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Life-Cycle Cost Analysis of Residential Heat Pumps and Alternative HVAC Systems

V. C. Mei E. A. Nephew

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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ENERGY DIVISION

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V.C. Mei and E. A. Nephew

Prepared for the
U.S. ARMY FACILITIES ENGINEERING SUPPORT AGENCY
Fort Belvoir, Virginia 22060
under
U.S. ARMY CONSERVATION EQUIPMENT EVALUATION AND TESTING PROGRAM
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CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES, Continued

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EXECUTIVE SUMMARY

This report presents a methodology for calculating the annual energy consumption and life-cycle costs of alternative heating, ventilating, and air-conditioning (HVAC) systems for residential buildings. Knowledge of these quantities enables selection of the most economical heating and cooling systems for residences at any given U.S. Army facility and provides a quantitative basis for implementing energy conservation policies that may have been adopted. Residential heating and cooling systems specifically considered in the report are (1) an air-to-air heat pump, (2) an electric furnace with a central air conditioner, and (3) a gas furnace with a central air conditioner. Oil-fired heating systems are not considered. It is assumed that, for strategic reasons, oil will be the fuel of choice only if gas or electricity is unavailable.

The annual energy consumption of the above three heating and cooling systems was computed for three sizes of single family residences, 1400, 1800 and 2200 ft^2, each having four different levels of insulation, for 117 different climatic locations across the United States. These calculations were performed by the Oak Ridge National Laboratory Annual Performance Factor computer program, which generates house loads using U.S. Army *Engineering Weather Data* (TM 5-785, Departments of the Air Force, the Army, and the Navy, Washington, D.C., July 1, 1978) temperature bins, sizes the HVAC equipment, and simulates operation of the HVAC system to determine its annual energy consumption.

The Department of Energy's projected energy costs for each of ten regions were used, together with initial costs for HVAC equipment obtained from a catalog of a company with nationwide distribution outlets, to estimate the life-cycle costs of each HVAC system over a 15-year period. The equipment maintenance and installation costs were estimated realistically and are included in the overall life-cycle costs. It was found that the gas furnace with a central air conditioner generally exhibits life-cycle cost advantages over the air-to-air heat pump in most regions. The cost advantage is not decisive, however, and could be reversed by future changes in fuel prices.

The results of the parametric calculations are plotted on a map of the United States for use in an easy-to-follow procedure for calculating the life-cycle costs of the three HVAC systems properly sized for houses of arbitrary sizes and insulation levels and at arbitrary locations. This calculational procedure is described fully in the report, and nine illustrative examples are provided to help the reader quickly understand its application.

ABSTRACT

A simple methodology is presented for calculating the life-cycle cost of a residential heat pump, an electric furnace with a central air conditioner, and a gas furnace with a central air conditioner. The procedure described in this report involves application of the Annual Performance Factor computer model developed by the Oak Ridge National Laboratory. This model was used to calculate the annual energy consumption of each of the three systems for 117 different climatic locations within the United States for residential buildings of varying sizes and insulation levels. Nine example calculations are included in the report to better explain the calculational procedure. These examples show that the life-cycle costs of the residential heat pump are somewhat higher than those of the gas furnace with central air conditioner. However, the cost advantage of the gas-fired system is not decisive and could disappear in locations having low power costs or if relative fuel prices change.

1. PURPOSE

The purpose of this study is to devise a means for evaluating the economic benefit of installing heat pumps in Army facilities by comparing the life-cycle costs of heat pumps with conventional heating and cooling systems. Toward this end, a simple yet accurate method of calculating the life-cycle costs of heat pumps and alternative systems was derived. The methodology can be applied at any specific location in the United States for different house sizes and insulation levels. The application of this methodology does not require any special knowledge or training.

2. SCOPE

In April 1986, the U.S. Army Facilities Engineering Support Agency at Fort Belvoir, Virginia, issued Task Order 0018 requesting that the life-cycle costs of heat pumps be evaluated and compared with those of conventional heating and cooling systems. The tasks outlined in the scope of work include (1) performing a market survey of heat pumps to identify and compare the specifications and characteristics of all heat pump models, and (2) comparing the different types of residential heat pumps.

Because many heat pump manufacturing companies have similar product designs, it is not feasible or productive to identify and compare the specifications and characteristics of all heat pump models. The Air-Conditioning and Refrigeration Institute (ARI) Directory of Certified Air Source Heat Pumps[1] provides comprehensive technical ratings for most air source heat pump models available on the market. Air-to-air heat pumps constitute the vast majority of all residential heat pump applications in the United States. The market share of all other types of residential heat pump systems is relatively small and, for the reasons given below, is likely to remain so.

Heat pumps with hydronic delivery systems are well suited for heating applications but present technical difficulties in cooling applications. Thus they are principally used in European countries in residential heating-only applications where air conditioning is considered unnecessary. Water- and ground-source heat pumps are not widely used in the United States.

Although water source heat pumps have high efficiencies, the costs of drilling wells add significantly to first costs. If a water source is readily available, the water-source heat pump should be seriously considered in applications where a life-cycle analysis shows them to be competitive. Ground-source heat pumps have an initial cost nearly twice that of a comparable air-source heat pump. Furthermore, this disadvantage is unlikely to be overcome because of technical problems associated with cooling mode operation.

Because of these considerations, the principal ORNL effort has been directed toward an evaluation of the life-cycle costs of residential, air-to-air heat pumps and a comparison of these costs with those of more conventional heating and cooling systems. The conventional systems chosen for evaluation are a gas furnace coupled with a central air conditioner and an electric furnace coupled with a central air conditioner. A major objective of the Oak Ridge National Laboratory (ORNL) effort was to develop an accurate method for assessing the life-cycle costs of these three heating, ventilating, and air-conditioning (HVAC) systems in applications involving different house sizes, insulation levels, and climates.

3. LITERATURE SURVEY AND SITE VISITATION

Technical researchers from ORNL contacted the U.S. Army Cold Region Research and Engineering Laboratory in the latter part of November 1986 to exchange heat pump information and data.[2,3] A literature search performed on the Defense Technical Information Center (DTIC) data base for heat pump applications at military facilities identified four reports.[4-7] However, these reports addressed special heat pump applications and were not directly applicable to the objectives of this study.

Personnel from ORNL visited Ft. Bragg, North Carolina, on November 14, 1986, and Ft. Belvoir, Virginia, on November 17, 1986, to survey applications of heat pumps at these U.S. Army facilities. Both facilities employ air-to-air heat pumps exclusively and contract local service companies for maintenance of the units. However, all of the heat pump installations were less than six years old and major maintenance problems had not yet been encountered. It was observed that heat pumps were selected over alternative systems primarily because they could supply heating as well as cooling. At

Ft. Bragg, insulation was extensively upgraded in those houses that were retrofitted with heat pump systems. The major concern of the local service contractor at Ft. Bragg was improper settings of the thermostats, indicating a need to educate the residents about the operation of a heat pump system.

4. INTRODUCTION TO ECONOMIC ANALYSIS

In this study, alternative heating and cooling systems for residences are compared on the basis of their life-cycle costs, defined as the current discounted value of all ownership and operating costs associated with a system over its active lifetime. Each of the three space-conditioning systems is assumed to have a lifetime of 15 years,[8] although major components may, of course, require replacement one or more times during the period. The salvage value of each system at the end of 15 years is assumed to be negligible. The discount rate used to calculate the current value is 7%, as specified in the procedures.[8]

The life-cycle cost for each system is composed of the equipment cost, installation cost, and the current value of the annual maintenance and energy costs.[8-10] The equipment cost is taken from the catalog of a company with nationwide distribution outlets, and the installation and maintenance costs are from Ref. 11 and updated to account for inflation. Estimating the annual cost of purchased energy for each system is a complex undertaking. First, the size and insulation level of the house must be specified. Second, the capacity and efficiency of the HVAC system must be estimated. Third, the annual energy consumption of the system in supplying the house heating and cooling loads in different climatic locations must be calculated. This must be done for a large number of U.S. cities so that the annual consumption of purchased energy at any location in the country can be reasonably estimated. In this study, the Annual Performance Factor (APF) computer program[12] was used to size equipment and calculate loads at 117 different locations around the nation with the input weather data taken from "Engineering Weather Data" by the Air Force, Army, and Navy.[13] The APF program calculates the capacities of the three different HVAC systems as needed to meet the design-day loads of the reference houses for local climatic conditions. The APF program then uses built-in algorithms to simulate the performance of each system and to calculate the monthly consumption of power for supplying the heating and cooling loads.

Section 5 describes the specifications of the reference houses and lists the capacities, efficiencies and costs of the HVAC equipment for the three systems. Section 6 lists the assumed installation and maintenance costs for each system. Section 7 describes how Figs. 1 through 5 and Appendices A through D are used in calculating the annual energy consumption and life-cycle energy costs of each system. Finally, Section 8 gives a systematic procedure for calculating life-cycle costs and provides examples of such analyses.

Appendix A shows the required capacities of the heating and cooling equipment, as calculated by the APF program, as well as the heating and cooling loads for an 1800-ft^2 house insulated to the U.S. Department of Housing and Urban Development (HUD) level required for regions with less than 2500 heating degree days (HDD). For regions with a higher number of HDD, Appendix B provides multipliers, calculated by the APF program, for estimating loads corresponding to different HUD minimum insulation requirements.[14] Appendix C lists the Uniform Present Worth (UPW) factors, which include the Department of Energy's (DOE) projected energy price escalations discounted at an annual rate of 7%. Appendix D presents the DOE projected energy costs for the ten DOE regions; and, finally, Appendix E presents the HVAC equipment life-cycle cost summary for Ft. Bragg and Ft. Belvoir.

5. DESCRIPTION OF HOUSES AND HVAC EQUIPMENT

5.1 REFERENCE RESIDENTIAL HOUSES

The reference houses are typical of dwellings currently being built according to HUD minimum insulation requirements.[14] Three house sizes, 1400, 1800, and 2200 ft^2, are considered in the analysis. Each house has a window area equal to 10% of the floor area. Table 1 lists the HUD minimum insulation requirements.

Table 1. Minimum R-values for ceiling, wall, and floor sections for electric resistance heat (ER) and heat pump or fossil fuel heat (FF)[a]

Insulation level	HDD	Ceiling		Walls		Floor		Windows	
		ER	FF	ER	FF	ER	FF	ER	FF
1	0-2500	20	20	12.5	12.5	----	----	0.885	0.885
2	2500-3500	33.3	25	12.0	12.5	14.3	----	1.45	0.885
3	3500-6000	33.3	33.3	20.0	14.3	20.0	20.0	1.45	1.45
4	6000 up	38.5	38.5	20.0	20.0	20.0	20.0	2.13	2.13

[a]For areas with 5,000 HDD or less, houses using heat pumps may be insulated to levels required for fossil fuels. In areas above 5,000 HDD, houses using air-to-air heat pumps shall be insulated to levels required for ER heating, except where the following are used:

- Water source heat pumps.
- Fossil fuel supplement heat.
- Units with multiple capacity
  - Dual compressors
  - Modulating compressor speed
  - Dual speed compressor.
- Unidirectional heat pumps [such as annual cycle energy systems (ACES)].
- Units with balanced heating and cooling load.

5.2 EFFICIENCY, CAPACITY, AND PRICE OF HVAC EQUIPMENT

5.2.1 Heat Pumps

The heat pumps analyzed are high-efficiency, air-to-air, split systems which have the indoor coil mounted within the fan unit. Table 2 lists the heating and cooling steady state efficiency, capacity, and price of each unit.

5.2.2 Central Air Conditioners

The central air conditioner is composed of an indoor air coil and an outdoor unit. Table 3 lists the efficiency, capacity, and price of each unit.

5.2.3 Electric Furnaces

The electric furnace consists of a multispeed blower unit containing the electrical heating elements and a filter assembly. Table 4 lists the heating capacity and price of each unit.

Table 2. Split-system heat pumps with an indoor coil and housing

Cooling cap. (Btu/h)	Heating cap. (Btu/h)	COPC[a] at 95°F	COPH[b] at 47°F	Electric insert heater (kW)	Price[c] ($)
20,500	19,700	2.72	2.75	10	1,515
24,400	24,200	2.65	2.80	15	1,770
30,200	30,600	2.84	3.00	15	1,970
35,200	35,800	2.64	2.91	20	2,190
41,500	42,000	2.64	2.95	20	2,490
47,000	48,000	2.64	2.89	30	2,770

[a] Cooling coefficient of performance.
[b] Heating coefficient of performance.
[c] 1987 dollars.

Table 3. Central air conditioners

Cooling capacity (Btu/h)	Blower power (hp)	SEER[a]	Price[b] ($)
25,000	1/4	10.35	1,280
31,100	1/3	10.15	1,480
35,600	1/3	10.10	1,580
42,000	1/3	10.00	1,780
47,500	1/2	10.00	1,880

[a] Seasonal energy efficiency ratio.
[b] 1987 dollars.

Table 4. Electric furnaces

Heating capacity (Btu/h)	Price[a] ($)
34,000	380
36,000	400
51,000	430
55,000	450
61,000	480
68,000	530
85,000	580
100,000	580

[a] 1987 dollars.

5.2.4 Gas Furnaces

Table 5 lists the heating capacity, efficiency, and price of each unit. Because of cycling losses, the seasonal efficiency of a gas furnace will be lower than the corresponding steady state value shown in Table 5. An analysis of 11 cities in locations throughout the United States indicates that the seasonal efficiency of a gas furnace supplying an 1800 ft^2 house with level 1 insulation is about 90% of the steady state value shown in the table.[15,16] Therefore, a seasonal efficiency of 71% is used in this report for calculating the annual gas consumption of the furnace. Table 6 shows the seasonal efficiency of a gas furnace in 11 different cities. It is assumed here that for different levels of house insulation, a variety of sizes of gas furnaces are available. Thus, the on-off cycling schedule will be roughly the same for all gas furnace installations.

Table 5. Gas furnaces

Heating capacity (Btu/h)	Efficiency (%)	Price[a] ($)
64,000	80.2	800
85,000	80.6	850
100,000	79.8	900

Table 6. Gas furnace[a] seasonal efficiencies for 11 cities

City	Annual heating load (MBtu)[b]	Blower electricity consumption (kWh)	Seasonal efficiency (%)
Falmouth, Mass.	69,767	382	71.83
Syracuse, N.Y.	81,586	446	72.43
Chicago	82,220	450	72.51
Kansas City	53,975	295	71.97
Atlanta	34,748	190	71.01
Knoxville, Tenn.	39,184	214	70.88
Ft. Wayne, Ind.	25,043	137	70.69
Boise, Idaho	67,362	368	71.80
Phoenix, Ariz.	13,918	76	68.93
Portland, Oreg.	49,181	269	70.40
Los Angeles	12,467	68	66.51

[a] Furnace capacity: 64,000 Btu/h.
[b] MBtu = thousands of Btu's.

6. INSTALLATION AND MAINTENANCE COSTS OF HVAC SYSTEMS

6.1 SYSTEM 1: ELECTRIC FURNACE WITH CENTRAL AIR CONDITIONER

6.1.1 Installation Cost

The estimated cost of installing a split-system air conditioner with an electric furnace is shown in Table 7. This table is taken from Ref. 11, and labor costs are updated. It is assumed that the cost of installing an electric furnace is the same as that of installing a fan unit with an indoor coil and electrical heating elements.

Table 7. Estimated cost of installing a split-system air conditioner and electric furnace

Cooling Capacity		Installation time[a]	Cost[b]
(kW)	(Btu/h)	(man-hour)	($)
2.9 to 6.4	10,000 to 21,700	12	360
6.4 to 9.8	21,700 to 33,500	14	420
9.8 to 16.1	33,500 to 55,000	18	540

[a] Reference 11.
[b] Assumed labor rate is $30 per man-hour (1987 dollars).

6.1.2 Maintenance Cost

System 1 requires routine service, refrigerant system repairs, and replacement (as needed) of electrical components. Routine service for this system consists of filter changes and equipment inspection. The estimated cost is about $15/year, except for every sixth year when this cost is doubled to allow for indoor and outdoor coil brushing. Maintenance of the refrigerant system, including the adjustment of refrigerant, is assumed to cost about $75 every five years. The replacement of electrical components, including contactors, fan motors, and starting capacitors, is assumed to cost $140 in the thirteenth year. Table 8 presents the assumed maintenance and components replacement cost schedule for system 1.

Table 8. Schedule of estimated annual maintenance costs for system 1

Year	Routine service ($)[a]	Refrigerant service ($)	Electric service ($)	Total ($)
1988	15			15
1989	15			15
1990	15			15
1991	15			15
1992	15			15
1993	30	75		105
1994	15			15
1995	15			15
1996	15			15
1997	15			15
1998	15			15
1999	30	75		105
2000	15		140	155
2001	15			15
2002	15			15
Total — current value				295

[a] All costs are in 1987 dollars.

6.2 SYSTEM 2: HIGH-PERFORMANCE AIR-TO-AIR HEAT PUMP

6.2.1 Installation Cost

The installation cost of the air-to-air heat pump is assumed to be the same as that of a split air conditioner. Therefore, it is estimated according to the data in Table 7.

6.2.2 Maintenance Cost

The routine service cost of system 2 is estimated to be about $15/year, or $30/year when indoor coil brushing is needed. Maintenance costs for refrigerant systems and replacement of electrical components are higher than for system 1 (Table 8) because more components are involved. In the ninth year, the compressor is assumed to need replacement at a cost of $710. Table 9 presents the assumed maintenance cost schedule for system

2 and the current value of the costs, based on a 15-year equipment life and a 7% annual discount rate.

Table 9. Schedule of estimated annual maintenance costs for system 2

Year	Routine service ($)[a]	Refrigerant system ($)	Electric system ($)	Replace compressor ($)	Total ($)
1988	15				15
1989	15				15
1990	15				15
1991	15				15
1992	30				30
1993	15	160			175
1994	15				15
1995	15				15
1996	15			710	725
1997	30				30
1998	15				15
1999	30	160			190
2000	15		160		175
2001	15				15
2002	30				30
Total—current value					797

[a] All costs are in 1987 dollars.

6.3 SYSTEM 3: GAS FURNACE WITH CENTRAL AIR CONDITIONER

6.3.1 Installation Cost

Table 7 gives the cost of installing a central air conditioner. The cost of installing a gas furnace, including the gas vent materials and filter assembly, is assumed to be $100.

6.3.2 Maintenance Cost

For system 3, routine service is assumed to cost $15/year for filter change and equipment inspection, except in the sixth and twelfth years when the indoor and outdoor coils require cleaning, thus raising the overall cost to $40. The air conditioner should be inspected and its refrigerant charge adjusted every six years, at a cost of about $75. Replacement of electrical components (as needed) is assumed to cost $140 at the end of the thirteenth year. Table 10 presents the estimated maintenance and components replacement cost schedule for system 3.

Table 10. Schedule of estimated annual maintenance costs for system 3

Year	Routine service ($)[a]	Refrigerant system ($)	Electric system ($)	Total ($)
1988	15			15
1989	15			15
1990	15			15
1991	15			15
1992	15			15
1993	40	75		115
1994	15			15
1995	15			15
1996	15			15
1997	15			15
1998	15			15
1999	40	75		115
2000	15		140	155
2001	15			15
2002	15			15
Total— current value				306

[a] All costs are in 1987 dollars.

7. CALCULATION OF ANNUAL ENERGY CONSUMPTION AND LIFE-CYCLE ENERGY COST

Figure 1 shows the constant annual HDD lines across the United States.[13] The HDD of a specific place can be estimated from the figure. Table 1 (see Sect. 5) shows HUD minimum house insulation requirements for different levels of HDD. However, an existing house might exceed, or might not meet, the HUD minimum insulation requirement. To estimate annual energy consumption of the HVAC equipment, the insulation level of a house must be specified. For areas where the HDD is less than 2,500, insulation level 1 should be used. The results of the APF program show that, in areas where the heating load is light and the cooling load is heavy, increasing the level of insulation causes the cooling load to increase. This occurs because lower internal heat dissipation results in a longer cooling season.[17]

Figures 2 through 5 present the annual energy consumption for the three HVAC systems for an 1800 ft^2 house with level 1 insulation (Table 1). For houses with different sizes and insulation levels, proper multipliers should be chosen from Appendix B.

To estimate the HVAC equipment's life-cycle energy cost, the following procedures should be followed:

1. Find the equipment annual energy consumption from Figs. 2 through 5.
2. From Appendix B, find the proper multiplier if the house to be analyzed is other than 1800 ft^2 in size and level 1 insulation.
3. The annual energy consumption is the product of the value found in step 1 and the multiplier found in step 2.
4. From Appendix D, find the energy cost.
5. From Appendix C, find the UPW factor.
6. The life-cycle energy cost for the HVAC equipment will be equal to the annual energy consumption (step 1) times the energy cost (step 4) times UPW (step 5).

As illustrative sample calculations, three HVAC systems will be analyzed for 15-year life-cycle energy costs for each of three different houses. The specifications and locations of the three houses are as follows:

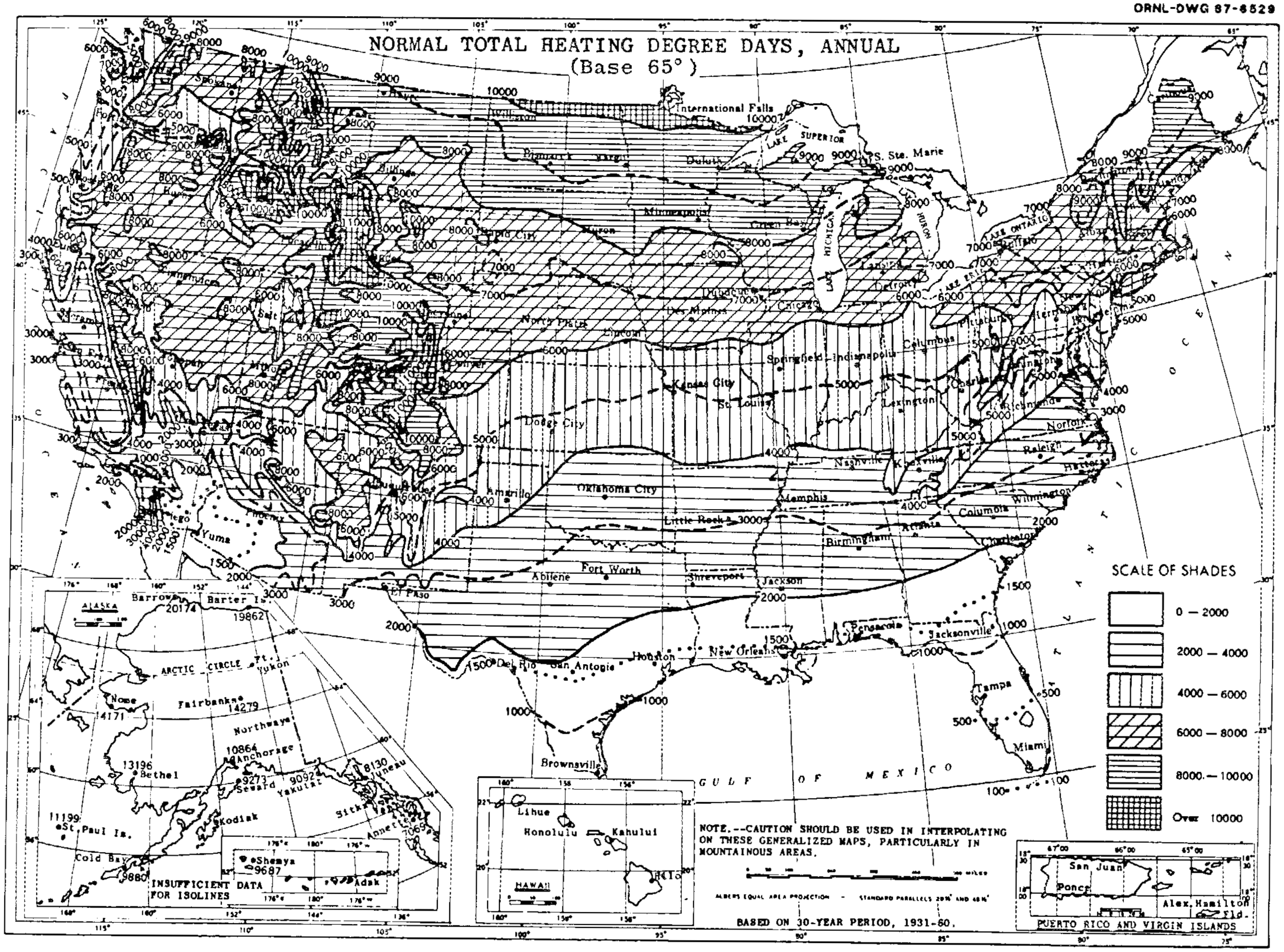

Fig. 1. Annual heating degree days. *Source:* Ref. 13.

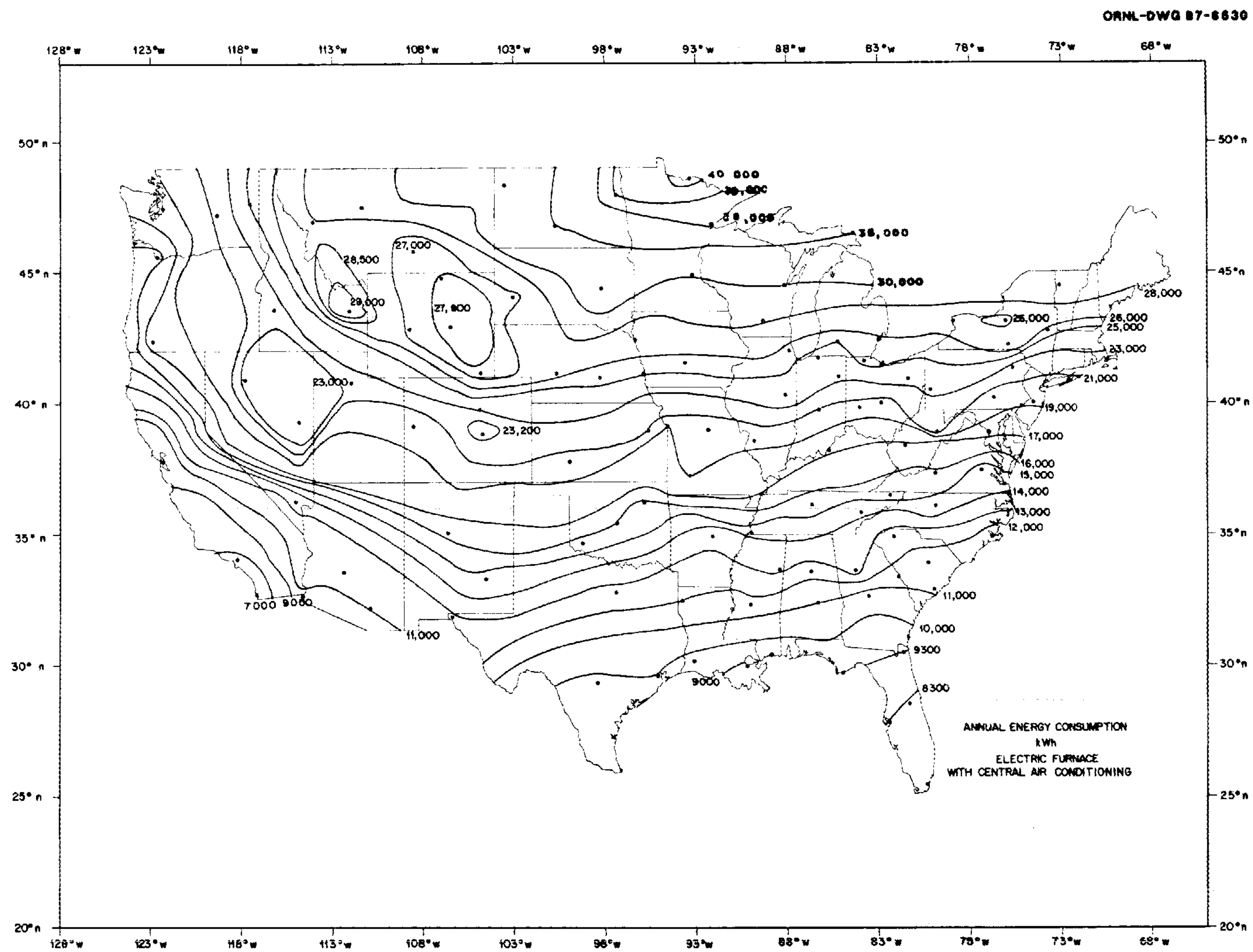

Fig. 2. System 1 annual energy consumption in kilowatt-hours: electric furnace and central air conditioner.

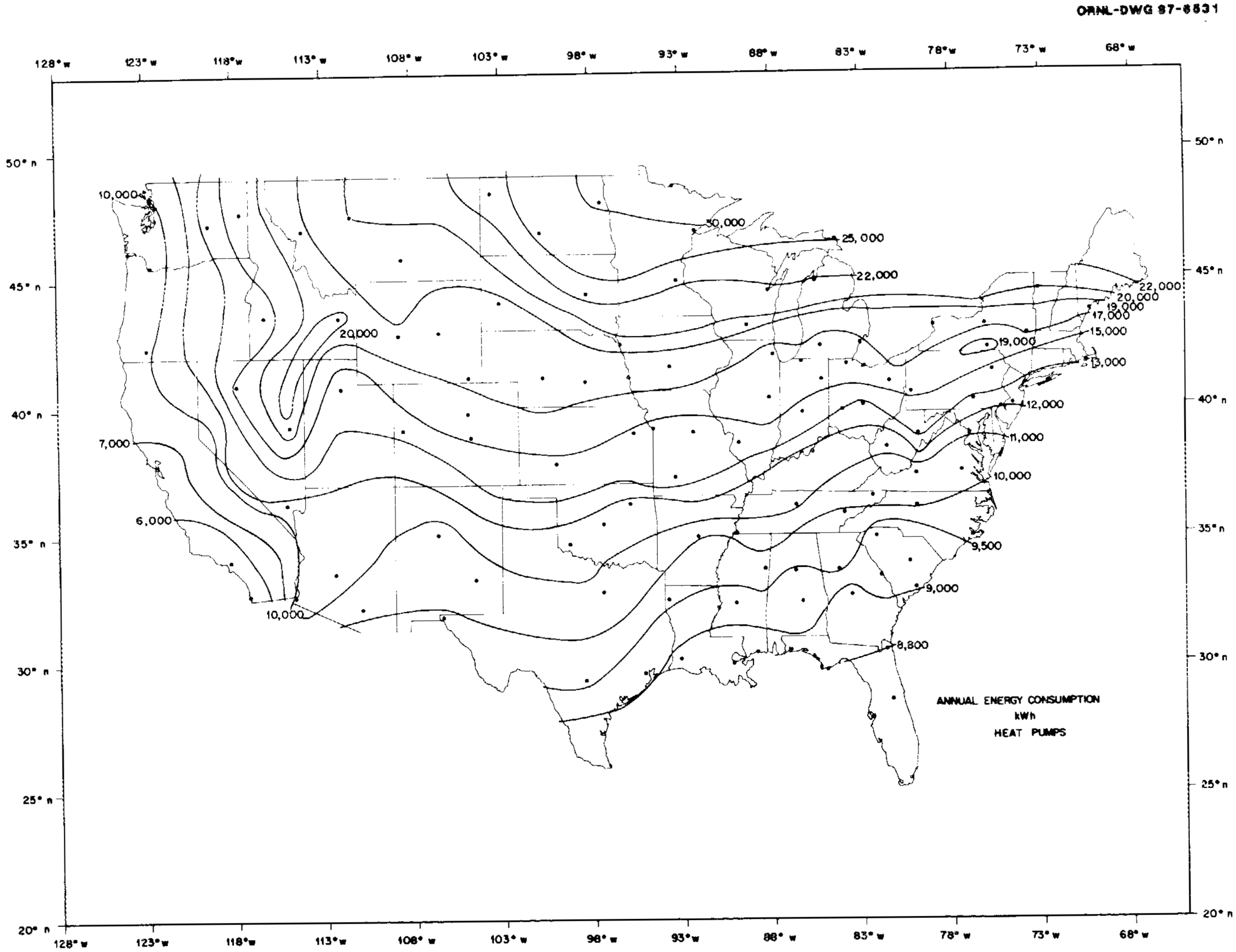

Fig. 3. System 2 annual energy consumption in kilowatt-hours: heat pump.

ORNL-DWG 87-6532

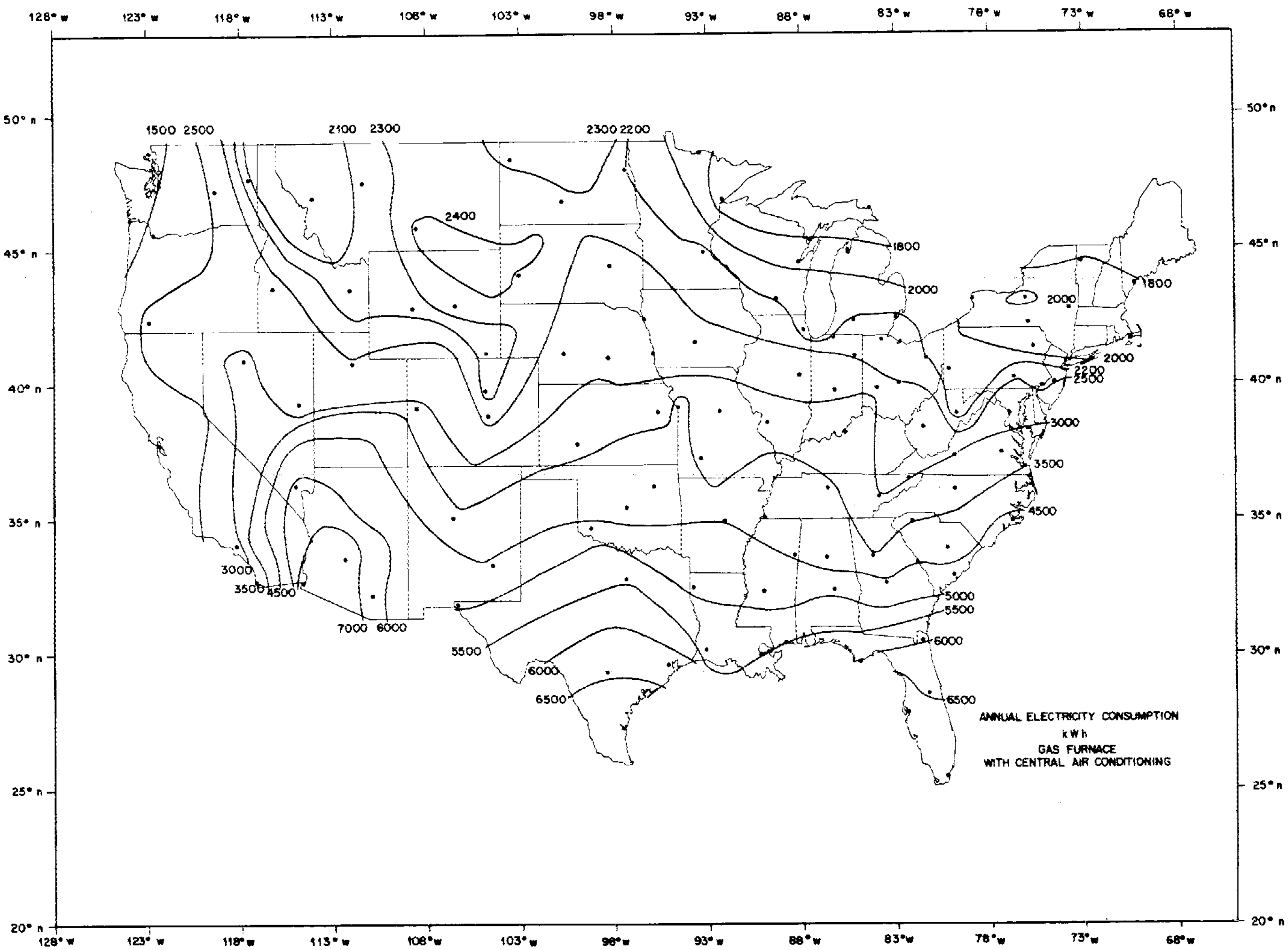

Fig. 4. System 3 annual electricity consumption in kilowatt-hours: gas furnace with central air conditioner.

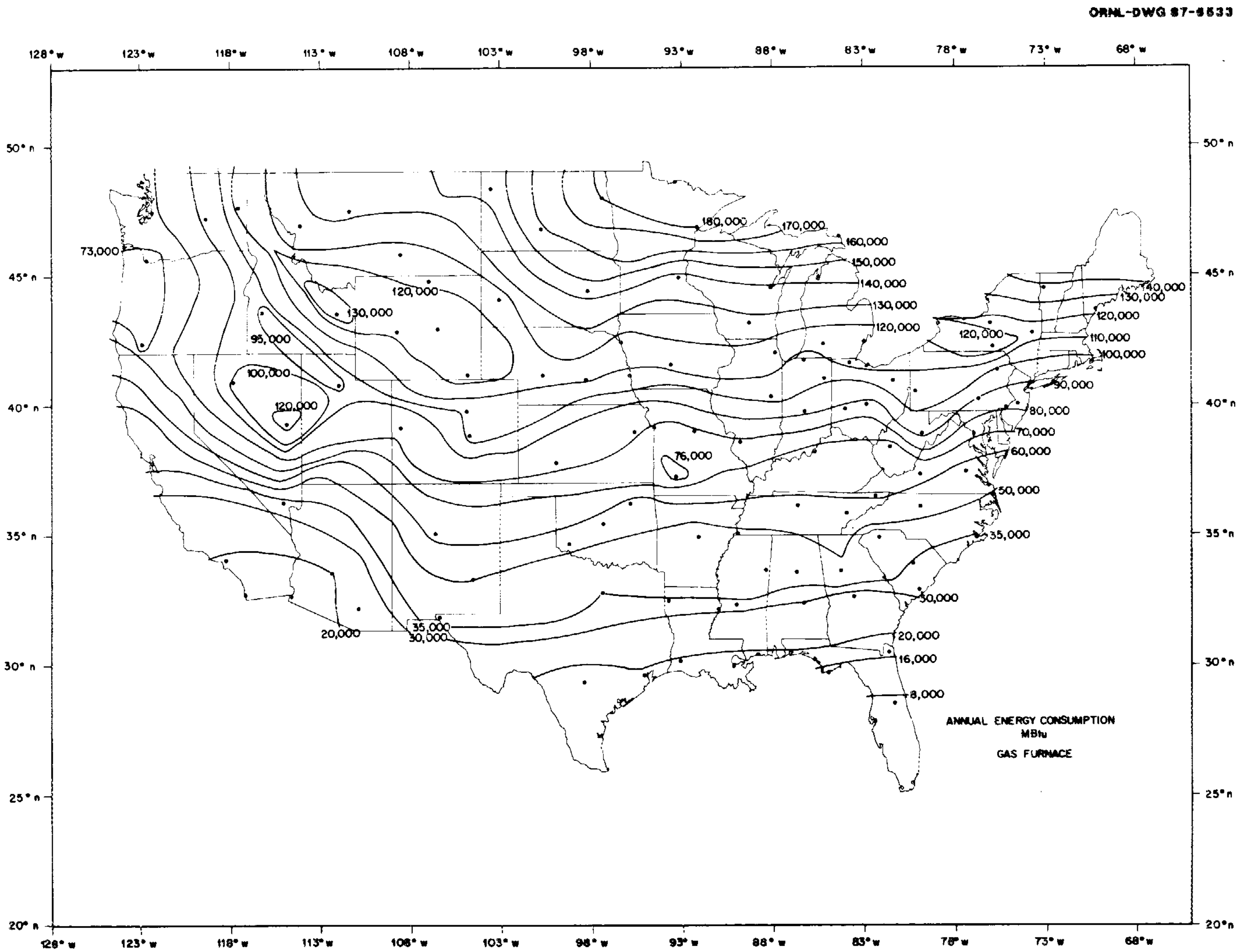

Fig. 5. System 3 annual natural gas consumption in thousands of Btu's: gas furnace with central air conditioner.

- House 1
  - Located at Ft. Bragg, North Carolina.
  - Size is 1800 ft^2.
  - Insulation level of 1.

- House 2
  - Located at Ft. Belvoir, Virginia.
  - Size is 1400 ft^2.
  - Insulation level is 2.

- House 3
  - Located in Rapid City, South Dakota.
  - Size is 2200 ft^2.
  - Insulation level is 4.

7.1 LIFE-CYCLE ENERGY COST CALCULATION

7.1.1 Examples of Life-Cycle Energy Cost Calculation for System 1

1. House 1
   a. From Fig. 2 (system 1), the annual energy consumption is approximately 13,000 kWh.
   b. From Appendix B.1, the multiplier is 1.
   c. Annual energy consumption = 1 × 13,000 = 13,000 kWh.
   d. From Appendix D, the electricity cost for region 4 is $16.49 per million Btu, or $0.0563 per kWh.
   e. From Appendix C, the UPW factor for region 4 over a 15-year period is 8.54 (This value is for 1985 to 2000; since the fuel price did not change much in the past two years, it is assumed that this value is also good for a period from 1987 to 2002).
   f. Life-cycle energy cost = 13,000 × 0.0563 × 8.54 = $6,250.

2. House 2
   a. From Fig. 2 (system 1), the annual energy consumption for house 2 is about 17,000 kWh.
   b. From Appendix B, Table B.1, the multiplier is 0.7301.
   c. Annual energy consumption = 17,000 × 0.7301 = 12,412 kWh.
   d. From Appendix D, the electricity cost for region 3 is $18.23 per million Btu, or $0.0622 per kWh.
   e. From Appendix C, the UPW factor for region 3 over a 15-year period is 9.03.
   f. Life-cycle energy cost = 12,412 × 0.0622 × 9.03 = $6,971.

3. House 3
   a. From Fig. 2 (system 1), the annual energy consumption for house 3 is about 26,500 kWh.
   b. From Appendix B, Table B.1, the multiplier is 0.7382.
   c. Annual energy consumption = 26,500 × 0.7382 = 19,562 kWh.
   d. From Appendix D, the electricity cost for region 8 is $16.09 per million Btu, or $0.0549 per kWh.
   e. From Appendix C, the UPW factor for region 8 over a 15-year period is 8.83.
   f. Life-cycle energy cost = 19,562 × 0.0549 × 8.83 = $9,483.

7.1.2 Examples of Life-Cycle Energy Cost Calculation for System 2

1. House 1
   a. From Fig. 3 (system 2), the annual energy consumption is 9500 kWh.
   b. From Appendix B, Table B.2, the multiplier is 1.0.
   c. Annual energy consumption = 9500 × 1 = 9500 kWh.
   d. This is the same as in example 1 of Sect. 7.1.1.
   e. This is the same as in example 1 of Sect. 7.1.1.
   f. Life-cycle energy cost = 9500 × 0.0563 × 8.54 = $4,568.

2. House 2

   a. From Fig. 3 (system 2), the annual energy consumption is 11,000 kWh.

   b. From Appendix B, Table B.1, the multiplier is 0.7686.

   c. Annual energy consumption = 11,000 × 0.7686 = 8455 kWh.

   d. This is the same as in example 2 of Sect. 7.1.1.

   e. This is the same as in example 2 of Sect. 7.1.1.

   f. Life-cycle energy cost = 8455 × 0.0622 × 9.03 = $4,749.

3. House 3

   a. From Fig. 3 (system 2), the annual energy consumption for house 3 is about 19,000 kWh.

   b. From Appendix B, Table B.2, the multiplier is 0.7869.

   c. Annual energy consumption = 19,000 × 0.7869 = 14,951 kWh.

   d. This is the same as in example 3 of Sect. 7.1.1.

   e. This is the same as in example 3 of Sect. 7.1.1.

   f. Life-cycle energy cost = 14,951 × 0.0549 × 8.83 = $7,248.

7.1.3 Examples of Life-Cycle Cost Calculation for System 3

1. House 1

   a. From Fig. 4 (system 3, electricity consumption), the annual electricity consumption is approximately 3700 kWh. From Fig. 5 (system 3, gas consumption), the annual gas consumption is about 42,000 MBtu.

   b. From Appendix B, Table B.3, the multiplier is 1.

   c. Annual electricity consumption is 3700 kWh and annual gas consumption is 42,000 MBtu.

   d. From Appendix D, the electricity cost for region 4 is $16.49 per million Btu, or $0.0563 per kWh. The gas cost is $4.40 per million Btu, or $0.00440 per MBtu.

   e. From Appendix C, region 4, over a 15-year period, the UPW factor is 8.54 for electricity, and 13.09 for gas.

   f. The life-cycle energy cost is then equal to 3700 × 0.0563 × 8.54 + 42,000 × 0.00440 × 13.09 = $4,198.

2. House 2

   a. From Fig. 4 (system 3, electricity consumption), the annual electricity consumption is approximately 2800 KWh. From Fig. 5, the annual gas consumption is approximately 70,000 MBtu.

   b. From Appendix B, Table B.3, the multiplier is 0.7198.

   c. The actual annual electricity consumption is 2800 × 0.7198 = 2015 kWh, and the actual gas consumption is 70,000 × 0.7198 = 50,386 MBtu.

   d. From Appendix D, the electricity cost for region 3 is $18.23 per million Btu, or $0.0622 per kWh. The gas cost is $4.97 per million Btu, or $0.00497 per MBtu.

   e. From Appendix C, region 3, over a 15-year period, the UPW factor is 8.54 for electricity and 13.09 for gas.

   f. The life-cycle energy cost is then equal to 2015 × 0.0622 × 8.54 + 50,386 × 0.00497 × 13.09 = 1071 + 3278 = $4,348.

3. House 3

   a. From Fig. 4 (system 3, electricity consumption), the annual electricity consumption is approximately 2400 kWh. From Fig. 5, the annual gas consumption is about 120,000 MBtu.

   b. From Appendix B, the multiplier is 0.7231.

   c. The actual annual electricity consumption is 2400 × 0.7231 = 1735 kWh. The actual gas consumption is 120,000 × 0.7231 = 86,772 MBtu.

   d. From Appendix D, the electricity cost for region 8 is $16.09 per million Btu, or $0.0549 per kWh. The gas cost is $4.355 per million Btu, or $0.004355 per MBtu.

   e. From Appendix C, region 8, over a 15-year period, the UPW factor is 8.83 for electricity and 11.87 for gas.

   f. The life-cycle energy cost = 1735 × 0.0549 + 8.83 + 86,772 × 0.004355 × 11.87 = 841 + 4,486 = $5,327.

7.2 OVERVIEW OF LIFE-CYCLE ENERGY COST EXAMPLES

Table 11 summarizes the examples for life-cycle energy cost for each of the systems.

Table 11. Overview of life-cycle energy cost examples

HVAC System	Life-cycle energy cost		
	House 1	House 2	House 3
1	$ 6,250	$ 6,971	$ 9,590
2	$ 4,568	$ 4,749	$ 7,248
3	$ 4,198	$ 4,348	$ 5,327

8. PROCEDURES FOR ESTIMATING HVAC EQUIPMENT LIFE-CYCLE COST

Once the size, location, and insulation level of the house are defined, the following procedures provide an easy-to-follow guide for estimating the life-cycle cost of the three HVAC systems studied in this report.

8.1 DETERMINING THE SIZE OF THE HVAC EQUIPMENT

Appendix A lists the needed capacities of HVAC systems in 117 cities across the United States for an 1800 ft^2 house with level 1 insulation. By checking the equipment capacity of the city near the location of interest, the equipment size can be determined. For electric and gas furnaces, the multipliers listed in Table B.4 of Appendix B can be applied to reflect the effect of house size and insulation level on needed equipment capacity. For example, the needed heating capacity at Ft. Bragg, North Carolina (near New Bern, North Carolina) is shown in Appendix A to be 30,000 Btu/h for an 1800-ft^2 house with level 1 insulation. The multiplier from Table B.4 is 0.7042 for a level 4 insulation. The needed heating capacity for level 4 insulation is then 30,000 × 0.7042, or 21,130 Btu/h. For a 1400-ft^2 house with level 3 insulation, the multiplier is 0.5627.

The gas or electric furnace capacity for this example is 30,000 × 0.5627, or 16,880 Btu/h. For cooling capacities of heat pumps and central air conditioners, the multipliers listed in Table B.5 of Appendix B can be applied to reflect the effect of house size and insulation level. For example, the cooling capacity of an 1800-ft^2 house with level 4 insulation should be 0.8451 (Table B.5, Appendix B) of the capacity needed for a level 1 house at the same location. For this example, the capacity is 33,000 Btu/h (from Appendix A) × 0.8451, or 27,900 Btu/h.

8.2 EQUIPMENT COST ESTIMATION

After the HVAC equipment has been properly sized to fit the house, its cost can be estimated as described in Sect. 5. Section 6 shows how to estimate installation and maintenance costs, and Section 7 describes estimation of life-cycle energy costs for different HVAC systems.

8.3 LIFE-CYCLE COST ESTIMATION

The components of life-cycle costs are equipment cost, installation cost, present worth of annual maintenance costs, and present worth of annual energy costs. Values of each of these components are obtained as described in the previous sections and summed to yield the overall HVAC life-cycle cost. This process is illustrated by examples provided in Appendix F.

9. SUMMARY AND CONCLUSIONS

Using the ORNL APF model, annual energy consumptions of different HVAC systems were calculated for three sizes of houses, each having four different levels of insulation. These data were used, together with DOE-projected future energy costs and realistically estimated costs for equipment, initial installation, and maintenance, to determine the overall life-cycle cost for three HVAC systems. The HVAC systems analyzed were a heat pump, an electric furnace with a central air conditioner, and a gas furnace with a central air conditioner. The results indicate that because the cost of natural gas is currently much lower than the cost of electricity, the system consisting of a gas furnace and central air conditioner has the lowest life-cycle costs. Exceptions occur in some areas where the winter heating load is extremely low or locally where perturbations in gas and electricity prices exist.

Generally, increasing the insulation level reduces the annual energy consumption of a house. Of the insulation measures studied, the greatest improvement occurs in going from insulation level 2 to level 3. This involves mainly the installation of floor insulation.

All nine examples in the report show that the life-cycle energy cost of the HVAC equipment is the single largest component of the system's overall life-cycle cost. In the future, the advantage of a gas furnace with a central air conditioner over a heat pump system could disappear or be reversed if the cost of natural gas were to increase faster than that of electricity.

Finally, the selection of a heating and cooling system for a residence should be made on the basis of a full life-cycle cost analysis. This report presents a simple, easy to follow procedure for estimating the life-cycle costs of alternative residential HVAC systems. By following the examples, one can easily estimate the life-cycle cost of any of the HVAC systems of this study. Special knowledge and expertise are not required.

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APPENDIX A

CALCULATED HVAC EQUIPMENT CAPACITY AND ANNUAL HEATING AND COOLING LOADS

Table A.1. HVAC systems 1, 2, and 3: Equipment capacity and annual heating and cooling loads ($1800-ft^2$ ranch, insulation level 1, no natural ventilation)

NO.	CITY, STATE	HCAP	CCAP	AHL	ACL	EUH	EUC
1	BIRMINGHAM, ALABAMA	33000.	30000.	28007.	41723.	4525.	5026.
2	MONTGOMERY, ALABAMA	30000.	33000.	21367.	48531.	3233.	5892.
3	PHOENIX, ARIZONA	22000.	39000.	13919.	75072.	2011.	9549.
4	TUCSON, ARIZONA	24000.	36000.	16439.	62993.	2336.	7819.
5	YUMA, ARIZONA	19000.	42000.	9243.	79837.	1322.	10337.
6	LITTLE ROCK, ARKANSAS	34000.	33000.	30258.	43786.	4726.	5353.
7	LOS ANGELES, CALIFORNIA	19000.	27000.	12470.	30940.	1664.	3581.
8	MERCED, CALIFORNIA	25000.	33000.	25619.	39721.	3788.	4849.
9	OAKLAND, CALIFORNIA	19000.	21000.	25832.	20216.	3398.	2158.
10	SAN DIEGO, CALIFORNIA	15000.	24000.	10717.	25388.	1418.	2955.
11	COLORADO SPRINGS, COLORADO	48000.	24000.	73459.	20124.	13390.	2298.
12	DENVER, COLORADO	50000.	30000.	72321.	18720.	12975.	2273.
13	GRAND JUNCTION, COLORADO	44000.	30000.	58286.	29261.	9614.	3525.
14	WASHINGTON, D. C.	35000.	30000.	50354.	25201.	7961.	3060.
15	APPALACHICOLA, FLORIDA	24000.	30000.	10968.	61591.	1568.	7293.
16	JACKSONVILLE, FLORIDA	23000.	30000.	11443.	60072.	1710.	7160.
17	MIAMI, FLORIDA	14000.	30000.	0.	83037.	0.	9830.
18	ORLANDO, FLORIDA	20000.	30000.	5863.	64719.	831.	7703.
19	TAMPA, FLORIDA	18000.	30000.	3916.	72370.	547.	8595.
20	ATLANTA, GEORGIA	33000.	27000.	34444.	34101.	5661.	4037.
21	AUGUSTA, GEORGIA	30000.	30000.	25809.	44218.	4108.	5294.
22	MACON, GEORGIA	30000.	33000.	19830.	45930.	3012.	5607.
23	BOISE, IDAHO	44000.	30000.	66680.	22764.	11546.	2732.
24	IDAHO FALLS, IDAHO	55000.	27000.	94955.	16500.	18889.	1865.
25	CHICAGO, ILLINOIS	52000.	39000.	81867.	16718.	14710.	2121.
26	EAST ST. LOUIS, ILLINOIS	45000.	33000.	56315.	30412.	9895.	3721.
27	URBANA, ILLINOIS	49000.	36000.	75368.	23491.	14222.	2907.
28	FORT WAYNE, INDIANA	49000.	30000.	72841.	21368.	13576.	2587.
29	INDIANAPOLIS, INDIANA	47000.	27000.	64715.	24911.	12121.	2962.
30	SOUTH BEND, INDIANA	48000.	30000.	77125.	19983.	14597.	2407.
31	DES MOINES, IOWA	54000.	36000.	80189.	21900.	15570.	2742.
32	SIOUX CITY, IOWA	55000.	36000.	83583.	24028.	16522.	2991.
33	DODGE CITY, KANSAS	46000.	30000.	58231.	31733.	10659.	3856.
34	TOPEKA, KANSAS	46000.	33000.	61521.	30006.	11362.	3687.
35	LOUISVILLE, KENTUCKY	42000.	30000.	47647.	33642.	8121.	4015.
36	LAKE CHARLES, LOUISIANA	25000.	30000.	13628.	57285.	2038.	6821.
37	NEW ORLEANS, LOUISIANA	24000.	30000.	11466.	54937.	1703.	6604.
38	SHREVEPORT, LOUISIANA	30000.	33000.	24452.	48008.	3854.	5838.
39	PORTLAND, MAINE	51000.	33000.	86016.	13809.	16149.	1644.
40	FALMOUTH, MASSACHUSETTS	42000.	30000.	69126.	13961.	11639.	1685.

NO.	CITY, STATE	HCAP	CCAP	AHL	ACL	EUH	EUC
41	BATTLE CREEK, MICHIGAN	46000.	36000.	78897.	18380.	14325.	2297.
42	DETROIT, MICHIGAN	44000.	36000.	82009.	18273.	14991.	2255.
43	SAULT SAINTE MARIE, MICH.	58000.	30000.	116053.	10040.	24456.	1161.
44	DULUTH, MINNESOTA	64000.	30000.	127830.	9591.	28137.	1117.
45	INTERNATIONAL FALLS, MINN.	71000.	30000.	133884.	11669.	30704.	1359.
46	MINNEAPOLIS, MINNESOTA	59000.	36000.	97788.	17462.	20069.	2167.
47	BILOXI, MISSISSIPPI	25000.	30000.	14052.	54802.	2080.	6572.
48	COLUMBUS, MISSISSIPPI	34000.	33000.	29959.	44284.	4821.	5386.
49	JACKSON, MISSISSIPPI	30000.	33000.	23770.	46468.	3717.	5653.
50	COLUMBIA, MISSOURI	46000.	30000.	56406.	30829.	10294.	3720.
51	KANSAS CITY, MISSOURI	44000.	33000.	53400.	32971.	9217.	4091.
52	SPRINGFIELD, MISSOURI	43000.	30000.	54372.	31140.	9818.	3734.
53	BILLINGS, MONTANA	58000.	27000.	81482.	20003.	15591.	2354.
54	GREAT FALLS, MONTANA	63000.	27000.	94489.	16235.	19094.	1890.
55	MISSOULA, MONTANA	71000.	27000.	91011.	15225.	17393.	1740.
56	GRAND ISLAND, NEBRASKA	52000.	30000.	78619.	24364.	15680.	2950.
57	LINCOLN, NEBRASKA	50000.	30000.	77646.	23913.	15592.	2915.
58	NORTH PLATTE, NEBRASKA	52000.	36000.	81908.	22220.	15700.	2761.
59	ELY, NEVADA	54000.	30000.	93919.	20710.	17181.	2379.
60	LAS VEGAS, NEVADA	27000.	39000.	23643.	64583.	3392.	8211.
61	WINNEMUCCA, NEVADA	47000.	30000.	72866.	26595.	13484.	3160.
62	TRENTON, NEW JERSEY	38000.	30000.	59048.	21959.	9601.	2651.
63	ALBUQUERQUE, NEW MEXICO	37000.	30000.	43913.	34518.	6623.	4115.
64	ROSWELL, NEW MEXICO	36000.	33000.	36169.	42607.	5696.	5229.
65	ALBANY, NEW YORK	51000.	33000.	82183.	14742.	15358.	1836.
66	BINGHAMTON, NEW YORK	48000.	30000.	91201.	12591.	17718.	1528.
67	NIAGARA FALLS, NEW YORK	43000.	33000.	85667.	14836.	16003.	1819.
68	SYRACUSE, NEW YORK	49000.	30000.	81025.	15884.	15538.	1931.
69	WESTHAMPTON BEACH, NEW YORK	41000.	24000.	62336.	16987.	10768.	1966.
70	GREENSBORO, NORTH CAROLINA	35000.	27000.	39557.	30714.	6524.	3629.
71	NEW BERN, NORTH CAROLINA	30000.	33000.	23743.	46516.	3645.	5543.
72	BISMARCK, NORTH DAKOTA	65000.	39000.	113209.	17602.	24321.	2206.
73	GRAND FORKS, NORTH DAKOTA	68000.	36000.	128263.	15164.	29206.	1850.
74	WILLISTON, NORTH DAKOTA	63000.	36000.	102263.	17407.	21628.	2168.
75	AKRON, OHIO	45000.	33000.	75802.	17967.	13858.	2190.
76	COLUMBUS, OHIO	46000.	27000.	61221.	22398.	10886.	2661.
77	DAYTON, OHIO	47000.	30000.	60700.	25889.	10932.	3145.
78	TOLEDO, OHIO	49000.	39000.	80938.	19757.	14751.	2470.
79	ALTUS, OKLAHOMA	37000.	33000.	37187.	46277.	6058.	5708.
80	OKLAHOMA CITY, OKLAHOMA	39000.	33000.	40716.	40987.	6732.	5015.
81	TULSA, OKLAHOMA	39000.	33000.	39794.	41736.	6697.	5121.
82	ASTORIA, OREGON	28000.	15000.	52346.	8383.	8274.	850.
83	MEDFORD, OREGON	32000.	30000.	52349.	24281.	8216.	2873.
84	PORTLAND, OREGON	33000.	27000.	48808.	15982.	7392.	1845.
85	MIDDLETOWN, PENNSYLVANIA	41000.	27000.	62480.	21944.	10526.	2629.
86	PHILADELPHIA, PENNSYLVANIA	38000.	30000.	58149.	20729.	9096.	2571.
87	PITTSBURGH, PENNSYLVANIA	45000.	30000.	74342.	16932.	13583.	2062.
88	WILKES-BARRE, PENNSYLVANIA	45000.	33000.	72055.	15936.	12734.	1962.
89	CHARLESTON, SOUTH CAROLINA	28000.	30000.	22904.	46158.	3538.	5460.
90	GREENVILLE, SOUTH CAROLINA	32000.	30000.	31578.	33548.	4821.	4049.
91	SUMTER, SOUTH CAROLINA	29000.	30000.	24212.	42138.	3607.	5053.
92	HURON, SOUTH DAKOTA	61000.	42000.	102136.	20274.	21163.	2578.

NO.	CITY, STATE	HCAP	CCAP	AHL	ACL	EUH	EUC
93	RAPID CITY, SOUTH DAKOTA	55000.	33000.	83456.	20120.	16208.	2459.
94	BRISTOL, TENNESSEE	39000.	27000.	43313.	27237.	7362.	3246.
95	KNOXVILLE, TENNESSEE	36000.	27000.	38828.	28999.	6401.	3508.
96	MEMPHIS, TENNESSEE	36000.	33000.	34691.	40503.	5609.	4939.
97	NASHVILLE, TENNESSEE	39000.	30000.	41741.	32884.	7186.	3975.
98	EL PASO, TEXAS	31000.	33000.	27058.	49087.	3950.	5995.
99	FORTH WORTH, TEXAS	32000.	36000.	24854.	54382.	3818.	6760.
100	HOUSTON, TEXAS	25000.	33000.	13226.	63281.	1971.	7614.
101	SAN ANTONIO, TEXAS	26000.	33000.	11157.	65609.	1638.	8007.
102	SALT LAKE CITY, UTAH	44000.	33000.	67168.	21913.	11103.	2687.
103	BURLINGTON, VERMONT	56000.	33000.	99000.	13002.	19344.	1588.
104	NORFOLK, VIRGINIA	31000.	30000.	37648.	33772.	6002.	4030.
105	RICHMOND, VIRGINIA	35000.	30000.	39082.	31315.	6234.	3747.
106	ROANOKE, VIRGINIA	37000.	27000.	44828.	27356.	7034.	3261.
107	MOSES LAKE, WASHINGTON	45000.	33000.	64916.	24263.	11259.	2946.
108	SEATTLE, WASHINGTON	30000.	21000.	57693.	11797.	9048.	1295.
109	SPOKANE, WASHINGTON	51000.	27000.	80229.	16727.	14682.	1929.
110	CHARLESTON, WEST VIRGINIA	40000.	27000.	47757.	26538.	8066.	3162.
111	ELKINS, WEST VIRGINIA	45000.	27000.	66672.	18355.	12267.	2158.
112	GREEN BAY, WISCONSIN	57000.	33000.	99061.	14476.	19919.	1766.
113	MADISON, WISCONSIN	55000.	33000.	90325.	17274.	17776.	2119.
114	CASPER, WYOMING	55000.	33000.	89264.	18998.	16379.	2308.
115	CHEYENNE, WYOMING	53000.	30000.	88964.	16917.	15856.	1967.
116	LANDER, WYOMING	59000.	36000.	86826.	17756.	15844.	2137.
117	SHERIDAN, WYOMING	57000.	36000.	88950.	18710.	16804.	2299.

HCAP = CALCULATED ELECTRIC OR GAS FURNACE HEATING CAPACITY, BTU/H
CCAP = CALCULATED HEAT PUMP OR CENTRAL AIR CONDITIONER COOLING CAPACITY, BTU/H
AHL = HOUSE ANNUAL HEATING LOAD, MBTU (1,000 BTU)
ACL = HOUSE ANNUAL COOLING LOAD, MBTU (1,000 BTU)
EUH = ANNUAL ELECTRICITY CONSUMPTION FOR HEATING, KWH
EUC = ANNUAL ELECTRICITY CONSUMPTION FOR COOLING, KWH

APPENDIX B

ENERGY CONSUMPTION AND EQUIPMENT CAPACITY MULTIPLIERS FOR DIFFERENT HOUSE SIZES AND INSULATION LEVELS

Table B.1. Annual energy consumption multipliers for system 1: electric furnace with central air conditioner

Insulation level (see Table 1 for insulation level description)	House Size (ft^2)		
	1400	1800	2200
1	0.7498	1	1.2518
2	0.7301	0.9741	1.2193
3[a]	0.4413	0.5961	0.7545
4[a]	0.4320	0.5837	0.7382

[a] For areas with heating degree days less than 3500, do not use multipliers for insulation level 3 and 4 houses.

Table B.2. Annual energy consumption multipliers for system 2: heat pump

Insulation level (see Table 1 for insulation level description)	House Size (ft^2)		
	1400	1800	2200
1	0.7848	1	1.2160
2	0.7686	0.9801	1.1902
3[a]	0.5189	0.6596	0.8010
4[a]	0.5106	0.6469	0.7869

[a] For areas with heating degree days less than 3500, do not use multipliers for insulation level 3 and 4 houses.

Table B.3. Annual energy consumption multipliers for system 3: gas furnace with central air conditioner

Insulation level (see Table 1 for insulation level description)	House Size (ft^2)		
	1400	1800	2200
1	0.7409	1	1.2610
2	0.7198	0.9723	1.2261
3[a]	0.4188	0.5776	0.7402
4[a]	0.4091	0.5646	0.7231

[a] For areas with heating degree days less than 3500, do not use multipliers for insulation level 3 and 4 houses.

Table B.4. Heating capacity multipliers for electric and gas furnaces

Insulation level (see Table 1 for insulation level description)	House Size (ft^2)		
	1400	1800	2200
1	0.7896	1	1.2113
2	0.7757	0.9806	1.1851
3[a]	0.5627	0.7149	0.8660
4[a]	0.5544	0.7042	0.8524

[a] For areas with heating degree days less than 3500, do not use multipliers for insulation level 3 and 4 houses.

Table B.5. Cooling capacity multipliers for heat pumps and central air conditioners

Insulation level (see Table 1 for insulation level description)	House Size (ft^2)		
	1400	1800	2200
1	0.8095	1	1.1857
2	0.8053	0.9847	1.1780
3[a]	0.7167	0.8580	0.9993
4[a]	0.7133	0.8541	0.9985

[a] For areas with heating degree days less than 3500, do not use multipliers for insulation level 3 and 4 houses.

APPENDIX C

UNIFORM PRESENT WORTH (UPW) FACTORS:

ADJUSTED FOR ENERGY PRICE ESCALATION

UPS DISCOUNT FACTORS ADJUSTED FOR ENERGY PRICE ESCALATION

The following "modified" uniform present worth discount (UPW) factors are based on a 7% discount rate and include the DOE projected escalation rates in energy prices developed from the Energy Information Administration's projected real average fuel price indices for each of the years from mid-1985 through mid-2010 for the 10 DOE Regions.

REGION 1: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island
REGION 2: New York, New Jersey, Puerto Rice, Virgin Islands
REGION 3: Pennsylvania, Maryland, West Virginia, Virginia, District of Columbia, Delaware
REGION 4: Kentucky, Tennessee, North Carolina, Mississippi, South Carolina, Alabama, Georgia, Florida, Canal Zone
REGION 5: Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio
REGION 6: Texas, New Mexico, Oklahoma, Arkansas, Louisiana
REGION 7: Kansas, Missouri, Iowa, Nebraska
REGION 8: Montana, North Dakota, South Dakota, Wyoming, Utah, Colorado
REGION 9: California, Nevada, Arizona, Hawaii, Guam, Trust Territory of the Pacific Islands, American Samoa
REGION 10: Washington, Oregon, Idaho, Alaska

	REGION 1					REGION 2				
SP	ELEC	DIST	RESID	NATGAS	COAL	ELEC	DIST	RESID	NATGAS	COAL
1	0.94	0.91	0.93	0.93	0.95	0.92	0.91	0.93	0.93	0.95
2	1.86	1.77	1.81	1.87	1.84	1.80	1.77	1.81	1.83	1.85
3	2.76	2.59	2.66	2.79	2.69	2.67	2.59	2.66	2.70	2.71
4	3.58	3.39	3.48	3.72	3.49	3.47	3.39	3.49	3.56	3.52
5	4.34	4.16	4.28	4.65	4.26	4.19	4.16	4.29	4.41	4.29
6	5.06	4.93	5.06	5.58	4.99	4.85	4.93	5.07	5.25	5.03
7	5.72	5.68	5.82	6.50	5.68	5.47	5.68	5.84	6.07	5.72
8	6.35	6.42	6.56	7.41	6.34	6.03	6.42	6.58	6.87	6.38
9	6.94	7.14	7.28	8.31	6.96	6.56	7.15	7.30	7.66	7.01
10	7.49	7.85	7.97	9.18	7.56	7.05	7.86	8.00	8.43	7.60
11	8.01	8.55	8.65	10.03	8.12	7.52	8.55	8.67	9.17	8.16
12	8.50	9.22	9.30	10.87	8.65	7.96	9.23	9.33	9.91	8.69
13	8.97	9.88	9.94	11.69	9.15	8.38	9.89	9.98	10.63	9.19
14	9.41	10.53	10.56	12.50	9.63	8.78	10.54	10.60	11.33	9.67
15	9.84	11.16	11.17	13.29	10.08	9.16	11.17	11.21	12.02	10.12
16	10.23	11.77	11.75	14.05	10.50	9.52	11.78	11.79	12.69	10.54
17	10.61	12.36	12.31	14.80	10.90	9.85	12.37	12.35	13.35	10.94
18	10.96	12.93	12.85	15.53	11.28	10.17	12.94	12.90	13.98	11.32
19	11.30	13.49	13.38	16.23	11.63	10.47	13.50	13.43	14.60	11.67
20	11.62	14.02	13.88	16.92	11.96	10.76	14.03	13.93	15.20	12.00
21	11.91	14.55	14.38	17.59	12.28	11.02	14.56	14.43	15.79	12.32
22	12.19	15.06	14.85	18.24	12.57	11.27	15.07	14.91	16.36	12.61
23	12.44	15.55	15.32	18.88	12.85	11.50	15.56	15.37	16.92	12.89
24	12.68	16.04	15.77	19.50	13.11	11.71	16.05	15.82	17.46	11.15
25	12.90	16.51	16.20	20.10	13.36	11.91	16.52	16.26	17.99	11.40

REGION 3

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.92	0.91	0.93	0.93	0.95
2	1.79	1.77	1.81	1.83	1.84
3	2.60	2.59	2.66	2.70	2.68
4	3.35	3.39	3.49	3.57	3.49
5	4.04	4.17	4.30	4.42	4.25
6	4.68	4.93	5.10	5.25	4.97
7	5.29	5.69	5.87	6.07	5.65
8	5.85	6.44	6.63	6.86	6.30
9	6.38	7.17	7.36	7.64	6.91
10	6.88	7.89	8.08	8.39	7.50
11	7.36	8.59	8.77	9.13	8.05
12	7.81	9.27	9.45	9.86	8.57
13	8.24	9.94	10.10	10.56	9.06
14	8.64	10.59	10.74	11.26	9.53
15	9.03	11.23	11.36	11.94	9.97
16	9.39	11.85	11.96	12.60	10.38
17	9.73	12.44	12.54	13.25	10.78
18	10.06	13.02	13.09	13.87	11.14
19	10.36	13.58	13.63	14.48	11.49
20	10.65	14.12	14.15	15.08	11.82
21	10.92	14.65	14.66	15.66	12.13
22	11.17	15.17	15.15	16.22	12.42
23	11.41	15.67	15.62	16.77	12.69
24	11.62	16.16	16.09	17.30	12.95
25	11.83	16.64	16.54	17.82	13.19

REGION 4

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.91	0.91	0.93	0.92	0.95
2	1.76	1.77	1.81	1.82	1.85
3	2.54	2.59	2.67	2.70	2.70
4	3.28	3.40	3.51	3.58	3.52
5	3.96	4.17	4.32	4.47	4.29
6	4.58	4.94	5.13	5.37	5.03
7	5.17	5.70	5.92	6.27	5.73
8	5.70	6.45	6.69	7.17	6.40
9	6.18	7.19	7.44	8.06	7.63
10	6.63	7.92	8.17	8.94	7.63
11	7.05	8.62	8.88	9.81	8.20
12	7.45	9.31	9.57	10.65	8.73
13	7.84	9.99	10.24	11.48	9.24
14	8.20	10.65	10.90	12.29	9.73
15	8.54	11.29	11.53	13.09	10.18
16	8.87	11.91	12.14	13.86	10.61
17	9.17	12.52	12.74	14.62	11.02
18	9.46	13.10	13.31	15.35	11.39
19	9.74	13.66	13.86	16.06	11.75
20	9.99	14.21	14.39	16.76	12.09
21	10.23	14.74	14.91	17.43	12.41
22	10.46	15.26	15.41	18.09	12.71
23	10.67	15.77	15.90	18.73	12.99
24	10.86	16.27	16.37	19.36	13.25
25	11.04	16.75	16.83	19.97	13.50

REGION 5

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.96	0.91	0.93	0.93	0.94
2	1.88	1.77	1.82	1.82	1.84
3	2.72	2.59	2.68	2.69	2.68
4	3.49	3.39	3.53	3.53	3.48
5	4.18	4.17	4.37	4.37	4.23
6	4.81	4.93	5.20	5.20	4.95
7	5.39	5.69	6.02	6.04	5.62
8	5.92	6.43	6.83	6.86	6.26
9	6.40	7.16	7.62	7.68	6.87
10	6.85	7.87	8.40	8.48	7.43
11	7.27	8.57	9.15	9.27	7.97
12	7.67	9.25	9.88	10.04	8.48
13	8.05	9.92	10.60	10.80	8.96
14	8.42	10.57	11.29	11.54	9.42
15	8.76	11.20	11.96	12.27	9.85
16	9.09	11.92	12.61	12.97	10.26
17	9.39	12.41	13.24	13.66	10.64
18	9.68	12.99	13.85	14.33	11.01
19	9.95	13.55	14.43	14.98	11.35
20	10.21	14.09	15.00	15.61	11.67
21	10.45	14.61	15.55	16.23	11.97
22	10.68	15.13	16.08	16.83	12.25
23	10.89	15.63	16.60	17.42	12.52
24	11.08	16.12	17.10	17.99	12.77
25	11.26	16.59	17.59	18.54	13.01

REGION 6

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.97	0.91	0.93	0.96	0.96
2	1.89	1.76	1.81	1.90	1.87
3	2.76	2.59	2.68	2.82	2.74
4	3.57	3.39	3.52	3.72	3.56
5	4.33	4.17	4.35	4.64	4.35
6	5.06	4.95	5.17	5.55	5.10
7	5.74	5.72	5.98	6.47	5.82
8	6.39	6.47	6.77	7.39	6.49
9	7.01	7.22	7.54	8.31	7.13
10	7.59	7.95	8.29	9.22	7.74
11	8.15	8.67	9.03	10.11	8.32
12	8.68	9.37	9.74	10.99	8.87
13	9.18	10.05	10.43	11.85	9.39
14	9.66	10.71	11.11	12.69	9.88
15	10.12	11.37	11.76	13.51	10.34
16	10.54	12.00	12.40	14.31	10.78
17	10.95	12.61	13.01	15.09	11.19
18	11.33	13.20	13.60	15.85	11.58
19	11.69	13.77	14.17	16.59	11.94
20	12.03	14.32	14.71	17.30	12.28
21	12.34	14.86	15.25	18.00	12.61
22	12.64	15.39	15.77	18.68	12.91
23	12.91	15.90	16.27	19.35	13.20
24	13.17	16.40	16.76	19.99	13.47
25	13.41	16.89	17.23	20.62	13.72

REGION 7

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.99	0.91	0.93	0.92	0.95
2	1.88	1.77	1.81	1.82	1.86
3	2.68	2.60	2.68	2.71	2.72
4	3.40	3.40	3.53	3.58	3.54
5	4.07	4.18	4.37	4.46	4.31
6	4.69	4.95	5.20	5.34	5.05
7	5.26	5.71	6.01	6.22	5.75
8	5.78	6.46	6.84	7.08	6.41
9	6.26	7.19	7.64	7.94	7.04
10	6.70	7.92	8.42	8.79	7.63
11	7.11	8.62	9.18	9.62	8.19
12	7.51	9.31	9.92	10.43	8.73
13	7.89	9.98	10.63	11.22	9.23
14	8.25	10.64	11.33	12.00	9.71
15	8.59	11.28	12.01	12.76	10.17
16	8.91	11.91	12.66	13.51	10.59
17	9.21	12.51	13.30	14.23	10.99
18	9.49	13.09	13.91	14.93	11.37
19	9.76	13.65	14.50	15.62	11.73
20	10.02	14.20	15.06	16.28	12.06
21	10.25	14.73	15.62	16.93	12.38
22	10.48	15.25	16.15	17.56	12.67
23	10.68	15.76	16.67	18.17	12.95
24	10.87	16.25	17.18	18.77	13.22
25	11.05	16.73	17.67	19.36	13.47

REGION 8

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.95	0.91	0.93	0.93	0.95
2	1.83	1.77	1.81	1.83	1.86
3	2.64	2.60	2.68	2.68	2.71
4	3.40	3.40	3.53	3.49	3.51
5	4.10	4.18	4.38	4.30	4.28
6	4.74	4.95	5.23	5.10	5.00
7	5.33	5.71	6.06	5.89	5.69
8	5.87	6.46	6.88	6.68	6.35
9	6.37	7.20	7.69	7.46	6.96
10	6.83	7.93	8.49	8.24	7.54
11	7.27	8.64	9.26	8.99	8.10
12	7.69	9.33	10.02	9.73	8.61
13	8.09	10.01	10.75	10.46	9.11
14	8.47	10.67	11.46	11.17	9.68
15	8.83	11.31	12.15	11.87	10.02
16	9.17	11.94	12.82	12.55	10.44
17	9.49	12.54	13.46	13.21	10.83
18	9.79	13.13	14.09	13.85	11.20
19	10.07	13.70	14.68	14.48	11.55
20	10.34	14.24	15.26	15.08	11.87
21	10.59	14.78	15.83	15.68	12.18
22	10.83	15.30	16.37	16.25	12.47
23	11.05	15.81	16.91	16.81	12.75
24	11.25	16.30	17.42	17.36	13.00
25	11.44	16.79	17.92	17.90	13.24

REGION 9

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.99	0.91	0.94	0.90	0.95
2	1.93	1.76	1.82	1.77	1.85
3	2.79	2.59	2.68	2.59	2.69
4	3.58	3.39	3.51	3.44	3.49
5	4.34	4.17	4.32	4.28	4.25
6	5.04	4.95	5.12	5.10	4.96
7	5.71	5.71	5.89	5.92	5.65
8	6.35	6.47	6.65	6.72	6.29
9	6.96	7.22	7.38	7.51	6.90
10	7.54	7.95	8.09	8.27	7.48
11	8.09	8.67	8.78	9.03	8.03
12	8.61	9.37	9.45	9.76	8.55
13	9.10	10.05	10.11	10.49	9.04
14	9.57	10.72	10.74	11.19	9.50
15	10.02	11.37	11.36	11.89	9.94
16	10.44	12.00	11.96	12.56	10.36
17	10.84	12.61	12.53	13.22	10.75
18	11.22	13.21	13.09	13.86	11.12
19	11.57	13.78	13.62	14.48	11.46
20	11.91	14.33	14.14	15.09	11.79
21	12.22	14.87	14.64	15.68	12.10
22	12.51	15.40	15.13	16.25	12.39
23	12.78	15.91	15.61	16.81	12.66
24	13.03	16.41	16.07	17.35	12.91
25	13.27	16.90	16.52	17.88	13.15

REGION 10

SP	ELEC	DIST	RESID	NATGAS	COAL
1	0.88	0.91	0.93	0.93	0.95
2	1.69	1.77	1.81	1.80	1.84
3	2.45	2.59	2.66	2.62	2.68
4	3.17	3.39	3.48	3.45	3.48
5	3.86	4.17	4.27	4.26	4.24
6	4.52	4.94	5.03	5.06	4.95
7	5.16	5.70	5.78	5.85	5.63
8	5.73	6.45	6.50	6.61	6.28
9	6.29	7.19	7.19	7.37	6.89
10	6.83	7.91	7.87	8.11	7.47
11	7.34	8.62	8.52	8.84	8.01
12	7.83	9.31	9.15	9.55	8.53
13	8.29	9.98	9.77	10.24	9.02
14	8.73	10.64	10.37	10.92	9.49
15	9.15	11.28	10.95	11.59	9.92
16	9.54	11.90	11.52	12.24	10.34
17	9.91	12.51	12.06	12.87	10.73
18	10.26	13.09	12.59	13.49	11.09
19	10.60	13.65	13.09	14.09	11.44
20	10.91	14.20	13.58	14.67	11.77
21	11.20	14.73	14.06	15.24	12.07

APPENDIX D

ENERGY COSTS FOR TEN DOE REGIONS

REGION 1: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island
REGION 2: New York, New Jersey, Puerto Rice, Virgin Islands
REGION 3: Pennsylvania, Maryland, West Virginia, Virginia, District of Columbia, Delaware
REGION 4: Kentucky, Tennessee, North Carolina, Mississippi, South Carolina, Alabama, Georgia, Florida, Canal Zone
REGION 5: Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio
REGION 6: Texas, New Mexico, Oklahoma, Arkansas, Louisiana
REGION 7: Kansas, Missouri, Iowa, Nebraska
REGION 8: Montana, North Dakota, South Dakota, Wyoming, Utah, Colorado
REGION 9: California, Nevada, Arizona, Hawaii, Guam, Trust Territory of the Pacific Islands, American Samoa
REGION 10: Washington, Oregon, Idaho, Alaska

DOE PROJECTED FUEL PRICE FROM MID-1985 TO MID-1990

SECTOR/FUEL	1985 AVERAGE FUEL PRICES (MID-1985 $/MILLION BTU)	PROJECTED AVERAGE FUEL PRICE INDICES					
		1985	1986	1987	1988	1989	1990
REGION 1							
ELECTRICITY	22.97	1.00	1.01	1.05	1.10	1.07	1.07
DISTILLATE FUEL	6.72	1.00	0.98	0.98	1.01	1.05	1.08
RESIDUAL FUEL	5.08	1.00	1.00	1.01	1.04	1.08	1.12
NATURAL GAS	5.16	1.00	1.00	1.07	1.13	1.21	1.31
STEAM COAL	2.48	1.00	1.01	1.03	1.04	1.05	1.08
REGION 2							
ELECTRICITY	22.61	1.00	0.98	1.02	1.06	1.04	1.02
DISTILLATE FUEL	6.70	1.00	9.98	0.98	1.01	1.05	1.08
RESIDUAL FUEL	5.00	1.00	1.00	1.01	1.04	1.08	1.13
NATURAL GAS	5.38	1.00	1.00	1.03	1.07	1.13	1.19
STEAM COAL	2.02	1.00	1.02	1.03	1.05	1.07	1.08
REGION 3							
ELECTRICITY	18.23	1.00	0.98	1.00	1.00	0.98	0.97
DISTILLATE FUEL	6.47	1.00	0.98	0.98	1.01	1.05	1.09
RESIDUAL FUEL	4.61	1.00	1.00	1.01	1.04	1.09	1.14
NATURAL GAS	4.83	1.00	1.00	1.03	1.07	1.13	1.20
STEAM COAL	1.81	1.00	1.01	1.02	1.03	1.05	1.07

REGION 4							
ELECTRICITY	17.00	1.00	0.98	0.97	0.96	0.96	0.95
DISTILLATE FUEL	6.28	1.00	0.98	0.98	1.01	1.05	1.09
RESIDUAL FUEL	4.27	1.00	1.00	1.01	1.05	1.09	1.15
NATURAL GAS	4.31	1.00	0.99	1.02	1.08	1.15	1.25
STEAM COAL	2.01	1.00	1.02	1.03	1.05	1.07	1.09
REGION 5							
ELECTRICITY	18.02	1.00	1.03	1.05	1.03	1.00	0.97
DISTILLATE FUEL	6.55	1.00	0.98	0.98	1.01	1.05	1.09
RESIDUAL FUEL	3.58	1.00	1.00	1.01	1.06	1.11	1.18
NATURAL GAS	4.95	1.00	1.00	1.02	1.06	1.11	1.18
STEAM COAL	1.92	1.00	1.01	1.02	1.03	1.04	1.06

SECTOR/FUEL	1985 AVERAGE FUEL PRICES (MID-1985 $/MILLION BTU)	PROJECTED AVERAGE FUEL PRICE INDICES 1985	1986	1987	1988	1989	1990
REGION 6							
ELECTRICITY	17.16	1.00	1.04	1.06	1.06	1.06	1.07
DISTILLATE FUEL	6.04	1.00	0.97	0.98	1.01	1.05	1.09
RESIDUAL FUEL	3.93	1.00	1.00	1.01	1.06	1.11	1.17
NATURAL GAS	3.91	1.00	1.02	1.07	1.13	1.19	1.28
STEAM COAL	2.59	1.00	1.02	1.04	1.06	1.08	1.10
REGION 7							
ELECTRICITY	19.41	1.00	1.06	1.02	0.98	0.95	0.94
DISTILLATE FUEL	6.33	1.00	0.98	0.98	1.01	1.05	1.09
RESIDUAL FUEL	3.49	1.00	1.00	1.01	1.06	1.11	1.18
NATURAL GAS	4.03	1.00	0.99	1.03	1.09	1.14	1.24
STEAM COAL	1.95	1.00	1.02	1.04	1.05	1.07	1.09
REGION 8							
ELECTRICITY	15.93	1.00	1.01	1.01	1.00	0.99	0.98
DISTILLATE FUEL	6.23	1.00	0.98	0.98	1.01	1.05	1.09
RESIDUAL FUEL	3.31	1.00	1.00	1.01	1.06	1.12	1.19
NATURAL GAS	4.27	1.00	1.00	1.02	1.05	1.05	1.14
STEAM COAL	1.16	1.00	1.02	1.04	1.04	1.05	1.07

REGION 9

ELECTRICITY	18.19	1.00	1.06	1.07	1.05	1.05	1.06
DISTILLATE FUEL	6.00	1.00	0.97	0.98	1.01	1.05	1.09
RESIDUAL FUEL	4.97	1.00	1.00	1.01	1.05	1.09	1.14
NATURAL GAS	5.10	1.00	0.96	0.99	1.01	1.11	1.18
STEAM COAL	2.70	1.00	1.02	1.03	1.03	1.05	1.06

REGION 10

ELECTRICITY	7.91	1.00	0.94	0.93	0.94	0.94	0.96
DISTILLATE FUEL	6.30	1.00	0.98	0.98	1.01	1.05	1.09
RESIDUAL FUEL	5.84	1.00	1.00	1.01	1.04	1.07	1.11
NATURAL GAS	5.45	1.00	1.00	1.00	1.00	1.08	1.15
STEAM COAL	2.80	1.00	1.01	1.02	1.03	1.04	1.06

APPENDIX E

LIFE-CYCLE COST ANALYSIS SUMMARY

FOR

ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Ft. BRAGG, NC. REGION NO. 4 PROJECT NUMBER ________

PROJECT TITLE APPLICATION OF HEAT PUMPS ON ARMY FACILITIES FISCAL YEAR ________

DISCRETE PORTION NAME HEAT PUMP VS ELECTRIC FURNACE WITH CENTRAL AIR CONDITIONER

ANALYSIS DATE APRIL, '87 ECONOMIC LIFE 15 YEARS PREPARED BY ________

1. INVESTMENT
   A. CONSTRUCTION COST $ 230 (ITEMS a AND b, TABLE 15 — ITEMS a, b, AND c, TABLE 12)
   B. SIOH $ INCLUDED IN A.
   C. DESIGN COST $ ________
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ ________
   E. SALVAGE VALUE -$ 0
   F. TOTAL INVESTMENT (1D-1E) $ 230

2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1) (ITEM d, EX. 1, 7.1.1)	SAVINGS MBTU/YR(2) (ITEM a, EX. 1, 7.1.2 — ITEM a, EX. 1, 7.1)	ANNUAL $ SAVINGS(3) =3(1)(2)	DISCOUNT FACTOR(4) (REGION 4, APP. C)	DISCOUNTED SAVINGS(5)
A. ELEC	$ 0.01649	11945.5	$ 197.0	8.54	$ 1,682
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$		$		$
E. COAL	$		$		$
F. TOTAL		11945.5	$ 197		---------->$ 1,682

3. NON ENERGY SAVINGS(+) / COST(-)
   A. ANNUAL RECURRING (+/-) (MAINTENANCE) $ -57 (ANNUAL AVERAGE)
      (1) DISCOUNT FACTOR (TABLE A) 9.11
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -523 (ITEM d TABLE 12 - ITEM c, TABLE 15)

   B. NON RECURRING SAVINGS(+) / COST(-)

ITEM	SAVINGS(+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(-) (3A2+3Bd4) $ -523

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ 555
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ________
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ 140

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ 1159

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= 5.04

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Ft. BRAGG, NC. REGION NO. 4 PROJECT NUMBER ______

PROJECT TITLE APPLICATION OF HEAT PUMPS ON ARMY FACILITIES FISCAL YEAR ______

DISCRETE PORTION NAME HEAT PUMP VS GAS FURNACE WITH CENTRAL AIR CONDITIONER

ANALYSIS DATE APRIL, '87 ECONOMIC LIFE 15 YEARS PREPARED BY ______

1. INVESTMENT
   A. CONSTRUCTION COST $ -290 (ITEMS a AND b, TABLE 15 − ITEMS a, b, c, AND D, TABLE 18)
   B. SIOH $ INCLUDED IN A
   C. DESIGN COST $ ______
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ ______
   E. SALVAGE VALUE -$ ______
   F. TOTAL INVESTMENT (1D−1E) $ -290[a]

2. ENERGY SAVINGS (+) / COST (−)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST \$/MBTU(1) (ITEM d, EX. 1, 7.1.1)	SAVINGS MBTU/YR(2) (ITEM C, EX. 1, 7.1.2 − ITEM C, EX. 1, 7.1.3) + 3413	ANNUAL \$ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELEC	\$0.01649	-19795.4	\$ -326.4	8.54	\$ -2787
B. DIST	\$		\$		\$
C. RESID	\$		\$		\$
D. NG	\$0.0044	42000	\$ 184.8	13.09	\$ 2419
E. COAL	\$		\$		\$
F. TOTAL		22204.6	\$ -141.6		---------->\$ -368

3. NON ENERGY SAVINGS(+) / COST(−)
   A. ANNUAL RECURRING (+/−) (MAINTENANCE) $ -56.2 (ANNUAL AVERAGE)
      (1) DISCOUNT FACTOR (TABLE A) 9.11
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -512 (ITEM e, TABLE 18 − ITEM C, TABLE 15)

   B. NON RECURRING SAVINGS(+) / COST(−)

ITEM	SAVINGS(+) COST (−)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(−)(4)
a.	\$			\$
b.	\$			\$
c.	\$			\$
d. TOTAL	\$			\$

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(−) (3A2+3Bd4) $ -512

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ ______
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ______
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ ______

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ -880[a]

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= ______

a. IT WILL COST $880 TO SAVE $290 IF HEAT PUMP IS USED INSTEAD OF GAS FURNACE WITH CENTRAL AIR CONDITIONER.

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: *Ft. Belvoir, VA.* REGION NO. *3* PROJECT NUMBER ________

PROJECT TITLE *Application of Heat Pumps on Army Facilities* FISCAL YEAR ________

DISCRETE PORTION NAME *Heat Pump vs Electric Furnace with Central Air Conditioner*

ANALYSIS DATE *April, 87* ECONOMIC LIFE *15* YEARS PREPARED BY ________

1. INVESTMENT
   - A. CONSTRUCTION COST $ *110* *(Items a and b, Table 16 − Items a, b, and c, Table 13)*
   - B. SIOH $ *Included in A*
   - C. DESIGN COST $________
   - D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $________
   - E. SALVAGE VALUE −$________
   - F. TOTAL INVESTMENT (1D−1E) $ *110*

2. ENERGY SAVINGS (+) / COST (−)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
	(Item d, Ex. 2, 7.1.1)	*(Item c, Ex. 2, 7.1.1 − Item c, Ex. 2, 7.1.2) → 3413*			
A. ELEC	$ *0.01823*	*13505.2*	$ *246.2*	*9.03*	$ *2223*
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$		$		$
E. COAL	$		$		$
F. TOTAL		*13505.2*	$ *246.2*	---------->	$ *2223*

3. NON ENERGY SAVINGS(+) / COST(−)
   - A. ANNUAL RECURRING (+/−) *(Maintenance)* $ *−57* *(Annual average)*
     - (1) DISCOUNT FACTOR (TABLE A) *9.11*
     - (2) DISCOUNTED SAVING/COST (3A X 3A1) $ *−523* *(Item d, Table 13 − Item c, Table 16)*
   - B. NON RECURRING SAVINGS(+) / COST(−)

ITEM	SAVINGS(+) COST (−)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(−)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

   - C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(−) (3A2+3Bd4) $ *−523*
   - D. PROJECT NON ENERGY QUALIFICATION TEST
     - (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ *734*
       - a IF 3D1 IS = OR > 3C GO TO ITEM 4
       - b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ________
       - c IF 3D1b IS = > 1 GO TO ITEM 4
       - d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ *189*

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ *1700*

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= *15.45*

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Ft. BELVOIR, VA REGION NO. 3 PROJECT NUMBER ____

PROJECT TITLE APPLICATION OF HEAT PUMPS ON ARMY FACILITIES FISCAL YEAR ____

DISCRETE PORTION NAME HEAT PUMP VS GAS FURNACE WITH CENTRAL AIR CONDITIONER

ANALYSIS DATE APRIL, '87 ECONOMIC LIFE 15 YEARS PREPARED BY ____

1. INVESTMENT
   A. CONSTRUCTION COST $ -410 (ITEMS a AND b, TABLE 16 – ITEMS a, b, c, AND d, TABLE 19)
   B. SIOH $ INCLUDED IN A
   C. DESIGN COST $ ____
   D. ENERGY CREDIT CALC (1A+1B+1C)X.9 $ ____
   E. SALVAGE VALUE -$ ____
   F. TOTAL INVESTMENT (1D-1E) $ -410 [a]

2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
	(ITEM d, EX. 2, 7.1.1)	(ITEM c, ELEC, EX. 2, 7.1.3 – ITEM c, EX. 2, 7.1.2) × 3,413			
A. ELEC	$0.01823	-21979.7	$ -400.7	9.03	$ -3618
B. DIST	$		$		$
C. RESID	$		$		$
D. NG	$0.0049	50386	$ 250.4		$ 3278
E. COAL	$		$		$
F. TOTAL	(ITEMS d AND c, EX. 2, 7.1.3)	28407	$ -150.3		---------->$ -340

3. NON ENERGY SAVINGS(+) / COST(-)
   A. ANNUAL RECURRING (+/-) (MAINTENANCE) $ -56.2 (ANNUAL AVERAGE)
      (1) DISCOUNT FACTOR (TABLE A) 9.11
      (2) DISCOUNTED SAVING/COST (3A X 3A1) $ -512 (ITEM e, TABLE 19 – ITEM c, TABLE 16)

   B. NON RECURRING SAVINGS(+) / COST(-)

ITEM	SAVINGS(+) COST (-)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS(+) COST(-)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

   C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(-) (3A2+3Bd4) $ -512

   D. PROJECT NON ENERGY QUALIFICATION TEST
      (1) 25% MAX NON ENERGY CALC (2F5 X .33) $ ____
         a IF 3D1 IS = OR > 3C GO TO ITEM 4
         b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F= ____
         c IF 3D1b IS = > 1 GO TO ITEM 4
         d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d ÷ YEARS ECONOMIC LIFE) $ -852 [a]

5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ ____

6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY) (SIR)=(5÷1F)= ____

a. IT WILL COST $852 TO SAVE $410 IF HEAT PUMP IS USED INSTEAD OF GAS FURNACE WITH CENTRAL AIR CONDITIONER.

APPENDIX F

EXAMPLES OF HVAC LIFE-CYCLE COST ANALYSIS

Tables F.1 through F.9 illustrate the application of the methodology developed in this report for calculating life-cycle costs of alternative HVAC systems. Life-cycle costs are estimated for nine sample cases involving three different HVAC systems installed in applications at three climatic locations in houses of varying size and insulation level. The three HVAC systems are an electric furnace with central air conditioner, a high-efficiency air-to-air heat pump, and a gas furnace with central air conditioner. The results of these nine sample calculations (see Table F.10) display the effects of climate and house construction on life-cycle costs.

Table F.10 shows that the gas furnace and central air conditioner system exhibits the lowest life-cycle costs and that the air-to-air heat pump is a close second. In the northern United States, where winter heating loads are high (e.g. Rapid City, South Dakota), the gas furnace system is advantageous because of the lower cost of natural gas relative to electricity. Because energy costs are the most important component of the life-cycle cost of HVAC systems, the life-cycle cost advantage of a given HVAC system over another system using a different fuel depends strongly upon the relative cost of the two fuels.

Table F.1. Estimated life-cycle cost for system 1 (electric furnace with central air conditioner at Ft. Bragg, North Carolina[a])

Item	Basis of estimation	Cost (1987 $)
	Equipment cost	
Electric furnace	Appendix A (34,000 Btu/h) and Table 4	380
Central air conditioner	Appendix A (35,600 Btu/h) and Table 3	1580
	Installation cost	
Electric furnace and air conditioner	Table 7	540
	Maintenance cost	
Current worth	Table 8	295
	Energy cost	
Current worth	Sect. 7.1.1, example 1.	6250
Life-cycle cost		9045

[a] For an 1800-ft^2 house with insulation level 1.

Table F.2. Estimated life-cycle cost for system 1 (electric furnace with central air conditioner at Ft. Belvoir, Virginia[a])

Item	Basis of estimation	Cost[b] (1987 $)
	Equipment cost	
Electric furnace	Appendix A, Table B.4, Appendix B and Table 4 (34,000 Btu/h)	380
Central air conditioner	Appendix A and Table 3 (25,000 Btu/h)	1280
	Installation cost	
Electric furnace and air conditioner	Table 7	420
	Maintenance cost	
Current worth	Table 8	295
	Energy cost	
Current worth	Sect. 7.1.1, example 2	6971
Life-cycle cost		9346

[a] For a 1400-ft^2 house with insulation level 2.

Table F.3. Estimated life-cycle cost for system 1 (electric furnace with central air conditioner at Rapid City, South Dakota[a])

Item	Basis of estimation	Cost[b] (1987 $)
	Equipment cost	
Electric furnace	Appendix A, Table B.4 Appendix B, and Table 4 (51,000 Btu/h)	430
Central air conditioner	Appendix A and Table 3 (35,600 Btu/h)	1580
	Installation cost	
Electric furnace and air conditioner	Table 7	540
	Maintenance cost	
Current worth	Table 8	295
	Energy cost	
Current worth	Sect. 7.1.1, example 3	9590
Life-cycle cost		12,435

[a] For a 2200-ft^2 house with insulation level 4.

Table F.4. Estimated life-cycle cost for system 2 (high-efficiency heat pump at Ft. Bragg, North Carolina[a])

Item	Basis of estimation	Cost[b] (1987 $)
	Equipment cost	
Split air-to-air heat pump	Appendix A and Table 2 (35,200-Btu/h cooling capacity)	2190
	Installation cost	
Heat pump	Table 7	540
	Maintenance cost	
Current worth	Table 9	797
	Energy cost	
Current worth	Sect. 7.1.2, example 1	4568
Life-cycle cost		8095

[a] For an 1800-ft^2 house with insulation level 1.

Table F.5. Estimated life-cycle cost for system 2 (high-efficiency heat pump at Ft. Belvoir, Virginia[a])

Item	Basis of estimation	Cost (1987 $)
	Equipment cost	
Split air-to-air heat pump	Appendix A and Table 2 (24,200-Btu/h capacity)	1770
	Installation cost	
Heat pump	Table 7	420
	Maintenance cost	
Current worth	Table 9	797
	Equipment cost	
Current worth	Sect. 7.1.2, example 2	4749
Life-cycle cost		7736

[a] For a 1400-ft^2 house with insulation level 2.

Table F.6. Estimated life-cycle cost for system 2 (high-efficiency heat pump at Rapid City, South Dakota[a])

Item	Basis of estimation	Cost (1987 $)
	Equipment cost	
Split air-to-air heat pump	Appendix A and Table 2 (35,200-Btu/h cooling capacity)	2190
	Installation cost	
Split air-to-air heat pump	Table 7	500
	Maintenance cost	
Current worth	Table 9	797
	Energy cost	
Current worth	Sect. 7.1.2, example 3	7248
Life-cycle cost		10,735

[a] For a 2200-ft^2 house with insulation level 4.

Table F.7. Estimated life-cycle cost for system 3 (gas furnace with central air conditioner at Ft. Bragg, North Carolina[a])

Item	Basis of estimation	Cost (1987 $)
	Equipment cost	
Gas furnace	Appendix A and Table 5 (64,000-Btu/h capacity)[b]	800
Central air conditioner	Appendix A and Table 3 (35,600-Btu/h cooling capacity)	1580
	Installation cost	
Gas furnace		100
Central air Conditioner	Table 7	540
	Maintenance cost	
Current worth	Table 10	306
	Energy cost	
Current worth	Sect. 7.1.3, example 1	4198
Life-cycle cost		7524

[a] For an 1800-ft^2 house with insulation level 1.
[b] If a smaller unit with the same efficiency is available, it should be used in the analysis.

Table F.8. Estimated life-cycle cost for system 3 (gas furnace with central air conditioner at Ft. Belvoir, Virginia[a])

Item	Basis of estimation	Cost (1987 $)
	Equipment cost	
Gas furnace	Appendix A, Table B.4, Appendix B and Table 5 (64,000-Btu/h capacity)[b]	800
Central air conditioner	Appendix A and Table 3 (25,000-Btu/h cooling capacity)	1280
	Installation cost	
Gas furnace		100
Central air conditioner	Table 7	420
	Maintenance cost	
Current worth	Table 10	306
	Life-cycle energy cost	
Current worth	Sect. 7.1.3, example 2	4354
Life-cycle cost		7260

[a] For a 1400-ft^2 house with insulation level 2.
[b] If a smaller unit with the same efficiency is available, it should be used in the analysis.

Table F.9. Estimated life-cycle cost for system 3 (gas furnace with central air conditioner at Rapid City, South Dakota[a])

Item	Basis of estimation	Cost (1987 $)
	Equipment cost	
Gas furnace	Appendix A, Table B.4 Appendix B and Table 5 (64,000-Btu/h capacity)[b]	800
Central air conditioner	Appendix A and Table 3 (35,600-Btu/h capacity)	1580
	Installation cost	
Gas furnace		100
Central air conditioner	Table 7	540
	Maintenance cost	
Current worth	Table 10	306
	Life-cycle energy cost	
Current worth	Sect. 7.1.3, example 3	5327
Life-cycle cost		8653

[a] For a 2200-ft^2 house with insulation level 4.
[b] If a smaller unit with the same efficiency is available, it should be used in the analysis.

Table F.10. Life-cycle costs for the three HVAC systems

HVAC system	1800-ft^2, L-1 House 1 (Ft. Bragg, N.C.)	1400-ft^2, L-2 House 2 (Ft. Belvoir, Va.)	2200-ft^2, L-4 House 3 (Rapid City, S.D.)
1 (EFAC)	$9,045 (Table F.1)	$9,346 (Table F.2)	$12,435 (Table F.3)
2 (AAHP)	$8,095 (Table F.4)	$7,736 (Table F.5)	$10,735 (Table F.6)
3 (GFAC)	$7,524 (Table F.7)	$7,260 (Table F.8)	$8,653 (Table F.9)

EFAC = Electric furnace and central air conditioner.
AAHP = High-efficiency air-to-air heat pump.
GFAC = Gas furnace and central air conditioner.

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