumption in each of the indicated building types. Non-sitework fuel usage constitutes a small percentage of this total, estimated at five percent, and thus has been eliminated to produce Column 2. Column 2 supplies the Btu/SF coefficient for sitework alone. To use Form 2, simply multiply the area of each building type (Column 3) by the value in Column 2, entering the product in Column 4. Sum Column 4 to obtain total estimated sitework energy costs.

Assuming two 1,500 ft² single family homes as before, 28,421 Btu/ft² (Column 2) x 3,000 ft² (Column 3) = 85,263,000 Btu (Column 4). This is four percent of the total estimated energy cost of the example described in Method 1.

Part 2: Materials

Part 2 of Method 2 provides a means of estimating material costs, including manufacturing, transport, and assembly. Again, there is a simplified method and a more detailed method. Both involve estimation of energy in the materials in a manner similar to that explained for previous techniques.

The first optional method in Part 2 is for use when material dollar costs are known for each type of material. Use Form 3 to compute embodied energy. Add sitework costs (from Form 2) to obtain totals for the project's construction and materials energy costs.

Procedure

In Form 3, enter project cost data in Column 4 for each applicable material sector. Multiply by the total energy coefficient shown in Column 3 (the sums of Columns 1 and 2), and enter the resultant products in Column 5. Enter sitework costs in the top row in Column 5. Sum Column 5 to obtain total in-place (assembled) materials costs.

FORM 3

EMBODIED ENERGY, BY MATERIAL SECTORS
(see Appendix C)

Material Sector	Manufacturing (Btu/\$) ^{1,2} (1)	Delivery and Assembly ² (Btu/\$) ² (2)	Total (Btu/\$) ² (3)	Project Costs ² (\$) (4)	Estimated Energy Costs (Stu) (Col. 3 x Col. 4) (5)
Sitework (from Form 2)					<input type="text"/>
Sawmill products	65,285	29,743	95,028		
Hardwood flooring	55,516	30,459	85,975		
Special sawmill products	39,319	22,107	61,426		
Millwork	47,350	15,765	63,115		
Veneer and plywood	67,686	21,353	89,039		
Prefab wood structures and buildings	55,182	7,746	62,928		
Wood panels, particle board	71,339	16,005	87,344		
Building paper and insulating board	189,900	35,151	225,051		
Paints	122,390	22,359	144,749		
Asphalt roofing materials and felt	478,610	15,222	493,832		
Plastic products					
Flat glass	102,810	15,258	118,058		
Cement	479,590	17,477	497,067		
Concrete pipe, precast products	108,490	6,260	114,750		
Concrete blocks	141,630	13,683	155,313		
Ready-mix concrete	180,130	655	180,785		
Bricks and tiles	340,290	17,865	358,155		
Ceramic tiles	110,610	10,547	121,157		
Structural clay products	259,790	17,253	277,043		
Vitreous plumbing fixtures	91,042	18,052	109,094		
Lime	507,010	37,482	544,492		
Gypsum products	158,540	19,998	178,538		
Mineral wool insulation	155,870	19,088	174,958		
Steel products	266,980	13,910	280,890		
Fabricated structural steel	124,320	5,704	130,024		
Copper products	101,700	2,643	104,343		
Aluminum products	244,200	3,479	247,679		
Nonferrous wire	91,433	3,290	94,723		
Metal plumbing fixtures	98,392	16,316	114,708		
Plumbing fittings, brass goods	74,662	12,862	87,524		
Heating equipment (except electric)	71,217	13,985	85,202		
Water heaters	82,264	5,915	88,179		
Metal doors, sash, trim	116,790	9,304	126,094		
Metal tanks	104,910	2,852	107,762		
Sheet metal	114,110	6,410	120,520		
Screw machine products	85,812	15,851	101,663		
Miscellaneous metalwork (lath, bar joists, etc.)	139,810	5,541	145,351		
Wiring devices (sockets, outlet boxes, etc.)	72,488	8,009	80,497		
Total Energy Costs					<input type="text"/>

¹ Hannon, 1977.

² In 1967 contractor's dollars - see page 9 to adjust for current costs.

If detailed lists of material are available the second option in Part 2 should be followed. Use Form 4 to compute energy costs for each material type. Reference must be made to Table A-1 in Appendix A for the energy coefficients for each material. Use of Form 4 is similar to previous methods.

- Step 1: In the far left column, list the required materials.
- Step 2: Enter in Columns 2, 3, 4, and 5 the appropriate multipliers from Table A-1.
- Step 3: List in Column 6, Project Requirements, the quantities of each material needed.
- Step 4: Multiply Project Requirements (Column 6) by the total Btu/unit coefficient (Column 5) and enter results in Column 7. Sum all totals in Column 7 of Form 4.

FORM 4

ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL
(see Appendix C)

Materials	Units (1)	Energy Coefficients				Project Requirements. (6)	Total Energy Cost (Btu) (7)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)		

OPERATIONAL ENERGY USAGE

Energy consumption during normal building operation should be seriously considered prior to construction. Often building configuration and characteristics are chosen arbitrarily, without consideration of their impacts upon energy consumption. The EIS might be an excellent place for such considerations to be made, provided the writer has the proper tools for such analysis. It is the purpose of this section to provide methodologies which can be accessed by the EIS writer with minimum knowledge of engineering techniques.

Of course, the depth of the analysis which the EIS writer can provide depends heavily upon the amount of building design information available to him. For this reason two methods of analysis have been devised. Energy consumption may be calculated directly through a detailed analysis of each consumption component, or indirectly by examination of several computer simulation studies which have been performed in recent years on various prototypical buildings. The direct method is presented below as Method 2. In many instances, this detailed computation cannot be completed because required data is not available to the EIS writer. In such instances the indirect approach (Method 1) may be helpful. *In all cases where designs and engineering data are available, Method 2 should be used, since it is clearly more accurate and allows the EIS writer to take project-specific factors and their alternatives into account.*

METHOD 1

(The Indirect Method)

This method should be used in cases where building design is only in the conceptual stage. Since building configuration and characteristics are not defined, the analysis of energy consumption must rely upon examination of data resulting from computer simulation studies for similar buildings. Several such studies have been performed in recent years, in both the residential and commercial sectors, which are applicable to the Pacific Northwest. The energy consumption results from five studies are shown in Table 2. Variation can be seen within each building type, due to climatic conditions and the relative assumptions made in choosing typical building characteristics. All of the results in this table reflect conventional building practice. The "best estimate" values given at the bottom of Table 2 represent typical or average consumption for each prototype and climatic zone. Consumption estimates for areas with 7,000 or more heating degree days have been included although these studies do not consider such severe weather conditions. It must be noted that the data provided for this zone are the results of rather crude approximations. Its use should be limited to cases where data from more formal analysis are not available.

Table 4 provides a list of energy conserving alternatives which ought to be considered during building design. Percentage energy savings values are noted where available. A range of savings is usually given which reflects variation in achievable savings with site specific considerations.

Use of the energy savings values from Table 4 is subject to two major restrictions. First of all, the savings percentages, unless otherwise noted, are applicable only to the category under which they are listed. In addition it must be understood that the percentage values are not necessarily additive.

When a conservation scheme is chosen and a percentage savings value is given in Table 4, its effect on total energy consumption can be computed. The savings value is applied to the respective proportion of total consumption (Table 2), through the use of the proper component breakdown given in Table 3. This procedure is clarified through the example given on page 24.

TABLE 2
ENERGY CONSUMPTION BY BUILDING TYPE
(Btu/ft²/yr)

Source***	Climate	Single Family	Multi Family	Small Office	Large Office	Retail Store	School
(1)	1	74,900	72,500	190,000	216,800	184,300	-
(2)	1	87,300	90,600	253,700	289,100	245,700	68,600
(3)	2	100,400	297,700	248,600	-	274,700	153,300
(4)	1	83,000	102,000	-	175,000	172,900	-
	2	106,500	122,300	-	305,300	200,700	-
(5)	1	59,800	81,600	-	181,000*	158,700*	-
Best estimate	1	76,200	86,700	221,900	215,500	190,400	68,600
	2	103,500	122,300	248,600	305,300	237,700	153,300
	3**	145,900	175,500	-	336,500	300,600	-

Climate 1 = 4,000-5,500 Heating Degree Days
Climate 2 = 5,500-7,000 Heating Degree Days
Climate 3 = 7,000-14,000 Heating Degree Days

See Figure B-1 for climate zone locations

* Estimated

** Extrapolated

*** See next page for Sources

SOURCE:

- (1) Skidmore, Owings, and Merrill, Inc. Commercial Conservation Choices. Portland Energy Conservation Project, June 1977a.
Referred to below as Skidmore, Owings and Merrill, 1977a.
- (2) Skidmore, Owings and Merrill, Inc. Residential Conservation Choices. Portland Energy Conservation Project, June 1977b. Referred to below as Skidmore, Owings and Merrill, 1977b.
- (2) Skidmore, Owings and Merrill, Inc. Bonneville Power Administration Electric Energy Conservation Study, June 1976. Referred to below as Skidmore, Owings and Merrill, 1976.
- (3) Little, Arthur D. Inc. Energy Conservation in New Building Design. An Impact Assessment of ASHRAE Standard 90-75. March 1976.
Referred below as A.D. Little, 1976.
- (4) Mathematical Sciences Northwest, Inc. Thermal Lighting and Efficiency Standards. December, 1978. Referred to below as Mathematical Sciences Northwest, Inc., 1978.
- (5) Graham, John and Company. Energy Conservation Code Analysis. A Study for the City of Seattle, 1977. Referred to below as Graham, 1977.

TABLE 3
ENERGY USAGE BREAKDOWN

Percent of Total Consumption													
Element	Residential						Element	Commercial					
	Single Family			Multi-Family				Office Building			Retail Store		
	Climate			Climate				Climate			Climate		
	1	2	3*	1	2	3*		1	2	3*	1	2	3*
Heating	60	53	75	48	51	71	Heating	34	33	53	28	39	62
Cooling	-	16	-	11	15	-	Cooling	5	15	2	11	9	-
Water Heating	18	12	11	17	14	12	Water Heating	1	1	1	1	1	1
Appliances	19	17	12	15	12	8	Lighting and Power	19	11	12	44	36	29
Lighting	3	2	2	9	8	8	Fans and Auxiliaries	41	40	32	16	15	9

Climate 1 = 4,000-5,500 Heating Degree Days
 Climate 2 = 5,500-7,000 Heating Degree Days
 Climate 3 = 7,000-14,000 Heating Degree Days
 See Figure B-1 for climate zone locations

Derived from Mathematical Sciences Northwest, Inc., 1978; A. D. Little, 1976; Skidmore, Owings, and Merrill, 1976.

* Extrapolated from data in Tables 2 and 3.

RESIDENTIALSET BACK THERMOSTAT DURING UNOCCUPIED PERIODS AND NIGHT

Range of Energy Savings: 5 percent to 25 percent space heating;
1 percent to 10 percent space cooling.

Comments: In cool climates, heating savings are low and cooling savings are high. In warm climates, heating savings are high and cooling savings are low. Savings also depend on how long the thermostat is set back and how many degrees it is set back. (Maximum heating savings shown are for an 80°F set back 8 hours each night of the heating season in a warm climate.)

RELAX COMFORT CONDITIONING: (Establishing thermostat settings which are cooler in the winter and warmer in the summer than it is currently kept.)

Range of Energy Savings: 10 percent to 40 percent space heating. 1 percent to 15 percent space cooling.

Comments: In cool climates, heating savings tend toward the low end of the range and cooling savings tend to be near the high end. The opposite is true in warm climates. Savings are also proportional to the number of degrees of temperature control relaxation. The upper end of the heating savings shown is for a permanent set back from 72°F to 66°F in a warm climate.

REDUCE LIGHTING USE

Range of Energy Savings: 1 percent to 8 percent of other electrical appliances energy use.

Comments: The range of energy savings is dependent on the degree to which lighting energy is reduced. The range shown above corresponds to reduction in lighting energy use of 5 percent to 30 percent. If every bulb in a residence were replaced with the next smaller standard size bulb, lighting energy would be reduced by 20 percent (7 percent reduction of other electrical appliances).

SET BACK THERMOSTAT ON WATER HEATER

Range of Energy Savings: 10 percent to 25 percent of water heating.

Comments: Lowering the thermostat setpoint from 150°F to 140°F would save about 10 percent of water heating energy; 20 percent would be saved by lowering the thermostat from 150°F to 120°F.

INCREASE WATER HEATER INSULATION: (Install additional insulation on water heaters to reduce the energy required for hot water.)

Range of Energy Savings: 8 percent of water heating.

Comments: Energy savings shown are based on increasing the amount of insulation from R-7 to R-14.

INCREASE USE OF DOUBLE GLAZING/STORM WINDOWS AND DOORS

Range of Energy Savings: 5 percent to 25 percent of heating. Up to 10 percent of space cooling.

Comments: Savings of about 5 percent of space heating and 2 percent of cooling would be achieved in a single family detached (SFD) residence which has no insulation in the walls, ceiling, or floor when it is changed from single-glazed to double-glazed windows. Savings of about 24 percent of space heating and 9 percent of space cooling would be achieved in SFD residence which has R-17 wall insulation, R-30 ceiling insulation, and R-19 floor insulation when storm windows are added to the single-glazed windows and storm doors are added.

INCREASE USE OF IMPROVED EFFICIENCY APPLIANCES

Range of Energy Savings: 5 percent to 30 percent cooking. 1 percent to 6 percent other electrical appliances.

Comments: The range of energy savings depends on the specific appliances chosen and the number of appliances in each residence. Improved refrigerator alone is about 2 percent of other. Improved clothes dryer, television, and dishwasher are each about 1 percent of other. The low end of the range for cooking represents savings in electric range/oven efficiency (5 to 10 percent). The high end indicates the potential saving by utilizing electric ignition on gas ranges instead of pilots.

INCREASE USE OF LANDSCAPING AND SHADING

Range of Energy Savings: 5 percent to 15 percent of heating. 5 percent to 15 percent of space cooling.

Comments: Savings of about 7 percent of space heating and 13 percent of cooling would be achieved in an uninsulated SFD residence if landscaping were planted which reduced the windspeed near the building by about 30 percent and which reduced the amount of sunlight reaching the windows in summer by about 50 percent. Savings equivalent to 15 percent of space heating and 5 percent of space cooling would be achieved in all dwelling units in an multi family low rise building with R-19 ceiling insulation, no floor insulation, and double-glazed windows if landscaping were planted which reduced windspeed near the building (first floor only) by 50 percent and reduced sunlight reaching the first floor windows in summer by 50 percent.

DECREASE USE OF HEATED SWIMMING POOLS

Range of Energy Savings: 15 to 45 million Btu/pool year.

INCREASE USE OF HEAT PUMPS

Range of Energy Savings: 30 percent to 60 percent space heating.

Comments: Savings are highest in warm climates and lowest in cold climates. The installation of a heat pump in a house which would otherwise be unair conditioned would cause more energy to be used for space cooling.

Savings of about 35 percent of space heating would be achieved in a cold climate (about 8400 heating degree days).

Savings of about 60 percent of space heating would be achieved in a warm climate (about 1400 heating degree days).

INCREASE INDIVIDUAL METERING OF MULTIFAMILY UNITS

Range of Energy Savings: Approximately 30 percent of the energy type that is changed from master to individual meters.

Comments: Provide energy metering for individual units in multifamily buildings instead of (or in addition to) one master meter for the entire building or complex. Some rewiring may be necessary when changing from master meter to individual meters in existing buildings.

INCREASE USE OF ON-SITE ALTERNATIVE ENERGY SOURCES

Range of Energy Savings: Up to 80 percent space heating. Up to 90 percent water heating. Up to 50 percent other electrical appliance energy.

Comments: Savings depend on the size and type of system installed. A solar energy system commonly supplies 90 percent of water heating energy, but can also be expanded to provide about 80 percent of the space heating requirements. A wind electric generator can easily supply the electricity for 50 percent of other electric energy use.

REDUCE DWELLING GLASS AREA

Range of Energy Savings: 5 percent to 25 percent of space heating. 5 percent to 10 percent of space cooling.

Comments: Savings of about 25 percent of space heating and 10 percent of space cooling would be achieved in a SFD residence with R-17 wall insulation, R-19 floor insulation, R-30 ceiling insulation and single-glazed windows if the window area were reduced to 90 square feet (50 percent reduction in window area) with a corresponding increase in wall area. Savings of about 6 percent of space heating and 5 percent of space cooling would be achieved in a SFD residence with R-11 wall insulation, R-19 ceiling insulation no floor insulation, and double-glazed windows if the window area were reduced to 144 square feet (20 percent reduction in window area) with a corresponding increase in wall area.

Comments: The midpoint of the range shown would be for heating a pool for three months to 10°F above the temperature it would be without heating.

INCREASE METERING OF PARTICULAR APPLIANCES AND EQUIPMENT

Range of Energy Savings: 10 percent of space heating. 5 percent of space cooling. 10 percent of water heating.

Comments: Meter major appliances and equipment separately to cause an awareness by the owner of the amount of energy consumed by particular high-use appliances and equipment.

INCREASE WEATHERIZATION

Range of Energy Savings: 5 percent to 20 percent space heating. 5 percent to 10 percent space cooling.

Comments: A SFD residence with no insulation in the walls, ceiling, and floor, and with single-glazed, non-weatherstripped windows will show about a 7 percent reduction in space heating energy use and an 8 percent reduction in cooling energy use if it is treated with weatherstripping and caulking. Savings of about 16 percent of space cooling and 10 percent of space heating would be achieved by adding weatherstripping and caulking to SFD residence with R-38 insulation in the ceiling, R-30 floor insulation, R-31 wall insulation, and single-glazed windows.

INCREASE DWELLING INSULATION

Range of Energy Savings: 5 percent to 40 percent of space heating. Less than 15 percent of space cooling.

Comments: A savings of about 5 percent of space heating and 1 percent of space cooling would be achieved by changing a SFD residence from R-11 walls, and R-19 ceiling to R-17 walls and R-30 ceiling. Savings of about 37 percent of space heating and 14 percent of space cooling would be achieved in changing a SFD with no insulation in the walls, ceiling, or floors, to R-17 wall insulation and R-30 ceiling insulation.

INCREASE USE OF HIGH EFFICIENCY AIR CONDITIONERS

Range of Energy Savings: 10 percent to 40 percent of space cooling.

Comments: Energy savings is determined by how efficient an air conditioner is used. The upper limit shown above is for using an air conditioner whose Energy Efficiency Ratio (EER) is 10.0 in place of one with an EER of 6.0.

OPTIMIZE PLACEMENT OF GLAZING (The design of glazing areas to face more in the southerly direction in cold climates and to any of the other directions in hot climates to take best advantage of the climatic characteristics of a given area.)

Range of Energy Savings: Up to 15 percent of space heating. Up to 5 percent of space cooling.

Comments: A decrease in space heating energy via this alternative causes an increase in space cooling and vice versa; i.e., if glazing is oriented mainly toward the south, the increased sunlight admitted to the house would decrease heating requirements and increase cooling requirements.

A savings of 11 percent of space heating and an increase of 4 percent in space cooling would occur in a SFD residence with R-11 wall insulation, R-19 ceiling insulation, no floor insulation and double-glazed windows if the windows are changed from approximately equal distribution to all facing south. An increase about 11 percent of space heating and a decrease of 4 percent in space cooling would result from changing the windows from evenly distributed to all facing north.

INCREASE USE OF SHADING OVERHANGS (New SFD houses and multifamily buildings of 3 stories or less.)

Range of Energy Savings: Up to 5 percent of space cooling.

Comments: Savings of about 5 percent of space cooling would be achieved in a single story SFD residence with R-11 wall insulation, R-19 ceiling insulation, no floor insulation, and double-glazed unshaded windows if the windows were shaded from summer sun 50 percent of the time (about a 3 foot overhang). A saving of about 2 percent of space cooling would be achieved in a 3 story MFLR building with R-11 insulation, R-19 ceiling insulation, no floor insulation, and double-glazed unshaded windows if a 3 foot roof overhang were added.

INCREASE USE OF TWO STORY HOUSING

Definition: The substitution of two story SFD residences for new single story units.

Range of Energy Savings: 5 percent to 25 percent of space heating. May increase space cooling by up to 30 percent.

Comments: Savings of about 7 percent of space heating and an increase of about 28 percent of space cooling would occur in a SFD residence with no wall or floor insulation, R-19 ceiling insulation, and double-glazed windows if it were changed from one story to two stories. Savings of about 22 percent of space heating and less than 1 percent of space cooling would occur in a SFD residence with R-17 wall insulation, R-19 floor insulation, no ceiling insulation, and double-glazed windows if it were changed from one story to two stories.

INCREASE MULTIFAMILY HOUSING

Range of Energy Savings: 45 percent to 90 percent space heating. 10 percent to 60 percent space cooling. 0 to 50 percent water heating. 0 to 20 percent cooking. 10 percent to 30 percent other.

Comments: In each of the areas of energy savings, the low end of the range represents increase of single family attached (SFA) units, the middle of the range represents increase of multi-family low rise (MFLR) units, and the high end of the range represents increase of multi-family high rise (MFHR) units, all as opposed to SFD units.

OPTIMIZE BUILDING ORIENTATION ON SITE

Range of Energy Savings: 1 percent to 5 percent space heating. 1 percent to 5 percent space cooling.

In areas with dominant prevailing winds, proper building orientation will result in energy savings on the high end of the range. Frequently, summer and winter wind directions are different enough that savings can be achieved for either heating or cooling, but not both. Savings for multifamily units and attached units are higher than for SFD units.

INCREASE THE USE OF TOTAL ENERGY SYSTEMS

Range of Energy Savings: 25 percent to 50 percent of community fuel input to utility systems. This translates essentially to a 25 percent to 50 percent reduction in energy use in all end uses. The exact savings depends on the extent of the systems involved.

Comments: Such systems are designed to provide all the energy supplies to a building or group of buildings. This is accomplished by providing an electric generating system with waste heat recovery integrated with a heat distribution system to provide space heating and water heating in addition to electricity. The heat obtained from recovery can also be used to drive absorption chillers for space cooling. Other utility systems, including solid waste disposal and waste water treatment, can also be integrated into the system to further reduce energy input requirements.

REDUCE USE OF APPLIANCE PILOT LIGHTS

Range of Energy Savings: 3 percent to 50 percent of space heating. 30 percent of cooking (for gas ranges only).

Comments: Pilot light elimination would have the secondary effects of decreasing cooling energy use by 2 percent to 7 percent and increasing heating energy use by 1 percent to 2 percent.

The largest cooling savings are in locations with long cooling seasons and the largest heating energy increases are in locations with long heating seasons.

INCREASE USE OF RAISED RANCH TYPE OF HOUSING

Range of Energy Savings: 1 percent to 5 percent of space heating. In cold climates (3500 heating degree days and above), energy savings will range from 3-5 percent of space heating energy for a SFD with good wall insulation to 4-6 percent for a SFD with very little wall insulation but good ceiling insulation.

Comments: Where terrain permits, 2 story units should have the first floor below grade to a depth of 36" to 42" (commonly referred to as a "Raised Ranch"). By increasing the use of this technique, energy would be saved by lowering the heat loss through the exterior wall placed below grade. Energy savings of a limited nature could also be made in applying this approach to townhouses.

COMMERCIAL/CIVIC/INSTITUTIONAL/MUNICIPALREDUCE OUTSIDE VENTILATION AIR

Range of Energy Savings: Up to 50,000 Btu/sq. ft.-yr.

Comments: Cooling savings are high in warm climates and low in cool climates. Heating savings are high in cold climates and low in warm climates. Savings will vary widely within a climate and within any land use type due to the amount of ventilation air currently being used.

INCREASE USE OF IMPROVED EFFICIENCY APPLIANCES/EQUIPMENT

Range of Energy Savings: Up to 10 percent of heating, up to 25 percent of cooling, and up to 10 percent of other electrical energy.

Comments: Exact savings in any specific case would depend on the efficiency of the improved unit. Because these efficiencies vary widely, the energy savings also vary widely. Highest savings in the other category would be in buildings with a lot of appliances and equipment such as restaurants and food stores. Lowest savings would be in buildings with very few appliances, such as terminals, warehouses, and motels.

INCREASE USE OF DOUBLE GLAZING (The use of windows with two panes of glass and a sealed space between them in place of single glazing.)

Comments: The primary determinant of energy savings is glass ratio, that is, the ratio of glass area to floor area. For a given glass ratio, savings are higher in cold climates than hot climates, with moderate climates falling in the middle. The maximum energy savings shown above is for a building with a very high glass ratio (0.4) located in a cold climate (8000 heating degree days, or similar to Idaho Falls).

INCREASE WEATHERIZATION

Range of Energy Savings: Up to 15,000 btu/sq ft.-yr.

Comments: Savings would be highest for small buildings with many operable windows and lowest for large, pressurized buildings with fixed glazing.

INCREASE USE OF REFLECTIVE GLAZING

Range of Energy Savings: Up to 7,000 Btu/sq. ft.-yr.

Comments: Savings are highest in warm climates and in buildings with a high ratio of glass area to floor area. In cool climates this alternative may result in higher energy use.

INCREASE USE OF BUILDING INSULATION

Range of Energy Savings: Up to 50,000 Btu/sq. ft.-yr.

Comments: Savings are highest in cold climates and for small buildings. Large buildings have less exterior area per sq. ft. of floor area which reduces the savings. The upper end of the savings shown above is for a 10,000 sq. ft., 1 story building in a cold (8,000 heating degree days) climate.

INCREASE USE OF AUTOMATIC TEMPERATURE CONTROL

Range of Energy Savings: Up to 20,000 Btu/sq. ft.-yr.

Comments: Heating savings are high in cold climates, cooling savings are high in warm climates. Savings are high in buildings with limited operating hours and low in buildings which operate over extensive hours, such as hospitals and terminals.

INCREASE USE OF HEAT PUMPS

Range of Energy Savings: 30 percent to 60 percent of heating.

Comments: Savings are higher in warm climates than in cold climates (when expressed as a percentage of heating).

INCREASE USE OF ONSITE ALTERNATIVE ENERGY SOURCES

Range of Energy Savings: Up to 50 percent of energy use.

Comments: Exact savings in any particular case depend on the extent of the alternative energy source used.

INCREASE USE OF TOTAL ENERGY SYSTEMS

Range of Energy Savings: 30 percent to 50 percent of energy use. Exact savings depend on the extent of the system involved.

Comments: These systems are designed to provide all the energy supplies to a building or group of buildings. This is accomplished by providing an electricity generating system (usually a diesel or gas-turbine powered generator) which has a heat recovery system attached for heating water, or air for distribution to heat the building(s). Such systems are most cost effective when heat and electric demands are relatively constant. This often means that cooling will be provided by an absorption system or other than by electricity.

DECREASE USE OF ESCALATORS AND ELEVATORS

Range of Energy Savings: 1 percent to 3 percent of other electrical energy use.

Savings would be highest in 2- and 3-level general merchandising establishments, which usually have escalators running all day. 2- and 3-level terminals would also have large savings.

SET BACK THERMOSTAT DURING UNOCCUPIED PERIODS

Range of Energy Savings: Up to 20 percent of space heating, and up to 10 percent of space cooling.

Comments: In cool climates, heating savings are low and cooling savings are high. In warm climates, cooling savings are low and heating savings are high. Savings also depend on how long and how many degrees the thermostat is set back. Maximum heating savings shown above are for an 80°F set back for 12 hours per day.

DECREASE OPERATING HOURS

Range of Energy Savings: Up to 20 percent of heating, up to 10 percent of cooling, and up to 50 percent of other electrical energy use.

Comments: Savings depend on current operating hours and the degree to which they can be reduced. Savings are much smaller if space conditioning equipment operating hours are not also reduced. The savings shown also assume that lights and other unnecessary equipment and appliances are turned off during unoccupied hours.

INDUSTRIALREDUCE LIGHTING USE

Range of Energy Savings: Up to 3 kwh/sq. ft.-yr.

Comments: Energy savings vary widely and should be evaluated on an individual basis. Typical savings will be within the 1 to 2 kwh/sq. ft.-yr. range.

INCREASE WEATHERIZATION

Range of Energy Savings: Up to 6,000 Btu/sq. ft.-yr.

Comments: Energy savings vary widely and should be evaluated on an individual basis. Values of savings reflect reduction in space heating energy only.

INCREASE USE OF LOCALIZED RADIATIVE HEATING

Range of Energy Savings: Up to 6,000 Btu/sq. ft.-yr.

Comments: Savings depend on the density of people within the building and the extent of substitution of space heat with localized radiant heating. Maximum savings can be achieved in very high ceiling areas which are sparsely populated (over 500 sq. ft. per employee) during working hours (such as some machine shops, warehouses, etc.). In such instances, waste heat from machines and lights is enough to protect the building from damage due to cold, while localized radiative heating would provide the employee comfort level of a building which is heated to normal conditions (70°F) without heating the entire building space or air volume.

Source: U.S. Department of Energy, Comprehensive Community Energy Planning, Vol. 2 November 1978c. Referred to below as DOE, 1978c.

Example

A 1,500 square foot single family detached house is being constructed in Spokane, Washington (climate zone 2). Find the effect on annual energy consumption due to the addition of storm windows and storm doors. The present design calls for single glazed windows.

Estimated energy consumption = 103,500 Btu/ft²/yr (Table 2)

Energy Usage Breakdown
(From Table 3)

<u>Element</u>	<u>Percent of Consumption</u>	<u>Btu/ft²/yr</u>
Heating	53	54,855
Cooling	16	16,560
Water Heating	12	12,420
Appliances & Power	17	17,595
Lighting	2	2,070
	<u>100</u>	<u>103,500</u>

Energy savings due to additions: 24% of heating consumption; 9% of cooling consumption. (Table 4).

Heating energy savings = $(.24) \times (54,855) = 13,165$ Btu/ft²/yr

Heating consumption with additions = $54,855 - 13,165 = 41,690$ Btu/ft²/yr.

Cooling energy savings = $(.09) \times (16,560) = 1,490$ Btu/ft²/yr

Cooling consumption with additions = $16,560 - 1,490 = 14,070$ Btu/ft²/yr

Total Consumption with
Storm Windows and Doors

<u>Element</u>	<u>Btu/ft²/yr</u>
Heating	41,690
Cooling	14,070
Water Heating	12,420
Appliances & Power	17,595
Lighting	<u>2,070</u>
	<u>87,485</u>

Net Percent Savings = $\frac{103,500 - 87,345}{103,500} = 15\%$

METHOD 2

(The Direct Method)

This method should be used when actual building plans have been formulated. It is far more rigorous and accurate than the first method. However, it also requires more user input and computation time. The method is based, for the most part, on the ASHRAE procedures outlined in the 1977 Handbook of Fundamentals and 1973 Systems Handbook. Much of the data was condensed or averaged, and procedures simplified to allow its use in this non-engineering context. Energy consumption is estimated through the following two-step process.

Hourly Energy Requirements (Step 1)

The consumption calculation process begins with the estimation of hourly thermal loads placed on the heating and cooling systems. A calculation sequence is provided which accounts for heat loss or gain from the following ten major building thermal components:

1. Roof/ceiling
2. External walls
3. External glass (transmission)
4. External glass (solar)
5. Floor
6. Infiltration
7. Ventilation
8. People
9. Lights, and
10. Equipment

Successful completion of this step requires that the user provide the series of inputs which are listed in Figure 2. Each of the input values are inserted into the proper position in the load calculation sequence. An example is provided following the procedure explanations to aid in understanding. The tables found in Appendix B are referenced throughout the calculation sequence. The results of the thermal load calculations are summed in the Load Summation Table (Form 5).

Annual Energy Consumption (Step 2)

Total energy consumption is the amount of energy actually used by the heating and cooling systems in meeting these thermal loads; combined with the energy consumption required for hot water, appliances, fans, lights, and other accessories. A consumption calculation sequence similar in format to that provided in Step 1 is given for each of these categories. Examples are again used to aid in understanding. Total annual consumption calculations are summed in the Consumption Summation Table (Form 6). The procedures outlined for estimating heating and cooling system consumption have been greatly simplified for use in this non-engineering context. This is especially true in the commercial sector where consideration of the complexities of the HVAC systems requires calculations which are beyond the scope of this manual.

FIGURE 2

USER INPUTS REQUIRED

1. Roof/ceiling constructions, area, and color
2. Wall constructions, area, and color
3. Floor constructions and area
4. Glass types and areas only (if no external shading)
5. Glass types, areas, and actual dimensions (if external shading)
6. Inside air temperature (thermostat setpoint) for heating and cooling
7. External shading dimensions
8. Internal shading type
9. Building volume
10. Area of natural ventilation inlets, if any
11. Number of people occupying building and the percent of each hour that this level is maintained
12. Total lighting wattage for building and percent of each hour that this level is maintained
13. List of heat-producing equipment to be used and percent of each hour that this equipment is used.

FORM 5

LOAD SUMMATION TABLE
(see Appendix C)

Category	Calculation Sequence	Heating	Cooling
Roof/ceiling	1		
External walls	2		
Glass (Transmission)	3		
Glass (Solar)	4		
Floor	5		
Infiltration	6		
Ventilation	7		
People	8		
Lights	9		
Equipment	10		
Total	-		

FORM 6
CONSUMPTION SUMMATION TABLE
(see Appendix C)

Calculation Sequence	Categories	Annual Energy Consumption (Btu/yr)
1	Hot Water	
2	Lighting	
3	Equipment	
4	Fans & Auxiliaries	
5	Heating	
6	Cooling	
	TOTAL	

EXAMPLE

A 12-unit, 12,000 square foot apartment building is being constructed in Spokane, Washington (48 °N latitude). Find the annual heating and cooling loads and resulting energy consumption given the following information:

NOTE: The information on pages 31-33 will be used throughout pages 34-73.

EXAMPLE (continued)

Construction: Walls - wood shingles (medium colored, felt-backed)
 (4,360 ft²) 1/2" plywood sheathing
 2" x 4" studding with R-11 insulation
 1/2" plasterboard

Roof/ceiling - built-up roofing (dark)
 (6,000 ft²) 3/4" plywood
 R-11 insulation
 1/2" plaster board

Floor - Carpet with rubber pad
 (6,000 ft²) 1 1/2" lightweight concrete
 3/4" plywood
 floor joists with R-11 insulation
 1/2" plasterboard

Glass - 1/8" double strength, single-glazing
 (1,400 ft²)

North and South faces: { 6 glass doors @ 6'8"x8' (53.4 ft² ea.)
 6 windows @ 5'x10'8" (53.4 ft² ea.)

<u>Wall</u>	<u>Wall ft²</u>	<u>Glass ft²</u>
N	1,160	640
E	1,020	60
S	1,160	640
W	1,020	60

EXAMPLE (continued)

External shading: 5' wide overhang from balcony which is assumed to be directly above all windows on north and south walls.
(Floors 1 and 2)

Internal shading: Light Venetian blinds (all glass)

People: 30

Lights: 1.95 watts/ft²

Night setback: None

Building volume: 108,000 ft³

Natural ventilation: None

Equipment: 12 typical kitchens (1,200 Btu/hr each)

Heating system: Unit electric resistance heating

Cooling system: Unit electric air conditioning

Using Method 1, the total estimated energy consumption for this building is:

$$(122,300 \text{ Btu/ft}^2/\text{yr})(12000 \text{ ft}^2) = \underline{146.8 \times 10^7 \text{ Btu/yr.}}$$

The calculations involved in Method 2 to compute the total estimated energy consumption for this building appear on the following pages 34-73.

HOURLY ENERGY REQUIREMENTS

1. ROOF/CEILING

HEATING (October-May)

$$Q_{\text{(Btu/hr)}} = U \times A \times \Delta T$$

Input by user: Roof/ceiling constructions (layers 1 to n),
 surface areas, and color

 Inside air temperature setting (T_{in})
Overall Heat Transfer Coefficient ($\text{Btu/hr/ft}^2/\text{°F}$)

$U = \frac{1}{R_T}$	Element	Resistance (R-value)	Reference Table
	Outside Surface	$R_o =$	Table B-2
	Layer 1	$R_1 =$	Table B-3
	.	.	
	.	.	
	Layer n	$R_n =$	
	Inside Surface	$R_i =$	Table B-2
	Total	R_T	

A = Roof area (ft^2) that encloses conditioned space (user input)

NOTE: If an unheated attic or crawl space is constructed between roof and ceiling, DO NOT include roof constructions in U-value calculation (ceiling and attic floor layers only)

NOTE: If the roof consists of multiple construction types:

$$UA = U_1 A_1 + U_2 A_2 + \dots + U_n A_n$$

$$\Delta T = T_{oa} - T_{in} \quad \begin{array}{l} T_{oa} = \text{outside air temperature (Table B-1)} \\ T_{in} = \text{inside air temperature (user input)} \end{array}$$

Example

<u>Element</u>	<u>Resistance (R-value)</u>	<u>Reference Table</u>
Outside surface	.17	Table B-2
Built up roofing	.33	Table B-3
3/4" plywood	.93	Table B-3
R-11 insulation	11.00	
1/2" plasterboard	.45	Table B-3
Inside surface	<u>.61</u>	Table B-2
Total	$R_T = 13.49$	

$$U = \frac{1}{R_T} = \frac{1}{13.49} = .0741 \text{ Btu/hr/ft}^2/\text{°F}$$

$$A = 6,000 \text{ ft}^2 \text{ (given)}$$

$$T_{\text{oa}} = 39 \text{ °F (Table B-1)}$$

$$T_{\text{in}} = 72 \text{ °F (given)}$$

$$Q = .0741(6000) (-33) = \underline{-14,672 \text{ Btu/hr}}$$

COOLING (June-September if Building is Air-Conditioned)

$$Q_{\text{(Btu/hr)}} = U \times A \times \text{CLTD}_{\text{cor}}$$

Input by user: Roof/ceiling constructions (layers 1 to n),
 surface areas, and color
 Inside air temperature setting (T_{in})

Overall Heat Transfer Coefficient (Btu/hr/ft²/°F)

$U = \frac{1}{R_T}$	Element	Resistance (R-value)	Reference Table
	Outside surface	$R_o =$	Table B-2
	Layer 1	$R_1 =$	} Table B-3
	·	·	
	·	·	
	Layer n	$R_n =$	
	Inside surface	$R_i =$ _____	Table B-2
	Total	R_T	

$A =$ Room area (ft²) that encloses conditioned space (user input)

NOTE: If an attic or crawl space is constructed between roof and ceiling which is not cooled, DO NOT include roof constructions in U-value calculation (ceiling and attic floor layers only)

CLTD_{cor} Corrected cooling load temperature difference based on value from Table B-4

$$\text{CLTD}_{\text{cor}} = \left[\text{CLTD}_{\text{(Table B-4)}} + \frac{L}{\text{(Latitude correction)}} + \frac{T_o}{\text{(Outdoor Temp.)}} + \frac{T_i}{\text{(Indoor Temp.)}} \right] \times \frac{R}{\text{(Roof Color)}}$$

Latitude correction (L)

$$L = \left\{ \frac{I_{TN}}{I_T} - 1 \right\} \times E \times \left\{ \frac{I_{TN}}{24} - 4 \right\}$$

I_{TN} = value from Table B-5 under HOR column
using proper latitude and month

I_T = value from HOR column of Table B-5 for 40° N latitude
using proper month

E = .15 for light-colored roofs
.30 for dark-colored roofs

T_o = Outdoor temperature correction

$$T_o = T_{oa} - 85$$

T_{oa} = outdoor air temperature (Table B-1)

T_i = Indoor temperature correction

$$T_i = 78 - T_{in}$$

T_{in} = indoor air temperature (user input)

R = Roof color correction

R = 1.0 for dark-colored roofs
.5 for light-colored roofs

NOTE: If the roof consists of multiple construction types:

$$U_x A_x CLTD = U_1 A_1 CLTD_1 + U_2 A_2 CLTD_2 + \dots + U_n A_n CLTD_n$$

Example

<u>Element</u>	<u>Resistance</u>	<u>Reference Table</u>
Outside surface	.25	Table B-2
Built up roofing	.33	Table B-3
3/4" plywood	.93	Table B-3
R-11 insulation	11.00	
1/2" plasterboard	.45	Table B-3
Inside surface	.61	Table B-2
Total	$R_T = 13.57$	

$$U = \frac{1}{R_T} = \frac{1}{13.57} = .0737 \text{ Btu/hr/ft}^2/\text{°F}$$

$$A = 6,000 \text{ ft}^2 \text{ (given)}$$

$$CLTD_{cor} = CLTD + L + T_o + T_i \times R$$

$$CLTD = 29 \text{ °F (Table B-4)}$$

$$L = \left(\frac{1924}{2029 - 1} \right) \times (.3 \times 1924/24-4) = -1 \text{ °F}$$

$$T_o = 78-85 = -7 \text{ °F}$$

$$T_i = 78-78 = 0 \text{ °F}$$

$$R = 1.0$$

$$\text{So } CLTD_{cor} = (29 -1 -7 + 0) \times 1.0 = 21 \text{ °F}$$

$$Q = .0737 (6000) (21) = \underline{9,286 \text{ Btu/hr}}$$

2. EXTERNAL WALLS

HEATING (October-May)

$$Q_{\text{(Btu/hr)}} = U \times A \times \Delta T$$

Input by user: External wall constructions (layers 1 to n),
 areas, and color
 Inside air temperature setting (T_{in})

Overall Heat Transfer Coefficient (Btu/hr/ft²/°F)

$U = \frac{1}{R_T}$	Element	Resistance (R-value)	Reference Table
	Outside surface	$R_o =$	Table B-2
	Layer 1	$R_1 =$	Table B-3
	.	.	
	.	.	
	Layer n	$R_n =$	
	Inside surface	$R_i =$	Table B-2
	Total	R_T	

A = External wall area (ft² -excluding glass) that encloses conditioned space (user input)

NOTE: If the external walls consist of multiple construction types:

$$UA = U_1A_1 + U_2A_2 + \dots + U_nA_n$$

$$\Delta T = T_{oa} - T_{in} \quad T_{oa} = \text{outside temperature (Table B-1)}$$

$$T_{in} = \text{inside air temperature (user input)}$$

Example

<u>Element</u>	<u>Resistance (R-value)</u>	<u>Reference Table</u>
Outside surface	.17	Table B-2
Wood shingles	.87	Table B-3
Permeable felt	.06	Table B-3
1/2" plywood	.62	Table B-3
R-11 insulation	11.00	
1/2" plaster board	.45	Table B-3
Inside surface	<u>.68</u>	Table B-2
Total	$R_T = 13.85$	

$$U = \frac{1}{R_T} = \frac{1}{13.85} = .0722 \text{ Btu/hr/ft}^2/\text{°F}$$

$$A = 1,160 \text{ ft}^2 \text{ (north and south walls)}$$

$$1,020 \text{ ft}^2 \text{ (east and west walls)}$$

$$T_{oa} = 39 \text{ °F (Table B-1)}$$

$$T_{in} = 72 \text{ °F (given)}$$

$$Q_{N,S} = .0722 (1160) (-33) = -2,764 \text{ Btu/hr (north and south walls)}$$

$$Q_{E,W} = .0722 (1020) (-33) = -2,430 \text{ Btu/hr (east and west walls)}$$

$$Q = 2Q_{N,S} + 2Q_{E,W} = \underline{-10,388 \text{ Btu/hr}}$$

COOLING (June-September and Building is Air-Conditioned)

$$Q_{\text{(Btu/hr)}} = U \times A \times \text{CLTD}_{\text{cor}}^{\text{wall 1}} + U \times A \times \text{CLTD}_{\text{cor}}^{\text{wall 2}} \\ + U \times A \times \text{CLTD}_{\text{cor}}^{\text{wall 3}} + U \times A \times \text{CLTD}_{\text{cor}}^{\text{wall 4}}$$

Input by user: Wall constructions (layers 1 to n),
surface areas, and color

Inside air temperature setting (T_{in})
Overall Heat Transfer Coefficient (Btu/hr/ft²/°F)

$$U = \frac{1}{R_T}$$

<u>Element</u>	<u>Resistance (R-value)</u>	<u>Reference Table</u>
Outside surface	$R_o =$	Table B-2
Layer 1	$R_1 =$	
.	.	
.	.	
.	.	Table B-3
.	.	
Layer n	$R_n =$	
Inside Surface	$R_i =$ _____	Table B-2
Total	R_T	

A = external wall area (ft² -excluding glass) that encloses conditioned space (user input)

CLTD_{cor} = corrected cooling load temperature difference based on value from Table B-6

$$\text{CLTD}_{\text{cor}} = \left[\text{CLTD}_{\text{(Table B-6)}} + \frac{L}{\text{(Latitude correction)}} + \frac{T_o}{\text{(Outdoor Temp.)}} + \frac{T_i}{\text{(Indoor Temp.)}} \right] \times \frac{W}{\text{(Wall Color)}}$$

Latitude Correction (L)

$$L = \left\{ \frac{I_{TN}}{I_T} - 1 \right\} \times E \times \left\{ \frac{I_{TN}}{24} \right\}$$

I_{TN} = value from Table B-5 using proper latitude, facing direction and month

I_T = value from Table B-5 for 40 °North Latitude for proper facing direction and month

E = .15 for light-colored walls
 = .25 for medium-colored walls
 = .30 for dark-colored walls

Outdoor Temperature Correction (T_o)

$$T_o = T_{oa} - 85$$

T_{oa} = outdoor air temperature (Table B-1)

Indoor Temperature Correction (T_i)

$$T_i = 78 - T_{in}$$

T_{in} = indoor air temperature (user input)

Wall Color Correction (W)

W = 1.0 for dark-colored walls
 = .5 for light-colored walls
 = .83 for medium-colored walls

NOTE: If the walls consist of multiple construction types:

$$U \times A \times CLTD = U_1 A_1 CLTD_1 + U_2 A_2 CLTD_2 + \dots U_n A_n CLTD_n$$

Example

<u>Element</u>	<u>Resistance (R-value)</u>	<u>Reference Table</u>
Outside surface	.25	Table B-2
Wood shingles	.87	Table B-3
Permeable felt	.06	Table B-3
1/2" plywood	.62	Table B-3
R-11 insulation	11.00	
Inside surfaces	<u>.68</u>	Table B-2
Total	$R_T = 13.48$	

$$U = \frac{1}{R_T} = \frac{1}{13.48} = .0742 \text{ Btu/hr/ft}^2/\text{°F}$$

$$A = \begin{array}{l} 1,160 \text{ ft}^2 \text{ (north and south walls)} \\ 1,020 \text{ ft}^2 \text{ (east and west walls)} \end{array}$$

<u>Wall</u>	<u>CLTD</u>	<u>L</u>	<u>To</u>	<u>Ti</u>	<u>W</u>	<u>CLTDcor</u>
N	12	-.05	-7	0	.83	4.1 °F
E	22	+ .09	-7	0	.83	12.5 °F
S	17	+3.0	-7	0	.83	10.8 °F
W	22	+ .33	-7	0	.83	12.7 °F

$$Q = .0742 \left[1,160 (4.1) + 1,020 (12.5) + 1,160 (10.8) + 1,020 (12.7) \right]$$

$$= \underline{3,190 \text{ Btu/hr}}$$

3. EXTERNAL GLASS (TRANSMISSION)

HEATING (October-May)

$$Q_{(\text{Btu/hr})} = U \times A \times \Delta T$$

Input by user: External glass types and areas
 Inside air temperature setting (T_{in})

U = Overall Heat Transfer Coefficient (Btu/hr/ft²/°F--Table B-7)

A = External glass area (ft²) enclosing conditioned space
 (user input)

NOTE: If multiple glass types are used:

$$UA = U_1A_1 + U_2A_2 + \dots + U_nA_n$$

$\Delta T = T_{oa} - T_{in}$ T_{oa} = outside air temperature (Table B-1)

T_{in} = inside air temperature (user input)

Example

$$U = 1.10 \text{ Btu/hr/ft}^2/\text{°F} \quad (\text{Table B-7})$$

$$A = 1,400 \text{ ft}^2 \quad (\text{given})$$

$$T_{\text{oa}} = 39 \text{ °F} \quad (\text{Table B-1})$$

$$T_{\text{in}} = 72 \text{ °F} \quad (\text{given})$$

$$Q = 1.10 (1,400) (-33) = \underline{-50,820 \text{ Btu/hr}}$$

COOLING (June-September and Building is Air-Conditioned)

$$Q_{\text{(Btu/hr)}} = U \times A \times \text{CLTD}_{\text{cor}}$$

Input by user: External glass types and areas
 Inside air temperature setting (T_{in})

U = Overall Heat Transfer Coefficient (Btu/hr/ft²/°F--Table B-7)

A = External glass area (ft²) enclosing conditioned space
 (user input)

NOTE: If multiple glass types are used:

$$UA = U_1 A_1 + U_2 A_2 + \dots + U_n A_n$$

CLTD_{cor} = corrected cooling load temperature difference

$$CLTD_{cor} = CLTD + T_o + T_i$$

$$CLTD = \begin{matrix} 9 & \text{with night setback} \\ 5 & \text{without night setback} \end{matrix}$$

T_o = Outdoor Temperature Correction

$$T_o = T_{oa} - 85$$

T_{oa} = outdoor air temperature (Table B-1)

T_i = Indoor Temperature Correction

$$T_i = 78 - T_{in}$$

T_{in} = indoor air temperature (user input)

NOTE: If multiple glass types are used

$$U \times A \times CLTD = U_1 A_1 CLTD_1 + U_2 A_2 CLTD_2 + \dots + U_n A_n CLTD_n$$

Example

$$U = 1.04 \text{ Btu/hr/ft}^2/\text{°F} \text{ (Table B-7)}$$

$$A = 1,400 \text{ ft}^2 \text{ (given)}$$

$$CLTD_{cor} = 5 + (78 - 85) + (78 - 78) = -2^\circ\text{F}$$

$$Q = 1.04 (1,400) (-2) = \underline{-2,912 \text{ Btu/hr}}$$

4. EXTERNAL GLASS (SOLAR)

COOLING ONLY (June-September and Building is Air-Conditioned)

$$Q_{(\text{Btu/hr})} = A \times SC \times MSHG \times CLF \times CCF$$

Input by user: External glass types, areas and dimensions

Dimensions of overhangs (external
attached glass shading)

Internal glass shading type

NOTE: If multiple glass types are used

$$Q = Q_1 + Q_2 + Q_3 + \dots + Q_n$$

A = External glass area (ft²) for glass type considered
(user input)

SC = Shading coefficient (Tables B-8 to B-10)

CLF = Cooling load factor (Table B-14)

CCF = Cloud cover factor (Table B-12) using cloud cover (CC) value
found in Table B-1

MSHG = Maximum solar heat gain
if no external overhang shading:
MSHG is found in Table B-13 using proper
facing direction, latitude and season

if external overhang shading:

$$MSHG = \left(\frac{A_s}{A} \times DIR \right) + DIF$$

$$A_s = \text{area in sun} = A - \left[(SLF \times Ow - L) \times Ww \right]$$

(if A_s is zero or negative, there is total shading; use $A_s = 0$ in this case.)

SLF = shading line factor (Table B-11)

Ow = width of overhang

L = distance from top of window to bottom of overhang

Ww = width of window below overhang

A = total window area below overhang (given)

DIR = direct component of insolation

= $.8 \times \text{MSHG}$ (cooling)

= $.6 \times \text{MSHG}$ (heating)

DIF = $.2 \times \text{MSHG}$ (cooling)

$.4 \times \text{MSHG}$ (heating)

(MSHG is taken from Table B-13)

Example

Wall	A	SC	MSHG	CLF (Table B-14)	CCF	Q(Btu/hr)
N	640	.55	7	.48	.92	1,088
E	60	.55	208	.23	.92	1,452
S	640	.55	34	.27	.92	2,973
W	60	.55	208	.23	.92	1,452
TOTAL						6,965

$$SC = .55 \text{ (Table B-9)}$$

$$CCF = .92 \text{ using CC value from Table B-1 and interpolating in Table B-12}$$

$$MSHG_{E,W} = 208 \text{ (Table B-13) (no external shading)}$$

$$MSHG_S = \left[\frac{A_s}{A} \times DIR \right] + DIF = \left[\frac{0}{640} \times 136 \right] + 34 = 34$$

$$\text{where } DIR = .8(170) = 136$$

$$DIF = .2(170) = 34$$

$$A_{s1} \text{ (windows)} = 53.4 - \left[(1.9(5) - 0)(8) \right] < 0 \text{ total shading}$$

$$A_{s2} \text{ (doors)} = 53.4 - \left[(1.9(5) - 0)(10.67) \right] < 0 \text{ total shading}$$

$$A_s = A_{s1} + A_{s2}$$

$$MSHG_N = \left[\frac{0}{640} \times 29 \right] + 7 = 7$$

$$\text{where } DIR = .8(36) = 29$$

$$DIF = .2(36) = 7$$

$$A_s = 0 \text{ for total shading}$$

5. FLOOR

HEATING (October-May)

$$Q_{\text{(Btu/hr)}} = U \times A \times \Delta T$$

Input by user: Floor construction (layers 1 to n), and area
(bottom floor only if multiple story)

Inside air temperature setting (T_{in})

Overall Heat Transfer Coefficient (Btu/hr/ft²/°F)

$U = \frac{1}{R_T}$	Element	Resistance (R-value)	Reference Table
	Outside surface	$R_0 =$	Table B-2
	Layer 1	$R_1 =$	Table B-3
	.	.	
	.	.	
	.	.	
	Layer n	$R_n =$	Table B-2
	Inside Surface	$R_i =$	
	Total	R_T	

NOTE: If floor is concrete slab on or below grade, use $U = .1$ Btu/hr/ft²/°F

A = external floor area (ft²) that encloses conditioned space

NOTE: If the floor consists of multiple construction types

$$UA = U_1 A_1 + U_2 A_2 + \dots + U_n A_n$$

$$\Delta T = T_{out} - T_{in}$$

$T_{out} = T_{oa}$ if floor is above grade (Table B-1)

T_{out} = ground temperature if floor is on or below grade

$$T_{out} = T_{oa} - T_G \text{ (Table B-1)}$$

Example

<u>Element</u>	<u>Resistance (R-value)</u>	<u>Reference Table</u>
Outside surface	.17	Table B-2
Carpet with rubber pad	1.23	Table B-3
1 1/2" lightweight concrete(80 lb/ft ³)	.60	Table B-3
3/4" plywood	.93	Table B-3
R-11 insulation	11.00	
1/2" plasterboard	.45	Table B-3
Inside surface	<u>.61</u>	Table B-2
Total	$R_T = 14.99$	

$$U = \frac{1}{R_T} = \frac{1}{14.99} = .0667$$

$$A = 6,000 \text{ ft}^2 \text{ (given)}$$

$$T_{oa} = 39^\circ\text{F (Table B-1)}$$

$$T_{in} = 72^\circ\text{F (given)}$$

$$Q = (.0667)(6,000)(-33) = \underline{-13,209 \text{ Btu/hr}}$$

COOLING (June-September and Building is Air-Conditioned)

NOTE: For floors directly in contact with the ground, or over an underground basement that is neither ventilated nor warmed, a cooling load calculation need not be made.

$$Q(\text{Btu/hr}) = U \times A \times \Delta T$$

If floor is not on grade, use procedure outlined in Heating above.

Example

<u>Element</u>	<u>Resistance</u>	<u>Reference Table</u>
Outside surface	.25	Table B-2
Carpet with rubber pad	1.23	Table B-3
1 1/2" lightweight concrete (80 lb/ft ³)	.60	Table B-3
3/4" plywood	.93	Table B-3
R-11 insulation	11.00	
1/2" plasterboard	.45	Table B-3
Inside surface	<u>.92</u>	Table B-2
Total R_T	= 15.38	

$$U = \frac{1}{R_T} = \frac{1}{15.38} = .0650 \text{ Btu/hr/ft}^2/\text{°F}$$

$$A = 6,000 \text{ ft}^2 \text{ (given)}$$

$$T_{\text{oa}} = 78^\circ\text{F (Table B-1)}$$

$$T_{\text{in}} = 78^\circ\text{F (given)}$$

$$Q = .0650 (6,000) (0) = \underline{0 \text{ Btu/hr}}$$

6. INFILTRATION

HEATING (October-May)

$$Q_{\text{(Btu/hr)}} = .018 \times A_c \times \text{Ft}^3 \times \Delta T \quad (\text{sensible*})$$

Input by user: Inside air temperature (T_{in})
 Building volume (Ft^3)

Sensible

A_c = Air changes (Table B-15)

$\Delta T = T_{\text{oa}} - T_{\text{in}}$ T_{oa} = outside air temperature (Table B-1)

T_{in} = inside air temperature (user input)

Example

Sensible

A_c = .75 air changes/hr (Table B-15)

Ft^3 = $18 \times 60 \times 100 = 108,000 \text{ ft}^3$ (given)

T_{in} = 72 °F (given)

T_{oa} = 39°F (Table B-1)

$$Q = .018 (.75) (108,000) (-33) = \underline{-48,114 \text{ Btu/hr}}$$

*Sensible heat gain is direct addition of heat to a conditioned space through conduction, convection and radiation.

COOLING (June-September and Building is Air-Conditioned)

$$Q_{\text{(Btu/hr)}} = .018 \times A_C \times \text{Ft}^3 \times \Delta T \text{ (sensible)}$$

$$Q_{\text{(Btu/hr)}} = 79.5 \times A_C \times \text{Ft}^3 \times \Delta W \text{ (latent*)}$$

Input by user: Inside air temperature (T_{in})
 Building volume (Ft^3)

Sensible

A_C = Air changes (Table B-15)

$\Delta T = T_{oa} - T_{in}$ T_{oa} = outside air temperature (Table B-1)
 T_{in} = inside air temperature (user input)

Latent

A_C = Air changes (Table B-15)

ΔW = Humidity ratio difference (see Table B-1 for elevation)
 $\Delta W = .002$ if elevation < 1000 ft.
 $\Delta W = .001$ if elevation > 1000 ft.

*Latent heat gain is the amount of energy required to maintain a constant humidity ratio in the space.

ExampleSensible

$$A_c = .75 \text{ Air changes/hr (Table B-15)}$$

$$Ft^3 = 108,000 \text{ ft}^3 \text{ (given)}$$

$$T_{in} = 78 \text{ }^\circ\text{F (given)}$$

$$T_{oa} = 78 \text{ }^\circ\text{F (Table B-1)}$$

$$Q = .018 (.75) (108,000) (0) = 0 \text{ Btu/hr}$$

Latent

$$A_c = .75 \text{ air changes/hr (Table B-15)}$$

$$Ft^3 = 108,000 \text{ ft}^3 \text{ (given)}$$

$$\Delta w = .001$$

$$Q = 79.5 (.75) (108,000) (.001) = \underline{6,440 \text{ Btu/hr}}$$

7. VENTILATION

NATURAL VENTILATION (Heating and Cooling)

NOTE: To be used only if natural ventilation inlet areas are provided in architectural plans.

$$Q_{(8tu/hr)} = 1.08 \times \Delta T \times E \times A_i \times V$$

Input by user: Indoor air temperature (T_{in})
 Area (ft^2) of natural ventilation inlets (A_i)

$\Delta T = T_{oa} - T_{in}$	T_{oa} = outside air temperature (Table B-1)
	T_{in} = inside air temperature (user input)
A_i =	Area (ft^2) of inlet openings (user input)
E =	.6 for perpendicular winds .35 for diagonal winds
V =	Wind velocity 1,320 ft/min for heating 660 ft/min for cooling

$$Q_{(Btu/hr)} = 1.08 \times CFM \times \Delta T$$

Input by user: Inside air temperature (T_{in})

CFM = Rate of outside air flow (Appropriate value from Table B-16 multiplied by number of occupants)

$$\Delta T = T_{oa} - T_{in}$$

T_{oa} = outside air temperature (Table B-1)
 T_{in} = inside air temperature (user input)

Example

There is no natural or mechanical ventilation included in the example building.

8. PEOPLE

HEATING (October-May)

$$Q_{\text{(Btu/hr)}} = \text{No.} \times \text{HG}_s \times \text{Percent}$$

Input by user: Average number of people in conditioned space(No.) and the percent of each hour that this level is maintained

HG_s = Sensible heat gain (Table B-17)

Percent = Percent of each hour that HG_s is used (user input)

NOTE: This percent value must reflect occupancy throughout an average day at the input level shown in Table B-17. Adjustments must be made if more or less strenuous activities are considered during part of the day.

Example

No. = 30 people (given)

HG_s = 255 Btu/hr (Table B-17)

Percent = .66 (see below)

<u>Hour</u>	<u>No.</u>	<u>HG_s</u>	<u>Btu/Hr</u>	<u>Hrs/Day</u>	<u>Btu/Day</u>
Mid-7 AM	30	210	6,300	7	44,100
7 AM-9 AM	30	315	9,450	2	18,900
9 AM-5 PM	10	255	2,550	8	20,400
5 PM-10 PM	20	255	5,100	5	25,500
10 PM-Mid	30	210	6,300	2	12,600
			29,700	24	121,500

$$\frac{121,500 \text{ Btu/day}}{24 \text{ hrs/day}} = 5,063 \text{ Btu/hr (average)}$$

$$\text{Reference Btu/hr} = 30 \times 255 = 7,650 \text{ Btu/hr}$$

$$\text{Percent} = \frac{5,063}{7,650} = 66\% = .66$$

$$Q = 30 (255) (.66) = \underline{5,049 \text{ Btu/hr}}$$

COOLING (June-September)

$$Q_{(Btu/hr)} = No. \times HG_{tot} \times Percent$$

Input by user: Average number of people in conditioned space (No.) and the percent of each hour that this level is maintained

HG_{tot} Reference heat gain (Table B-17)

Percent Percent of each hour that HG_{TOT} is used (user input)

NOTE: This percent value must reflect occupancy throughout the day at the input level shown in Table B-17. Adjustments must be made if more or less strenuous activities are considered during part of the day.

Example

No. = 30 people (given)

$HG_{tot} = 510 \text{ Btu/hr}$ (Table B-17)

Percent = .61 (see below)

<u>Hour</u>	<u>No.</u>	<u>HG_{tot}</u>	<u>Btu/Hr</u>	<u>Hrs/Day</u>	<u>Btu/Day</u>
Mid-7 AM	30	350	10,500	7	73,500
7 AM-9 AM	30	640	19,200	2	38,400
9 AM-5 PM	10	510	5,100	8	40,800
5 PM-10 PM	20	510	10,200	5	51,000
10 PM-Mid	30	350	<u>10,500</u>	<u>2</u>	<u>21,000</u>
			55,500	24	224,700

$$\frac{224,700 \text{ Btu/day}}{24 \text{ hrs/day}} = 9,363 \text{ Btu/hr (average)}$$

$$\text{Reference Btu/hr} = 30 \times 510 = 15,300 \text{ Btu/hr}$$

$$\text{Percent} = \frac{9,363}{15,300} = 61\% = .61$$

$$Q = 30 (510) (.61) = \underline{9,333 \text{ Btu/hr}}$$

9.LIGHTS

HEATING AND COOLING

$$Q_{(\text{Btu/hr})} = \text{wattage} \times \text{percent} \times 3.41$$

Input by user: Total lighting wattage for building and percent of each hour that this level is maintained

Wattage = (watts/ft²) x (ft²) or total wattage (user input)

NOTE: The following watts/ft² guidelines are derived from Reference 4, "Thermal and Lighting Efficiency Standards" report produced by Mathematical Sciences Northwest, Inc. (MSNW) for the Washington State Energy Office. These values should be used only when no other values are available.

Typical Wattage Values

Residential Buildings¹

Building Type	Current Practice (Watts/ft ²)	Energy Conserving ASHRAE 90-75 (Watts/ft ²)
Single Family Residence	2.0	1.2
Multi-Family Residence	1.7	1.5

Commercial Buildings (See Table B-23)

If the building has a return air plenum, only a portion (typically 10-50 percent) of the lighting load calculated with Table B-23 will contribute to the total heating or cooling load. Consult the lighting manufacturer for an accurate value.

¹Mathematical Sciences Northwest, Inc., 1978.

Example

<u>Hour</u>	<u>Hourly Percent</u>	<u>Watts</u>	<u>Hours</u>	<u>Watt-Hours</u>
Mid-7 AM	5	1,170	7	8,190
7 AM-9AM	30	7,020	2	14,040
9 AM-5PM	10	2,340	8	18,720
5 PM-10 PM	30	7,020	5	35,100
10 PM-Mid	5	1,170	<u>2</u>	<u>2,340</u>
			24	78,390

$$\text{Wattage} = 1.95 \text{ watts/ft}^2 \times 12,000 \text{ ft}^2 = 23,400 \text{ watts (given)}$$

$$\text{Watts} = \text{Wattage} \times \text{hourly percent}$$

$$\frac{78,390 \text{ Watt-hours}}{24 \text{ hours}} = 3,266 \text{ watts (average)}$$

$$\text{Percent} = \frac{3,266}{23,400} = 14\% = .14$$

$$Q = 23,400 \times .14 \times 3.41 = \underline{11,138 \text{ Btu/hr}}$$

10. EQUIPMENT

HEATING AND COOLING

Commercial Buildings

$$Q_{(Btu/hr)} = HG \times \text{Percent}$$

Input by user: List of heat producing equipment to be used and percent of each hour that this equipment is used

HG = Heat gain from equipment (Table B-18) using sensible values for heating and total (sensible and latent) for cooling. There is no latent component if a hood is used.(user input)

Residential Buildings

$$Q_{(Btu/hr)} = HG \times \text{Percent}$$

Input by user: List of heat producing equipment to be used and percent of each hour that this equipment is used

HG = Heat gain from equipment (Table B-19) using sensible values for heating and latent plus sensible values for cooling (user input)

NOTE: Q value typically used for a residential kitchen is 1,200 Btu/hr, which is based on a 24 hour heating/cooling day

Example

Twelve typical kitchens (one per apartment) are assumed

$$Q = 12 \times 1,200 \text{ Btu/hr} = \underline{+14,400 \text{ Btu/hr}}$$

Example

LOAD SUMMATION TABLE
(FORM 5)

Category	Calculation Sequence	Heating	Cooling
Roof/Ceiling	1	-14,672	+ 9,286
External Walls	2	-10,388	+ 3,190
Glass (transmission)	3	-50,820	- 2,912
Glass (solar)	4	-	6,965
Floor	5	-13,209	0
Infiltration	6	-48,114	6,440
Ventilation	7	-	-
People	8	+ 5,049	+9,333
Lights	9	+11,138	+11,138
Equipment	10	<u>+14,400</u>	<u>+14,400</u>
Total		-106,616	+57,840

ANNUAL ENERGY CONSUMPTION

1. HOT WATER

$$Q_{(Btu/yr)} = \frac{gpd \times \Delta T \times 3040}{E_{ff}}$$

gpd hot water consumption for an average day (Table B-21)
 $\Delta T = T_H - T_C$ temperature rise of water
 T_H = output temperature (Table B-20)
 T_C = input temperature
 $T_C = 50^\circ F$ Washington, Idaho, Oregon
 $T_C = 40^\circ F$ Alaska

E_{ff} efficiency of energy conversion
 $E_{ff} = .7-.8$ (natural gas)
 1.0 (electric-point of use)
 $.30$ (electric-source)

Example

$gpd = 42 \text{ gal/apt/day} \times 12 \text{ apt} = 504 \text{ gal/day}$ (Table B-21)

$\Delta T = 150 - 50 = 100^\circ F$

where $T_H = 150^\circ F$ (Table B-20)

$T_C = 50^\circ F$ (Washington)

$E_{ff} = 1.0$ (electric-point of use)

$$Q = \frac{504 \times 100 \times 3040}{1.0} = 1.532 \times 10^8 \text{ Btu/yr}$$

2. LIGHTING

$$Q_{(\text{Btu/yr})} = \text{wattage} \times \text{percent} \times 29,872$$

wattage = watts/ft² x ft² or total wattage

percent = percentage of each hour that the above wattage level is maintained

NOTE: The values used for this calculation should be identical to those used in Section 9 of the load calculations.

Example

wattage = 1.95 watts/ft² x 12,000 ft² = 23,400 watts

percent = .14 (see details in Section 9 of load calculations)

Q = 23,400 x .14 x 29,872 = 9.786 x 10⁷ Btu/yr

3. EQUIPMENT

COMMERCIAL

$$Q_{\text{(Btu/yr)}} = \text{Input} \times \text{Percent} \times 8,760$$

Input = sum of rated inputs (Table B-18)

Percent = percent of each hour that equipment is used (user input)

NOTE: The percent value used here must account for all building equipment.

RESIDENTIAL

$$Q_{\text{(Btu/yr)}} = \text{Kwh} \times 3,413$$

Kwh = sum of values from Table B-22

Example

<u>Appliances</u>	<u>Amount</u>	<u>Kwh/Yr</u>
refrigerator	12	19,200
range	12	14,400
clothes dryer	2	2,000
clothes washer	2	200
dishwasher	12	3,600
color TV	12	6,000
miscellaneous	12	<u>8,400</u>
Total		53,800

$$Q = 53,800 \times 3,413 = \underline{1.836 \times 10^6 \text{ Btu/yr}}$$

4. FANS AND AUXILIARIES (COMMERCIAL ONLY)

$$Q_{\text{(Btu/yr)}} = Kw \times \text{Percent} \times (3 \times 10^7)$$

Kw = sum of manufacturers input ratings for all fans, motors, and other auxiliary equipment used for distribution of or in conjunction with the heating, cooling and ventilating equipment. Fan part load curves should be used when applicable.

Percent = percent of each hour that the kW level is maintained

5. HEATING

$$Q_{\text{(Btu/yr)}} = \frac{X_H \times DD \times \text{Hrs}}{(65 - T_{\text{oa}}) \times E}$$

X_H = heating load (Btu/hr) taken from Load Summation Table

DD = annual heating degree days (Table B-1)

Hrs = hours per day that heating system is operating (setback hours are not counted)

T_{oa} = average outside air temperature taken from Table B-1

E = efficiency of furnace or boiler

RESIDENTIAL

- $E \cong .7-.8$ new gas or oil furnace
- $= 1.0$ electric resistance (point of use)
- $\cong .30$ electric resistance (source)
- $\cong 1.8-2.0$ heat pump

COMMERCIAL

Due to the system complexities inherent in most commercial heating equipment, efficiency values vary widely with the operating and ambient conditions specific to each building. Greatest accuracy will be obtained by estimation of a system efficiency through consultation with the system manufacturer or the HVAC consultant who has designed the system under consideration.

¹Mathematical Sciences Northwest, Inc., 1978.

Example

heating system = electric resistance (given)

$X = 106,616 \text{ Btu/hr}$ (Load Summation Table) (minus sign should be ignored here)

$DD = 6,835 \text{ degrees days}$ (Table B-1, Spokane)

$Hrs = 24$ (no night setback)

$T_{oa} = 39 \text{ }^{\circ}\text{F}$ (Table B-1, Spokane)

$E = 1.0$ (point of use)

$$Q = \frac{106,616 \times 6,835 \times 24}{(65 - 39) \times 1.0} = 6.73 \times 10^8 \text{ Btu/hr}$$

6. COOLING (June-September)

$$Q_{(\text{Btu/yr})} = \frac{X_c \times N \times \text{Hrs}}{E}$$

X_c = cooling load (Btu/hr) taken from Load Summation Table

Hrs = number of hours per day that cooling system is operating
(setup hours are not counted)

N = number of days per year that cooling system is operating

N = 122 days (4 month cooling season)

E = efficiency of air-conditioner or chiller

The efficiency of cooling systems varies with the operating and ambient conditions specific to each building. The efficiency of the system under consideration can best be estimated by consultation with the manufacturer or system designer.

Example

cooling system = electric unit air conditioning ($E=1.0$)

X_c = 57.840 Btu/hr (Load Summation Table)

N = 122 days (4 month cooling season)

Hrs = 24 (no night setup)

$$Q = \frac{57.804 \times 122 \times 24}{1.0} = 1.69 \times 10^8 \text{ Btu/yr}$$

Example

CONSUMPTION SUMMATION TABLE
(FORM 6)

<u>Calculation Sequence</u>	<u>Categories</u>	<u>Annual Energy Consumption (Btu/yr x 10⁷)</u>
1	Hot Water	15.3
2	Lighting	9.8
3	Equipment	18.4
4	Fans & Auxiliaries	-
5	Heating	67.3
6	Cooling	<u>16.9</u>
	Total	127.7

Comparison of results from Methods 1 and 2

Method 1 146.8×10^7 Btu/yr consumed (from page 33)

Method 2 127.7×10^7 Btu/yr consumed

ALTERNATIVE ENERGY SOURCES

Energy sources considered in the two energy consumption estimation procedures were limited to those in standard use, namely electricity and fossil fuels. There are, however, several other forms of energy which can be successfully employed in meeting building energy requirements. The most commonly used alternative sources include solar, wind, wood, and geothermal energy. Although none of these alternative sources have been put into widespread use by the construction industry, their feasibility is being seriously considered in light of current trends in costs of the standard energy sources.

The great advantage to these alternative energy sources is that they are often found in directly usable forms and in great abundance in certain geographical regions and climatic areas. Problems often arise, however, in the economics of collection and distribution, and in the geographic and climatic limitations. Solar and wind energy are often unpredictable, which adds the complication of questionable reliability. Economic constraints are slowly being overcome as the supply of standard energy forms dwindle and their production costs increase. Although geographic and climatic constraints will always limit the application of alternative sources, most areas of this country have at least one of the sources available to it. Therefore it is worthwhile to consider the use of one or more of these sources in all new construction.

These sources will rarely be able to supply all building energy requirements. This necessitates the use of reduced capacity supplementary systems, which utilize standard energy sources. Incorporation of energy consumption by alternative sources into Methods 1 and 2 can be made through reductions in heating and/or cooling hours and decreased electrical demands. Precise calculation of the proportion of energy requirements that can be supplied by these sources is difficult because of site dependency. Current research is attempting to quantify their potential. The results of such an analysis by the Department of Energy¹ which focused on Region X solar heating were recently released. A sample of the results for two of the twelve cities studied is shown in Table B-24. Examination of the data shows that a substantial portion of water and space heating requirements can be met by solar energy. The percentage of water and space heating requirements derived from this table can be applied to the respective consumption values. Since this source has no operational energy costs, these impacts can be considered a direct reduction in total building energy usage.

¹U.S. Department of Energy, Solar Energy for Pacific Northwest Residential Heating. Interagency Report, May 1978a. Referred to below as DOE, 1978a.

ENERGY AND LAND USE

INTRODUCTION

Energy consumption can be greatly reduced by locating residential and commercial buildings within areas of existing urban or suburban development. Building within existing developments often results in, and many times requires, an emphasis on higher density development than currently practiced, and on mixed use development. These form the backbone of a multitude of energy-conserving land use goals. Corbin Crews Harwood, in her book on energy and land use, summarizes the benefits of higher density and mixed use development:

Multiunit buildings can cut space heating and cooling costs by about 60 percent per unit since units are smaller and have fewer exposed surfaces that permit temperature exchanges. Dense development allows the use of total energy systems that reuse waste heat generated during the production of electricity. It also can permit and encourage the use of energy-efficient public transportation systems and, when it has the effect of bringing trip origins and destinations closer together, it will reduce the length of trips and can even make walking and bicycling reasonable substitutes for the automobile. Similarly, when higher density development is combined with energy-efficient locational choices, it will reduce the length of roads and utility systems whose unnecessarily extensive construction wastes fuel. In spite of these energy efficiencies and the fiscal economies that accompany them, higher density development is not desirable everywhere, nor will it contribute to energy savings unless properly located.

Although ways to save energy in land use planning are all interrelated, the means for saving energy can conveniently be divided into three categories: density development, mixed use development, and infrastructure.

¹Harwood, Corbin Crews. Using Land to Save Energy. Cambridge, Ballinger Publishing Company, 1977. Referred to below as Harwood, 1977.

DENSITY DEVELOPMENT

Increasing the density of developable land generally refers to providing more dwelling units on a given piece of land. Instead of single family detached housing, density development consists of single family attached--town houses or row houses--cluster development, or multi-family housing--low rise or small high rise (up to ten stories). Increasing the density of dwelling units in this manner saves energy in two ways:

1. Space heating and cooling energy is saved by taking advantage of common walls, ceilings and floors, which decreases heat loss, and
2. Less space heating and cooling is used because such units tend to be smaller.

Many different variables--climate, the number of windows and storm windows in a building, the amount of insulation used, the number of square feet of floor space, and so on--can influence the energy demands made by space heating and cooling. Nevertheless, studies show that we can expect to consume about 30 percent less energy per square foot in medium-sized multifamily structures (ranging from apartment buildings with as few as twenty units up to small high rises of ten stories or less) than in detached single family homes. And, because they are typically smaller than single family houses, units in multifamily buildings will use 60 percent less energy for space heating and cooling on a per unit basis than will single family detached homes. The actual energy savings can, therefore, be far greater than the 30 percent figure if people switch from single family to multifamily housing...

It is essential to note, however, that the location of the thermal-efficient building remains crucial. Unless it is placed near adequate transportation lines and close to employment and shopping centers, the savings on heating and cooling may be outweighed by transportation energy requirements.¹

Thus the objective of increased density is to save both initial embodied energy and energy required for building space heating and cooling. These subjects are discussed in Parts I and II of this manual.

¹Harwood, 1977.

MIXED USE DEVELOPMENT

Mixed use development covers a broad range of options. The term connotes:

- Mixing buildings that have different uses,
- Mixing uses within buildings, and
- Mixing residential buildings of various sizes and prices to bring people with different housing needs closer to varying job opportunities

The end result will be more emphasis on mixed use planned unit developments (PUDs).

Segregating land uses unnecessarily consumes travel time and energy. As a result of separating commercial, residential, industrial, recreational, and cultural land uses, transportation fuel demands are increased--for example, by forcing people to leave their residential zone to shop, to leave their work zone to play, or to leave their school zone to go to the dentist.

The energy objective of mixed use development is to reduce travel demands. Another energy saving opportunity that arises from mixed use is the possibility of integrated community energy systems, where the waste heat from industrial processes is used to heat nearby residential or commercial buildings. Estimates of the potential of use for waste heat are very dependent on specific industrial activities and are not attempted here. However, the EIS writer/reviewer should look for opportunities to use industrial waste heat in new residential and commercial development. The remainder of this section will focus on transportation energy use and how it can be affected by mixed use development.

There are two objectives that, if met, will result in decreased energy use:

1. Shift transportation demands to more efficient modes, and
2. Decrease trip length and frequency

Both objectives can be met in part by utilizing specific land development techniques.

Land developments best able to reduce transportation energy demand have the following characteristics:

- They promote moderately high density of use,
- They promote contiguous development,
- They mix residential and employment opportunities, and
- They are served by adequate public transportation lines

In areas not served by public transportation, energy savings must rely even more on mixed uses and dispersion of convenience stores and services at the neighborhood level. One study for the Washington, D.C., metropolitan area concluded that one-half the additional transportation energy could be saved by avoiding low density, non-contiguous development.¹

Procedures

To estimate the energy impacts resulting from various land development plans, the EIS writer/reviewer must first establish a standard or baseline against which to compare alternatives. The following steps will establish that baseline. An example, assuming a residential development outside a major city, accompanies each step, and the results are entered in Form 7.

- Step 1. Enter in Column 1, Form 7, the number of single family residences and multi-family residences planned as part of the development. For the example, we assume 50 single family units and 100 multi-family units, in a suburban area.
- Step 2. From Table 6, enter in Column 2, Form 7, the typical annual vehicle miles traveled, depending on the location of the development. (Additional detail on daily trips and lengths is given to facilitate different assumptions or substitutions of more applicable data.) Since it is assumed that residents of apartments travel 20 percent less than persons in single family households,¹ multiply annual miles traveled by single family households times 0.8 to get annual miles traveled by a multi-family household.

¹Skidmore, Owings, and Merrill, Inc. Transportation and Land Use Conservation Choices. Portland Energy Conservation Project, June 1977c. Referred to below as Skidmore, Owings, and Merrill, 1977c.

- Step 3. Multiply Column 1 by Column 2 to obtain total miles traveled and enter in Column 3. This Column 3 may be summed before doing further calculations unless one assumes that the private auto/public transit modal split is different for multi-family residents than for single family residents. The example assumes that the modal split is the same.
- Step 4. For each type of housing (or combined, as in the example), estimate the percent of miles traveled by private automobile and by public transit. If public transit is a factor, call the local transit company for an estimate. Multiply the percent traveled by auto times the total miles traveled in Column 3 and enter in Column 4. Multiply the percent traveled by public transit times total miles traveled in Column 3 and enter in Column 5.
- Step 5. Enter in Column 5 the Btus per mile per automobile shown in Table 5. (The values in Table 5 assume no carpooling. If carpooling is a factor in the baseline, then it would be more appropriate to use Btus per passenger-mile. Since trip mileage [Table 6] is measured in miles per household, it does not matter if more than one person is in the car as long as all riders are from the same household).
- Step 6. Enter in Column 7 the Btus per passenger-mile for busses. To get this figure, call the transit company and find out the average number of people riding the route serving the development. Then divide the average number of people riding into the Btus per mile shown in Column 3, Table 5B. If this information is not available, use the values found in Table 5B, Column 5.
- Step 7. Multiply Column 4 by Column 6 to get total annual Btus by auto, and enter in Column 8.
- Step 8. Multiply Column 5 by Column 7 to get total annual Btus by bus, and enter in Column 9.
- Step 9. Sum Columns 8 and 9 to get total transportation Btus and enter in Column 10. This is the baseline transportation energy use attributable to the proposed development.
- Step 10. Consider conservation options, such as those described on the following pages and modify the baseline as appropriate.

USE MORE EFFICIENT STREET LIGHTS

Range of Energy Savings: 40 to 50 percent savings per lamp (150 watt-hour) without any decrease in lighting level. Substitution of mercury vapor lamps with high pressure sodium lamps can save 50 percent of electric energy without reducing lighting levels.

Comments: Substitution of existing street lights with more efficient types (such as sodium vapor lamps) could provide a substantial savings in the energy used for lighting. A substantial cost might be incurred, however, especially if the lamp power units (ballasts) which provide the appropriate current and voltage to the light must be replaced with the lamps. Another way to achieve energy savings in street lighting is to reduce the number of lights or use lower wattage lamps which decreases energy use but also results in lower lighting levels.

ENCOURAGE INCREASED USE OF BICYCLE MODES

Range of Energy Savings: 1 percent. Fifty-four percent of all trips (11 percent of vehicle miles) are less than 5 miles long. If 10 percent of these trips could be switched to bicycle and pedestrian modes, a one percent savings of transportation energy would occur (100 Btu/vehicle mile).

Comments: Bicycle travel is one of the most efficient transportation modes that can be used on short trips. Currently, this mode is used for a very small portion of all travel. In many cases, small improvements or changes in transportation system could increase the safety or convenience of bicycling modes, increasing its use. Costs of bicycle improvements are relatively low. Bicycle paths cost between \$22,000 (fully separated right of way) and \$1,000 (lane on existing street) per mile.

INCREASE USE OF PEDESTRIAN MODES

Range of Energy Savings: 0-1 percent.

Comments: A 100 percent savings would occur for each trip shifted. Since only a small percentage of vehicle miles are less than one mile (a reasonable upper limit for walking distances) only small savings would result from this strategy (0-1 percent or 0-100 Btu/vehicle mile).

ENCOURAGE INCREASED CARPOOLING

Range of Energy Savings: 2-4 percent (200-400 Btu/vehicle mile). 50 percent savings per vehicle assumes two riders who previously drove separately, share one car. The high energy saving of 4 percent regional savings assumes that the work trip occupancies increase from 1.4 to 1.7 persons per vehicle and that 28 percent of all travel is due to auto work trips which are potential carpool trips (400 Btu/vehicle mile).

Comments: Carpooling is one of the most effective alternatives for conservation of energy in transportation. It can also be implemented quickly and requires very little investment and no radical changes in lifestyle. Carpooling is only applicable to trips which are made at regular intervals; these trips are primarily work trips.

ENCOURAGE INCREASED VANPOOLING

Range of Energy Savings: 1-4 percent. On a passenger mile basis an 8 person vanpool uses 17 percent of the energy used by a single occupant automobile. (Savings of 7800 Btu/passenger mile.) Regional energy savings ranges from 1-4 percent of the transportation energy (100-400 Btu/vehicle mile).

Comments: Vanpooling is similar to carpooling except that in vanpooling the vehicles used for ridesharing are owned by the employer and have been purchased especially for the purpose of commuting. In most vanpools, one person, selected to be the van driver, receives the van in exchange for driving and administrative services. The other persons in the vanpool pay a small fare which covers the cost of the van, insurance, fuel, and maintenance. Due to the fact that a van can carry up to 12 people comfortably, this type of ridesharing is one of the most efficient modes for transporting people to and from work.

INCREASE USE OF SYNCHRONIZATION OF TRAFFIC SIGNALS

Range of Energy Savings: 1-4 percent. Assuming that the installation would increase average travel speed by 5-15 percent and no increase in VMT occurs, a savings of 1-4 percent of a community's transportation energy use could be obtained (100-400 Btu/vehicle mile).

Comments: Optimization of traffic signals can significantly reduce the number of stops made by vehicles in traffic. Since stopping and idling both increase fuel consumption, the streamlining of flow patterns will not only save the motorist time, it will also reduce the fuel consumed on a given trip. Care must be taken to discourage increases in vehicle miles of travel because of the increased quality of travel in the community. The increased VMT could cancel out any energy savings.

LOCATE HOUSING NEAR EMPLOYMENT AND SERVICES

Range of Energy Savings: Vehicle miles of travel (and the related energy consumption) can be reduced if work and non-work trip lengths can be reduced. The community must strive to encourage workers to live close to the employment centers, encourage the continued use of carpools and transit by these workers, and discourage the possible creation of new trips because of the close proximity of new opportunities.

Comments: Many other considerations other than proximity to work enter a person's choice of where to live and it may be difficult to encourage this type of development.

INCREASE BUILDING OF LOCAL RECREATIONAL FACILITIES

Range of Energy Savings: The energy savings produced by this alternative depends on the number of neighborhood parks created, their location, and the number of people switching from the automobile to walking or bicycling.

If neighborhood parks were located within walking or bicycling distance to residential areas, travel to recreational facilities by other than the auto modes would be enhanced.

Source: DOE, 1978c.

FORM 7

TRANSPORTATION ENERGY USE CALCULATIONS
(See Appendix C)

	Number of Households (1)	Miles Traveled per Year per Household (From Table 6) (2)	Total Miles Traveled (Col.1 x Col.2) (3)	Miles Traveled by Car (4)	Miles Traveled by Transit (5)
Single Family	50	15,100	755,000		
Multi-Family	100	12,080	1,208,000		
Total	-	-	1,963,000	1,766,700	196,300

	Automobile Btus per Mile (From Table 5A) (6)	Bus Btus per Passenger Mile (From Table 5B) (7)	Total Auto Btus (Col.4 x Col.6) (8)	Total Bus Btus (Col.5 x Col.7) (9)	Total Transportation Btus (Col.8 + Col.9) (10)
Single Family					
Multi-Family					
Total	8,452	3,640	14,932 Million Btus	715 Million Btus	15,647 Million Btus

TABLE 5¹

TRANSPORTATION MODE EFFICIENCIES

Table 5A--Automobile Efficiency (for Column 6, Form 7)

Year	Adopted Federal Mileage Standards for New Cars	Average Vehicle Mileage for All Cars (Assuming New Federal Car Standards are Met)	Btu/Mile
1975	No standard	13.8	9,066
1978	18.0 mpg	14.8	8,452
1979	19.0 mpg	15.2	8,229
1980	20.0 mpg	15.6	8,021
1985	27.5 mpg	17.9	6,985
1995	No standard	19.0	6,579

Table 5B--Bus Efficiency (for Column 7, Form 7)

Btu/Gal Bus Diesel (1)	Typical Bus Mileage (2)	Btu/Mile Col(1)xCol(2) (3)	Avg. No. of People Riding (4)	Btus per Passenger Mile Col(3)xCol(4) (5)
136,000	4.5	30,200	12.6 In City	2,400
			8.3 Out of City	3,640

¹ Skidmore, Owings and Merrill, 1977c.

TABLE 6
HOUSEHOLD TRAVEL CHARACTERISTICS¹

Table 2A--Households in the City (Urban)

Typical Daily Vehicle Travel for a Single Family Household (12,228 Miles per Year)
(Multi-Family Household Travels 20 Percent Fewer Miles)

	Trips per Household per Day* No. (1)	Length of Trip (Miles) (2)	Miles Traveled per Household per Day No. (3)
Work	2.5	6	15.0
Shopping	1.5	4	6.0
Personal business	0.9	4	3.6
Doctor-Dentist	0.1	4	0.4
Restaurant	0.3	4	1.2
Social	1.2	4	4.8
Recreational	0.3 ₄	4	1.4
School	0.3 ₄	3	1.1
Total	7.2	-	33.5

Table 2B--Households Outside the City (Suburban)

Typical Daily Vehicle Travel for a Single Family Household (15,100 Miles per Year)
(Multi-Family Household Travels 20 Percent Fewer Miles)

	Trips per Household per Day* No. (1)	Length of Trip (Miles) (2)	Miles Traveled per Household per Day No. (3)
Work	2.5	8	20.0
Shopping	1.5	5	7.5
Personal business	0.9	5	4.5
Doctor-Dentist	0.1	5	0.5
Restaurant	0.3	5	1.5
Social	1.2	4	4.8
Recreational	0.3 ₄	4	1.4
School	0.3 ₄	3 ₄	1.2
Total	7.2	-	41.4

Table 2C--Portland SMSA (Average)

Typical Daily Vehicle Travel for a Single Family Household (14,089 Miles per Year)
(Multi-Family Household Travels 20 Percent Fewer Miles)

	Trips per Household per Day* No. (1)	Length of Trip (Miles) (2)	Miles Traveled per Household per Day No. (3)
Work	2.5	7.5	18.8
Shopping	1.5	4.5	6.8
Personal business	0.9	4.5	4.1
Doctor-Dentist	0.1	4	0.4
Restaurant	0.3	4	1.2
Social	1.2	4	4.8
Recreational	0.3 ₄	4	1.4
School	0.3 ₄	3	1.1
Total	7.2	-	38.6

NOTE: While these figures are specifically applicable to the Portland, Oregon area, their use in other Region I locations is not improper for examining energy related transportation effects.

*Going to a destination is one trip. Going to a destination and returning is considered two trips.

¹Skidmore, Owings and Merrill, 1977c.

INFRASTRUCTURE

Street Design

The provision of capital facilities - streets, sewage lines, storm water drains, water mains - to new development carries embodied energy costs which must be accounted for. Infrastructure costs can be minimized by locating new building development within areas already served by these facilities, or at the fringe of such areas. The objective here is to avoid "leapfrogging" over developable land.

Streets and roads are particularly notorious energy consumers. In addition to encouraging automobile use, asphalt streets use petroleum as a base; pound for pound, the concrete in concrete streets requires even more energy to manufacture than aluminum does. In spite of the hidden high energy costs of road building, however, streets not only are extended to serve developments prematurely located on the urban fringe, but are also often made far wider than they need to be to bear the traffic they were designed to serve. Consequently, streets intended for residential use have become major thoroughfares, thus adding to unnecessary energy expenditures for construction and making walking and bicycling unpleasant and even unsafe. Where possible, clustered development should replace grid patterns, since clusters require fewer linear feet of street and have the additional energy benefits of helping to preserve the natural landscape and are permitting flexible orientation. One study recommends that collector and subcollector streets be reduced to twenty six feet in width and streets in cul-de-sacs should be reduced to sixteen to eighteen feet.¹

Properly planned neighborhoods can considerably reduce street size without impeding traffic flow or safety considerations. A workable mix of residential streets and thoroughfares which minimizes street area should be devised through careful consideration of community needs. In low use residential areas serious consideration should be given to alternative street designs such as the one shown in Figure 4. Adequate parking space is provided in driveways and other off street bays which allows for a narrower street width fully devoted to traffic flow. In this way energy is conserved through reduced material volume and installation. In addition, usable lot space will be increased allowing for additional landscaping and a more pleasant neighborhood atmosphere.

¹Harwood, 1977.

More heavily used sub-collector streets will need some on street parking. However, the requirements can often be reduced to one lane by fronting homes on cul-de-sacs or loops, as shown in Figures 3 and 5, leaving on street parking for traffic from outside the neighborhood. Cul-de-sac and loop configurations not only reduce land, energy, and maintenance costs, but also add variety in lot size and shape. Pedestrian safety and neighborhood identity can also be enhanced.

Before considering the energy saving potential of infrastructure adjustments, it will be helpful to have a clear understanding of how energy consumption in infrastructure development can be calculated. The particular infrastructure items considered here are paved streets and parking lots, curbs and sidewalks, sewer pipe, water pipe, storm water drains. Other items, such as telephone lines and electric or gas utilities, can be added.

There are certain things related to each of these items the EIS writer/reviewer must know or estimate before beginning energy impact calculations:

- Square feet of paved area,
- Linear feet of curb and sidewalks,
- Linear feet of sewer mains,
- Linear feet of water mains, and
- Linear feet of storm water drains.

This may be referred to as a materials list.

Calculation Procedure

- Step 1. Using the materials list as a starting point, fill in Column 2 of Form 8.
- Step 2. Multiply the quantities in Column 2 by the direct and indirect energy coefficients shown in Column 3. Enter results in Column 4.
- Step 3. Sum Column 4 for total infrastructure energy costs.
- Step 4. If materials other than those listed in Form 8 are used, or other infrastructure items than those listed above are desired, consult Appendix A for a complete listing of materials and their energy costs.

These steps should be carried out for the proposed development and repeated for each alternative. For example, if a grid street pattern is proposed with a street width of 36 feet, alternative energy costs could be estimated for a curvilinear street pattern with street widths reduced to 20 to 26 feet with offstreet parking. This alternative would also affect the length and energy costs of sidewalks and curbs, sewers, water mains, etc.

FORM 8

INFRASTRUCTURE EMBODIED ENERGY COSTS
(See Appendix C)

Material (1)	Quantity (2)	Direct and Indirect Btus (3)	Total Btus (Col. 2 x Col. 3) (4)
<u>Sewer, Water, Storm Drainage Pipe</u>		<u>Btus/LF</u>	
Concrete Pipe (all types)			
4-inch Inside Diameter		26,512	
6 10		40,926	
8		65,934	
10		90,832	
12		119,391	
15		136,321	
24		217,812	
36		326,765	
60		544,951	
Galvanized Pipe			
8-inch ID, 16 Gauge		206,380	
12 16 "		309,570	
15 16 "		386,562	
24 14 "		743,321	
36 12 "		1,301,244	
60 10 "		2,479,194	
Vitrified Clay (Std. Strength)			
4-inch ID		77,787	
6		138,228	
8		198,789	
10		311,148	
12		414,854	
15		622,296	
18		878,000	
24		1,574,563	
30		2,510,360	
36		3,745,184	
<u>Pavement: Streets, Driveways, Parking</u>		<u>Square Feet (SF)</u>	<u>Btus/SF</u>
Asphalt with aggregate			
4 inches thick		54,000	
Asphalt blocks			
5" x 12" x 3"		40,500	
Concrete (Reinforced)			
5 inches thick		45,100	
10 inches thick		80,075	
Brick (on Sand)			
		153,555	
<u>Curb</u>		<u>Linear Feet (LF)</u>	<u>Btus/LF</u>
Asphalt 6" x 18"			121,215
Concrete 6" x 18"			72,065
<u>Sidewalk</u>		<u>Square Feet (SF)</u>	<u>Btus/SF</u>
Bituminous (Asphalt Concrete)			
2 inches thick		26,400	
Brick			
Laid flat on sand		115,119	
Laid on end on sand		184,190	
Concrete 4 inches thick			21,915

SOURCE: Hannon, 1977.

Example

Compare the embodied energy costs between rectilinear and cluster development for 4 inch thick, 36 foot wide asphalt pavement using the distribution given in Figure 3 (page 90).

Embodied Energy Cost (Form 8) = 54,000 Btus/SF

	<u>Street Length(ft)</u>	<u>Street Area(SF)</u>	<u>Embodied Energy (Btu x 10¹⁰)</u>
Rectilinear	12,000	432,000	2.332
Cluster	6,000	216,000	1.166

$$\text{Energy Savings} = 2.332 \times 10^{10} - 1.166 \times 10^{10} = \underline{1.166 \times 10^{10} \text{ Btus}}$$

STORM WATER MANAGEMENT

In addition to their basic function of providing for transportation needs, many streets serve as storm water collectors. The engineering philosophy often used in storm water management is to achieve maximum convenience by the most rapid possible elimination of excess surface water. This approach, however, often results in adverse and unnecessary environmental impacts.

Through redesign of developments, land can be set aside for channelization and detention of storm water. This will often lead to elimination of curbs and gutters, and can minimize the need for storm water pipes, headwalls, inlets and manholes - all of which can save large amounts of direct and embodied energy, as well as reduce site development costs (by as much as \$1000 per lot¹). By fully considering the resources, requirements and conditions present at each building site, engineering design can effectively utilize and enhance the existing natural systems rather than negate, replace or ignore them. Ideally this would result in absorption or retention of water falling on a site to the extent that runoff after development would not be much more than that before development.

¹Mackie, M. and Mackie, B. Relationships of Energy to Land Use. Yamhill County Planning Department Energy Office. McMinnville, Oregon, November, 1977. Referred to below as Mackie, 1977.

Some principles to consider for environmentally sound and energy conscious drainage management include the following:

1. The design of permanent and temporary ponding and/or storage should be an integral part of the overall development planning process, and should consider opportunities within the open space and landscaped areas for the creation of such facilities.
2. Storm water runoff systems should be designed to facilitate aquifer recharge when it may be advantageous to compensate for groundwater withdrawals. Conversely, designs should avoid recharge where groundwater effects might be harmful.
3. Natural overland flows, and open channel and swale routings should be the preferred alignments for major components of a residential drainage system (Figure 6).
4. Storm water management systems, street layout, lotting patterns, and the horizontal and vertical locations of curbs, inlets and site drainage and overflow swales should be concurrently designed.
5. Enclosed components of a storm water runoff system should help manage storm water, not just dispose of it.

Local government should study and develop master plans for each drainage basin within its jurisdiction which may be impacted by development. Hopefully, neighboring communities will collaborate on plans for drainage basins which extend across jurisdictional boundaries. In addition, all individual land development proposals should include storm water runoff system plans that will be compatible with the master plan for that drainage area, and that anticipate and provide for potential effects of upstream developments.¹

¹Mackie, 1977.

Reprinted from:

New Approaches to Land Development/A Study of Concepts and Innovations, Technical Bulletin 40 (Washington, D.C.: The Urban Land Institute, 1961), p. 29.

Figure 3. Alternative Development Patterns¹

¹Harwood, 1977.

BUILDING RELATIONSHIPS

A major design consideration often overlooked during building development is the specific unit orientation or siting. The impacts of wind and solar response on energy consumption can be significant; and should be an integral part of the planning process. Optimum placement of individual or clustered buildings will vary with latitude and weather conditions. The following set of guidelines are derived from recent studies which focus on the cold and temperate climatic regions which encompass the Pacific Northwest and Alaska.

Wind Response

Winter winds increase building energy consumption in cold and temperate regions by increasing unintentional air infiltration. Building design should consider the following orientation, clustering and buffering techniques as ways to effectively reduce the amount of exterior wall surface exposed to the wind.¹

1. Orient the long axis of attached units parallel to the prevailing wind. This results in a parallel air flow with the least cold air infiltration for the exposed end units. Much of the end unit infiltration impact can be negated by the placement of a windward evergreen tree buffer of equal height to the unit, at a distance of $1\frac{1}{2}$ -2 times the building height.
2. When the above long axis orientation can be utilized, consider attaching solid fences $5\frac{1}{2}$ feet in height and 6 inches from the ground along the north side of each unit to add additional buffering. Measurement of infiltration rates using the combined orientation and buffering techniques, show a substantial reduction in air leakage for townhouse units.
3. If design conditions require the use of a front wall exposure perpendicular to the prevailing wind, consider:
 - a. the placement of fences described above on the windward side of each unit. A 20% reduction in air infiltration has been shown to result from this strategy.
 - b. the placement of a straight line of evergreen trees on the windward side, located a distance $1\frac{1}{2}$ -2 times the building height and spaced so that the bottom boughs touch. This has been shown to result in a 40% reduction in air infiltration.
 - c. combining strategies a and b for a 42% reduction in air infiltration.

¹Mattingly, George E., and Peters, Eugene F., Wind and Trees - Air Infiltration Effects on Energy in Housing. Center for Environmental Studies Report No. 20. Princeton, New Jersey, May 1975.
See also U.S. Department of Energy, Options for Passive Energy Conservation in Site Design, June 1978.

Figure 4. Street with Parking Bays¹

Figure 5. Minimize House Frontage on Subcollector Streets¹

Figure 6. Natural Engineering for Stormwater Runoff¹

¹Mackie, 1977.

Sun Response

Although winter sunlight utilization will vary, and may not be as significant in one location as in another, the following building relationships should still be considered in maximizing the sunlight that does exist:

1. An orientation of south to southeast has been shown to be most effective in capturing the winter sun. South facing walls receive about twice as much solar radiation as east or west.
2. Avoid placing taller buildings between the sun and lower structures. Place taller buildings down sun to minimize shading.
3. Place structures halfway up S-SE slopes to prevent excess wind effects and cool air pockets.
4. Place blank walls, garages and storage areas on the north side of dwellings.
5. Shade streets and parking areas with deciduous vegetation to channel summer breezes and reduce summer radiation while allowing the sun to penetrate during the winter.
6. Cluster buildings to create sun pockets and take full advantage of the winter sun.

BIBLIOGRAPHY

- American Retail Federation, Energy-Cost Reduction in Retailing. American Retail Federation, Washington, D.C., 1977.
- ASHRAE, Handbook and Product Directory, Fundamentals, 1977.
- ASHRAE, Handbook and Product Directory, Systems, 1973.
- Electric Power Research Institute, Efficient Electricity Use, Pergamon Press, 1976.
- Federal Energy Administration, Energy Conservation in Buildings, March 1976.
- Graham, John and Company. Energy Conservation Code Analysis. A Study for the City of Seattle, 1977.
- Hannon, B., et al. Energy Use for Building Construction, CAC Doc. No. 228, February, 1977; and Energy Use for Building Construction Supplement, CAC Doc. No. 228A, October, 1977. Center for Advanced Computation, University of Illinois at Urbana-Champaign.
- Hannon, B., et al. "Energy and Labor in the Construction Sector". Science, Vol. 202, November, 1978.
- Harwood, Corbin Crews. Using Land to Save Energy. Cambridge, Ballinger Publishing Company, 1977.
- Little, Arthur D. Inc. Energy Conservation in New Building Design. An Impact Assessment of ASHRAE Standard 90-75. March, 1976.
- Mackie, M. and Mackie, B. Relationships of Energy to Land Use. Yamhill County Planning Department Energy Office. McMinnville, Oregon, November, 1977.
- Mathematical Sciences Northwest, Inc. Thermal Lighting and Efficiency Standards. December, 1978.
- Mattingly, George E., and Peters, Eugene F., Wind and Trees-Air Infiltration Effects on Energy in Housing, Center for Environmental Studies Report No. 20. Princeton, New Jersey, May 1975.
- NOAA, Climatology of the United States (Idaho, Oregon, Washington and Alaska), 1977.
- Pacific Northwest River Basin Commission (Meteorology Committee). Climatological Handbook Columbia Basin States, July, 1969.
- Seattle Energy Office, Proposed Seattle Energy Code, February 14, 1979.
- Skidmore, Owings and Merrill, Inc. Bonneville Power Administration Electric Energy Conservation Study, June 1976.
- Skidmore, Owings and Merrill, Inc. Commercial Conservation Choices. Portland Energy Conservation Project, June 1977a.
- Skidmore, Owings and Merrill, Inc. Residential Conservation Choices. Portland Energy Conservation Project, June 1977b.
- Skidmore, Owings and Merrill, Inc. Transportation and Land Use Conservation Choices. Portland Energy Conservation Project, June 1977c.

U.S. Department of Energy, Solar Energy for Pacific Northwest Residential Heating. Interagency Report, May 1978a.

U.S. Department of Energy, Options for Passive Energy Conservation in Site Design, June, 1978b

U.S. Department of Energy, Comprehensive Community Energy Planning, November 1978c.

APPENDIX A

TABLES FOR PART I

TABLE A-1

ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Sawmill products						
Rough lumber (softwood)	BF	5,230	428	1,958	7,610	
Dressed lumber (softwood)	BF	5,400	436	2,024	7,860	
(hardwood)	BF	6,630	536	2,486	9,652	
Flooring						
Softwood	BF	7,043	549	2,661	10,253	
Hardwood	BF	9,225	897	4,163	14,285	
Shingles and shakes	SF	4,680	674	1,956	7,310	
Millwork						
Wood window units						
Double hung	1 each	846	11	271	1,128	
Awnings and casement	1 each	893	12	285	1,190	
Other	1 each	1,373	18	439	1,830	
Wood window sash						
Knock-down, open	1 each	126	2	40	168	
Glazed	1 each	218	3	69	290	
Storm sash	1 each	320	4	103	427	
Wood doors						
Panel type	1 each	655	9	209	873	
Hollow core	1 each	260	3	84	347	
Solid core	1 each	894	12	285	1,191	
Other						
Storm/screen	1 each	601	8	192	801	
Garage	1 each	2,492	32	798	3,324	
Louvers	1 each	357	4	86	360	
Wood moldings	BF	13.4	.18	4	18	

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Building Paper						
Construction paper	lb	8.8	.25	1	10	
Insulation board	lb	12.9	.38	2	15	
Veneer and Plywood						
Plywood	SF	12,940	825	3,258	17,023	
Hardwood, utility	SF					
Hardwood, prefinished	SF	7,709	492	1,940	10,141	
Softwood, interior	SF	3,790	242	954	4,986	
Softwood, exterior	SF	4,393	280	1,106	5,779	
Hardboard						
Paneling	SF	3,774	121	726	4,621	
Particleboard	SF	6,243	200	1,201	7,644	
Veneer						
Hardwood, special	SF	2,600	166	654	3,420	
Hardwood, com. & util.	SF	1,700	108	428	2,236	
Hardwood, container	SF	1,164	74	293	1,531	
Softwood, plywood	SF	6,282	401	1,581	8,264	
Prefabricated Wood Structures						
Fabricated structural wood members ¹						

¹Due to variety among units, buildings and structural members should be analyzed piece by piece to get accurate value.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Glue-Lam. lumber	BF	14,673	107	1,953	16,733	
Sawn lumber	BF	5,623	41	748	6,412	
Glued and sawn lumber	BF	14,426	105	1,920	16,451	
Paint						
Exterior	Gal	413	4	72	489	1 gallon covers: 300-350 SF exterior 475 SF interior 475 SF interior trim 525 SF exterior trim
Interior						
Oils, enamels, varnish, and stains	Gal	430	4	74	509	
Water-type	Gal	370	3	64	438	
Asphalt						
Roofing asphalt	lb	6,700	51	162	6,913	
	Gal	189,380 ¹	683	2,163	192,226	
Asphalt rolls	SF	7,500	57	182	7,739	
Mineral surface	SF	10,673	81	258	11,012	

¹Includes manufacturing overhead costs, etc. Raw fuel value of one gallon of asphalt is 158,095 Btu.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Strip shingles	SF	28,812	220	696	29,728	
self-sealing	SF	24,600	200	600	25,400	
other	SF					
Sidings	SF	13,162	101	318	13,581	
Insulating Bd. Siding	SF	65,426	499	1,581	67,506	
Saturated Felts						
Asphalt	SF	13,210	101	319	13,630	
Tar	SF	16,416	125	397	16,938	
Flat Glass	SF					
Sheet glass						
Single Str.	SF	11,895	159	1,764	13,818	
Double Str.	SF	13,437	180	1,993	15,610	
Heavy sheet	SF	12,676	170	1,880	14,726	
Thin glass	SF	17,395	233	2,582	20,210	
Plate and flat glass						
<1/8" thick	SF	32,683	437	4,847	37,967	
1/8-14" thick	SF	41,828	559	6,203	48,590	
7 1/4" rolled wire	SF	47,611	637	7,061	55,309	
Laminated glass						
Plate	SF	185,058	2,475	27,446	214,979	
Sheet, other	SF	98,820	1,321	14,653	114,794	
Other flat glass						
Tempered	SF	63,197	845	9,373	73,415	
Other, custom	SF	30,143	403	4,471	35,017	

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Cement						
Portland Cement	1 bbl (376 lbs)	1,526,500	29,286	26,342	1,582,128	
Prepared cement	1 bbl (280 lbs)	1,530,995	29,372	26,420	1,586,787	
Brick and Tile						
Brick (2.25x3.63x7.63 inches)						
Building	1 Brick	13,570	333	380	14,283	
Other	1 Brick	24,306	597	679	25,582	
Glazed	1 Brick	31,749	780	887	33,416	
Tile (2.25x3.63x7.63 inches)						
Structural clay	1 Tile	26,304	646	735	27,685	
Facing tile	1 Tile	31,749	780	887	33,416	
Unglazed and salt glazed (8x5x12 inches)	1 Tile	64,817	1,591	1,812	68,220	
Ceramic Tile						
Quarry and prom.	SF	46,589	972	3,470	51,031	
Mosaic and acc. (glazed)	SF	62,682	1,308	4,669	68,659	
Mosaic and acc. (unglazed)	SF	58,081	1,212	4,326	63,619	

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Concrete						
Ready Mix	cu. yd	2,584,938	59	9,341	2,594,338	
Concrete pipe ¹	lb	1,685	1	96	1,782	
Dry mix concrete	lb	1,012	1	57	1,070	
Prestressed products						
Tees	SF	120,376	44	6,902	127,322	
Piling and piles	LF	419,356	153	24,044	443,553	
Concrete block						
Blocks	1 block	29,018	376	2,427	31,821	
Bricks	1 brick	4,546	59	380	4,985	
Clay Products						
Sewer pipe ²	lb	8,105	274	264	8,643	
Drain tile	lb	3,420	116	111	3,647	
Vitreous Plumbing Fixtures						
Lavatories	each	1,011,622	26,543	174,043	1,212,208	
Bowls	each	1,068,736	28,041	183,870	1,280,647	
Flush tanks	each	877,380	23,020	150,949	1,051,349	

¹See Table A-2 for LF costs.

²See Table A-3 for LF costs.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Lime						
Quicklime	1 ton	6,395	376	96	6,868	
Hydrated lime	1 ton	8,812	519	133	9,464	
Deadburned dolomite	1 ton	9,077	534	137	9,748	
Gypsum Products	1 ton	6,189	382	399	6,970	
Calcined gypsum, Building products, Plasters, and Prefab. building material						
Other calcined gypsum	1 ton	3,918	217	227	4,362	
Mineral Wool ¹						
Loose fiber	1 ton	11,427	554	845	12,826	
Thick batts ($\geq 4.5"$)	SF	7.4	.36	1	8	
Medium batts (2-4.5")	SF	6.1	.28	.42	7	
Thin batts ($< 2"$)	SF	4.5	.20	.30	5	

¹See Figure 1 for energy values for insulation, general.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Steel Products						
Pig iron	1b	7,075	153	216	7,444	
Steel sheets ¹						
Ht. Rld. Enam.	1b	15,965	348	490	16,803	
Galvanized	1b	26,458	572	806	27,836	
Bars and Shapes						
Structural; Sheet and	1b	17,808	385	543	18,736	
Bearing piles						
Reinforcing bars ²	1b	14,888	322	454	15,664	
Alloy steel plates	1b	25,577	554	779	26,910	
and shapes						
Wire and Nails						
Strand, for concrete ³	1b	42,423	918	1,292	44,633	
Nails, staples ⁴	1b	32,331	700	985	34,016	
Plain steel wire	1b	29,635	641	903	31,179	
Galvanized wire	1b	32,683	707	995	34,385	
Welded wire	1b	22,989	498	700	24,187	
Pipes and Tubes ⁵						
Standard pipe	1b	24,535	531	747	25,813	
Stainless Steel						
Sheets, cold rolled	1b	131,449	2,845	4,004	138,298	
Sheets, hot rolled	1b	76,814	1,662	2,340	80,816	
Strips	1b	114,842	2,485	3,498	120,825	

¹See Table A-4 for square foot costs for typical gauges.

²See Table A-5 for linear foot costs for typical rebar sizes.

³See Table A-6 for linear foot costs for typical wire sizes.

⁴See Table A-7 for per nail costs.

⁵See Table A-8 for linear foot costs for pipe sizes.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Plates	1b	151,455	3,278	4,613	159,346	
Bars--hot rolled	1b	149,454	3,234	4,553	157,241	
Bars--cold finished	1b	183,579	3,973	5,592	193,144	
Wire	1b	228,046	4,935	6,946	239,927	
Fabricated Structural Steel						
Fabric. shapes for buildings	1b	21,711	539	457	22,707	
Screw Machine Products						
Nuts and bolts ¹	1b	22,474	79	4,072	26,625	
Rivets ²	1b	14,640	52	2,652	17,344	

¹See Table A-9 for typical per bolt costs.

²See Table A-10 for typical per rivet costs.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Aluminum ¹						
Plate ²	lb	113,949	649	974	115,572	
Sheet ³	lb	94,596	539	808	95,943	
Rod, bar shape ⁴	lb	90,852	518	776	92,146	
Bare electrical wire ⁵	lb	95,029	542	812	96,383	
Reinforcing cable	lb	80,768	460	691	81,919	

A-11

¹Energy coefficient reflects such variables as 1967 ore quality and recycling.
More recent data not available.

²See Table A-11 for costs per square foot for typical aluminum plate.

³See Table A-12 for costs per square foot for typical aluminum sheet.

⁴See Table A-13 for costs per linear foot for typical aluminum shapes.

⁵See Table A-14 for costs per linear foot for typical aluminum wire.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Plastics						
Polystyrene insulation ¹	lb	68,253	1,270	6,920	76,443	
PVC pipe ²	lb	41,634	775	4,221	46,630	
Copper						
Unalloyed misc. shapes						
Rod, bar and shapes	lb	45,607	597	588	46,792	
Flat prod.	lb	67,863	889	875	69,627	
Pipe and tube ³	lb	71,275	933	919	73,127	
Alloyed						
Rod, bar and shapes	lb	47,217	618	609	48,444	
Flat	lb	61,422	804	792	63,018	
Pipe and tube ³	lb	69,011	903	890	70,804	
Wire and cable ⁴						
Elect. trans.	lb	50,874	521	1,310	52,705	
Strand and cable	lb	57,284	587	1,474	59,345	

¹See Table A-15 for square foot costs.

²See Table A-16 for linear foot costs.

³See Table A-17 for linear foot costs.

⁴See Table A-18 for linear foot costs.

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Metal Plumbing Fixtures	1 each					
Drinking fountains		3,377,300	85,015	475,031	3,897,346	
Lavatories						
Cast iron		1,159,034	29,175	163,022	1,351,232	
Other		575,535	14,488	80,951	670,974	
Urinals		3,392,827	85,406	477,215	3,955,448	
Sinks, kitchen						
Steel, enameled		1,022,060	25,728	143,757	1,191,545	
Stainless		1,959,196	49,318	275,569	2,284,083	
Other		1,813,081	45,640	346,297	2,113,738	
Sinks, wash		5,639,541	141,961	793,224	6,574,726	
Bath tubs						
Cast iron		5,164,954	130,014	726,472	6,021,440	
Other		2,596,780	65,367	365,248	3,027,395	
Shower stalls		4,744,165	119,422	667,286	5,530,873	

TABLE A-1

ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Plumbing Fittings and Brass Goods						
Bath and shower fittings	1 each					
Controls		853,947	8,333	138,776	1,001,056	
Fillers		538,631	5,646	94,035	638,312	
Shower head, fittings		634,627	6,193	103,134	743,954	
Drains		440,747	4,301	71,626	516,674	
Faucets, other fittings		211,542	2,064	34,378	247,984	
Lavatory fittings	1 each	674,673	6,583	109,643	790,899	
Controls						
Drains and single faucets		275,675	2,690	44,800	323,165	
Sink fittings	1 each	670,860	6,543	109,023	786,429	
Controls						
Other		113,429	1,107	18,433	132,969	

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Heating Equipment (Except Electric)						
Oil burners	1 each					
Residential						
High-pressure		4,031,151	61,209	730,395	4,822,755	
Low-pressure		3,536,952	53,705	640,852	4,231,509	
Commercial and Industrial						
Low-pressure		46,017,138	698,720	8,337,742	55,053,600	
High-pressure		28,660,500	435,178	5,192,932	34,288,610	
Forced Air Furnace	1 each					
Solid fuel						
>150,000 Btu		71,217,000	1,081,352	12,903,648	85,202,000	
<150,000 Btu		19,422,818	294,914	3,519,177	23,236,909	
Oil						
>150,000 Btu		28,590,766	434,119	5,180,297	34,205,182	
<150,000 Btu		13,568,713	206,026	2,458,485	16,233,224	
Gas						
>150,000 Btu		42,485,678	645,098	7,697,885	50,828,661	
<150,000 Btu		8,957,833	136,015	1,623,049	10,716,897	
Cast Iron Boilers	1 each					
Oil and solid fuel		25,764,249	391,202	4,668,166	30,823,617	
Gas		31,423,584	477,133	5,693,568	37,594,285	
Radiators	1 each					
Cast Iron		56,683	861	10,270	67,814	
Aluminum-residential		31,037	471	5,624	37,132	
Aluminum-industrial		38,132	579	6,909	45,620	

TABLE A-1

ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Domestic Heating Stoves.						
Gas	1 each					
Vented circulator		4,685,329	71,147	848,985	1,605,461	
Unvented circulator		1,145,854	17,400	207,629	1,370,883	
Radiants		1,419,019	21,548	257,127	1,697,694	
Wood (sheet-metal, air tight)	1 ea.	291,356	4,424	52,794	348,574	
Coal and wood circulators	1 each	5,634,255	85,556	1,020,931	6,740,742	
Radiants, magazine		2,403,028	36,490	435,430	2,874,948	
Other		2,423,411	36,799	439,124	2,899,334	
Kerosene, Gasoline, Fuel Oil	1 ea.					
Circulators, pot-type		5,934,750	90,119	1,075,381	7,100,250	
Radiant, pot-type		4,181,037	63,489	757,607	5,002,133	
Other		811,590	12,324	147,061	970,975	
Steel Heating Boiler	1 each					
< 294 SF heating area		30,860,700	468,616	5,591,937	36,921,253	
> 294 SF heating area		143,858,340	2,184,487	26,067,233	172,110,060	
Scotch type horizontal firebox		275,156,586	4,178,249	49,858,568	329,193,403	
Gas conversion burners	1 each	7,065,734	107,285	1,280,225	8,453,244	
Gas-fired floor furnaces	1 each	5,745,745	87,243	1,041,058	6,874,046	
Gas-fired wall furnaces	1 each	5,194,652	78,875	941,207	6,214,734	
Oil-fired floor furnaces	1 each	10,371,408	157,478	1,879,172	12,408,058	
Oil-fired wall furnaces	1 each	9,339,934	141,817	1,692,281	11,174,032	
Range boilers	1 each	1,855,818	28,179	336,251	2,220,248	
Expansion tanks	1 each	935,368	14,203	169,477	1,119,048	
Hot water storage tanks	1 each	13,428,121	203,891	2,433,011	16,065,023	

TABLE A-1
ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Metal Doors, Sash and Trim	1 each					
Aluminum						
Garage doors		10,578,804	52,910	789,844	11,421,558	
Sliding doors		7,021,647	35,119	524,256	7,581,022	
Door frames		5,961,547	29,817	445,106	6,436,470	
Double, single hung windows		1,369,016	6,847	102,215	1,478,078	
Horizontal sliding windows		1,749,532	8,750	130,625	1,888,907	
Storm doors--sash		1,053,828	5,271	78,682	1,137,781	
Storm doors--doors		2,278,047	11,394	170,085	2,459,526	
Window screens with frame		245,592	1,228	18,337	265,157	
Iron and Steel	1 each					
Garage		8,648,419	42,000	626,971	9,317,390	
Door frames		2,406,909	12,038	179,707	2,598,654	
Window sash and frames		906,430	4,534	67,676	978,640	
Fabricated Platework						
Basement oil tanks	1 each	3,320,341	33,294	56,970	3,410,605	
Septic tanks	1 each	5,074,077	50,888	87,060	5,212,017	
Sheet Metal Work						
Metal roofing						
Steel	1b	14,112	91	702	14,905	
Aluminum	1b	43,131	278	2,145	45,554	
Metal siding						
Aluminum	1b	73,717	476	3,665	77,858	

TABLE A-1

ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Notes (6)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)	
Miscellaneous Metalwork						
Expanded metal lath	SF	5,567	-15	206	5,788	
Fabricated bar joists	lb	15,216	40	563	15,819	
Household Appliances	1 each					
Electric water heaters		3,434,278	30,867	216,067	3,681,212	
Gas water heaters		3,400,215	30,561	213,924	3,644,699	
Oil water heaters		12,187,259	109,537	766,759	13,063,555	
Industrial water heaters		8,091,541	72,725	509,078	8,673,344	
Wiring Devices						
Lampholders						
Incandescent	1 each					
Metal shell		11,079	140	1,084	12,303	
Outlet box		26,096	329	2,554	28,979	
Others		6,895	87	675	7,657	
Flourescent	1 each	5,526	70	541	6,137	
Outlets	1 each	15,642	197	1,531	17,370	

SOURCE: Hannon, 1977

CHART SHOWS INTERPOLATED BTU VALUES FOR DIFFERENT THICKNESSES OF INSULATION BASED ON SPECIFIC VALUES DERIVED THROUGH SEA DATA. IT IS ASSUMED THAT THE ENERGY EMBODIMENT OF THIS MATERIAL IS A DIRECT FUNCTION OF QUANTITY OF MATERIAL.

Figure A-1. Embodied Energy In Insulation

SOURCE: Hannon, 1977.

TABLE A-2

PRODUCT EXAMPLE: CONCRETE PIPE

Inside Diameter	Pounds/ Linear Foot	Btu/ Linear Foot
4 inches	16	28,512
6	23	40,986
8	37	65,934
10	51	90,882
12	67	119,394

TABLE A-3

PRODUCT EXAMPLE: CLAY PIPE

Diameter	Pounds/ Linear Foot	Btu/ Linear Foot
4 inches	9	77,787
6	16	138,288
8	23	198,789
10	36	311,148
12	48	414,864
15	72	622,296

TABLE A-4

PRODUCT EXAMPLE: CARBON STEEL SHEETS

Thickness	Hot Rolled + Enameled		Galvanized	
	Pounds/ Square Foot	Btu/ Square Foot	Pounds/ Square Foot	Btu/ Square Foot
22 GA	1.75	29,406	1.79	49,826
20 GA	2.14	35,286	2.14	59,526
18 GA	2.83	47,048	2.83	78,776
16 GA	3.54	58,811	3.54	98,539

TABLE A-5

PRODUCT EXAMPLE: REINFORCING BAR

Size	Pounds/ Linear Foot	Btu/ Linear Foot
# 2	0.167	2,569
3	0.376	5,890
4	0.668	10,464
5	1.043	16,338
6	1.502	23,527
7	2.044	32,017
8	2.570	41,823

TABLE A-6

PRODUCT EXAMPLE: STEEL 7-STRAND WIRE

Diameter	Pounds/ Linear Foot	Btu/ Linear Foot
1/4 in	0.122	5,445
1/2	0.198	8,837
3/8	0.274	12,229
7/16	0.373	16,648

TABLE A-7

PRODUCT EXAMPLE: COMMON NAILS

Size	Pounds/ Nail	BTU/Nail
2 Penny	0.0012	41
3 Penny	0.0018	61
4 Penny	0.0033	112
5 Penny	0.0034	133
10 Penny	0.0150	510

TABLE A-8

PRODUCT EXAMPLE: PIPES

Nom. Diameter	Pounds/ Linear Foot	Btu/ Linear Foot
1/2 inch	0.85	27,941
3/4	1.13	29,169
1	1.68	43,366
2	3.65	94,217
6	18.97	489,673

TABLE A-9

PRODUCT EXAMPLE: BOLTS

Size	Pound/ Bolt	BTU/Bolt
1" x 1/4"	0.02	533
2" x 1/2"	0.18	4,793
3" x 1/2"	0.23	6,124
4" x 1/2"	0.29	7,721
5" x 3/8"	0.18	4,793

TABLE A-10

PRODUCT EXAMPLE: RIVETS

Size	Pounds/ Rivet	Total Stu/Rivet
1 1/4" x 1/2"	0.11	1,908
1 1/2" x 1/2"	0.12	2,081
2" x 1/2"	0.15	2,602
3" x 3/4"	0.70	12,141
4" x 1"	1.16	20,119

TABLE A-11

PRODUCT EXAMPLE: ALUMINUM PLATE

Thickness	Pounds/ Square Foot	Total Stu/ Square Foot
1/4 in	3.64 LB	420,663
1/2 in	7.27 LB	840,172
3/4 in	10.91 LB	1,260,836
1 in	14.54 LB	1,680,344

TABLE A-12

PRODUCT EXAMPLE: ALUMINUM SHEET

Thickness	Pounds/ Square Foot	Total Stu/ Square Foot
1/8 in	1.82 LB	174,876
3/16 in	2.73 LB	261,924

TABLE A-13

PRODUCT EXAMPLE: ALUMINUM SHAPES

Size	Pounds/ Linear Foot	Total Stu/ Linear Foot
818.81	8.81 LB	817,806
716.05	6.05 LB	557,483
615.10	5.70 LB	469,945

TABLE A-14

PRODUCT EXAMPLE: ALUMINUM WIRE

Size	Diameter	Pounds/ Linear Foot	Btu/ Linear Foot
No. 14	.0641	.00116	111
12	.0808	.00182	175
10	.1019	.00297	286
8	.1620	.00759	732
2	.2576	.01896	1,828
1	.2893	.02393	2,306
1/0	.3249	.03020	2,910

TABLE A-15

PRODUCT EXAMPLE: POLYSTYRENE INSULATION

Thickness	Pounds/ Square Foot	Total Btu/ Square Foot
1 in	0.29	22,158
2	0.58	44,337
3	0.88	67,270
4	1.16	88,674
5	1.46	111,607

TABLE A-16

PRODUCT EXAMPLE: PVC PIPE

Diameter	Pound/ Linear Foot	Btu/ Linear Foot
3 in	1.53	71,344
4	2.16	100,821
6	3.76	175,329
8	5.80	270,454

TABLE A-17

PRODUCT EXAMPLE: COPPER ALLOY PIPE

Size	Pounds/ Linear Foot	Btu/ Linear Foot
1/2 in	0.98	69,389
3/4 in	1.31	92,613
1 in	1.94	137,645
1 1/4 in	2.63	186,217
1 1/2 in	3.13	221,620

TABLE A-18
 PRODUCT EXAMPLE: COPPER WIRE

Size	Diameter	Pounds/ Linear Foot	Btu/ Linear Foot
No. 14	.0641	.00396	210
12	.0808	.00630	333
10	.1019	.00100	503
6	.1620	.02533	1,340
2	.2576	.06405	3,389
1	.2893	.08079	4,274
1/0	.3249	.10189	5,391

SOURCE: Hannon, 1977.

APPENDIX B

TABLES FOR PART II

TABLE B-1
CLIMATOLOGICAL DATA

State and City	Ave. Temp (°F)		Cloud Cover		Elevation (ft.)	Heating Degree Days	Latitude		Longitude		T _G (°F)
	H	T ₀₂ C	H	C			Degrees	Min	Degrees	Min	
ALASKA											
Anchorage	25	62	71	79	114	10,864	61	10	150	01	16
Fairbanks	11	66	67	75	436	14,279	64	49	147	52	22
Juneau	34	61	83	83	12	9,075	58	22	134	35	17
Nome	15	53	63	76	13	14,325	64	30	165	26	13
IDAHO											
Boise	42	84	67	35	2842	5,809	43	34	116	13	19
Lewiston	43	83	76	44	1413	5,464	46	23	117	01	19
Pocatello	37	82	69	39	4454	7,033	42	55	112	36	20
OREGON											
Astoria	46	67	81	68	8	5,295	46	9	123	53	17
Burns	37	80	66	36	4151	7,212	43	35	119	3	17
Eugene	47	79	79	48	364	4,726	44	7	123	13	18
Medford	46	85	72	31	1298	4,930	42	22	122	52	18
Pendleton	44	82	73	38	1482	5,240	45	41	118	51	19
Portland	47	76	80	55	21	4,792	45	36	122	36	17
Salem	46	79	78	50	196	4,852	44	55	123	01	18
WASHINGTON											
Aberdeen	46	68	NA	NA	12	5,349	47	0	123	49	17
Bellingham	44	70	NA	NA	150	5,797	48	50	122	30	17
Kennewick	46	86	NA	NA	392	4,947	46	13	119	08	19
Olympia	44	75	82	61	190	5,530	47	0	122	54	18
Quillayute	44	66	81	69	179	5,951	47	57	123	33	17
Seattle	47	73	75	55	14	4,838	47	39	122	18	17
Spokane	39	78	75	47	2357	6,835	47	38	117	32	19
Yakima	42	83	69	40	1061	5,009	46	34	120	32	19

H = heating (8 month average)

C = cooling (4 month average)

NA = Data not available.

SOURCE: NOAA, Climatology of the United States, 1977;

ASHRAE, 1977 Handbook of Fundamentals.

FIGURE B-1

CLIMATE ZONES

This map shows the general boundaries of the climate zones to be used in Method 1 of Part 2. The map is very general and is for illustrative purposes only. In all cases, the heating degree days for a project location should be determined from the best available data. For example, Burns, Oregon is shown in Zone 2 (5,500-7,000 heating degree days) on the map, but the actual value of 7,212 heating degree days (Table B-1) should be used. Thus, Burns is in Climate Zone 3 (7,000-14,000 heating degree days).

NOTE: The map does not consider areas of extremely high altitude.

Climate 1 = 4,000-5,500 Heating Degree Days
 Climate 2 = 5,500-7,000 Heating Degree Days
 Climate 3 = 7,000-14,000 Heating Degree Days

TABLE B-2
SURFACE RESISTANCES

Position of Surface	Heat/Cool	Surface Resistance
INSIDE		
Horizontal	Heating	.61
Sloping--45 deg.	Heating	.62
Vertical	Both	.68
Sloping--45 deg.	Cooling	.76
Horizontal	Cooling	.92
OUTSIDE		
Any position	Heating	.17
Any position	Cooling	.25

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 22.

TABLE B-3

THERMAL RESISTANCES OF BUILDING
AND INSULATION MATERIALS

Description	Thickness (in Inches)	Resistance (R)	
		Per Inch Thickness	For Thickness Listed
BUILDING BOARD			
(Boards, Panels, Subflooring, Sheathing, Woodboard Panel Products)			
Asbestos-cement board		0.25	
Asbestos-cement board	0.125		0.03
Asbestos-cement board	0.25		0.06
Gypsum or plaster board	0.375		0.32
Gypsum or plaster board	0.5		0.45
Gypsum or plaster board	0.625		0.56
Plywood (Douglas Fir)		1.25	
Plywood (Douglas Fir)	0.25		0.31
Plywood (Douglas Fir)	0.375		0.47
Plywood (Douglas Fir)	0.5		0.62
Plywood (Douglas Fir)	0.625		0.77
Plywood or wood panels	0.75		0.93
Vegetable Fiber Board			
Sheathing, regular density	0.5		1.32
	0.75		2.06
Sheathing, intermediate density	0.5		1.22
Nail-base sheathing	0.5		1.14
Shingle backer	0.375		0.94
Shingle backer	0.5		0.78
Sound deadening board	0.5		1.35
Tile and lay-in panels, plain or acoustic	0.5	2.50	
	0.75		1.89
Laminated paperboard		2.00	
Homogeneous board from recycled paper		2.00	
Hardboard			
Medium density		1.37	
High density service underlay		1.22	
High density, std. tempered		1.00	
Particleboard			
Low density		1.85	
Medium density		1.06	
High density		0.85	
Underlayment	0.625		0.82
Wood subfloor	0.75		0.94
BUILDING MEMBRANE			
Vapor-permeable felt			0.06
Vapor-seal, 2 layers of mopped 15 lb. felt			0.12
Vapor-seal, plastic film			Regl.
FINISHING FLOORING MATERIALS			
Carpet and fibrous pad			2.08
Carpet and rubber pad			1.23
Cork tile	0.125		0.28
Terrazzo	1.00		0.08
Tile-asphalt, linoleum, vinyl, rubber			0.05
Wood, hardwood finish	0.75		0.68

TABLE B-3 (continued)

Description	Thickness (in Inches)	Resistance (R)	
		Per Inch Thickness	For Thickness Listed
Gypsum partition tile:			
3x12x30 in. solid			1.26
3x12x30 in. 4-cell			1.35
4x12x30 in. 3-cell			1.67
PLASTERING MATERIALS			
Cement plaster, sand aggregate		0.20	
Sand aggregate	0.375		0.08
Sand aggregate	0.75		0.15
Gypsum plaster:			
Lightweight aggregate	0.5		0.32
Lightweight aggregate	0.625		0.39
Lightweight aggregate on metal lath	0.75		0.47
Perlite aggregate		0.67	
Sand aggregate		0.10	
Sand aggregate	0.5		0.09
Sand aggregate	0.625		0.11
Sand aggregate on metal lath	0.75		0.13
Vermiculite aggregate		0.59	
ROOFING			
Asbestos-cement shingles			0.21
Asphalt roll roofing			0.15
Asphalt shingles			0.44
Built-up roofing	0.375		0.33
Slate	0.5		0.05
Wood shingles, plain and plastic film faced			0.94
SIDING MATERIALS (ON FLAT SURFACE)			
Shingles			
Asbestos-cement			0.21
Wood, 16 in., 7.5 exposure			0.87
Wood, double, 16-in. 12-in. exposure			1.19
Wood, plus insul. backer board, 0.3125 in.			1.40
Siding			
Asbestos-cement, 0.25 in., lapped			0.21
Asbestos roll siding			0.15
Asbestos insulating siding (0.5 in. bed.)			1.46
Wood drop, 1 x 8 in.			0.79
Wood, bevel, 0.5 x 8 in., lapped			0.81
Wood, bevel, 0.75 x 10 in., lapped			1.05
Wood, plywood, 0.375 in., lapped			0.59
Wood, medium density siding, 0.4375 in.		0.67	
Aluminum or Steel, over sheathing			
Hollow-backed			0.61
Insulating-board backed nominal, 0.375 in.			1.82
Insulating-board backed nominal, 0.375 in. foil backed			2.96
Architectural glass			0.10
WOODS			
Maple, oak, and similar hardwoods		0.91	
Fir, pine, and similar softwoods		1.25	
Fir, pine, and similar softwoods	0.75		0.94
Fir, pine, and similar softwoods	1.5		1.89
Fir, pine, and similar softwoods	2.5		3.12
Fir, pine, and similar softwoods	3.5		4.35

TABLE B-3 (continued)

Description	Thickness (in inches)	Resistance (R)	
		Per Inch Thickness	For Thickness Listed
INSULATING MATERIALS			
Blanket and Batt			
Mineral Fiber, fibrous form processed from rock, slag, or glass			
approximately 2-2.75 in.			7
approximately 3-3.5 in.			11
approximately 3.50-6.5 in.			19
approximately 6-7 in.			22
approximately 8.5 in.			30
Board and Slabs			
Cellular glass		2.63	
Glass fiber, organic bonded		4.00	
Expanded rubber (rigid)		4.55	
Expanded polystyrene extruded cut cell surface		4.00	
Expanded polystyrene extruded smooth skin surface(2.2 lb/ft ³)		5.00	
Expanded polystyrene extruded smooth skin surface(3.5 lb/ft ³)		5.26	
Expanded polystyrene, molded beads		3.57	
Expanded polyurethane (R-11 exp.) (Thickness 1 in. or greater)		6.25	
Mineral fiber with resin binder		3.45	
Mineral fiberboard, wet felted			
Core or roof insulation		2.94	
Acoustical tile		2.86	
Acoustical tile		2.70	
Mineral fiberboard, wet molded			
Acoustical tile		2.38	
Wood or cane fiberboard			
Acoustical tile	0.5		1.25
Acoustical tile	0.75		1.89
Interior finish (plank, tile)		2.86	
Wood shredded (cemented in preformed slabs)		1.67	
LOOSE FILL			
Cellulosic insulation (milled paper or wood pulp)		3.13-3.70	
Sawdust or shavings		2.22	
Wood fiber, softwoods		3.33	
Perlite, expanded		2.70	
Mineral fiber (rock, slag or glass)			
approximately 3.75-5 in.			11
approximately 6.5-8.75 in.			19
approximately 7.5-10 in.			22
approximately 10.25-13.75 in.			30
Vermiculite, exfoliated		2.13	
		2.27	
AIR SPACE			
Wood, paper, masonry surfaces	1.5-3.5		1
Metal surfaces	1.5-3.5		2

TABLE B-3 (continued)

Description	Thickness (in Inches)	Resistance (R)	
		Per Inch Thickness	For Thickness Listed
MASONRY MATERIALS			
Concretes			
Cement mortar		0.20	
Gypsum-fiber concrete 87.5% gypsum, 15% wood chips		0.60	
Lightweight aggregates including		0.19 (120 lb/ft ³)	
expanded shale, clay or slate;		0.28 (100)	
expanded slags; cinders; pumice;		0.40 (80)	
vermiculite; also cellular concretes		0.59 (60)	
		0.86 (40)	
		1.11 (30)	
		1.43 (20)	
Perlite, expanded		1.08 (40 lb/ft ³)	
		1.41 (30)	
		2.00 (20)	
Sand and gravel or stone aggregate (oven dried)		0.11	
Sand and gravel or stone aggregate (not dried)		0.08	
Stucco		0.20	
MASONRY UNITS			
Brick, common		0.20	
Brick, face		0.11	
Clay tile, hollow:			
1 cell deep	3		0.80
1 cell deep	4		1.11
2 cells deep	6		1.52
2 cells deep	8		1.85
2 cells deep	10		2.22
3 cells deep	12		2.50
Concrete blocks, three oval core:			
Sand and gravel aggregate	4		0.71
	8		1.11
	12		1.28
Cinder aggregate	3		0.86
	4		1.11
	8		1.72
	12		1.89
Lightweight aggregate	3		1.27
(expanded shale, clay, slate or slag; pumice)	4		1.50
	8		2.00
	12		2.27
Concrete blocks, rectangular core			
Sand and gravel aggregate			
2 core, 8 in. 36 lb.			1.04
Same with filled cores			1.93
Lightweight aggregate (expanded shale, clay, slate or slag, pumice):			
3 core, 6 in. 19 lb.			1.65
Same with filled cores			2.99
2 core, 8 in. 24 lb.			2.18
Same with filled cores			5.03
3 core, 12 in. 38 lb.			2.48
Same with filled cores			5.82
Stone, lime or sand		0.08	

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals,
Chapter 22.

TABLE B-4
COOLING LOAD TEMPERATURE DIFFERENCE FOR ROOFS

Construction Type	CLTD	
	With Night Setback	Without Night Setback
LIGHT WEIGHT	46	29
METAL		
Up to 1 inch Wood		
Up to 4 inches L. W. Concrete		
Up to 2 inches H. W. Concrete		
MEDIUM WEIGHT	36	29
4-6 inches L. W. Concrete		
2-4 inches H. W. Concrete		
1-3 inches Wood		
HEAVY WEIGHT	31	29
Over 6 inches L. W. Concrete		
Over 4 inches H. W. Concrete		
Over 3 inches Wood		

Night setback hours 10 P.M. to 8 A.M.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 25.

TABLE B-5
 SOLAR HEAT GAIN FACTORS (Btu/hr/ft²)
 (FOUR-MONTH AVERAGES JUNE-SEPTEMBER)

Degrees North Latitude	Facing Direction								
	N	NE	E	SE	S	SW	W	NW	HOR
40°	404	721	1,116	1,120	828	1,087	1,161	801	2,029
48°	399	689	1,125	1,233	1,054	1,229	1,192	773	1,924
56°	405	670	1,129	1,304	1,258	1,333	1,224	763	1,779
64°	441	675	1,137	1,398	1,418	1,465	1,270	786	1,606

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals,
 Chapter 26.

TABLE B-6
COOLING LOAD TEMPERATURE DIFFERENCE FOR WALLS

Construction Type	Facing Direction	CLTD	
		With Night Setback	Without Night Setback
LIGHT WEIGHT	N	18	12
	E	33	22
	S	27	17
	W	35	22
MEDIUM WEIGHT	N	14	12
	E	30	22
	S	21	17
	W	23	22
HEAVY WEIGHT	N	11	12
	E	22	22
	S	16	17
	W	18	22
<hr/>			
LIGHT WEIGHT	MEDIUM WEIGHT	HEAVY WEIGHT	
• METAL CURTAIN	• 4" brick + 8" brick	• 4" brick + 4" brick	
• WOOD FRAME	• 4" brick + concrete	• 4" brick + 4" block	
	• 4" brick + 8" block	• H.W. concrete +	
	• H.W. Concrete + over 4"	0-4" concrete	
	concrete	• block + 4-8" block	
	• Tile + 8" tile	• Tile + 4" tile	

Night setback hours 10 P.M. to 8 A.M.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 25.

TABLE B-7

U-VALUES FOR WINDOWS, SKYLIGHTS, AND
LIGHT TRANSMITTING PARTITIONSPart A--Vertical Panels (Exterior Windows,
Sliding Patio Doors and Partitions)

Description	Exterior	
	Heating	Cooling
Flat glass		
Single glass	1.10	1.04
Insulating glass--double		
0.1875-in. air space ^a	0.62	0.65
0.25-in. air space ^a	0.58	0.61
0.5-in. air space ^b	0.49	0.56
Insulating glass--triple		
0.25-in. air spaces ^a	0.39	0.44
0.5-in. air spaces ^c	0.31	0.39
Storm windows		
1 in. to 4-in. air space ^a	0.50	0.50
Plastic sheet		
Single glazed		
0.125-in. thick	1.06	0.98
0.25-in. thick	0.96	0.89
0.5-in. thick	0.81	0.76
Insulating unit--double		
0.25-in. air space ^a	0.55	0.56
0.5-in. air space	0.43	0.45

TABLE B-7 (Continued)

Part B--Horizontal Panels (Skylights)

Description	Exterior	
	Heating	Cooling
Flat glass ^b		
Single glass	1.23	0.83
Insulating glass--double		
0.1875-in. air space ^a	0.70	0.57
0.25-in. air space ^a	0.65	0.54
0.5-in. air space ^b	0.59	0.49
Plastic domes ^d		
Single-walled	1.15	0.80
Double-walled	0.70	0.46

TABLE B-7 (Continued)

Part C-- Adjustment Factors for Various Window and Sliding Door Types (Multiply U Values in Parts A and B By These Factors)

Descriptions	Single Glass	Double or Triple Glass	Storm Windows
Windows			
All glass	1.00	1.00	1.00
Wood sash--80 percent glass	0.90	0.95	0.90
Wood sash--60 percent glass	0.80	0.85	0.80
Metal sash--80 percent glass	1.00	1.20	1.20
Sliding patio doors			
Wood frame	0.95	1.00	-
Metal frame	1.00	1.10	-

^a0.125-in. glass.

^b0.25-in. glass.

^cWindow design: 0.25-in. glass-0.125-in. glass-0.25-in. glass.

^dBased on area of opening, not total surface.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 22.

TABLE B-8
SHADING COEFFICIENTS FOR GLASS

Type of Glass	Single Glass	
	Thickness (in.)	Shading Coefficient
Clear	1/8	1.0
	1/4	.94
	3/8	.90
	1/2	.87
Heat absorbing	1/8	.83
	1/4	.69
	3/8	.60
	1/2	.53
Insulating Glass ^c		
Clear out, clear in	1/8 ^a	.88
Clear out, clear in	1/4	.81
Heat absorbing ^b out, clear in	1/4	.55

^aThickness of each pane, not assembled unit.

^bGray, bronze, and green tinted.

^cRefers to factory-fabricated units with 3/10, 1/4, or 1/2 inch air space or to prime windows plus storm sash.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 26.

TABLE B-9
SHADING COEFFICIENTS FOR SINGLE GLASS
WITH INDOOR SHADING

	Nominal Thickness	Type of Shading				
		Venetian Blinds		Roller Shade		
		Medium	Light	Opaque Dark	White	Translucent Light
Clear	3/32 to 1/2	0.64	0.55	0.59	0.25	0.39
Clear Pattern	1/8 to 1/2					
Heat Absorbing Pattern	1/8					
Tinted	3/16, 7/32					
Heat-Absorbing ^b	3/16, 1/4	0.57	0.53	0.45	0.30	0.36
Heat-Absorbing Pattern	3/16, 1/4					
Tinted	1/8, 7/32					
Heat-Absorbing or Pattern	3/8	0.54	0.52	0.40	0.28	0.32
Heat-Absorbing ^b	3/8					
Heat-Absorbing or Pattern	1/2	0.42	0.40	0.36	0.28	0.31
Reflective Coated Glass ^a						
S.C. = 0.30		0.25	0.23			
0.40		0.33	0.29			
0.50		0.42	0.38			
0.60		0.50	0.44			

^aSC for glass with no shading device.

^bRefers to grey, bronze, and green tinted heat-absorbing glass.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 26.

TABLE B-10
SHADING COEFFICIENTS FOR INSULATING GLASS^a
WITH INDOOR SHADING

Type of Glass	Nominal Thickness, in., Each Light	Type of Shading				
		Venetian Blinds		Roller Shade		
		Medium	Light	Dark	Opaque White	Translucent Light
Clear Outer and Inner	3/32 - 1/4	0.57	0.51	0.60	0.25	0.37
Heat-Absorbing ^b Outer Clear Inner	1/4	0.39	0.36	0.40	0.22	0.30
Reflective Coated Glass						
SC ^c = 0.20		0.19	0.18			
0.30		0.27	0.26			
0.40		0.34	0.33			

^aRefers to factory-fabricated units with 3/16, 1/4, or 1/2-in. air space, or to prime window plus storm windows.

^bRefers to bronze, or green tinted, heat absorbing glass

^cSC for glass with no shading device.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 26.

TABLE B-11
SHADE LINE FACTORS

Window Faces ^a	Degrees North Latitude			
	40	45	50	55
E	.8	.8	.8	.8
SE	1.3	1.1	1.0	.9
S	2.6	2.0	1.7	1.4
SW	1.3	1.1	1.0	.9
W	.8	.8	.8	.8

^a Northeast, north, and northwest-facing windows are not effectively protected by roof overhang.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 25.

TABLE B-12
CLOUD COVER FACTOR (CCF)

Cloud Cover (Table I)	CCF
0	1
1	1
2	1
3	1
4	.95
5	.90
6	.80
7	.70
8	.58
9	.44
10	.27

SOURCE: "Procedure for Determining Heating and Cooling Loads for Computerizing Energy Calculations," ASHRAE, 1976.

TABLE B-13
 MAXIMUM SOLAR HEAT GAIN FACTORS
 (Btu/hr/ft²)

COOLING (Four-Month Average, June-September)						
Degrees North Latitude	Facing Direction					
	N	NE/NW	E/W	SE/SW	S	HOR
40	38	139	213	188	138	248
48	36	130	208	201	170	225
56	36	121	200	210	195	197
64	39	116	190	212	209	164

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals,
 Chapter 25.

TABLE B-14
COOLING LOAD FACTORS FOR GLASS^a

Facing Direction	CLF	
	With Night Setback	Without Night Setback ^b
N	.66	.48
NE/NW	.29	.21
E/W	.30	.23
SE/SW	.36	.26
S	.40	.27
HOR	.48	.34

^aIncludes reflective and heat-absorbing glass.

^bNight setback 10 P.M. to 8 A.M.

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals,
Chapter 25.

TABLE B-15
AIR CHANGES DUE TO INFILTRATION

Room or Building Type	Number of Walls With Windows	Air Changes*
A	None	.05
	1	.75
	2	1.5
	3 or 4	2
B	Any	3
C	Any	2-3
D	Any	1-1.5
E	Any	1.5-3

A = Offices, apartments, hotels, multistory buildings in general.

B = Entrance halls or vestibules

C = Industrial buildings

D = Houses

E = Public or institutional buildings

* If windows and doors are tightly sealed (weatherstripped), use next lowest value (Type A) or lower of two figures (Type C-E).

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 21.

TABLE B-16
VENTILATION REQUIREMENTS FOR OCCUPANTS

	Required Ventilation Air Per Human Occupant	
	Minimum cfm	Recommended cfm
COMMERCIAL		
Public Rest Rooms	15	20-25
General Requirements--Merchandising (Apply to all forms unless specially noted)		
Sales Floors	7	10-15
Storage Areas (Serving Sales Areas and Storerooms)	5	7-10
Malls and Arcades	7	10-15
Warehouses	7	10-15
Meat Processing Rooms	5	5
Dining Rooms	10	15-20
Kitchens	30	35
Cafeterias, Short Order; Drive-Ins, Seating Areas	30	35
Cocktail Lounges	30	35-40
Hotels, Motels, Resorts		
Bedrooms	7	10-15
Living Rooms (Suites)	10	15-20
Baths, Toilets (attached to bedrooms)	20	30-50
Corridors	5	7-10
Lobbies	7	10-15
Conference Rooms (Small)	30	25-30
Assembly Rooms (Large)	15	20-25

TABLE B-16 (Continued)

	Required Ventilation Air Per Human Occupant	
	Minimum cfm	Recommended cfm
Gymnasiums and Arenas		
Playing Floors-Minimal or No Seating	20	25-30
Locker Rooms	30	40-50
Spectator Areas	20	25-30
Ramps, Foyers, and Lobbies	10	15-20
Tennis, Squash, Handball Courts	20	25-30
Swimming Pools	15	20-25
Offices		
General Office Space	15	15-25
Conference Rooms	25	30-40
Drafting Rooms, Art Rooms	7	10-15
Waiting Rooms	10	15-20
Computer Rooms	5	7-10
INSTITUTIONAL		
Schools		
Classrooms	10	10-15
Laboratories	10	10-15
Craft and Vocational Training Shops	10	10-15
Auditoriums	5	5-7.5
Offices	7	10-15
Lavatories	15	20-25
Locker Rooms	30	40-50
Lunchrooms, Dining Halls	10	15-20
Corridors	15	20-25
Dormitory Bedrooms	7	10-15

TABLE B-16 (Continued)

	Required Ventilation Air Per Human Occupant	
	Minimum cfm	Recommended cfm
Hospitals, Nursing and Convalescent Homes		
Foyers	20	25-30
Hallways	20	25-30
Single, Dual Bedrooms	10	15-20
Wards	10	15-20
Food Service Centers	35	17.5
Operating Rooms, Delivery Rooms	20	--
Physical Therapy Areas	15	20-25
Autopsy Rooms	30	40-50
Research Institutes		
Laboratories	15	20-25
Machine Shops	15	20-25
Darkroom, Spectroscopy Rooms	10	15-20
Animal Rooms	40	45-50

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 21.

TABLE B-17
 RATES OF HEAT GAIN FROM OCCUPANTS
 OF CONDITIONED SPACES

Degree of Activity	Typical Application	Total Heat Adjusted (Btu/hr)		
		HG _S	HG _L	HG _{TOT}
Seated at rest	Theater, Movie	210	140	350
Seated, very light work, writing	Offices	230	190	420
Seated, eating	Restaurant	255	325	580
Seated, light work, typing	Offices, Hotels, Apartments	255	255	510
Standing, light work or walking slowly	Retail store, Bank	315	325	640
Light bench work	Factory	345	435	780
Walking, 3 mph, light machine work	Factory	345	695	1,040
Bowling	Bowling Alley	345	615	960
Moderate dancing	Dance hall	405	875	1,280
Heavy work, heavy machine work, lifting	Factory	565	1,035	1,600
Heavy work, athletics	Gymnasium	635	1,165	1,800

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 25.

TABLE B-18
RECOMMENDED RATE OF HEAT GAIN FROM
COMMERCIAL COOKING APPLIANCES
LOCATED IN THE AIR-CONDITIONED AREA

Appliance	Capacity	Recommended Rate of Heat Gain, Btu/h			Rated Input (Btu/hr)
		Without Hood	With Hood	Total	
		Sensible	Latent		
<u>Gas-Burning, Counter Type</u>					
Broiler-griddle		11,700	6,300	18,000	36,000
Coffee brewer					
per burner		1,750	750	2,500	5,500
Water heater burner		3,850	1,650	5,500	11,000
Coffee urn	3 gal.	3,500	1,500	5,000	10,000
	5 gal.	5,250	2,250	7,500	15,000
	8 gal. twin	7,000	3,000	10,000	20,000
	15 lb. fat	7,500	7,500	15,000	30,000
Deep fat fryer					
Dry food warmer					
per sq. ft. of top		560	140	700	1,400
Griddle frying					
per sq. ft. of top		4,900	2,600	7,500	15,000
Short order stove					
per burner		3,200	1,800	5,000	10,000
Steam table					
per sq. ft. of top		750	500	1,250	2,500
Toaster, continuous	360 slices	3,600	2,400	6,000	12,000
	per hr.				
	720 slices	6,000	4,000	10,000	20,000
	per hr.				
<u>Gas-Burning, Floor-Mounted Type</u>					
Boiler, unit					7,000
Deep fat fryer	32 lb. fat				6,500
	56 lb. fat				10,000
Oven, deck, per sq. ft.					
of hearth area					400
Oven, roasting		Exhaust	Exhaust	Exhaust	8,000
		hood	hood	hood	
		required	required	required	
Range, heavy duty					
Top section					6,400
Oven					4,000
Range, jr., heavy duty					
Top section					4,500
Oven					3,500
Range, restaurant type					
per 2-burner set					2,400
per oven					3,000
per broiler-griddle					3,500

TABLE B-18 (CONTINUED)

Appliance	Capacity	Recommended Rate of Heat Gain, Btuh			Rated Input (Btu/hr)
		Without Hood	With Hood	Total	
		Sensible	Latent		AT: Sensible
<u>Electric, Counter Type</u>					
Coffee brewer					
per burner		770	230	1,000	340
per warmer		230	70	300	90
automatic	240 cups per hour	6,500	2,000	8,500	1,700
Coffee urn	3 gal.	2,550	850	3,400	1,000
	8 gal.	3,850	1,250	5,100	1,600
	8 gal. twin	5,200	1,600	6,800	2,100
Deep fat fryer	14 lb. fat	2,800	6,600	9,400	3,000
	21 lb. fat	4,100	9,600	13,700	4,300
Dry food warmer, per sq. ft. of top		320	80	400	130
Egg boiler	2 cups	1,140	760	1,900	600
Griddle frying, per sq. ft. of top		3,000	1,600	4,600	1,500
Griddle grill		6,600	3,600	10,200	3,200
Hot plate		5,300	3,600	8,900	2,800
Roaster		1,700	1,100	2,800	900
Roll warmer		2,600	200	2,800	900
Toaster, continuous	360 sl./hr.	1,960	1,740	3,700	1,200
	720 sl./hr.	2,700	2,400	5,100	1,600
Toaster, pop-up	4-slice	2,230	1,970	4,200	1,300
Waffle iron		1,680	1,120	2,800	900
<u>Electric, Floor-Mounted Type</u>					
Griddle					2,060
Broiler, no oven					6,500
with oven					9,800
Broiler					
single deck					10,800
Deep fat fryer	28 lb. fat				6,500
	60 lb. fat				9,800
Fryer					730
Oven, baking, per sq. ft. of hearth		Exhaust hood required	Exhaust hood required	Exhaust hood required	720
		"	"	"	
Oven, roasting, per sq. ft. of hearth					490
Range, heavy duty					
Top section					19,100
Oven					1,700
Range, medium duty					
Top section					4,300
Oven					1,900
Range, light duty					
Top section					3,600
Oven					1,600
Convection oven					1,540
Charbroiler					4,320
Steam cooker, two sections					3,140

SOURCE: Derived from 1977 ASHRAE Handbook of Fundamentals, Chapter 25.

TABLE B-19

RECOMMENDED RATE OF HEAT GAIN FROM
ELECTRIC RESIDENTIAL APPLIANCES

Appliance	Without Hood (Btu/hr)			With Hood (Btu/hr) All Sensible	Average Annual Usage (Hours)
	Sensible	Latent	Total		
Broiler	1,770	890	2,660	850	60
Clothes dryer	4,930	2,470	7,400		200
Coffee maker (automatic)	1,450	480	1,450		110
Deep fat fryer	1,630	820	2,450	800	70
Dishwasher	1,330	670	2,000		300
Food freezer (standard, 15 ft ³)	400	200	600		3,000
Food freezer (frostless, 15 ft ³)	500	250	750		3,500
Frying pan (automatic)	1,330	670	2,000		170
Iron	1,230	620	1,850		130
Range	13,700	6,800	20,500	6,500	100
Refrigerator (standard, 12 ft ³)	300	150	450		3,200
Refrigerator (frostless, 12 ft ³)	330	170	500		3,200
Refrigerator-freezer (standard, 14 ft ³)	330	170	500		4,150
Refrigerator-freezer (frostless, 14 ft ³)	500	250	750		3,600
Roaster	1,530	770	2,300	700	150
Toaster	1,270	630	1,900		30

SOURCE: Electric Power Research Institute, 1976.

TABLE B-20
REPRESENTATIVE HOT WATER UTILIZATION TEMPERATURES

Use	Temperature (°F)
Residential without dishwasher and laundry	110
Residential Dishwashing and Laundry	150
Commercial and Institutional Dishwashing	
Wash	140
Sanitizing rinse	180
Commercial and Institutional Laundry	180

SOURCE: 1973 ASHRAE Systems Handbook, Chapter 37.

TABLE B-21

HOT WATER DEMANDS FOR VARIOUS BUILDING TYPES

Building Type	Average Day
Dormitory	13 gal/student
Motel: No. of Units	
20 or less	20 gal/unit
60	14 gal/unit
100 or more	10 gal/unit
Nursing Homes	18.4 gal/bed
Office Building	1 gal/person
Food Service Establishment:	
Restaurants, Cafeteria	2.4 gal/avg meals/day*
Drive-In, Grill, Sandwich & Snack Shop	.7 gal/avg meals/day*
Single Family Residences	50 gal/family
Apartment Houses: No. of Apartments	
20 or less	42 gal/apt
50	40 gal/apt.
75	38 gal/apt
100	37 gal/apt
200 or more	35 gal/apt
Elementary Schools	.6 gal/student*
High Schools	1.8 gal/student*

*per day of operation

SOURCE: 1973 ASHRAE Systems Handbook, Chapter 37.

TABLE B-22
 APPLIANCE ENERGY USAGE
 (kWh/yr)

Source	Refrig- erator	Range	Clothes Washer	Clothes Dryer	Dish Washer	Color TV	Freezer
Seattle City Light (1975)	1,800	1,200	100	1,000	300	500	1,500
Edison Electric	1,137	1,175	103	993	363	502	1,195
Federal Power Commission	650	1,200	70	975	310	—	1,100
Stanford Research Institute	1,270	1,180	98	990	360	490	1,405
Rand, Inc.	1,150	1,200	110	1,000	400	500	1,200
Library of Congress (1973)	1,140 to 1,830	1,200	103	993	363	—	1,195 to 1,761
Drag Smith, Ed., Efficient Energy Use (1976)	1,200 to 1,572	1,200	84	840	348	456	1,056 to 1,524
ESTIMATE USED FOR THIS STUDY	1,600	1,200	100	1,000	300	500	—
MISCELLANEOUS SMALL APPLIANCES:					12 kWh/yr.		
Seattle City Light, 1975.					144		
					12		
					24		
					156		
					84		
					20		
					72		
					12		
					164		
TOTAL					700 kWh/yr. (Estimate used for this study)		

SOURCE: Skidmore, Owings and Merrill, 1977b.

TABLE B-23
 LIGHTING POWER BUDGET
 Commercial Buildings

Occupancy Type	Unit Power Budget Watts/ft ²
Auditorium, Theaters, Public Assembly	1.1
Hospitals	2.0
Indoor Parking	.3
Libraries	2.0
Museums	1.5
Offices	2.0
Restaurants	1.5
Retail Stores	2.5
Schools	2.1
Warehouse	0.7

SOURCE: Seattle Energy Office, Proposed Seattle Energy Code, 1979.

TABLE B- 24
SOLAR-HEATING POTENTIAL
NEW CONSTRUCTION

Seattle, Washington

Solar System Cost \$/ft ²	Energy Cost ¢/Kwh	Percent Energy Supplied by Solar System	
		Hot Water	Hot Water and Heating
5	1	47	(a)
	2	74	50
	3	97	57
10	2	47	(a)
	3	58	43
20	3	(a)	(a)

Spokane, Washington

5	1	66	45
	2	75	64
	3	89	72
10	1	40	(a)
	2	66	45
	3	71	58
20	2	40	(a)
	3	58	(a)

(a) Less than 40%

SOURCE: DOE, 1978a.

APPENDIX C

BLANK FORMS

FORM 1

ENERGY COSTS FOR NEW BUILDINGS, BY TYPE OF BUILDING

TYPE OF BUILDING	Energy Costs		Project Data		Cost (1x3) Btu	Area (2x4) Btu	Value Selected Btu
	Total Project	Coefficients	Total	Total			
	Btu/\$ ¹	Btu/SF	Cost ¹ \$	Area SF			
	1	2	3	4	5	6	7
Residential							
Single family	55,500	702,000					
2-4 family	52,100	630,000					
Garden apartment	52,900	650,000					
High rise	60,000	740,000					
Alterations & Additions	51,600	(2)					
Hotel/Motel	69,200	1,230,000					
Dormitory	70,600	1,430,000					
Industrial building	70,900	970,000					
Office building	68,700	1,640,000					
Warehouse	77,600	560,000					
Garages/Service station	76,200	770,000					
Stores/Restaurant	73,200	940,000					
Religious building	65,600	1,260,000					
Educational building	67,900	1,390,000					
Hospital building	60,600	1,720,000					
Farm residence	53,800	560,000					
Farm service building	77,000	149,000					
Other non-farm	69,900	1,450,000					
Social/Recreational	69,900	1,380,000					
Laboratory	69,900	2,075,000					
Library/Museum	69,900	1,744,000					

¹ In 1967 new contractor's costs - see page 9 to adjust for current costs

² Use new construction values

FORM 2

SITWORK ENERGY COST ESTIMATION FOR NEW BUILDINGS
BY TYPE OF BUILDING

	Direct Petroleum Products Usage (Btu/SF) (1)	Sitework Coefficient (Btu/SF) (2)	Project Data (Total Area) (3)	Sitework Energy (2 x 3) (4)
Residential				
Single family	29,917	28,421		
2-4 family	32,496	30,871		
Garden apartment	33,962	32,264		
High rise	54,336	51,619		
Hotel/Motel	96,569	91,741		
Dormitory	119,307	113,342		
Industrial building	51,165	48,607		
Office building	137,500	130,625		
Warehouse	33,333	31,666		
Garage/Service station	86,363	82,045		
Store/Restaurant	87,004	82,654		
Religious building	106,410	101,090		
Educational building	100,824	95,783		
Hospital	122,907	116,762		
Farm residence	13,578	12,899		
Farm service building	4,945	4,698		
Other non-farm buildings	125,596	119,316		
Social/Recreational				
Laboratory				
Library				
Project Total _____				Btu

FORM 3

EMBODIED ENERGY, BY MATERIAL SECTORS

Material Sector	Manufacturing (Btu/\$) (1)	Delivery and Assembly (Btu/\$) (2)	Total (Btu/\$) (3)	Project Costs (\$) (4)	Estimated Energy Costs (Btu) (Col. 3 x Col. 4) (5)
Sitework (from Form 2)					
Sawmill products	65,285	29,743	95,028		
Hardwood flooring	55,516	30,459	85,975		
Special sawmill products	39,319	22,107	61,426		
Millwork	47,350	15,765	63,115		
Veneer and plywood	67,686	21,353	89,039		
Prefab wood structures and buildings	55,182	7,746	62,928		
Wood panels, particle board	71,339	16,005	87,344		
Building paper and insulating board	189,900	35,151	225,051		
Paints	122,390	22,359	144,749		
Asphalt roofing materials and felt	478,610	15,222	493,832		
Plastic products					
Flat glass	102,810	15,258	118,058		
Cement	479,590	17,477	497,067		
Concrete pipe, precast products	108,490	6,260	114,750		
Concrete blocks	141,630	13,683	155,313		
Ready-mix concrete	180,130	655	180,785		
Bricks and tiles	340,290	17,865	358,155		
Ceramic tiles	110,610	10,547	121,157		
Structural clay products	259,790	17,253	277,043		
Vitreous plumbing fixtures	91,042	18,052	109,094		
Lime	507,010	37,482	544,492		
Gypsum products	158,540	19,998	178,538		
Mineral wool insulation	155,870	19,088	174,958		
Steel products	266,980	13,910	280,890		
Fabricated structural steel	124,320	5,704	130,024		
Copper products	101,700	2,643	104,343		
Aluminum products	244,200	3,479	247,679		
Nonferrous wire	91,433	3,290	94,723		
Metal plumbing fixtures	98,392	16,316	114,708		
Plumbing fittings, brass goods	74,662	12,862	87,524		
Heating equipment (except electric)	71,217	13,985	85,202		
Water heaters	82,264	5,915	88,179		
Metal doors, sash, trim	116,790	9,304	126,094		
Metal tanks	104,910	2,852	107,762		
Sheet metal	114,110	6,410	120,520		
Screw machine products	65,812	15,851	101,663		
Miscellaneous metalwork (lath, bar joists, etc.)	139,810	5,541	145,351		
Wiring devices (sockets, outlet boxes, etc.)	72,488	8,009	80,497		
Total Energy Costs					

NOTE: Project costs must be in 1967 contractor's dollars - see page 9 to
adjust for current costs

FORM 4

ENERGY EMBODIMENT PER UNIT OF MATERIAL
BY TYPE OF MATERIAL

Materials	Units (1)	Energy Coefficients				Project Requirements. (6)	Total Energy Cost (Btu) (7)
		Manufact. Btu/Unit (2)	Delivery Btu/Unit (3)	Assembly Btu/Unit (4)	Total Btu/Unit (5)		

FORM 5
LOAD SUMMATION TABLE

Category	Calculation Sequence	Heating	Cooling
Roof/ceiling	1		
External walls	2		
Glass (Transmission)	3		
Glass (Solar)	4		
Floor	5		
Infiltration	6		
Ventilation	7		
People	8		
Lights	9		
Equipment	10		
Total			

FORM 6
CONSUMPTION SUMMATION TABLE

Calculation Sequence	Categories	Annual Energy Consumption (Btu/yr)
1	Hot Water	
2	Lighting	
3	Equipment	
4	Fans & Auxiliaries	
5	Heating	
6	Cooling	
	TOTAL	

FORM 7

TRANSPORTATION ENERGY USE CALCULATIONS

Number of Households (1)	Miles Traveled per Year per Household (From Table 6) (2)	Total Miles Traveled (Col.1 x Col.2) (3)	Miles Traveled by Car (4)	Miles Traveled by Transit (5)
Single Family				
Multi-Family				
Total				

Automobile Btus per Mile (From Table 5A) (6)	Bus Btus per Passenger Mile (From Table 5B) (7)	Total Auto Btus (Col.4 x Col.6) (8)	Total Bus Btus (Col.5 x Col.7) (9)	Total Transportation Btus (Col.8 x Col.9) (10)
Single Family				
Multi-Family				
Total				

FORM 8

INFRASTRUCTURE EMBODIED ENERGY COSTS

Material (1)	Quantity (2)	Direct and Indirect Btus (3)	Total Btus (Col. 2 x Col. 3) (4)
<u>Sewer, Water, Storm Drainage Pipe</u>		<u>Btus/LF</u>	
Concrete Pipe (all types)			
4-inch Inside Diameter		28,512	
6 ID		40,985	
8		65,934	
10		90,832	
12		119,394	
15		136,323	
24		217,832	
36		326,765	
60		544,953	
Galvanized Pipe			
8-inch ID, 16 Gauge		205,380	
12 16 "		309,570	
15 16 "		386,962	
24 14 "		743,321	
36 12 "		1,301,244	
60 10 "		2,479,194	
Vitrified Clay (Std. Strength)			
4-inch ID		77,787	
6		138,288	
8		198,789	
10		311,148	
12		414,864	
15		622,296	
18		878,000	
24		1,574,063	
30		2,510,360	
36		3,745,184	
<u>Pavement: Streets, Driveways, Parking</u>		<u>Square Feet (SF)</u>	<u>Btus/SF</u>
Asphalt with aggregate			
4 inches thick		54,000	
Asphalt blocks			
5" x 12" x 3"		40,500	
Concrete (Reinforced)			
5 inches thick		45,100	
10 inches thick		80,075	
Brick (on Sand)			
		153,555	
<u>Curb</u>		<u>Linear Feet (LF)</u>	<u>Btus/LF</u>
Asphalt 6" x 18"			121,215
Concrete 6" x 18"			72,065
<u>Sidewalk</u>		<u>Square Feet (SF)</u>	<u>Btus/SF</u>
Bituminous (Asphalt Concrete)			
2 inches thick		26,400	
Brick			
Laid flat on sand		115,119	
Laid on end on sand		184,190	
Concrete 4 inches thick			21,915