ASSESSING the ENERGY CONSERVATION BENEFITS of HISTORIC PRESERVATION: Methods and Examples

ADVISORY COUNCIL on HISTORIC PRESERVATION

JANUARY 1979

This study contains formulas to measure the energy needed to restore and rehabilitate existing buildings and that needed to demolish and replace them with comparable new construction. The Advisory Council on Historic Preservation has developed these formulas to assist it in discharging its responsibilities under Section 106 of the National Historic Preservation Act, which requires Federal agencies to seek the comments of the Council when their undertakings affect properties included in or eligible for inclusion in the National Register of Historic Places, and Title I of the Public Buildings Cooperative Use Act, which requires the Council to advise the General Services Administration on the suitability of historic buildings in a given geographical area for needed Federal office space or other mixed uses. This study provides the Council with another tool for determining the total worth of historic structures, and, in specific cases, whether the retention and continued use of threatened properties are in the public interest. This study provides the Council with another tool for determining the total worth of threatened properties, and, in particular cases, whether retention and continued use are in the public interest.

In addition, formulas have been used to compute the amounts of energy needed to rehabilitate and replace three National Register properties: Lockefield Garden Apartments, an early Federal housing project in Indianapolis, Indiana, recently the subject of Council comment; the Grand Central Arcade, a pivotal commercial complex in Pioneer Square Historic District, Seattle, Washington; and the Austin House, a three-unit apartment building converted from a carriage house in the Capitol Hill Historic District of Washington, D.C. In each instance, analysis shows that renovation, instead of comparable new construction, results in impressive energy savings.

The Council encourages planners, designers, and adminstrators to use this methodology in determining the advantages of supporting restoration and rehabilitation of existing buildings as an alternative to demolition or new construction. Energy conservation is an important concern, and one that needs careful consideration in decisions affecting the built environment.

		Page Number
Exhibit 1	Embodied Energy of Materials and Construction Per Square Foot of Construction	19
Exhibit 2	Demolition Energy of Construction Materials for Existing Buildings	19
Exhibit 3	Annual Operation Energy	22
Exhibit 4	Energy Embodiment of Primary Materials	26
Exhibit 5	Energy Embodiment of Construction	26
Exhibit 6	Weight of Materials	28
Exhibit 7	Degree-Hrs of Heating and Cooling Required for Various Locations Within the United States	31
Exhibit 8	Heating System and Cooling System Efficiencies	31
Exhibit 9	Heating Energy and Cooling Energy Source Efficiencies	32
Exhibit 10	Thermal Transmission, U, Values for Exposed Roof, Walls, and Glazing	32

exhibits

I. overview

OVERVIEW

THE BUILT ENVIRONMENT REPRESENTS A MAJOR ENERGY INVESTMENT BY OUR CULTURE

- Processing, transporting, and putting construction materials in place requires substantial amounts of energy—about 5 percent of United States energy consumption annually just for new buildings.

- Replacing all existing buildings in the United States would require the entire world's energy output for about a year just for materials and construction processes—approximately 200 quadrillion Btus of energy.

COMMON SENSE SUGGESTS THAT PRESERVATION OF EXISTING FACILITIES IS LESS COSTLY, IN MANY WAYS, THAN DEMOLITION AND BUILDING ANEW

While the social and cultural benefits of historic preservation are becoming widely accepted, there is disagreement about applying this conventional wisdom to energy conservation.

Some opponents of preservation might argue that "new buildings can be made more energy efficient than old buildings."

The Advisory Council on Historic Preservation has investigated this issue and developed tools for assessing the potential value of rehabilitation in terms of energy conservation.

ANALYSIS OF THREE DISSIMILAR PRESERVATION PROJECTS HAS SHOWN THAT REHABILITATION OF HISTORIC BUILDINGS CAN PRODUCE SIGNIFICANT ENERGY CONSERVATION BENEFITS

- Individual existing buildings represent large energy investments in materials and construction processes

  - Lockefield Garden Apartments, Indianapolis, Indiana, one of the first government sponsored, low-cost housing projects built in the United States, represents over 550 billion Btus of energy embodied in its construction. This investment in the existing complex is equivalent to 4.5 million gallons of gasoline.

  - The shell of a Washington, D.C. carriage house, a small two-story brick structures, embodies over 1 billion Btus of energy in its materials. This energy in the shell materials is equivalent to about 8000 gallons of gasoline.

- Rehabilitation of existing buildings requires much less initial investment of energy than constructing comparable new facilities.

  - The Grand Central Arcade, an adaptive reuse of a hotel in Seattle's Pioneer Square Historic District, required less than one-fifth as much energy for rehabilitation materials and construction activities than would have been needed to produce the materials for and build a comparable new facility. The rehabilitation "savings" came to more than 90 billion Btus or over 700,000 gallons of gasoline.

  - Rehabilitation of the Lockefield Garden Apartments would potentially require only one third as much energy for materials and construction processes as a new complex providing the same services. In this case, the rehabilitation "savings" would be equivalent to over 2250 billion Btus or almost 2 million gallons of gasoline.

  - An extensive rehabilitation of "Austin House", a 3-unit apartment adaptive reuse of a Capitol Hill carriage house in Washington, DC, left only the exterior shell intact. Even so, the rehabilitation materials and construction activities required less than half as much energy as would have been required in the materials and building of an equivalent new structure. Initial rehabilitation "savings" for this small structure (2700 s.f.) are over 1000 million Btus or over 8000 gallons of gasoline.

- <u>Rehabilitated buildings will annually consume about the same amount of energy as equivalent new structures</u>

  - The Grand Central Arcade was restored prior to the oil embargo without particular emphasis on energy conservation. It annually consumes about 5 percent more energy than an average equivalent new structure in the same climatic region would if designed in accordance with present day energy conservation standards.

  - Lockefield Garden Apartments, when restored, would use approximately one sixth more energy annually than average comparable new facilities in the same climatic region. The analysis procedures did not take into account the effect of massive construction in the existing buildings which might offset the excess energy consumption somewhat. Also, no attempt was made to assess the potential effects of energy conservation measures which might be incorporated in the rehabilitation.

  - Austin House will use approximately 5 percent <u>less</u> energy than an average equivalent new apartment building in Washington, D.C. because of the particular efforts made to incorporate energy conserving design features such as double glazed windows, additional insulation, and efficient HVAC systems.

- Rehabilitation of existing buildings, rather than demolition and new construction, results in a net energy investment "savings" over the expected life of the structures.

  - The total energy investment to renovate and operate a rehabilitated Lockefield Garden Apartment will be less than the energy required to construct and operate new facilities for over 50 years—even though new facilities might use less energy annually for operations.

  - The Grand Central Arcade will have a net energy investment advantage over an equivalent new structure for the next two centuries.

  - Over a 30-year period, the rehabilitated Austin House will conserve enough energy to heat and cool an equivalent new apartment building for over 10 years.

IT IS IMPORTANT THAT PRESERVATION RECEIVE PROPER CREDIT FOR ITS ENERGY SAVINGS

- Once energy is embodied in a building, it cannot be recovered and used for another purpose--8 bricks embody energy equivalent to a gallon of gasoline but cannot fuel a car.

- Preservation saves energy by taking advantage of the nonrecoverable energy embodied in an existing building and extending the use of it.

- Because the energy embodied in an existing building was invested long ago, and is nonrecoverable, its economic value is not adequately recognized by normal economic comparisons of preservation versus new construction.

- Publicizing the energy conservation benefits of preservation can increase public awareness of this hidden benefit of preservation, even though the energy savings do not translate directly into dollar savings in the marketplace.

THE METHODS DEVELOPED AND USED IN THE ANALYSIS OF THE THREE CASE STUDIES CAN BE APPLIED TO ANY EXISTING BUILDING TO ASSESS THE POTENTIAL ENERGY CONSERVATION BENEFITS OF REHABILITATION

- The Council has developed tools for assessing the potential energy conservation value of preservation and rehabilitation using combinations of three measurements of energy use.

  - Embodied Energy of Materials and Construction for Existing, Rehabilitated, and New Construction—The amount of energy required to process and put materials of construction in place. Embodied energy increases with the amount of processing and is not recoverable.

  - Demolition Energy for Existing Buildings—The amount of energy required to raze, load, and haul away building construction materials.

  - Annual Operational Energy for Existing, Rehabilitated, and New Construction—The amount of energy required to operate the facility. Operational energy depends upon:

    - Climate
    - Occupancy characteristics
    - Physical design of the building.

- The methods developed by the Council can be used to perform a number of different analyses of energy use in renovated and new buildings.

  - Existing Energy Investment in Materials and Construction—Calculate the embodied energy of materials and construction for the existing building.

  - Energy Investment in Rehabilitation Materials and Construction versus New Materials and Construction—Compare the embodied energy of rehabilitation materials and construction with the corresponding quantity for new construction which provides the same level of service. If razing an existing building would be necessary for new development, then Demolition Energy should be added to the embodied energy of materials and construction for the comparable new building.

  - Annual Operational Energy for the Rehabilitation versus Annual Operational Energy for a Comparable New Facility—Compare the estimated amount of energy needed annually to operate the rehabilitated facility with the corresponding estimated energy required for operation of comparable new construction which incorporates contemporary energy conservation standards in the same climatic region.

  - Rehabilitation Total Energy Investment versus Total Energy Investment for a Comparable New Building—Combine Embodied Energy of Materials and Construction and Annual Operational Energy over a pre-determined life expectancy for the rehabilitated structure and a comparable new building. This comparison reveals the net energy "savings" of preservation.

    Alternatively, the total energy investment advantage of preservation can be represented by the time period required for the rehabilitation energy investment to equal the comparable new construction energy.

THE ENERGY CONSERVATION ANALYSIS METHODS AND TOOLS DEVELOPED BY THE COUNCIL CAN BE APPLIED AT ANY POINT IN THE DECISIONMAKING PROCESS, REGARDLESS OF THE AMOUNT OF DETAIL OF INFORMATION AVAILABLE

- The Council's objectives for this study were twofold:
  - Provide methods for determination of the energy conservation aspects of renovation.
  - Demonstrate application of resultant methods to actual preservation examples.
- The analysis methods are intended to be useful in a variety of applications:
  - The techniques are designed to be usable by individuals or groups with different skill levels and expertise.
  - The particular analytical problems or questions to be addressed will involve different levels of detail depending on the availability of information and resources.
  - Highly detailed procedures, while useful to some, require more time and money than can be practically invested in many cases.
- To accomplish these goals, the Council has developed a series of computation techniques for different levels of detail and precision:
  - Building Concept Model—simple methods
  - Building Survey Model—intermediate methods
  - Building Inventory Model—detailed methods.

- Building Concept Model—The simplest method requires minimum information. Consequently, the results are generally correct but not precise.

  - Embodied Energy: Based upon building type and gross size, a single calculation is required for energy emobdiment of construction, and for energy emobdiment of demolition. The approach measures the energy embodied in materials for existing buildings in terms of present day levels.

  - Demolition Energy: Based upon building type and gross size, a single calculation is required to estimate the amount of energy needed to raze, load, and haul away construction materials.

  - Operational Energy: Based upon the building type, location, and gross size, a single calculation is required for an approximation of total annual operational energy.

- <u>Building Survey Model</u>—The intermediate method may be the most useful. It yields refined results with relatively little additional effort.

  - <u>Embodied Energy</u>: Based upon a coarse survey of quantities of primary building materials and their respective energy embodiment, up to eight calculations are required to obtain the energy embodied in materials. A single calculation is required for energy embodiment of construction.

  - <u>Demolition Energy</u>: Based upon a coarse survey of quantities of primary building materials and their respective weights, up to nine calculations are required to approximate demolition energy.

  - <u>Operational Energy</u>: Based upon a coarse analysis of climate, building envelope composition, and physical properties, approximately 16 calculations are required to obtain an approximation of annual energy consumption.

- <u>Building Inventory Model</u>—The most complex model requires substantial detailed information and provides correspondingly precise results.

  - <u>Embodied Energy</u>: Based upon a detailed inventory of material quantities and an analysis of energy embodied for each material type, many calculations are required to obtain the energy embodied in materials. A single calculation is required for energy embodiment of construction.

  - <u>Demolition Energy</u>: Based upon a detailed inventory of material quantities, and the weight of construction materials, many calculations are required to obtain the energy required to raze, load, and haul away the demolished structure.

  - <u>Operational Energy</u>: Based upon an assessment of the complex interactions of site climate, building envelope, and occupancy characteristics, several hundred calculations are required to obtain the total annual operational energy. Manual and computer aided data reduction techniques are provided. Exhibit 15 is a listing of the coding for the computer program. Exhibit 16 lists the input data requirements necessary to run the program.

- In making comparisons between the energy investment requirements of Preservation and Comparable New Construction, more than one analysis model may be used.

  - New building energy investment requirements will often be calculated using concept model procedures due to the lack of detailed information.

  - Better information will generally be available for the existing building or proposed rehabilitation, allowing use of more detailed survey model and inventory model techniques.

The following sections describe the analysis procedures and provide detailed reference materials as required.

1. BUILDING CONCEPT MODEL
2. BUILDING SURVEY MODEL
3. BUILDING INVENTORY MODEL

II. analysis models

analysis models

The following matrix lists the procedural methods available in each of the analysis models. Select particular procedures on the basis of information and time available.

PROCEDURES	Concept Model	Survey Model	Inventory Model
Embodied Energy Investment in Existing Buildings	1.1	2.1	3.1
Demolition Energy for Existing Buildings	1.2	2.2	3.2
Embodied Energy Investment in Renovated Buildings	1.3	2.3	3.3
Annual Operational Energy in Renovated Buildings	1.4	2.4	3.4
Embodied Energy Investment in New Buildings	1.5	2.5	3.5
Annual Operational Energy in New Buildings	1.6	2.6	3.6

1. concept model

1.1 CONCEPT MODEL EMBODIED ENERGY INVESTMENT IN EXISTING BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.

PROCEDURES

Embodied Energy Investment = [Gross floor area of historic building x Invested energy per square foot specific to the building type from Exhibit 1]

1.2 CONCEPT MODEL DEMOLITION ENERGY FOR EXISTING BUILDINGS

INFORMATION REQUIRED

- Construction materials type (light, medium, or heavy)
- Gross s.f.

PROCEDURE

$$\text{Demolition Energy} = \left[\begin{array}{l} \text{Gross floor} \\ \text{area of} \\ \text{existing} \\ \text{building} \end{array} \times \begin{array}{l} \text{Demolition energy of materials} \\ \text{per square foot of construction} \\ \text{for buildings of similar size} \\ \text{and construction type,} \\ \text{Exhibit 2} \end{array} \right]$$

EXHIBIT 1
Embodied Energy of Materials and Construction[1]
Per Square Foot of Construction

	MBTU/Sq. Ft.
Residential - 1 Family	700
Residential - 2-4 Family	630
Residential - Garden Apt	650
Residential - High Rise	740
Hotel/Motel	1130
Dormitories	1430
Industrial Buildings	970
Office Buildings	1640
Warehouses	560
Garages/Service Stations	770
Stores/Restaurants	940
Religious Buildings	1260
Educational	1390
Hospital Buildings	1720
Other Nonfarm Buildings	1450
a. Amusement, Social & Rec	1380
b. Misc Nonresidential Bldg	1100
c. Laboratories	2070
d. Libraries, Museums, etc.	1740

1 Energy Use for Building Construction, Energy Research Group, Center for Advanced Computation, University of Illinois and Richard G. Stein and Associates, December 1976.

EXHIBIT 2
Demolition Energy of Construction Materials for Existing Buildings

Construction Type	Building Size		
	Small 5000-15,000 s.f.	Medium 50,000-150,000 s.f.	Large 500,000-1,500,000 s.f.
Light (e.g., wood frame)	3100 Btu/s.f.	2400 Btu/s.f.	2100 Btu/s.f.
Medium (e.g., steel frame)	9300 Btu/s.f.	7200 Btu/s.f.	6300 Btu/s.f.
Heavy (e.g., masonry, concrete)	15,500 Btu/s.f.	12,000 Btu/s.f.	10,500 Btu/s.f.

1.3 CONCEPT MODEL EMBODIED ENERGY INVESTMENT IN RENOVATED BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.
- f_1, fraction of materials and construction of the existing historic building that is being replaced or added in the renovation process. The value of f_1 is largely a matter of judgment

PROCEDURE

$$\text{Embodied Energy Investment} = \left[\text{Gross floor area of historic building} \times \text{Invested energy per square foot specific to the building type from Exhibit 1} \times f_1\right]$$

1.4 CONCEPT MODEL ANNUAL OPERATIONAL ENERGY IN RENOVATED BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.
- f_2, multiplier representing the extent to which renovations may be expected to make the historic building energy consumption equivalent to new buildings. The value of f_2 is largely a matter of judgment

PROCEDURE

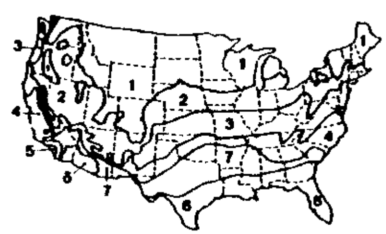
$$\text{Annual Operational Energy} = \left[\text{Gross floor area of historic building} \times \text{Energy consumption in buildings of similar type in the same climatic region, 1975 levels, Exhibit 3} \times f_2 \right]$$

EXHIBIT 3
Annual Operational Energy (MBtu/sf)[1]

Building Type	Nation	Region 1	2	3	4	5	6	7
Office	64	65	76	65	61	51	50	64
Elementary	65	114	70	68	70	53	48	57
Secondary	52	77	66	55	51	37	41	34
College/Univ.	65	67	70	46	59	—	—	83
Hospital	190	—	200	171	227	207	—	197
Clinic	69	84	72	71	65	61	59	59
Assembly	61	58	76	66	51	44	68	57
Restaurant	159	162	178	186	144	123	137	137
Mercantile	84	99	98	86	81	67	83	80
Warehouse	65	75	82	65	50	36	37	39
Residential Non-Housekeeping	95	99	84	94	125	90	93	106
High Rise Apt.	49	53	53	52	53	34	29	—
Multifamily Low Rise	43	58	55	41	31	27	22	32
Single Family Attached	47	65	54	45	37	35	33	45
Single Family Detached	69	104	73	61	52	43	38	58
Mobile Homes	75	103	84	81	67	42	54	70

1 PHASE ONE/BASE DATA for the development of ENERGY PERFORMANCE STANDARDS FOR NEW BUILDINGS, HUD, DOE, January, 1978

CLIMATIC REGIONS



1.5 CONCEPT MODEL EMBODIED ENERGY INVESTMENT IN NEW BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.

PROCEDURE

Embodied Energy Investment = [Gross floor area of new building x Invested energy per square foot specific to the building type from Exhibit 1]

1.6 CONCEPT MODEL ANNUAL OPERATIONAL ENERGY IN NEW BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.

PROCEDURE

$$\text{Annual Operational Energy} = \left[\text{Gross floor area of new building} \times \text{Energy consumption in buildings of similar type in the same climatic region, 1975 levels, Exhibit 3} \right]$$

2. survey model

2.1 SURVEY MODEL EMBODIED ENERGY INVESTMENT IN EXISTING BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.
- Materials quantity survey in terms of seven primary material categories

PROCEDURE

$$\text{Embodied Energy Investment} = \left[\text{Energy used in construction} + \text{Energy invested in materials}\right]$$

$$\text{Energy Used in Construction} = \left[\text{Gross floor area of historic building} \times \text{Invested construction energy per square foot specific to the building type from Exhibit 5}\right]$$

$$\text{Energy Invested in Materials} = 1.4^{*} \sum \left[\text{Quantity of material} \times \text{Invested energy per material unit from Exhibit 4}\right]$$

i=1 - Wood
2 - Paint
3 - Asphalt
4 - Glass
5 - Stone and clay
6 - Primary iron and steel
7 - Primary non-ferrous

* The surveyed materials account for about 50 percent of the total embodied energy of building construction. The surveyed materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of surveyed materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 _Energy Use for Building Construction_, December 1976

EXHIBIT 4
Energy Embodiment of Primary Materials*

Material Category	Embodied Energy per Material unit
Wood Products	9000 Btu/BDFT
Paint Products	1000 Btu/sf (450sf/gal.)
Asphalt Products	2000 Btu/sf
Glass Products	15000 Btu/sf-windows
	40000 Btu/sf-plate
Stone & Clay Products	96000 Btu/cf concrete
	400000 Btu/cf brick
Primary Iron & Steel Products	25000 Btu/lb
Primary Non-Ferrous Products	95000 Btu/lb

* Note that these values are approximations based on data for a variety of products included in Energy Use for Buildings, December 1976.

EXHIBIT 5
Energy Embodiment of Construction[1]

Building Construction Type	Energy Embodied in (Direct Fuel Purchases for) Construction*
	MBtu/SF
Residential - 1 family	90
Residential - 2-4 family	100
Residential - Garden Apt	120
Residential - Highrise	150
Hotel/Motel	250
Dormitories	330
Industrial Buildings	100
Office Buildings	360
Warehouses	80
Garages/Service Stations	150
Stores/Restaurants	220
Religious Building	260
Educational Buildings	270
Hospital Buildings	350
Other non-Farm Buildings	310
a. Amusement, Social, Recreation	300
b. Misc Non-Residential Buildings	240
c. Laboratories	450
d. Libraries, Museums, etc.	380
Farm Residences	70

1 Energy Use for Building Construction, Energy Research Group, Center for Advanced Computation, University of Illinois and Richard G. Stein and Associates, December 1976.

2.2 SURVEY MODEL DEMOLITION ENERGY FOR EXISTING BUILDINGS

INFORMATION REQUIRED

- Materials quantity survey in terms of seven primary material categories

PROCEDURE

$$\text{Demolition Energy} = 50^{*}\ \text{Btu/lb of materials} \times 1.4^{**} \sum_i \left[\text{Quantity of Material} \times \text{Weight per material unit, Exhibit 6}\right]$$

---

*NOTE: Range is 35-65 Btu/lb of materials

** The surveyed materials account for about 50 percent of the total embodied energy of building construction. The surveyed materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of surveyed materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 Energy Use for Building Construction, December 1976

EXHIBIT 6
Weight of Materials

Weight of Materials	Weight per Unit Quantity
Wood Products	4 lb/b.f. (board feet)
Paint Products	12 lb/gallon
Asphalt Products	100 lb/c.f. (cubic feet)
Glass Products	170 lb/c.f.
Stone & Clay Products	144 lb/c.f.
Primary Iron and Steel Products	500 lb/c.f.
Primary Non-Ferrous Products	250 lb/c.f.

2.3 SURVEY MODEL EMBODIED ENERGY INVESTMENT IN RENOVATED BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.
- Materials of renovation quantity survey in terms of seven primary categories
- f_3, fraction of energy intensity of new building construction for the total building which would be expended in renovation activities

PROCEDURES

$$\text{Embodied Energy Investment (BTU)} = \left[\text{Energy used in renovation construction} + \text{Energy invested in renovation materials}\right]$$

$$\text{Energy used in renovation construction} = \left[\text{Gross floor area of historic building} \times \text{Invested construction energy per square foot specific to the building type, Exhibit 5} \times f_3\right]$$

$$\text{Energy invested in materials} = 1.4^{*}\sum_{i}\left[\text{Quantity of renovation materials} \times \text{Invested energy per material unit, Exhibit 4}\right]$$

i
1-wood
2-paint
3-asphalt
4-glass
5-stone and clay
6-primary iron and steel
7-primary non-ferrous

* The surveyed materials account for about 50 percent of the total embodied energy of building construction. The surveyed materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of surveyed materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 Energy Use for Building Construction, December 1976

2.4 SURVEY MODEL ANNUAL OPERATIONAL ENERGY* IN RENOVATED BUILDING

INFORMATION REQUIRED

- Enclosed volume
- Exposed roof, wall, and glass areas
- Exposed roof, wall, and glass thermal transmission, U, values, Exhibit 10
- Heating system type
- Cooling system type

PROCEDURE

$$\text{Annual Operational Energy,} = \left[\text{Energy required to offset heating loads} + \text{Energy required to offset cooling loads}\right]$$

$$\text{Energy required to offset heating loads} = \left[\sum_i U \times A \times \text{Climate heating factor, Exhibit 7}\right] \div \left[\text{Heating system efficiency, Exhibit 8} \times \text{Source energy efficiency Exhibit 9}\right]$$

$$\text{Energy required to offset cooling loads} = \left[\sum_i U \times A \times \text{Climate cooling factor, Exhibit 7}\right] \div \left[\text{Cooling system efficiency, Exhibit 8} \times \text{Source energy efficiency Exhibit 9}\right]$$

i=1 - roof
2 - wall
3 - glazing

* The formulas used in calculating operational energy in this study are simplified methods. They are not intended to be considered analytically rigorous and therefore can produce only approximations of the energy which can be expected to be consumed in buildings. More detailed, rigorous, or accurate methods may be substituted in this analysis at the user's option.

EXHIBIT 7
Degree-Hrs. of Heating and Cooling Required for Various Locations Within the United States*

Location	Degree-Hrs of Heating Required (Thousands)	Degree-Hrs of Cooling Required (Thousands)	Location	Degree-Hrs of Heating Required (Thousands)	Degree-Hrs of Cooling Required (Thousands)
Albany, NY	161	9	Los Angeles, CA	35	0
Albuquerque, NM	174	36	Louisville, KY	105	35
Atlanta, GA	74	35	Lubbock, TX	78	42
Bismarck, ND	188	18	Memphis, TN	78	45
Boise, ID	140	19	Miami, FL	3	67
Boston, MA	155	9	Minneapolis, MN	183	13
Billings, MT	154	15	New Orleans, LA	28	54
Buffalo, NY	161	6	Omaha, NE	146	23
Charleston, SC	46	42	Pearl Harbor, HI	0	70
Chicago, IL	156	11	Phoenix, AZ	9	104
Corpus Christi, TX	18	65	Pittsburgh, PA	89	11
Dallas, TX	57	63	Portland, ME	174	3
Denver, CO	127	20	Portland, OR	122	0
Detroit, MI	166	9	Roosevelt Rds, PR	0	96
Ellsworth, SD	156	17	Sacramento, CA	64	65
Fairchild, WA	169	8	Salt Lake City, UT	151	24
Greensboro, NC	89	33	San Diego, CA	37	0
Helena, MT	186	8	San Francisco, CA	75	0
Kansas City, MO	114	35	Traverse City, MI	182	6
Kodiak, AK	240	0	Tulsa, OK	85	45
Las Vegas, NV	51	94	Washington, DC	114	26

* Based on average heating season temperature and length and average cooling season temperature and length from Energy Conservation With Comfort, Honeywell, 1976.

EXHIBIT 8
Heating System and Cooling System Efficiencies

System Type	Heating Efficiency	Cooling Efficiency
Fuel Fired	.7 - .8	0.5 (Absorption Cooling)
Electric	1.0 (Resistance)	3.0 (Refrigeration)
	1.7 (Heat Pump)	2.4 (Heat Pump)

EXHIBIT 9
Heating Energy and Cooling Energy Source Efficiencies

Source Efficiency			
Coal	Oil	Gas	Electricity
1.0	1.0	1.0	.3

EXHIBIT 10
Thermal Transmission, U, Values for Exposed Roofs, Walls, and Glazing

Description	Transmission, U, Btu/ft^2 ^{o}F
Roof Construction	0.05-0.20
Wall Construction	0.10-0.60
Glazing	0.60-1.13

2.5 SURVEY MODEL EMBODIED ENERGY INVESTMENT IN NEW BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross ft.
- Materials quantity survey in terms of seven primary categories

PROCEDURE

$$\text{Embodied energy investment (BTU)} = \left[\text{Energy used in new construction} + \text{Energy invested in materials}\right]$$

$$\text{Energy used in new construction} = \left[\text{Gross floor area of new building} \times \text{Invested construction energy per square foot specific to the building type, Exhibit 5}\right]$$

$$\text{Energy invested in materials} = 1.4^{*} \sum_{i} \left[\text{Quantity of material} \times \text{Invested energy per material unit, Exhibit 4}\right]$$

i=1-wood
2-paint
3-asphalt
4-glass
5-stone and clay
6-primary iron and steel
7-primary non-ferrous

* The surveyed materials account for about 50 percent of the total embodied energy of building construction. The surveyed materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of surveyed materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 <u>Energy Use for Building Construction</u>, December 1976

2.6 SURVEY LIFE CYCLE OPERATIONAL ENERGY IN A NEW BUILDING

INFORMATION REQUIRED

- Enclosed volume
- Exposed roof, wall, and glass areas
- Exposed roof, wall, and glass thermal transmission, U, values, Exhibit 10
- Heating system type
- Cooling system type

PROCEDURE

$$\text{Annual Operational Energy} = \left[\text{Energy required to offset heating loads} + \text{Energy required to offset cooling loads}\right]$$

$$\text{Energy req. to offset heating loads} = \left[\sum_{i} U \times A \times \text{Climate heating factor, Exhibit 7}\right] \div \left[\text{Heating system efficiency, Exhibit 8} \times \text{Source energy efficiency Exhibit 9}\right]$$

$$\text{Energy req. to offset cooling loads} = \left[\sum_{i} U \times A \times \text{Climate cooling factor, Exhibit 7}\right] \div \left[\text{Cooling system efficiency, Exhibit 8} \times \text{Source energy efficiency Exhibit 9}\right]$$

i=1 - roof
2 - wall
3 - glazing

3. inventory model

3.1 INVENTORY MODEL EMBODIED ENERGY INVESTMENT IN EXISTING BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.
- Materials quantity inventory

PROCEDURE

$$\text{Embodied energy investment} = \left[\text{Energy used in construction} + \text{Energy invested in materials}\right]$$

$$\text{Energy used in construction} = \left[\text{Gross floor area of historic building} \times \text{Invested construction energy per square foot specific to the building type from Exhibit 5}\right]$$

$$\text{Energy invested in materials} = 1.4^{*} \sum_{i}^{n} \left[\text{Quantity of materials} \times \text{Invested energy per material unit Exhibit 11}\right]$$

i=1 - Rough lumber, softwood bds
2 - Dressed lumber, softwood bds
.
.
.
n - Nuts, bolts, and other standard fasteners

* The inventoried materials account for about 50 percent of the total embodied energy of building construction. The inventoried materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of inventoried materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 <u>Energy Use for Building Construction</u>, December 1976

EXHIBIT 11
Embodied Energy of Materials[1]

Material Classification	Description	Unit	Embodied Energy Per Material Unit
WOOD PRODUCTS			
Sawmill + Planing[1] Mill Products	Rough Lumber: Softwd boards	bd ft	7,600
	Dressed Lumber: Softwd boards	bd ft	7,900
	Rough Lumber: Hardwood	bd ft	9,300
	Dressed Lumber: Hardwood	bd ft	9,700
Softwood Flooring	Softwood Flooring	bd ft	10,300
Hardwood Flooring	Oak strip flooring Oak specialty flooring Maple flooring Other hardwoods	bd ft	10,300
Shingles, Cooperage Stock + Excelsior: Red Cedar	Shingles Remanufactured Handsplit Shakes	sq ft	7,300
Window Units, Wood	Conventional Double Hung	1 ea	1,127,000
	Awnings + Casement	1 ea	1,190,000
	All other wood windows	1 ea	1,830,000
	Wood Window Sash		
	Knock down	1 ea	167,000
	Open	1 ea	168,000
	Glazed	1 ea	291,000
	Storm Sash	1 ea	427,000

1 Energy Use for Building Construction, B. M. Harmon, R. A. Stein, B. Z. Segal, D. Suber, C. Stein, Energy Research Group, Center for Advanced Computation, University of Illinois; Richard A. Stein and Associates, Architects, New York, NY, December 1976.

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
WOOD PRODUCTS (Continued)			
Window Units, Wood (Continued)	Doors, Wood, Interior + Exterior, Panel Type		
	Douglas Fir Western Pine Other Species	1 ea	873,000
	Flush Type, Hollow Core		
	Softwood Faces Hardwood Other Faces	1 ea	347,000
	Flush Type, Solid Core		
	Hardwood Faces Softwood + Other	1 ea	1,191,000
	Other Wood Doors		
	Combination Storm + Screen	1 ea	801,000
	Garage Doors	1 ea	3,321,000
	Screen Doors	1 ea	360,000
	Louvre Doors	1 ea	475,000
	Finished Wood Moldings		
	Softwood Hardwood	bd ft	18,000
Veneer + Plywood	Hardwood Plywood	sq ft sm	17,000
	Softwood Plywood (Interior Type)	sq ft 3/8"	5,000
	Softwood Plywood (Exterior Type)	sq ft 3/8"	6,000

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
WOOD PRODUCTS (Continued)			
Veneer + Plywood (Continued)	Prefinished Hardwood Plywood	sq ft sm	10,200
	Prefinished Hdwd Bases Prefinished Sftwd Bases	sq ft sm	8,800
	Hardwood Veneer Special + Type Face	sq ft sm	3,400
	Commercial + Utility Type	sq ft sm	2,200
	Container Type Flat Type	sq ft sm	1,500
	Softwood Veneer		
	Plywood Veneer	sq ft 1"	8,300
	Container Veneer	sq ft 1"	9,600
Fabricated Structural Wood Members	Glued Laminated Lumber	bd ft	16,700
	Sawn Lumber	bd ft	6,400
	Combination Glued + Sawn Lumber	bd ft	16,500
	Ready-cut + Prefab Wood Buildings		
	Dwellings	1 ea	
	Farm Buildings	1 ea	
	Roof Trusses Made of Sawn Lumber - Light Construction	1 ea	
Construction Paper	Construction Paper (Dry basis before saturating)	lb	10,500

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
WOOD PRODUCTS (Continued)			
Construction Paper (Continued)	PRODUCT EXAMPLE - BLDG PAPER Size / lb/sq ft / Total Btu/sq ft 1 ply / .05 lb / 524 2 ply / .10 lb / 1,048		
PAINT PRODUCTS			
Exterior Oil-Type Paint Products	Semi-paste oil + alkyd paints	gal	489,000
	Exterior water-type trade sales paint products	gal	489,000
	Interior oil-type trade sales paint products	gal	508,000
	Interior water-type trade sales paint products	gal	437,000
ASPHALT PRODUCTS			
Asphalt Felts & Coatings	Roof Asphalts + Patches		
	Roof Asphalt	lb	6,900
	Asphalt + Tar Roofing + Siding Products		
	Asphalt Roofing: Smooth Surfaced Rooled Roofing & Cap Sheet, Including Sanded, Talc, Mica, & Other Fine Material Surfacing	sq ft	7,800
	Mineral Surfaced Roll Roofing & Cap Sheet	sq ft	11,000

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
ASPHALT PRODUCTS (Continued)			
Asphalt Felts & Coatings	Strip Shingles-Self sealing	sq ft	29,700
	Standard or regular strip shingles	sq ft	25,300
	Indiv. Shingles-all styles	sq ft	25,600
	Asphalt Bldg sidings: roll form & shingle form all patterns	sq ft	13,600
	Mineral-surfaced insulating board base siding (all types and finishes)	sq ft	67,500
	Saturated felts: asphalt saturated felts for roofing and sidings	lb	13,600
	Saturated felts: tar saturated felts for roofing and sidings	lb	16,900
GLASS PRODUCTS			
Flat Glass	Sheet Glass (Windows)		
	Single strength	sq ft	13,700
	Double strength	sq ft	15,400
	Heavy sheet	sq ft	14,600
	Thin, including picture glass + tinted (all thicknesses)	sq ft	20,000
	Other Flat Glass		
	Tempered glass for architectural construction purposes	sq ft	72,600

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
GLASS PRODUCTS (Continued)			
Flat Glass (Continued)	Other flat glass (such as plate glass blanks, bent or enameled sheet, plate float and rolled glass, multiple glazed and sealed insulation units	sq ft	34,600
	Plate + Float Glass		
	Plate + Float Glass less than 1/8" thick	sq ft	37,500
	Plate + Float Glass betweel 1/8"-1/4" thick	sq ft	48,000
	Plate + Float Glass over 1/4" thick + rolled wire glass	sq ft	54,700
	Laminated Glass		
	Laminated glass 1/4" and under Laminated glass 1/4" and over	sq ft	212,500
	Laminated sheet (window) glass Other laminated glass	sq ft	113,500
STONE & CLAY PRODUCTS			
Cement, Hydraulic	Portland cement	1 bbl @ 376 lbs	1,582,000
	Prepared or mixed Hydraulic & Masonry cements other than special Portlands	1 bbl @ 280 lbs	1,587,000

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
STONE & CLAY PRODUCTS (Continued)			
Cement, Hydraulic (Continued)	Brick & Structural Clay Tile	-	-
	Brick, except Ceramic Glazed + Refractory		
	Bldg or Common Brick & Face (2-1/4"x1-5/8"x7-5/8")	1 brk	14,300
	Other Brick (Paving, Floor & Sewer) (2-1/4"x3-5/8"x7-5/8")	1 brk	25,600
	Glazed Brick + Structural Hollow Tile		
	Structural Clay Tile except facing including load bearing & non-load bearing tile	1 tile	27,700
	Facing tile (structural) & Ceramic glazed brick (2-1/4"x3-5/8"x7-5/8")	1 brk	33,400
	Unglazed & salt glazed facing tile (8"x5"x11")	1 tile	68,200
	Ceramic Wall & Floor Tile	-	-
	Quarry tile & Promenade Tile	sq ft	51,000
	Ceramic Mosaic Tile & Accessories - Unglazed	sq ft	63,600

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
STONE & CLAY PRODUCTS (Continued)			
Concrete Blocks	Structural Block - Heavy weight aggregate 8"x8"x16"	1 blk	31,800
	Structural Block - Decorative		
	Brick (2-1/4"x3-5/8"x7-5/8")	1 brk	5,000
	Ready Mix Concrete	cu yd	2,594,000
	Lime	-	-
	Quicklime	1 T	6,867,000
	Hydrated Lime	1 T	9,464,000
	Dead Burned Dolomite	1 T	9,748,000
	Gypsum Products		-
	Calcined gypsum bldg materials, bldg plasters & prefab bldg materials	1 T	6,970,000
	Other calcined gypsum	1 T	4,362,000

PRODUCT EXAMPLE - GYP BOARD

Size	lb/sq ft	Total Btu/sq ft
3/8"	1.52	5,300
1/2"	2.00	7,000

Material Classification	Description	Unit	Embodied Energy Per Material Unit
Mineral Wool	Mineral Wool for Structural Insulation		
	Loose Fiber (Blowing + Pouring + Granulated Fiber)	sm T	12,826,000

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
STONE & CLAY PRODUCTS (Continued)			
Mineral Wool (Continued)	4.5 inches or more thick (bldg batts, blankets + rolls)	sq ft	8,000
	2.0 to 4.4 inches thick	sq ft	6,900
	Less than 2.0 inches thick	sq ft	4,800
PRIMARY IRON & STEEL			
Steel Products	Coke Oven + Blast Furnace Products		
	Pig Iron	lb	7,400
	Steel Products	-	-
	Tin Mill Products		
	Carbon Steel Sheets: Hot Rolled + Enameled	lb	16,800
	Steel Products	-	-
	Tin Mill Products		
	Carbon Steel Sheets: Galvanized	lb	27,800

PRODUCT EXAMPLE - GALV SHEETS

Thickness	lb/sq ft	Total Btu/sq ft
22 GA	1.79 lb	49,800
20 GA	2.14 lb	59,500
18 GA	2.83 lb	78,800
16 GA	3.54 lb	98,500

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
PRIMARY IRON & STEEL (Continued)			
Steel Products (Continued)	Hot Rolled Bars + Shapes Carbon Steel: Structural Shapes Sheet Pilings Bearing Piles	lb	18,700

PRODUCT EXAMPLE -

Size	lb/LF	Total Btu/LF
W12 x 65	65 lb	1,218,000
W16 x 36	36 lb	656,000
C x 2 x 30	30 lb	562,000
L x 8 x 4 x 1	37.4 lb	701,000
WT6 x 27	29 lb	543,000

Description	Unit	Embodied Energy Per Material Unit
Steel Products	-	
Hot Rolled Bars + Shapes Carbon Steel Conc Reinf Bars Rolled from New Billet Rolled from Old Material	lb	15,700

PRODUCT EXAMPLE - REINF BARS

Bar Size	lb/LF	Total Btu/LF
#2	.167 lb	2,600
#3	.376 lb	5,900
#4	.668 lb	10,500
#5	1.043 lb	16,400
#6	1.502 lb	23,700
#7	2.044 lb	32,000
#8	2.670 lb	41,800

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
PRIMARY IRON & STEEL (Continued)			
Steel Products (Continued)	Steel Products	-	-
	Hot Rolled Bars and Shapes		
	Alloy Steel: Plates + Structural Shapes	lb	26,900

PRODUCT EXAMPLE - STEEL SHAPES

Size	lb/LF	Total Btu/LF
W12 x 65	65 lb	1,749,000
W16 x 36	36 lb	969,000
C x 2 x 30	30 lb	807,000
L x 8 x 4 x 1	37.4 lb	1,006,000
WT6 x 27	29 lb	780,000

Material Classification	Description	Unit	Embodied Energy Per Material Unit
	Noninsulated Ferrous Wire		
	Wire Strand for Pre-stressed Concrete	lb	44,600
	Steel Products	-	-
	Steel Nails + Spikes		
	Carbon Steel Wire Products: Nails + Staples	lb	34,000

PRODUCT EXAMPLE - COMMON NAILS

Size	lb/Nail	Total Btu/Nail
2 penny	.0012 lb	40
3 penny	.0018 lb	60
4 penny	.0033 lb	110
5 penny	.0039 lb	130
10 penny	.015 lb	510

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
PRIMARY IRON & STEEL (Continued)			
Steel Products (Continued)	Steel Products	-	-
	Steel Wire		
	Plain Wire	lb	31,200
	Galvanized Wire	lb	34,400

PRODUCT EXAMPLE - 7 WIRE STRAND

Dia	lb/LF	Total Btu/LF
1/4"	.122 lb	5,400
1/2"	.198 lb	8,800
3/8"	.274 lb	12,200
7/16"	.373 lb	16,600

Material Classification	Description	Unit	Embodied Energy Per Material Unit
	Other fabricated wire products		
	Conc Reinforcing Mesh (Welded Wire)	lb	24,200

PRODUCT EXAMPLE - WIRE MESH

Size	lb/SF	Total Btu/SF
2 x 4 14/14	.16 lb	3,900
2 x 12 8/8	1.05 lb	25,400
2 x 16 8/12	.46 lb	11,100
2 x 16 6/10	.65 lb	15,700

Material Classification	Description	Unit	Embodied Energy Per Material Unit
	Steel Products	-	-
	Steel Pipes and Tubes		
	Carbon Steel Finished Shapes + Forms: Standard Pipe	lb	25,800

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
PRIMARY IRON & STEEL (Continued)			
Steel Products (Continued)	PRODUCT EXAMPLE - STANDARD PIPE		

Nom Dia		Total Btu/LF
1/2"	.85 lb	21,900
3/4"	1.13 lb	29,200
1"	1.68 lb	43,300
2"	3.65 lb	94,200
6"	18.97 lb	489,700

Material Classification	Description	Unit	Embodied Energy Per Material Unit
	Stainless Steel - Finished Shapes + Forms		
	Sheets - Cold Rolled	lb	138,000
	Sheets - Hot Rolled	lb	81,000
	Strip - Hot + Cold Rolled	lb	121,000
	Plates	lb	159,000
	Bars - Hot Rolled	lb	157,000
	Bars - Cold Finished	lb	193,000
	Wire	lb	240,000
PRIMARY NONFERROUS			
Aluminum Rolling	Aluminum Plate + Sheet		
	Plate: Non-Heat Treatable	lb	116,000

PRODUCT EXAMPLE - ALUM PLATE

Thickness	lb/SF	Total Btu/SF
1/4"	3.64 lb	421,000
1/2"	7.27 lb	840,000
3/4"	10.91 lb	1,261,000
1"	14.54 lb	1,680,000

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
PRIMARY NONFERROUS (Continued)			
Aluminum Rolling (Continued)	Aluminum Plate + Sheet		
	Sheet: Non-Heat Treatable	lb	96,000

PRODUCT EXAMPLE - ALUM SHEET

Thickness	lb/SF	Total Btu/SF
1/8"	1.82 lb	175,000
3/16"	2.73 lb	262,000

Material Classification	Description	Unit	Embodied Energy Per Material Unit
	Aluminum Rolling	-	-
	Rolled Aluminum Rod, Bar + Structural Shape		
	Rolled Bar + Rod Continuous Cast Rolled Structural Shape	lb	92,000

PRODUCT EXAMPLE - STANDARD SHAPES

Size	lb/LF	Total Btu/LF
818.81	8.81 lb	812,000
716.05	6.05 lb	557,500
615.10	5.10 lb	470,000

Material Classification	Description	Unit	Embodied Energy Per Material Unit
FABRICATED METAL PRODUCTS			
Fabricated Structural Steel	Fabricated Structural Metal for Buildings		
	Industrial Commercial, Residential + Institutional Public Utilities	lb	22,700

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
FABRICATED METAL PRODUCTS (Continued)			
Fabricated Structural Steel (Continued)	PRODUCT EXAMPLE - STEEL SHAPES		

Size	lb/LF	Total Btu/LF
W12 x 65	65 lb	1,475,000
W16 x 36	36 lb	817,000
C x 2 x 30	30 lb	681,000
L x 8 x 4 x 1	37.4 lb	849,000

Material Classification	Description	Unit	Embodied Energy Per Material Unit
SCREW MACHINE PRODUCTS			
Screw Machine Products	Nuts, Bolts and Other Standard Fasteners		
	Standard Hex Standard Round Lag Screws + Bolts Studs + Threaded Rods	lb	26,600

PRODUCT EXAMPLE - BOLTS

Size	lb/Bolt	Total Btu/Bolt
1" x 1/4"	.02 lb	500
2" x 1/2"	.18 lb	4,800
3" x 1/2"	.23 lb	6,200
4" x 1/2"	.29 lb	7,700
5" x 3/8"	.18 lb	4,800

EXHIBIT 11
(Continued)

Material Classification	Description	Unit	Embodied Energy Per Material Unit
SCREW MACHINE PRODUCTS (Continued)			
Screw Machine Products (Continued)	Nuts, Bolts + Other Standard Fasteners		
	Rivets 1/2" and over	lb	17,300

PRODUCT EXAMPLE - RIVETS

Size	lb/Rivet	Total Btu/Rivet
1-1/4" x 1/2"	.11	1,900
1-1/2" x 1/2"	.12	2,100
2" x 1/2"	.15	2,600
3" x 3/4"	.70	12,100
4" x 1"	1.16	20,100

3.2 INVENTORY MODEL DEMOLITION ENERGY FOR EXISTING BUILDINGS

INFORMATION REQUIRED

Materials quantity inventory

PROCEDURE

$$\text{Demolition Energy} = 50^{*}\ \text{Btu/lb of materials} \times 1.4^{**} \sum_{i=1}^{n} \left[\text{Quantity of Material} \times \text{Weight per material unit, Exhibit 6} \right]$$

*NOTE: Range is 35-65 Btu/lb of materials

** The inventoried materials account for about 50 percent of the total embodied energy of building construction. The inventoried materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of inventoried materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 Energy Use for Building Construction, December 1976

3.3 INVENTORY MODEL EMBODIED ENERGY INVESTMENT IN RENOVATED BUILDINGS

INFORMATION REQUIRED

- Building type
- Gross s.f.
- Materials of renovation quantity inventory
- f_3, fraction of energy intensity of new building construction for total building which would be expended in renovation activities

PROCEDURE

Embodied energy investment = [Energy used in renovation construction + Energy invested in renovation materials]

Energy used in renovation construction = [Gross floor area of historic building x Invested construction energy per square foot specific to the building type, Exhibit 5 x f_3]

Energy invested in materials $= 1.4^{*} \sum_{i}^{n}$ [Quantity of renovation materials x Invested energy per material unit, Exhibit 11]

i=1 - Rough lumber, softwood boards
2 - Dressed lumber, softwood boards
.
.
.
n - Nuts, bolts, and other standard fasteners

---

* The inventoried materials account for about 50 percent of the total embodied energy of building construction. The inventoried materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of inventoried materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 Energy Use for Building Construction, December 1976

3.4 INVENTORY MODEL ANNUAL OPERATIONAL* ENERGY IN RENOVATED BUILDINGS

INFORMATION REQUIRED

- Enclosed volume
- Exposed roof, wall, glazing areas and orientations
- Exposed surface area transmission values, U
- Exposed surface area absorbtivity/transmission, f
- Ventilation rates
- Internal heat gains due to people, equipment, lights
- Cooling system type
- Heating system type

PROCEDURE

$$\text{Annual operational energy} = \left[\text{Energy required to offset heating loads} + \text{Energy required to offset cooling loads}\right]$$

$$\text{Energy Required to offset heating loads} = \left[\text{Annual heating load}\right] \div \left[\text{Heating system efficiency Exhibit 8} \times \text{Fuel source energy efficiency, Exhibit 9}\right]$$

$$\text{Energy Required to offset cooling loads} = \left[\text{Annual cooling load}\right] \div \left[\text{Cooling system efficiency Exhibit 8} \times \text{Fuel source energy efficiency, Exhibit 9}\right]$$

* Formulas and procedures used in calculating operational energy in this study are simplified methods. The inventory model is a simplification of energy consumption simulation computer techniques. This method is intended only to produce approximations of energy consumption in buildings as it varies throughout the year. More detailed, rigorous or accurate methods may be substituted in this analysis at the user's option.

$$\text{Annual heating load} = \sum \text{Heat loss for all data points}$$

$$\text{Annual cooling load} = \sum \text{Heat gain for all data points}$$

$$\text{Heat gain/loss} = \sum \left[\text{Transmission gain/loss} + \text{Ventilation gain/loss} + \text{Solar gain} + \text{Internal gain}\right]$$

$$\text{Transmission gain/loss} = \sum \left[\text{Transmittance} \times \text{Area} \times \text{Temperature differential, Exhibit 12}\right]$$

$$\text{Ventilation gain/loss} = \left[\text{Ventilation rate} \times \text{Temperature differential, Exhibit 12}\right]$$

$$\text{Internal heat gain} = \sum \left[\text{Heat loads of equipment, people, lights}\right]$$

$$\text{Solar heat gain} = \sum \left[\text{Absorptivity, Exhibit 14} \times \text{Area} \times \text{Incident insolation, Exhibit 13}\right]$$

EXHIBIT 12
Diurnal Temperatures (°F)[1]

City	21 March						21 June						21 September						21 December					
	AM			PM			AM			PM			AM			PM			AM			PM		
	2	6	10	2	6	10	2	6	10	2	6	10	2	6	10	2	6	10	2	6	10	2	6	10
Indianapolis, Indiana	53	45	53	61	70	61	74	67	74	81	89	81	52	44	51	58	65	58	17	11	17	23	30	23
Seattle, Washington	43	42	47	55	53	45	59	59	67	74	72	65	48	48	55	59	54	49	38	37	40	44	42	38

1 Local Climatological Data, National Oceanic and Atmospheric Administration Environmental Data Service, National Climatic Center, Asheville, N.C.

EXHIBIT 13
Insolation Btu/sf[1]

City	Orientation	21 March						21 June						21 September						21 December					
		AM			PM			AM			PM			AM			PM			AM			PM		
		2	6	10	2	6	10	2	6	10	2	6	10	2	6	10	2	6	10	2	6	10	2	6	10
Indianapolis	S	0	7	99	99	7	0	0	12	97	97	12	0	0	0	144	144	0	0	0	0	98	98	0	0
	SW	0	7	49	130	32	0	0	12	54	141	53	0	0	0	57	167	0	0	0	0	45	108	0	0
	W	0	7	49	113	49	0	0	12	54	135	94	0	0	0	35	113	0	0	0	0	24	69	0	0
	NW	0	7	49	59	41	0	0	12	54	81	86	0	0	0	35	35	0	0	0	0	24	24	0	0
	N	0	14	49	49	14	0	0	36	54	54	36	0	0	0	35	35	0	0	0	0	24	24	0	0
	NE	0	41	59	44	7	0	0	86	81	54	12	0	0	0	35	35	0	0	0	0	24	24	0	0
	E	0	49	113	49	7	0	0	94	135	54	12	0	0	0	113	35	0	0	0	0	69	24	0	0
	SE	0	32	130	49	7	0	0	55	141	54	12	0	0	0	167	57	0	0	0	0	108	45	0	0
	H	0	16	167	167	16	0	0	37	212	212	37	0	0	0	129	129	0	0	0	0	73	73	0	0
Seattle	S	0	8	109	109	8	0	0	15	103	103	15	0	0	0	93	93	0	0	0	0	50	50	0	0
	SW	0	8	45	136	39	0	0	15	50	135	56	0	0	0	42	105	0	0	0	0	26	53	0	0
	W	0	8	45	109	59	0	0	15	50	118	93	0	0	0	25	70	0	0	0	0	16	35	0	0
	NW	0	8	45	45	44	0	0	15	50	61	84	0	0	0	25	25	0	0	0	0	16	16	0	0
	N	0	16	45	45	16	0	0	34	50	50	34	0	0	0	25	25	0	0	0	0	16	16	0	0
	NE	0	49	45	45	8	0	0	84	61	50	15	0	0	0	25	25	0	0	0	0	16	16	0	0
	E	0	59	109	45	8	0	0	93	118	50	15	0	0	0	70	25	0	0	0	0	35	16	0	0
	SE	0	39	136	45	8	0	0	56	135	50	15	0	0	0	105	42	0	0	0	0	53	26	0	0
	H	0	20	155	155	20	0	0	42	181	181	42	0	0	0	75	75	0	0	0	0	37	37	0	0

1 Hourly Solar Radiation Rates for Vertical and Horizontal Surfaces on Average Days in the United States and Canada, NBS Building Science Series No. 96, T. Kusuda and K. Islini

EXHIBIT 14
Solar Radiation Absorptivity/Transmission Factors

Exposed Surface Characteristics	Percent of Incident Insolation Which Is Absorbed and Transmitted Through the Building Envelope
Clear single glazing	0.90
Clear double glazing	0.82
Dark color wall	0.20
Light color wall	0.05
Dark color roof	0.05
Light color roof	0.02

INFORMATION REQUIRED

- Building type
- Gross s.f.
- Materials quantity inventory

PROCEDURE

$$\text{Embodied energy investment} = \left[\text{Energy used in construction} + \text{Energy invested in materials}\right]$$

$$\text{Energy used in construction} = \left[\text{Gross floor area of new building} \times \text{Invested construction energy per square foot specific to the building type, Exhibit 5}\right]$$

$$\text{Energy invested in materials} = 1.4^{*} \sum_{i}^{n} \left[\text{Quantity of materials} \times \text{Invested energy per material unit, Exhibit 11}\right]$$

i=1 - Rough lumber, softwood boards
2 - Dressed lumber, softwood boards
.
.
.
n - Nuts, bolts, and other standard fasteners

* The inventoried materials account for about 50 percent of the total embodied energy of building construction. The inventoried materials do not include "miscellaneous plastics; paving; non-ferrous wire; mechanical, plumbing and electrical equipment and fixtures; sheet metal work; metal doors and plate work; miscellaneous and architectural metalwork,"[1] and many other items which do not, individually, contribute significantly to the total embodied energy. To account for these materials, which together comprise about 20 percent of the total embodied energy of building construction, the embodied energy of inventoried materials is increased so that, altogether, materials account for 70 percent of the total embodied energy of building construction.

1 Energy Use for Building Construction, December 1976

3.6 INVENTORY MODEL ANNUAL OPERATIONAL* ENERGY IN NEW BUILDINGS

INFORMATION REQUIRED

- Enclosed volume
- Exposed roof, wall, glazing areas, and orientations
- Exposed surface area transmittance values, U
- Exposed surface area absorbtivity/transmission, f
- Ventilation rates
- Internal heat gains due to people, equipment, lights
- Heating system type
- Cooling system type

PROCEDURE

Annual operational energy = [Energy required to offset heating loads + Energy required to offset cooling loads]

Energy required to offset heating loads = [Annual heating load] ÷ [Heating system efficiency Exhibit 8 x Fuel source energy efficiency, Exhibit 9]

Energy required to offset cooling loads = [Annual cooling load] ÷ [Cooling system efficiency Exhibit 8 x Fuel source energy efficiency, Exhibit 9]

---

* Formulas and procedures used in calculating operational energy in this study are simplified methods. The inventory model is a simplification of energy consumption simulation computer techniques. This method is intended only to produce approximations of energy consumption in buildings as it varies throughout the year. More detailed, rigorous or accurate methods may be substituted in this analysis at the user's option.

$$\text{Annual heating load} = \sum \text{Heat loss for all data points}$$

$$\text{Annual cooling load} = \sum \text{Heat gain for all data points}$$

$$\text{Heat gain/loss} = \sum \left[\text{Transmission gain/loss} + \text{Ventilation gain/loss} + \text{Solar gain} + \text{Internal gain} \right]$$

$$\text{Transmission gain/loss} = \sum \left[\text{Transmittance} \times \text{Area} \times \text{Temperature differential, Exhibit 12} \right]$$

$$\text{Ventilation gain/loss} = 1.08 \left[\text{Ventilation rate} \times \text{Temperature differential, Exhibit 12} \right]$$

$$\text{Internal heat gain} = \sum \left[\text{Heat loads of equipment, people, lights} \right]$$

$$\text{Solar heat gain} = \sum \left[\text{Absorptivity, Exhibit 14} \times \text{area} \times \text{Incident insolation, Exhibit 13} \right]$$

EXHIBIT 15

Inventory Model Annual Operational Energy Computer Program Coding

```
C ACHP INVENTORY MODEL OF OPERATIONAL ENERGY
C DEVELOPED AT BOOZ, ALLEN & HAMILTON  APRIL,1978
C
C DIMENSION STATEMENTS
      DIMENSION TEMPOT(6,4),TEMPIN(6,4),VENT(6,4),HTGAIN(6,4)
      DIMENSION PEOPLE(6,4),WSQFT(6,4)
      DIMENSION BLDG(10),SPACE(10)
      DIMENSION AREA(9),UVAL(9),ABSTRN(9)
      DIMENSION EFF(2),SEFF(2)
      DIMENSION SOLAR(9,6,4)
C
      REAL LOAD
      INTEGER OR
C SET READ/WRITE DEVICE NUMBERS
      KRD=7
      KWRT=6
C
C READ BUILDING DATA
      READ(KRD,2001)(BLDG(I),I=1,10)
      READ(KRD,2002)N
C INITIALIZE BUILDING TOTALS
      BH=0
      BC=0
      BEQ=0
      BEN=0
      BSF=0
C READ IN WEATHER DATA
      READ(KRD,2004)((TEMPOT(IHR,IS),IS=1,4),IHR=1,6)
      READ(KRD,2004)(((SOLAR(OR,IHR,IS),IS=1,4),OR=1,9),IHR=1,6)
C HEADING
      WRITE(KWRT,1000)
C START SPACE DO LOOP
      DO 9000 NC=1,N
C INITIALIZE FOR EACH SPACE
      HTLOAD=0
      CLOAD=0
      EQUIP=0
C
C READ IN DATA FOR EACH SPACE
C  IF END OF FILE IS REACHED, PRINT BUILDING SUMMARY REPORT AND STOP
      READ(KRD,2001,END=9001)(SPACE(I),I=1,10)
      READ(KRD,2006)SIZE,XND
      READ(KRD,2004)((TEMPIN(IHR,IS),IS=1,4),IHR=1,6)
      READ(KRD,2004)((VENT(IHR,IS),IS=1,4),IHR=1,6)
      READ(KRD,2004)((PEOPLE(IHR,IS),IS=1,4),IHR=1,6)
      READ(KRD,2004)((HTGAIN(IHR,IS),IS=1,4),IHR=1,6)
      READ(KRD,2004)((WSQFT(IHR,IS),IS=1,4),IHR=1,6)
      READ(KRD,2005)((AREA(OR),UVAL(OR),ABSTRN(OR)),OR=1,9)
      READ(KRD,2006)EFF(1),EFF(2)
      READ(KRD,2005)SEFF(1),SEFF(2),ELEFF
C
C START HOUR DO LOOP
      DO 8000 IS=1,4
      DO 7000 IHR=1,6
C
C INITIALIZE FOR EACH HOUR
      COND=0
      SOLGN=0
      VENTEN=0
C
C CALCULATE DELTA T
      DELTAT=TEMPOT(IHR,IS)-TEMPIN(IHR,IS)
C
C START ORIENTATION DO LOOP
      DO 6000 OR=1,9
C CALCULATE CONDUCTION & SOLAR LOAD FOR EACH ORIENTATION
      COND=COND+DELTAT*AREA(OR)*UVAL(OR)
      SOLGN=SOLGN+ABSTRN(OR)*AREA(OR)*SOLAR(OR,IHR,IS)
C END OF ORIENTATION DO LOOP
 6000 CONTINUE
C
C CALCULATE LOAD COMPONENTS
      VENTEN=1080*VENT(IHR,IS)*DELTAT
      HTGAIN(IHR,IS)=(HTGAIN(IHR,IS)+SIZE*WSQFT(IHR,IS)/1000)*3413
C
C CALCULATE CUMULATIVE EQUIPMENT LOAD
      EQUIP=EQUIP+HTGAIN(IHR,IS)
C
C CALCULATE TOTAL HEATING/COOLING LOAD AND ACCUMULATE
      LOAD=VENTEN+COND+SOLGN+HTGAIN(IHR,IS)+250*PEOPLE(IHR,IS)
      IF(LOAD)6100,7000,6200
 6100 HTLOAD=HTLOAD-LOAD
      GO TO 7000
 6200 CLOAD=CLOAD+LOAD+250*PEOPLE(IHR,IS)
 7000 CONTINUE
 8000 CONTINUE
C CALCULATE ENERGY USED BY SPACE
      HEATEN=XND*.000001*HTLOAD/(EFF(1)*SEFF(1))
      COOLEN=XND*.000001*CLOAD/(EFF(2)*SEFF(2))
      EQUIP=XND*.000001*EQUIP/ELEFF
       SEN=HEATEN+COOLEN+EQUIP
       SENSF=(SEN/SIZE)*1000000.
C
```

```
C ACCUMULATE BUILDING ENERGY USE TOTALS
        BH=BH+HEATEN
        BC=BC+COOLEN
        BEQ=BEQ+EQUIP
        BSF=BSF+SIZE
        BEN=BEN+SEN
C
C OUTPUT FEPUPTS
C
C
C SPACE OUTPUT REPORT
        WRITE(KWRT,1001)(SPACE(I),I=1,10)
        WRITE(KWRT,1002)HEATEN,COOLEN,EQUIP,SEN
        WRITE(KWRT,1004)SENSF
C
C END SPACE DO LOOP
 9000   CONTINUE
C
C CALCULATE BUILDING SQ FT ENEPGY USE
C
        BENSF=(BEN/BSF)*1000000.
C BUILDING OUTPUT REPORT
 9001   WRITE(KWRT,1003)(BLDG(I),I=1,10)
        WRITE(KWRT,1002)BH,BC,BEQ,BEN
        WRITE(KWRT,1005)BENSF
C
C WRITE FORMAT STATEMENTS
 1000   FORMAT(' THIS IS THE ACHP INVENTORY MODEL OF OPERATIONAL',
       1' ENERGY',/,' DEVELOPED AT BOOZ, ALLEN & HAMILTON')
 1001   FORMAT(///,1X,10A4)
 1002   FORMAT(41X,'TOTAL',/,'      HEATING',5X,'COOLING',5X,
       1'EQUIPMENT  OPERATIONAL',/,'      ENERGY',6X,'ENERGY',6X,
       2' ENERGY',5X,'ENERGY',/,'      (MMBTU)',5X,'(MMBTU)',6X,
       3'(MMBTU)',4X,'(MMBTU)',/,48('-'),/,4F12.0)
 1003   FORMAT(/////,48('*'),/,' BUILDING TOTAL',/,1X,10A4)
 1004   FORMAT(' ANNUAL ENEFGY USE IN THIS SPACE IS ',F8.0,
       1' BTU PEP SQUARE FOUT PER YEAR.')
 1005   FORMAT(' ANNUAL ENERGY USE IN THE BUILDING IS ',F8.0,
       1' BTU PER SQUARE FOOT PER YEAR.')
C
C READ FORMAT STATEMENTS
 2001   FORMAT(10A4)
 2002   FORMAT(I3)
 2004   FORMAT(6F10.2)
 2005   FORMAT(3F10.2)
 2006   FORMAT(2F10.2)
C
C
        STOP
        END
END OF FILE
```

EXHIBIT 16
Input Sequence for ACHP Inventory Model
of Operational Energy

Card	Description of Input	Units	Format
I-1	Building name		Up to 40 characters
I-2	Number of zones in the building	(Integer)	I3
I-3 a	Outside temperature at 6 hours, winter	°F	6F10.2
b	" " spring	°F	6F10.2
c	" " summer	°F	6F10.2
d	" " fall	°F	6F10.2
I-4 a (1-9)	Insolation at 6 hours, H, N, NE, E, SE, S, SW, W, NW (9 cards) winter	BTU/ft²	6F10.2
b (1-9)	" " spring	"	"
c (1-9)	" " summer	"	"
d (1-9)	" " fall	"	"
REPEAT THE REMAINING SEQUENCE ONCE FOR EACH ZONE IN THE BUILDING			
II-1	Zone name		Up to 40 characters
II-2	Floor area of zone, # days of operation per year, Window code: 0 = Fixed, 1 = Operable	s.f., days/year, code	3F10.2
II-3 a	Interior temperature at 6 hours, winter	°F	6F10.2
b	" " spring	°F	"
c	" " summer	°F	"
d	" " fall	°F	"
II-4 a	Ventilation air at 6 hours, winter	Thousand CFM	6F10.2
b	" " spring	"	"
c	" " summer	"	"
d	" " fall	"	"

EXHIBIT 16 (Continued)

Card	Description of Input	Units	Format
II-5 a	Number of people at 6 hours, winter	# people	6F10.2
b	" " spring	"	"
c	" " summer	"	"
d	" " fall	"	"
II-6 a	Equipment operation at 6 hours, winter	KW	6F10.2
b	" " spring	"	"
c	" " summer	"	"
d	" " fall	"	"
II-7 a	Lighting load at 6 hours, winter	W/sq.ft.	6F10.2
b	" " spring	"	"
c	" " summer	"	"
d	" " fall	"	"
II-8 a	Area, U-value, and absorption/transmission coefficient (f) Horiz.	ft^2, U, %	3F10.2
b	" " N	"	"
c	" " NE	"	"
d	" " E	"	"
e	" " SE	"	"
f	" " S	"	"
g	" " SW	"	"
h	" " W	"	"
i	" " NW	"	"
II-9	Efficiency of heating equipment, efficiency of cooling equipment	%, COP	2F10.2
II-10	Source efficiency of (heating fuel, cooling fuel, electricity)	%	3F10.2

III. appendices

LOCKEFIELD GARDEN APARTMENTS

appendix A

APPENDIX A
CASE STUDY: LOCKEFIELD GARDEN APARTMENTS, INDIANAPOLIS, INDIANA

Lockefield Garden Apartments is an abandoned, low-income housing project in Indianapolis, Indiana. Built by the PWA in 1935, the complex represents one of the first government sponsored housing developments built in the United States. Demolition of the Lockefield Garden Apartments is currently being proposed.

This case study analysis of the Lockefield Garden Apartments and potential rehabilitation demonstrates Inventory Model techniques for estimating embodied energy of materials in the existing structures, embodied energy of potential rehabilitation materials and construction, and the amount of energy required for demolition of the structures.

THE EMBODIED ENERGY OF MATERIALS IN THE EXISTING LOCKEFIELD GARDEN APARTMENTS IS MORE THAN ONE- AND ONE-HALF TIMES THE ENERGY INVESTMENT WHICH WOULD BE REQUIRED TO BUILD A NEW COMPLEX

- Embodied Energy of Materials in the Existing Buildings Was Determined by Using an Inventory of Materials From the Original Architectural Plans

Materials were inventoried from the plans for a typical building in the complex. Exhibit A-1 lists the quantity of materials inventoried for building 10. Because these materials represent about two-thirds of all materials used in construction, the subtotal of embodied energy was increased to account for the remaining materials.

70% Embodied Energy of Inventoried Materials, Building #10 = 25800 MMBtu

100% Embodied Energy of All Materials, Building #10 = 36800 MMBtu

Building #10 was considered typical of construction throughout the complex. The embodied energy of materials per square foot of typical construction was calculated and then multiplied by the total complex construction area to estimate the embodied energy of materials for all buildings.

$$\text{Embodied Energy of materials/s.f. (typical)} = \frac{36800 \text{ MMBtu}}{33400 \text{ s.f.}} = 1.10 \text{ MMBtu}$$

Embodied Energy of materials for the complex =
516980 s.f. (complex area) x 1.10 MMBtu/s.f. (typical) = 568700 MMBtu

EXHIBIT A-1
Materials Inventory for Building #10

Material	Energy/Unit	Unit Quantity	Energy (MMBtu)
Hardwood flooring	14,283 Btu/b.f.	12,523 b.f.	179
Doors	872,881 Btu/ea.	380 count	332
Paint	508,475 Btu/gal.	256 gal.	130
Roofing	7,753 Btu/s.f.	10,239 s.f.	79
Window glass	13,659 Btu/s.f.	4,250 s.f.	58
Masonry Cement	1,586,787 Btu/bbl.	1,670 bbl.	2,650
Face brick	14,283 Btu/ea.	438,984 count	6,270
Structural tile	33,416 Btu/ea.	219,492 count	7,334
Ceramic tile	68,660 Btu/s.f.	9,980 s.f.	685
Concrete block	31,821 Btu/ea.	2,688 count	86
Ready mixed concrete	2,594,338 Btu/c.y.	2,082 c.y.	5,188
Plaster, 1/2"	6,970 Btu/s.f.	235,264 s.f.	1,640
Batt insulation	6,860 Btu/s.f.	8,350 s.f.	57
Rebars	16,338 Btu/c.f.	10,282 l.f.	168
Wire mesh	3,870 Btu/s.f.	800 s.f.	3
Steel pipe	164,106 Btu/l.f.	4,710	773
		TOTAL	36,650 MMBtu

• <u>The Existing Building Represents More Than One- and One-Half Times The Energy Investment Required to Build a New Complex Today</u>

Concept model calculation techniques were used to estimate the Embodied Energy of Materials and Construction required for a comparable new complex. Quantities of embodied energy per square foot of new construction were obtained from Exhibit 1.

Embodied Energy of New Materials and New Construction =
516980 s.f. x 0.68 MMBtu/s.f. (New) = 351,500 MMBtu

Comparing this estimate with the embodied energy of materials for the existing buildings calculated above shows that the embodied energy of the complex is more than double the energy investment required for a new building providing the same services.

568700 MMBtu (Existing/351500 MMBtu (New) = 1.61

REHABILITATION OF LOCKEFIELD GARDEN APARTMENTS POTENTIALLY REQUIRES ONLY A FRACTION OF THE ENERGY NEEDED TO CONSTRUCT A COMPARABLE NEW COMPLEX

Rehabilitation of Lockefield Garden Apartments could range anywhere from minimal renovation to extensive alteration of the existing structures. At a minimum, the following activities would be required:

- Refinish all interior surfaces (paint, plaster, flooring, etc.)
- Reglaze all windows
- Replace all mechanical, electrical and plumbing systems.

- **Embodied Energy of Rehabilitation Materials Was Estimated by Using Survey Model Techniques**

Rehabilitation materials quantities were approximated for a typical building and the results used to estimate the embodied energy of rehabilitation materials for the entire complex. Exhibit A-2 lists the survey of rehabilitation materials for Building #10. All systems and miscellaneous materials would account for about one-fifth the embodied energy of materials for a comparable new facility. Therefore, the total embodied energy of rehabilitation materials includes 20 percent of the embodied energy of materials required for a new building.

Embodied Energy of Inventoried Rehabilitation Materials, Bldg. #10	= 2,000 MMBtu
20% Embodied Energy of New Construction materials	= 4,542 MMBtu
Total Embodied Energy of Rehabilitation Materials	= 6,542 MMBtu

Dividing by the gross area of Building #10 yields an estimate of the embodied energy of rehabilitation materials per square foot of typical construction and, in turn, an estimate of the total materials energy investment required for all the buildings.

Embodied Energy of Rehab. Materials per Typical Square Foot
6542 MMBtu/33400 s.f. (Building #10) = 0.20 MMBtu/s.f.

Total Embodied Energy of Rehab Materials for Complex
= 516980 s.f. x 0.20 Btu/s.f.
= 103400 MMBtu

Construction Energy for the Rehabilitation of Lockefield Garden Apartments Will Only be One-Quarter the Amount Required to Build a New Complex

Rehabilitation of Lockefield Garden Apartments would require substantially less construction effort than constructing a comparable new facility. For analysis purposes, it is assumed that about one-fourth the amount of construction activity will be required and, for estimating purposes, the relative requirements for energy use is directly proportional. Quantities of energy per square foot required for new construction were obtained from Exhibit 5.

Rehab. Construction Energy = ¼ [516980 s.f. x 0.15 MMBtu/s.f. (New)]

= 19400 MMBtu

EXHIBIT A-2
Survey of Rehabilitation Materials
for Building #10

Item	Quantity	MMBtu
Hardwood Floors	12523 b.f.	179
Interior Oil Paint	256 gal	130
Window Glass	4250 s.f.	58
Plaster	235264 s.f.	1640

Surveyed materials subtotal: 2007 MMBtu

- <u>Rehabilitation of Lockefield Gardens Will Require About One-Third as Much Initial Energy Investment as Building a Comparable New Complex</u>

  Embodied Energy of Rehabilitation Materials and Construction represents less than 35 percent of the Embodied Energy of New Materials and New Construction.

$$\frac{122600 \text{ MMBtu (Rehabilitation)}}{351500 \text{ MMBtu (New)}} = 0.35$$

DEMOLITION OF LOCKEFIELD GARDEN APARTMENTS WILL REQUIRE ONE-EIGHTH AS MUCH ENERGY AS REHABILITATING THE COMPLEX

- The Amount of Energy for Demolition Is Estimated in Proportion to the Weight of the Materials to be Hauled From the Site

The weight of construction materials in Building 10 was estimated from the materials takeoff used for determining embodied energy. From this result, the weight of materials for the entire complex was calculated. Exhibit A-3 lists the inventoried materials and weights for Building 10.

Material weight, Building #10 = 7700 tons = 0.23 tons/s.f. (Typical)

100% material weight, Complex = 516980 s.f. x 0.23 tons/s.f. (Typical)
= 118000 Tons

EXHIBIT A-3
Material Weight Inventory for Building #10

Material	Material Weight (tons)
Hardwood flooring	25
Doors	19
Paint	2
Roofing	16
Window glass	6
Masonry cement	491
Face brick	1,369
Structural tile	1,369
Ceramic tile	45
Concrete block	54
Ready mixed concrete	4,047
Plaster, 1/2"	205
Batt insulation	1
Rebars	5
Wire mesh	1
Steel pipe	2

Demolition of Lockefield Garden Apartments Will Potentially Consume One-Eighth as Much Energy as Rehabilitating the Complex

Demolition Energy can range from 0.07 MMBtu/ton to 0.13 MMBtu/ton to load and haul away building materials. It does not include landfill or regrading the site.

Lockefield Garden Apartments Demolition Energy =
118000 tons x 0.13 MMBtu/ton (Materials) = 15300 MMBtu

Demolition Energy is about one eighth the Embodied Energy of Rehabilitation for the Lockefield Garden Apartments.

15300 MMBtu (Demolition)/122600 MMBtu (Rehab.) = 0.12

ANNUAL OPERATIONAL ENERGY FOR THE REHABILITATED LOCKEFIELD GARDEN APARTMENTS WOULD BE GREATER THAN ANNUAL OPERATIONAL ENERGY FOR AN EQUIVALENT NEW COMPLEX

- Annual Operational Energy for a Typical Building in the Complex Was Calculated Using the Inventory Model Method

  Exhibit A-4 displays the calculation results for Building #10 which was considered typical of complex facilities.

  Building 10 Annual Operational Energy = 2132 MMBTU
  = 0.0638 MMBtu/s.f. (Typical)

- The Annual Operation Energy for the Entire Complex Was Obtained by Multiplying the Typical Consumption Per Square Foot by the Total Building Area

  Complex Annual Operational Energy = 516980 s.f. (Area) x 0.0638 MMBtu/s.f. (Typical)
  = 33000 MMBtu

EXHIBIT A-4
Annual Operational Energy,
Building 10

THIS IS THE ACHP INVENTORY MODEL OF OPERATIONAL ENERGY

BUILDING 10 TYPICAL

HEATING ENERGY (MMBTU)	COOLING ENERGY (MMBTU)	EQUIPMENT ENERGY (MMBTU)	TOTAL OPERATIONAL ENERGY (MMBTU)
1945.	187.	0.	2132.

ANNUAL ENERGY USE IN THIS SPACE IS 63818. BTU PER SQUARE FOOT PER YEAR.

◆◆

BUILDING TOTAL
LOCKFIELD GARDEN APTS. - BUILDING 10

HEATING ENERGY (MMBTU)	COOLING ENERGY (MMBTU)	EQUIPMENT ENERGY (MMBTU)	TOTAL OPERATIONAL ENERGY (MMBTU)
1945.	187.	0.	2132.

ANNUAL ENERGY USE IN THE BUILDING IS 63818. BTU PER SQUARE FOOT PER YEAR.

- Lockefield Garden Apartments Will Annually Use Approximately One-Sixth More Energy Than Average Comparable New Facilities in the Same Climatic Region

Annual operational energy for a comparable new complex was estimated using the Concept Model method. Values for the amount of operational energy per square foot of new consturction were obtained from Exhibit 3.

New Construction Annual Operational Energy

= 516980 s.f. (Area) x 0.055 MMBtu/s.f. (Multifamily, Low Rise)
= 28400 MMBtu

Comparing the annual operational energy for the rehabilitated Lockefield Garden Apartments to the annual heating and cooling consumption of an average new complex shows that the existing structures will consume approximately 16 more percent energy each year.

33000 MMBtu (Lockefield Garden Apts.)/28400 MMBtu (New) = 1.16

THE REHABILITATED LOCKEFIELD GARDEN APARTMENTS COMPLEX WILL HAVE A NET ENERGY INVESTMENT ADVANTAGE OVER AN EQUIVALENT NEW COMPLEX FOR MORE THAN 50 YEARS

- The Lockefield Garden Apartments annual operational energy deficit is small when compared to the energy savings in rehabilitation. The total energy invested in the rehabilitated complex will be less than the energy invested in equivalent new facilities until the net accumulated operational energy deficit is equal to the energy savings in rehabilitation materials and construction. From the previous analysis:

Embodied Energy Savings	= 351500 MMBtu	(New)
	122600 MMBtu	(Rehab.)
	= 228900 MMBTU	
Annual Operational Energy Deficit =	33000 MMBTU	(Rehab.)
	-28900 MMBtu	(New)
	4600 MMBtu	

- Therefore, it will take 50 years before the total energy investment in the rehabilitation and a new complex are equivalent.

$$\frac{\text{Rehab. Embodied Energy Savings}}{\text{Rehab. Operational Energy Deficit}} = \frac{230000 \text{ MMBtu}}{4600 \text{ MMBtu/Yr.}} = 50 \text{ Years}$$

GRAND CENTRAL ARCADE

appendix B

APPENDIX B
CASE STUDY: GRAND CENTRAL ARCADE, SEATTLE, WASHINGTON

The Grand Central Arcade is an adaptive reuse of a hotel in the Pioneer Square Historic District in Seattle. The 80,000 s.f. rehabilitated building includes both office and commercial uses.

In this case study, the Arcade renovation is analyzed to demonstrate the use of the Inventory Model methods for calculating Embodied Energy of Materials and Construction and Annual Operating Energy.

EMBODIED ENERGY OF REHABILITATION MATERIALS AND CONSTRUCTION FOR THE GRAND CENTRAL ARCADE IS ONLY A FRACTION OF THE ENERGY EMBODIED IN AN EQUIVALENT NEW STRUCTURE

- Embodied Energy of Rehabilitation Materials

The Inventory Model for calculating embodied energy requires a thorough inventory of rehabilitation materials. Exhibit B-1 tabulates the inventory of materials obtained from the architectural plans for the Grand Central Arcade. The materials inventoried are only those for which embodied energy characteristics are available. Because these materials represent about 70 percent of the total energy invested in materials, the subtotal of embodied energy obtained from the inventory is increased.

Inventoried Materials, 70% of Rehabilitation Materials, Embodied Energy	= 3300 MMBtu
100% of Rehabilitation Materials Embodied Energy	= 4700 MMBtu

EXHIBIT B-1
Rehabilitation Materials Inventory for
the Grand Central Arcade

Material	Energy/Unit	Quantity	Energy (MMBtu)
Wood studs	7,611/b.f.	14,300 b.f.	108.8
Wood doors	346,502/ea.	90 count	31.2
Plywood	5,779/s.f.	59,584 s.f.	344.3
Sheet glass	15,430/s.f.	9,090 s.f.	140.3
Float glass	54,672/s.f.	81 s.f.	4.4
Ceramic tile	68,660/s.f.	200 s.f.	13.7
Concrete block	31,821/ea.	615 count	19.6
Brick	4,985/ea.	2,663 count	13.3
Concrete	2,594,338/c.y.	43 c.y.	111.6
5/8" gypsum board	5,297/s.f.	72,482 s.f.	383.9
6" batt insulation	8,345/s.f.	16,662 s.f.	139.0
Nails	34,016/lb.	1,376 lb.	46.8
Rebars	15,664/lb.	1,923 lb.	30.1
Angle iron	26,910/lb.	15,334 lb.	412.6
Steel strip	120,825/lb.	7,818 lb.	944.6
Steel beam	22,707/lb.	17,792 lb.	404.0
Steel bolts	26,625/lb.	120 lb.	3.2
Interior ap. paint	437,025/gal.	340 gal.	148.6
			3,300 MMBtu

Embodied Energy of Rehabilitation Construction

The Inventory model requires an estimate of Rehabilitation construction energy based upon the construction energy for comparable new construction. Professional judgment must be used in determining whether and to what extent rehabilitation construction will require more or less energy than new construction. According to the architect and owner, the Grand Central Arcade required considerably less construction activity than a comparable new building. Almost all energy consuming materials activities associated with construction of the building shell were eliminated, as well as much of the major interior work. Therefore, it was conservatively estimated that one-half the amount of construction energy for an equivalent new building was consumed by the rehabilitation.

The Grand Central Arcade incorporates both office space and commercial space, each type requiring a different amount of construction energy. The total construction energy for the rehabilitation is made up of proportional contributions for each type of space. Quantities of construction energy per square foot of new construction were obtained from Exhibit 5.

Rehabilitation construction energy = .5[32000 s.f. x 0.22 MMBtu/s.f. (Commercial)
+48000 s.f. x 0.36 MMBtu/s.f. (Office)]
=12200 MMBtu

Embodied Energy of Rehabilitation Materials and Construction

The embodied energy of Rehabilitation materials, added to the energy of rehabilitation construction energy, yields the total embodied energy of Rehabilitation Materials and Construction.

Embodied Energy of Rehabilitation Materials and Construction =

4700 MMBtu (Materials)

12200 MMBtu (Construction)

16900 MMBtu

The Grand Central Arcade Required Less Than One-Fifth as Much Energy for Materials and Construction as a Comparable New Facility

The embodied energy of materials and construction for a comparable new building was obtained by using the concept model method of calculation because more detailed plans were not available. Quantities for embodied energy per square foot of new construction were obtained from Exhibit 5.

Embodied Energy of New Materials and New Construction

= 32000 s.f. x 0.94 MMBtu/s.f. (Commercial)

+ 48000 s.f. x 1.64 MMBtu/s.f. (Office)

=108800 MMBtu

Comparing embodied energy of materials and construction for the rehabilitation and a comparable new facility shows that the rehabilitation requires considerably less initial energy investment.

16900 MMBtu (Rehabilitated)/108800 MMBtu (New) = 0.16

ANNUAL OPERATIONAL ENERGY FOR THE GRAND CENTRAL ARCADE IS SLIGHTLY GREATER THAN OPERATIONAL ENERGY FOR AN EQUIVALENT NEW BUILDING

- Inventory Model Calculation of Annual Operational Energy

  Annual operational energy for the Grand Central Arcade was estimated by assuming that the commercial spaces and office spaces had different schedule and use requirements. Exhibit B-2 displays the computer print-out for the building and each zone.

Grand Central Arcade Annual Operational Energy =

3325 MMBtu (Commercial Spaces)

+2389 MMBtu (Office Spaces)

=6215 MMBtu (Total)

EXHIBIT B-2
Annual Operational Energy for
the Grand Central Arcade

THIS IS THE ACHP INVENTORY MODEL OF OPERATIONAL ENERGY
DEVELOPED AT BOOZ, ALLEN & HAMILTON

OFFICE SPACE

HEATING ENERGY (MMBTU)	COOLING ENERGY (MMBTU)	EQUIPMENT ENERGY (MMBTU)	TOTAL OPERATIONAL ENERGY (MMBTU)
38.	1194.	1658.	2890.

ANNUAL ENERGY USE IN THIS SPACE IS 60213. BTU PER SQUARE FOOT PER YEAR.

RETAIL SPACE

HEATING ENERGY (MMBTU)	COOLING ENERGY (MMBTU)	EQUIPMENT ENERGY (MMBTU)	TOTAL OPERATIONAL ENERGY (MMBTU)
9.	1084.	2232.	3325.

ANNUAL ENERGY USE IN THIS SPACE IS 103906. BTU PER SQUARE FOOT PER YEAR.

****

BUILDING TOTAL
GRAND CENTRAL HOTEL, SEATTLE, WASHINGTON

HEATING ENERGY (MMBTU)	COOLING ENERGY (MMBTU)	EQUIPMENT ENERGY (MMBTU)	TOTAL OPERATIONAL ENERGY (MMBTU)
48.	2278.	3890.	6215.

ANNUAL ENERGY USE IN THE BUILDING IS 77690. BTU PER SQUARE FOOT PER YEAR.

- The Grand Central Arcade Will Annually Use Approximately 6 Percent More Energy Than an Average Comparable New Facility in the Same Climatic Region

Annual operational energy consumption for a comparable new building was estimated using the Concept model method. Values for the amount of operational energy per square foot of new construction were obtained from Exhibit 4.

New Construction Annual Operational Energy

= [32000 s.f. x 0.086 MMBtu/s.f. (Commercial Space)

+48000 s.f. x 0.065 MMBtu/s.f. (Office Space)]

= 2752 MMBtu + 3120 MMBtu

= 5872 MMBtu

Comparing the annual operational energy for the Grand Central Arcade to the annual consumption of an average comparable new facility shows that the rehabilitated structure will consume approximately six percent more energy each year. It should be pointed out, however, that the Grand Central Arcade was completed prior to the 1973 oil embargo.

6215 MMBtu (Grand Central Arcade)/5872 MMBtu (New) = 1.06

THE GRAND CENTRAL ARCADE WILL HAVE A NET ENERGY INVESTMENT ADVANTAGE OVER AN EQUIVALENT NEW STRUCTURE FOR THE NEXT TWO CENTURIES

The Grand Central Arcade annual operational energy deficit is very small. The total energy invested in the Grand Central Arcade will be less than the energy invested in a new equivalent facility until the net accumulated operational energy deficit is equal to the energy savings in rehabilitation materials and construction. From the previous analyses:

Embodied Energy Savings = 108800 MMBtu (New)

− 16900 MMBtu (Rehabilitated)

91900 MMBtu

Annual Operational Energy Deficit = 6215 MMBtu (Rehabilitated)

5872 MMBtu (New)

343 MMBtu

Therefore, it will take approximately 250 years before the energy investment in the two schemes are equivalent.

$$\frac{\text{Rehab. Embodied Energy Savings}}{\text{Rehab. Operational Energy Deficit}} = \frac{91900 \text{ MMBtu}}{343 \text{ MMBtu/year}} = 268 \text{ years}$$

AUSTIN HOUSE

appendix C

APPENDIX C
CASE STUDY: "AUSTIN HOUSE", WASHINGTON, DC

"Austin House" is a 3-unit apartment adaptive reuse of a carriage house in the Capitol Hill Historic District of Washington, DC. The extensive rehabilitation of the carriage house left only the original exterior shell intact.

This case study analyzes the rehabilitation of the Austin House to demonstrate the Survey Model methods for determining embodied energy of materials and construction for the adaptive reuse of the structure, the energy investment represented by the building shell, and the annual energy consumption for heating and cooling.

THE "AUSTIN HOUSE" REHABILITATION REQUIRED LESS THAN HALF OF THE ENERGY EMBODIED IN MATERIALS AND CONSTRUCTION FOR AN EQUIVALENT NEW STRUCTURE

Embodied Energy of Rehabilitation Materials and Construction Was Calculated Using Survey Model Techniques

A survey of building materials was taken from architectural plans and notes of an inspection of the building. Materials were grouped into five categories and quantities estimated for each. Exhibit C-1 lists the categories and quantities of surveyed materials. Because the surveyed material categories represented only about two-thirds of the total energy of construction materials, the subtotal from the survey was increased to account for the remaining materials.

70% of Rehabilitation Materials	= 260 MMBtu
100% of Embodied Energy of Rehabilitated Materials	= 371 MMBtu

EXHIBIT C-1
Survey of Embodied Energy of Materials
and Construction

EMBODIED ENERGY OF REHABILITATION MATERIALS

Wood	3078 b.f.	x	9,000 Btu/b.f.	=	28 MMBtu
Brick	304 c.f.	x	400,000 Btu/c.f.	=	121 MMBtu
Concrete (Plaster)	720 c.f.	x	96,000 Btu/c.f.	=	69 MMBtu
Window	388 s.f.	x	15,000 Btu/s.f.	=	6 MMBtu
Insulation	4472 s.f.	x	8,000 Btu/s.f.	=	36 MMBtu
	SURVEYED MATERIALS SUBTOTAL			=	260 MMBtu

The Extensive Rehabilitation of "Austin House" Required at Least as Much Construction Energy as Building a New Structure

Both the owner and the contractor asserted that the rehabilitation effort required as much or more construction activity than building a new facility. In the analysis, it was assumed that construction energy for the rehabilitation equalled what would be required for a comparable new structure. Quantities of construction energy per square foot of new construction were obtained from Exhibit 5

Rehabilitation construction energy = 2700 s.f. x 0.10 MMBtu/s.f. (New)
= 270 MMBtu

- Embodied Energy of Rehabilitation Materials and Construction for "Austin House" Is Only 40 Percent of the Initial Energy Investment Which Would Be Required for a Comparable New Building

The embodied energy of materials and construction for a comparable new building was estimated using Concept Model methods. Quantities of energy per square foot of new construction were obtained from Exhibit 4.

Embodied Energy of New Materials and New Construction

= 2700 s.f. x 0.63 MMBtu/s.f. (New)
= 1701 MMBtu

The embodied energy of rehabilitation materials and construction is less than half the initial energy investment for a comparable new building.

$$\frac{\text{371 MMBtu (Rehab. Materials) + 270 MMBtu (Rehab. Construction)}}{\text{1701 MMBtu (New Materials and Construction)}} = 0.38$$

THE EXISTING EXTERIOR SHELL OF THE "AUSTIN HOUSE" REPRESENTS OVER HALF THE ENERGY INVESTMENT REQUIRED TO BUILD A NEW 3 UNIT APARTMENT BUILDING

- Analysis of the "Austin House" rehabilitation suggests that the exterior shell accounts for more than half the total energy investment in buildings of this size and use because everything else (interiors, etc.) amounts to only 45 percent. To verify this, survey model techniques were used to estimate the embodied energy of materials in the existing shell.

```
Existing Shell Embodied Energy = 1817 c.f. (brick skin) x 0.40 MMBtu/c.f.
                               + 6108 b.f. (roof structure & sheathing) x 0.01 MMBtu/b.f.
                               +  128 c.f. (clay tile) x 0.40 MMBtu/c.f.
                               + 1773 c.f. (concrete) x 0.10 MMBtu/c.f.
                                 1016 MMBtu
```

- Comparing the existing shell embodied energy to the total energy investment required for a comparable new building shows that the brick skin does account for over half the needed energy.

1016 MMBtu (brick skin)/1701 MMBtu (new building) = 0.60

THE REHABILITATED "AUSTIN HOUSE" WILL ANNUALLY CONSUME LESS ENERGY FOR HEATING AND COOLING THAN THE AVERAGE NEW 3-UNIT APARTMENT IN THE WASHINGTON, DC CLIMATIC REGION

- The rehabilitation of the carriage house included particular attention to energy conservation measures. Extra wall and roof insulation and double glazed windows were included, as well as construction details to reduce infiltration.

- Heating and cooling energy consumption was 10 percent less in the rehabilitated "Austin House" than in an average comparable new three-family residence.

Exhibit C-2 displays the computed annual operational energy. The proportion of energy used to operate lights and equipment has been subtracted from the total to determine the energy required for heating and cooling.

Comparing heating and cooling energy for the rehabilitation to annual consumption for an average new facility shows that "Austin House" will consume approximately 5 percent less energy each year.

4300 Btu/s.f. (Austin House)/4500 Btu/s.f. (new building) = 0.95

EXHIBIT C-2
Annual Operational Energy
for the Austin House

```
->XQT GROO.MODEL
 THIS IS THE ACHP INVENTORY MODEL OF OPERATIONAL ENERGY
 DEVELOPED AT BOOZ, ALLEN & HAMILTON


 AUSTIN HOUSE
                                                     TOTAL
     HEATING       COOLING       EQUIPMENT   OPERATIONAL
     ENERGY        ENERGY         ENERGY       ENERGY
     (MMBTU)       (MMBTU)        (MMBTU)      (MMBTU)
 -----------------------------------------------------
         72.          114.          203.          389.
 ANNUAL ENERGY USE IN THIS SPACE IS   38964. BTU PER SQUARE FOOT PER YEAR.
```

ENERGY USE FOR HEATING AND COOLING IS 43000 BTU PER SQUARE FOOT PER YEAR.

```
 *****************************************************
 BUILDING TOTAL
 AUSTIN HOUSE    WASHINGTON, D.C.
                                                     TOTAL
     HEATING       COOLING       EQUIPMENT   OPERATIONAL
     ENERGY        ENERGY         ENERGY       ENERGY
     (MMBTU)       (MMBTU)        (MMBTU)      (MMBTU)
 -----------------------------------------------------
         72.          114.          203.          389.
 ANNUAL ENERGY USE IN THE BUILDING IS   38964. BTU PER SQUARE FOOT PER YEAR.
NORMAL EXIT.  EXECUTION TIME:           351 MILLISECONDS.
->@FIN
```

OVER ITS EXPECTED LIFE, AUSTIN HOUSE WILL CONSERVE ENOUGH ENERGY TO HEAT AND COOL AN EQUIVALENT NEW APARTMENT BUILDING FOR OVER 10 YEARS

- Energy savings continue to grow over the expected life of the rehabilitated Austin House.

Rehabilitation Embodied Energy Savings = 1701 MMBtu (New building)
− 641 MMBtu (Rehabilitation)
= 1060 MMBtu

30-Year Expected Life Operational Energy Savings = 5.4 MMBtu/yr
x 30 yrs
= 162 MMBtu

1060 MMBtu
162 MMBtu
Total energy savings = 1222 MMBtu

- Total energy savings over the life of Austin House will be enough energy to heat and cool an equivalent new apartment building for over 10 years.

Total Rehabilitation Energy = 1222 MMBtu

Annual heating and cooling requirement for equivalent new apartment = 2700 s.f. x 45000 Btu/s.f. = 122 MMBtu/yr.
1222 MMBtu/122/MMBtu/yr. = 10 yr.

* U.S.G.P.O. 625-050/1302-1233

ACKNOWLEDGEMENTS

This study was prepared for the Advisory Council on Historic Preservation by Booz, Allen & Hamilton, Inc. John D. McDermott--Director of Special Studies--directed the study for the Council's Preservation Economics Policy Group, chaired by Calvin W. Carter. For Booz, Allen & Hamilton, William I. Whiddon, Associate, was primarily responsible for conducting the research work, together with Paul Narayanan and Michael Eckhart, under the overall direction of John M. Kurtz, Principal Investigator.

In addition, completion of the study would not have been possible without the cooperation and assistance of:

- Ralph D. Anderson, Ralph D. Anderson & Partners, Seattle, Washington
- Mrs. Granville S. Austin, Alexandria, Virginia
- Fred N. Thomas, Jr., Executive Director, Housing Authority of the City of Indianapolis.