ENERGY CONSERVATION

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ENERGY CONSERVATION OPPORTUNITIES IN COMMERCIAL APPLIANCES

December 1978

Prepared By

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Work Performed For
Oak Ridge National Laboratory
Operated By
Union Carbide Corporation
For The

U. S. DEPARTMENT OF ENERGY

Division of Buildings and Community Systems

Thermo Electron
CORPORATION

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FINAL REPORT

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1. INTRODUCTION

It has been estimated that, in 1975, the commercial sector of the United States consumed approximately 20 percent (6882 trillion Btu) of the combined total energy utilized in the residential, commercial, and industrial sectors. Since the energy consumption in the commercial sector is substantial, the Department of Energy (DOE), formerly the Energy Research and Development Administration (ERDA), is prepared to sponsor research, development, and demonstration programs that will promote energy conservation. To assist in planning and setting priorities for programs in the commercial appliance field, a comprehensive data base of appliances used in the commercial sector is required, along with an analysis and evaluation of the data base to ascertain present and future energy consumption. Specific opportunities for the development of energy-saving devices must then be identified where DOE RD&D funding can most effectively promote the use of more efficient equipment to achieve energy savings of national significance.

To assist DOE in its efforts, Thermo Electron Corporation has been contracted (UCC-ND Contract No. 7261) to accomplish the following objectives in a study program monitored by the Union Carbide Corporation, Oak Ridge National Laboratory Technical Manager (ORNL-TM):

- Establish and provide a comprehensive data base of the appliances used in the commercial sector that consume a significant amount of energy (electricity, oil, or gas).
- Identify specific opportunities where DOE RD&D funding can promote the use of more efficient commercial equipment to achieve energy savings of national significance.

- Establish a method of rating the specific development opportunities.

These objectives are detailed in the project's Scope of Work presented in Appendix E.

The following report presents the results obtained in an effort to fulfill the above listed objectives. In this report a comprehensive data base of 45 commercial appliance types and their energy use is presented. Additionally, over 30 opportunities for development of energy savings equipment have been identified and evaluated for future DOE consideration. The opportunities were identified by means of literature search and contact with industry representatives. Since unavailable information (proprietary concepts) could not be included, it is felt that the opportunity list is not complete.

We believe that the assumptions and computations used result in a report that realistically reflects the inventory and energy consumption trends by equipment in each of the functional use/fuel type combinations. Additionally, this report reflects a realistic estimate of potential energy savings for the identified present and planned appliance development opportunities.

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2. SUMMARY

The purpose of this study is to establish a data base of energy-consuming appliances in the commercial sector, and to identify and rate the most promising development opportunities that would save significant amounts of energy on a national level. In the process of conducting this study, a detailed national inventory of 45 major appliances and their energy consumption was established for the year 1975. The data base was established for the year 1975 since this was the latest year in which accurate shipping information was available. Additionally, 34 potential appliance improvements were identified, evaluated, and ranked.

For the purposes of this study, the commercial sector is defined in terms of the divisions prescribed in the S.I.C. Manual (1972) of the Office of Management and Budget. These are shown in Table 2.1; however, due to the availability of information used in estimating the appliance energy consumption, these groups were recombined into the commercial subsectors shown below.

• Communications	E-48
• Utilities	E-49
• Wholesale	F
• Retail	G
• Finance, Insurance, Real Estate, Services	H&I (70-79, 81, 83-89)
• Hospital	I-80
• Schools	I-82
• Public Administration	J

TABLE 2.1

COMMERCIAL SECTOR: DIVISIONS AND MAJOR GROUPS FROM STANDARD INDUSTRIAL CLASSIFICATION MANUAL

Parts of Division E.	Transportation, communications, electric, gas, and sanitary services	
	Major Group 48.	Communication
	Major Group 49.	Electric, gas, and sanitary services
Division F.	Wholesale trade	
	Major Group 50.	Wholesale trade – durable goods
	Major Group 51.	Wholesale trade – nondurable goods
Division G.	Retail trade	
	Major Group 52.	Building materials, hardware, garden supply, and mobile home dealers
	Major Group 53.	General merchandise stores
	Major Group 54.	Food stores
	Major Group 55.	Automotive dealers and gasoline service stations
	Major Group 56.	Apparel and accessory stores
	Major Group 57.	Furniture, home furnishings, and equipment stores
	Major Group 58.	Eating and drinking places
	Major Group 59.	Miscellaneous retail
Division H.	Finance, insurance, and real estate	
	Major Group 60.	Banking
	Major Group 61.	Credit agencies other than banks
	Major Group 62.	Security and commodity brokers, dealers, exchanges, and services
	Major Group 63.	Insurance
	Major Group 64.	Insurance agents, brokers, and service
	Major Group 65.	Real estate
	Major Group 66.	Combinations of real estate, insurance, loans, law offices
	Major Group 67.	Holding and other investment offices
Division I.	Services	
	Major Group 70.	Hotels, rooming houses, camps, and other lodging places
	Major Group 72.	Personal services
	Major Group 73.	Business services
	Major Group 75.	Automotive repair, services, and garages
	Major Group 76.	Miscellaneous repair services
	Major Group 78.	Motion pictures
	Major Group 79.	Amusement and recreation services, except motion pictures
	Major Group 80.	Health services
	Major Group 81.	Legal services
	Major Group 82.	Educational services
	Major Group 83.	Social services
	Major Group 84.	Museums, art galleries, botanical and zoological gardens
	Major Group 86.	Membership organizations
	Major Group 88.	Private households
	Major Group 89.	Miscellaneous services
Division J.	Public administration	
	Major Group 91.	Executive, legislative, and general government, except finance
	Major Group 92.	Justice, public order, and safety
	Major Group 93.	Public finance, taxation, and monetary policy
	Major Group 94.	Administration of human resources programs
	Major Group 95.	Administration of environmental quality and housing programs
	Major Group 96.	Administration of economic programs
	Major Group 97.	National security and international affairs
Division K.	Nonclassifiable establishments	
	Major Group 99.	Nonclassifiable establishments

In this study, the major energy-consuming appliances in the following six functional use categories were identified:

- Space Heating
- Space Cooling
- Water Heating
- Refrigeration
- Cooking
- Lighting

The equipment in these categories, as presented in Section 4, was estimated to consume 87 percent of the total energy used in the commercial sector. The remaining 13 percent of the energy is consumed by equipment such as computers, business machines, laundry equipment, dishwashing, and other food service equipment. In some cases the energy consumption of the equipment was estimated to be insignificant, while in other cases specific information on the equipment was unavailable; therefore, the equipment was not identified in separate categories. This equipment was, however, grouped into a general category entitled, "other."

2.1 APPLIANCE INVENTORY

The national inventory of an appliance was determined by using the annual shipment data for an appliance type and the energy input size that were available from various national trade associations. The annual shipment data were usually presented for only the more recent time interval (e.g., the past 10 years). Discussions with representatives of several leading manufacturers produced a consensus as to when, from a historical standpoint, these appliance types would have been shipped initially. Plotting the actual shipping data and projecting a curve back to the time of zero shipment produced

a graphical function relating the number of units shipped annually versus calendar year. By an accumulation process, the gross number of appliances for any year was realized. Additional information on appliance replacement rate was factored into the accumulation process, resulting in the net number of units in operation during any year. This procedure was followed for each of the 45 major appliances studied. The results of this procedure are summarized in Table 2.2.

In the absence of explicit appliance replacement rate data, it was necessary to estimate replacement rates based on available annual shipping information and estimates of the average useful life. The replacement rate is defined here as the percentage of annual sales that is used to replace wornout equipment (see Appendix B).

2.2 CALCULATED ENERGY CONSUMPTION

The general method used to estimate the annual energy consumption of the appliances considered in the study is described in this section. The annual energy consumption for a specific appliance type was computed by the following relationship:

$$EC = N \times C \times T$$

where

EC = Annual Energy Consumption - Btu/yr

N = National Appliance Inventory - Number of Installed Units

C = Input Capacity - Btu/hr

T = Annual Operating Time - hr/yr

TABLE 2.2

1975 APPLIANCE INVENTORY COMMERCIAL SECTOR

A-2230a-r

Appliance Type	Fuel Type	Size Range (x 10^3 Btu/Hr)	Ave. Size (x 10^3 Btu/Hr)	1975 Inventory (x 10^3)	Replacement Rate	1975 Energy Consumption (x 10^{12} Btu)	
						End Use	Prime
SPACE HEATING							
1. CI Boilers (H.W. & Stm)	G	200-5500	850	501	42	507.2	507.2
2. Unit Heaters	G	25-500	165	1343.7	63	251.3	251.3
3. Duct Furnaces	G	62-500	260	476.7	61	147.5	147.5
4. Warm Air Furnaces	G	150-480	250	347.2	35	102.5	102.5
5. St'l Boilers (H.W. & Stm)	G	500-23,000	5200	11.5	42	94.6	94.6
6. CI Boilers (H.W. & Stm)	O	200-5500	840	466.3	33	504.8	504.8
7. Warm Air Furnaces	O	230-830	450	823.1	60	474.9	474.9
8. St'l Boilers (H.W. & Stm)	O	500-23,000	5000	37.8	49	324	324
9. Unit Heaters	O	100-500	250	89.1	54	22.3	22.3
10. Baseboard Heaters	E	5	5	380.6	33	1.9	6.4
11. Heat Pumps (Sing. & Split)	E	54-250	40	127.6	39	5.65	19.2
12. Unit Heaters	E	10-200	70	409	29	28.8	97.8
AIR CONDITIONING							
13. Direct Absorption (Un.)	G	125-250	180	161.4	40	29	29
14. Direct Absorption (Built Up)	G	600	600	3.9	38	2.3	2.3
15. Indirect Fired Absorp.	G	1200-18,000	6000	8.6	23	38.7	38.7
16. A/C Year Round Unit	E	54-640	60	655.6	37	38.2	129.8
17. A/C Condenser Only	E	54-640	50	1751.6	34	86.1	292.5
18. Horizontal	E	54-640	60	878.6	37	51.1	173.6
19. Heat Pump (Sing. & Split)	E	54-250	40	127.6	39	4.8	16.3
20. Centrifugal Liq. Chill.	E	900-12,000	4000	37.5	30.2	34.3	116.5
21. Reciprocating Liq. Chill.	E	78-1500	240	67.4	13.1	15.9	54
WATER HEATING							
22. Water Heater	G	75-1000	250	805.7	67	536.4	536.4
23. Water Heater	O	200-700	300	155.7	33	136.1	136.1
24. Water Heater	E	150	150	171	40	68.5	232
REFRIGERATION							
25. Ref. Cent. Warehouse Stor.	E	-	-	-	-	114.8	398.9
26. Ref. Display Supermarket	E	2-40	-	-	-	96.9	329.1
27. Ref. Restaurant Stor.	E	2-8	5	1984.8	53	44.5	151.2

TABLE 2.2 (continued)

1975 APPLIANCE INVENTORY COMMERCIAL SECTOR

A-2230b

Appliance Type	Fuel Type	Size Range (x 10^3 Btu/hr)	Ave. Size (x 10^3 Btu/hr)	Replacement Rate	1975 Inventory (x 10^3)	1975 Energy Consumption (x 10^{12} Btu)	
						End Use	Prime
COOKING							
28. Coffee Makers & Urns	G	15-25	20	65	202.0	3.7	3.7
29. Kettle, Cooker & Press. Cooker	G	100-180	140	60	167.2	21.5	21.5
30. Boilers	G	100-120	110	75	129.6	11.9	11.9
31. Fryers	G	100-120	110	71	420.8	42.5	42.5
32. Griddles & Grills	G	80-120	100	63	356.3	32.7	32.7
33. Deck & Convect. Ovens	G	80-140	110	62	429.7	35.3	35.3
34. Ranges & Braising Pans	G	110-170	140	56	392.6	50.5	50.5
35. Coffee Makers & Urns	E	5-15	10	65	360.0	3.2	10.9
36. Kettle, Cooker & Press. Cooker	E	50-90	70	60	75.8	4.7	16.0
37. Broilers	E	50-60	55	75	32.4	1.4	4.8
38. Fryers	E	50-60	55	71	105.2	5.1	17.3
39. Griddles & Grills	E	40-60	50	63	118.7	5.2	17.7
40. Deck & Convect. Ovens	E	40-70	55	62	142.6	5.6	19.0
41. Ranges & Braising Pans	E	55-85	70	56	65.4	4.0	13.6
LIGHTING							
42. Incandescent Lights	E	-	75*	95	670,000	170.7	579.8
43. Fluorescent Lights	E	-	40*	90	585,000	397.6	1350.0
44. Hi Intensity Disch.	E	-	400*	85	20,000	110.6	375.0
45. Metal Halide	E	-	-	-	-	12.3	41.8

G - Natural Gas
E - Electricity
O - Oil

*Listed in terms of "watts"

The appliance operating time for space-heating and cooling equipment was assumed to be dependent upon building type (commercial subsector) and ambient weather conditions (geographical location by census division). This implied that a national appliance inventory (number of units in operation) was needed, together with a means of distributing the equipment to commercial subsectors and census divisions, in order to apply the above relationship. Once this was done, the energy consumption values were summed over all commercial subsectors and census divisions to obtain national totals.

In the absence of an adequate commercial building inventory, it was felt that a meaningful appliance distribution to the various building types would not be possible. However, by using energy consumption ratios that were available from a previous study[7] on the commercial sector, a logical method for distributing the appliance data to the various commercial subsectors and census divisions was devised.

The operating times of space-heating and air-conditioning equipment for various building categories were obtained indirectly from metered operating times of air-conditioning equipment in Chicago, Illinois, and Baltimore, Maryland presented in a building survey study[8] performed by Hittman Associates, which were used to estimate operating times for HVAC equipment. Degree-day maps published by the U.S. Climatic Service were used to determine the average heating and cooling degree days in nine census divisions. Operating times of the equipment in the Baltimore study were adjusted, by the appropriate degree-day ratio, to obtain the corresponding operating time of HVAC equipment in the specified census divisions.

The operating time for the equipment other than heating and air conditioning was presumed to be dependent upon the building use characteristics and independent of the ambient conditions, which assume constant water temperature inlet conditions. Average operating times for water heaters and cooking equipment in various types of businesses are listed in the Gas Engineers Handbook.[12] These values, coupled with information from manufacturers and equipment users, produced a set of operating times for this equipment. A computer program was written to aid the computational process. A summary of the results of the program, listing the computed energy consumption of the six functional uses distributed in the eight commercial subsectors, is presented in Table 2.3. The complete computer output has been reproduced and is presented in Appendix A.

2.3 COMPARISON OF ENERGY CONSUMPTION ESTIMATES

Estimates of energy consumption, based on information obtained from several authoritative sources[*2,3,4,&5] for the commercial sector in 1975, were compared to the energy information generated in the data previously discussed.

The information obtained from these sources led to the estimate that $10,063 \times 10^{12*}$ Btu were consumed by all functional uses in the commercial sector in 1975. Of this total, $7833 \times 10^{12*}$ Btu or 78 percent are accounted for by the calculated energy consumption based on the appliance inventory. The reference source information was broken down into functional use categories, and the values corresponding to the six functional uses considered in this study were extracted. Table 2.4 shows a comparison of energy consumption between the reference source estimates and the calculated estimates for the six functional

*Values based on prime energy.

TABLE 2.3

ENERGY CONSUMPTION BY COMMERCIAL SECTOR
AND FUNCTIONAL USE (TRILLION BTU)

1975

A-2231

	Natural Gas				Petroleum		Electricity					
	Space Heat	A/C	Water Heat	Cook	Space Heat	Water Heat	Space Heat	A/C	Water Heat	Refrig.	Cook	Light
Communication	6.8	0.5	1.56	-	9.6	0.5	0.25	2.53	0.2	-	-	-
Utility	7.8	0.7	1.89	-	7.2	0.4	0.23	3.4	0.3	-	-	-
Wholesale	136.6	3.5	3.11	-	52.6	0.96	15.7	11.2	0.4	114.8	-	-
Retail	154.3	9.2	141	150.3	105.3	4.98	7.26	163.9	17.9	91.6	33	-
Services	156.2	13.3	123.7	-	134.5	34	7.21	98.4	15.7	-	-	-
Hospitals	183.4	7.1	107.5	51.3	262.8	35.4	2.6	43.4	13.6	44.5	-	-
Schools	188.7	15.4	93.5	-	263.6	31.8	2.53	32.8	11.8	-	-	-
Public Admin.	269.5	20.3	64.1	1.3	490.3	28	3.63	55	8.1	-	-	-
Total	1103.3	70	536.4	202.9	1326	136	36.4	410.6	68	250.9	33	692
	Total Gas = 1912				Total Oil = 1462		Total Electricity = 1491					

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TABLE 2.4

1975 COMMERCIAL ENERGY CONSUMPTION
REFERENCE SOURCE AND
CALCULATED (TRILLION BTU)

A-2232r

	Total		Nat. Gas		Electricity		Petroleum	
	Ref.*	Cal.**	Ref.	Cal.	Ref.	Cal.	Ref.	Cal.
Space Heating	3430	2465	1207	1103	128	36	2095	1326
A/C	533	300	124	70	409	230	-	-
Water Heating	649	740	544	536	105	68	-	136
Refrigeration	221	251	-	-	221	251	-	-
Cooking	196	236	196	203	-	33	-	-
Lighting	612	692	-	-	612	692	-	-
TOTAL	5641	4684	2071	1912	1475	1310	2095	1462
% of Total Accounted for	83		92		89		70	

Sources of Information

- Private Communication with AGA
- AGA Gas Facts, 1975
- EEI Statistical Year Book, 1975
- Private Communication with N.E. Fuel Oil Association
- ACHV - Statistical Panorama, 1975
- U.S. Bureau of Mines - Mineral Survey, 1975

*Ref. = Reference information based on the sources listed above.

**Cal. = Calculated information arrived at in this study.

categories. This table indicates, based on prime energy, that in these functional categories the study accounted for 85 percent of the reference values.

2.4 PROJECTED APPLIANCE INVENTORY - 1990

The 1975 appliance inventory and energy consumption was projected to the year 1990 as shown in Table 2.5. This projection was performed first to establish a ranking of the major energy-consuming appliances as indicated in Table 2.5. Additionally, this projection was made to establish a baseline for potential energy savings. This baseline established the maximum potential market for both retrofit and new-sale energy-saving equipment.

In making the projections, it was assumed that the average annual sales of equipment from 1974 to 1976 were to be constant. The equipment sales were then divided, by using the calculated replacement rates, into replacement and new market sales to compute the increase in inventory. One purpose of these projections was to establish the baseline of energy consumption if efficiency improvements were not made to equipment. Therefore, the unit energy consumption of equipment in 1975 was assumed to be constant.

2.5 IDENTIFICATION OF ENERGY SAVINGS OPPORTUNITIES

The objective of this effort was to identify present or on-going and planned commercial appliance development programs as they relate to energy conservation. Appropriate information, such as anticipated efficiencies, cost premium, development time, etc., for these developments were identified. Table 2.6 summarizes some of the appliance improvement opportunities that could be applied to commercial equipment, either in new or retrofit application, to reduce

TABLE 2.5

PROJECTED DATA BASE
(1990)

A-2199

	Appliance Type	Fuel Type	Ave Annual New Sales $\times 10^3$	Annual Growth Rate %	Ave Size of Unit Btu/hr $\times 10^3$	1980 Inventory $\times 10^3$	Unit Energy Consumption Btu $\times 10^9$	Total Sales 1980 1990 $\times 10^3$	1990 Inventory $\times 10^3$	1990 Energy Consumption End Use Btu $\times 10^{12}$	1990 Energy Consumption Prime Btu $\times 10^{12}$	Ranking - Based on End Use	Ranking - Based on Prime
1	CI Boilers (HW & Stm)	G	12.8	1.34	850	536.0	1.01	128	605.1	612.7	612.7	5	7
2	Unit Heaters	G	70.7	1.96	165	1478.0	0.19	707	1740.0	326.1	326.1	7	13
3	Duct Furnace	G	19.1	1.56	260	514.9	0.31	191	589.4	182.4	182.4	11	19
4	Warm Air Furnace	G	21.3	4.0	250	423.5	0.295	213	561.5	165.7	165.7	12	21
5	St'l Boilers (HW & Stm)	G	0.4	2.0	5000	12.6	8.23	4	14.9	122.6	122.6	17	22
6	CI Boilers (HW & Stm)	O	18.3	2.6	840	531.5	1.13	183	654.1	714.4	714.4	3	5
7	Warm Air Furnaces	O	41.1	2.0	450	905.4	0.58	411	1069.8	617.3	617.3	4	6
8	St'l Boilers (HW & Stm)	O	1.2	1.6	5000	40.9	8.55	12	47.0	401.8	401.8	6	10
9	Unit Heaters	O	6.4	3.3	250	105.1	0.25	64	134.5	33.6	33.6	30	32
10	Baseboard Heaters	E	26.7	4.7	5	479.5	0.004	267	658.4	3.0	10.2	43	41
11	Heat Pump (Single & Split)	E	22.3	17.5	40	285.8	0.044	223	508.8	22.5	76.4	32	25
12	Unit Heaters	E	41.5	0.1	70	413.0	0.07	415	707.6	49.6	168.5	28	20
13	Direct Absorption (Un.)	G	14.5	5.4	180	209.8	0.18	145	296.8	53.3	53.3	26	29
14	Direct Absorption (Built Up)	G	0.21	3.3	600	4.6	0.59	2.1	6.0	3.5	3.5	42	44
15	Indirect Fired Absorption	G	0.43	4.6	6000	9.0	5.3	4.3	12.3	65.2	65.2	22	27
16	A/C Year Round Unit	E	64.1	6.2	60	885.0	0.058	641	1288.8	75.0	254.8	20	15
17	A/C Condenser Only	E	142.2	5.3	50	2259.5	0.049	1432	3198.5	157.1	533.6	13	8
18	Horizontal	E	74.2	5.3	60	1133.3	0.058	742	1600.8	93.1	316.2	18	14
19	Heat Pump (Single & Split)	E	22.2	10.7	40	211.8	0.038	222	346.8	13.0	44.2	34	31
20	Centrifugal Liquid Chiller	E	2.4	4.5	4000	46.9	0.914	24	63.7	58.0	197.0	24	18
21	Reciprocating Liquid Chiller	E	6.2	8.0	650	99.1	0.235	62	153.0	36.0	122.3	29	23
22	Water Heater	G	71.2	2.9	250	926.5	0.666	712	1161.5	773.8	773.8	2	4
23	Water Heater	O	8.0	3.4	300	183.7	0.785	80	237.3	202.6	202.6	10	16
24	Water Heater	E	23.0	7.5	150	246.2	0.40	230	375.2	150.3	510.5	16	9
25	Ref. Cent. Warehouse Stor.	E								(114.5)	388.9	14	11
26	Ref. Display Supermarket	E								(96.9)	329.1	15	12
27	Ref. Restaurant Stor.	E	107.0	2.7	5	2262.6	0.02	1270	2765.6	60.9	206.9	23	17
28	Coffee Makers & Urns	G	23.0	3.9	20	244.4	0.018	230	324.9	5.8	5.8	40	43
29	Kettle, Cooker & Pres. Ck	G	12.4	3.1	140	193.9	0.128	124	243.5	31.2	31.2	31	33
30	Broilers	G	20.1	4.2	110	159.4	0.091	200	209.6	19.2	19.2	33	39
31	Fryers	G	55.3	4.1	110	513.3	0.100	553	673.6	67.8	67.8	21	26
32	Griddles & Grills	G	37.3	4.1	100	434.6	0.091	373	572.6	52.3	52.3	27	30
33	Deck & Convect. Ovens	G	36.9	3.7	110	515.6	0.082	367	655.8	53.7	53.7	25	28
34	Ranges & Braising Pans	G	34.7	3.1	140	455.4	0.128	347	608.0	78.3	78.3	19	24
35	Coffee Makers & Urns	E	46.1	4.2	10	442.8	0.008	461	604.1	5.1	17.3	41	40
36	Kettle, Cooker & Pres. Ck	E	5.7	3.1	70	87.9	0.062	57	110.7	6.8	23.1	38	37
37	Broilers	E	5.1	4.2	55	39.8	0.043	51	52.5	2.2	7.5	44	42
38	Fryers	E	18.4	4.7	55	132.5	0.048	53	185.8	8.9	30.2	35	34
39	Griddles & Grills	E	12.4	4.1	50	144.8	0.044	124	190.6	8.3	28.2	36	35
40	Deck & Convect. Ovens	E	6.3	3.7	55	171.1	0.039	63	195.0	7.6	25.8	37	36
41	Ranges & Braising Pans	E	5.9	2.4	70	73.9	0.061	59	99.8	6.0	20.4	39	38
42	Incandescent Lights	E	455,600	3.4	75*	790,000	0.25×10^{-3}		1,106,000	282.0	957.9	8	2
43	Fluorescent Lights	E	298,000	5.1	40*	749,000	0.68×10^{-3}		1,233,000	839.0	2849.9	1	1
44	High Intensity Discharge	E	7,000	5.0	400*	25,000	5.5×10^{-3}		42,000	230.0	781.3	9	3

* Listed in watts

G = Gas
E = Electric
O = Oil

TABLE 2.6

SUMMARY
EQUIPMENT IMPROVEMENT CONCEPTS

A-2200r

Improvements	Application	Energy Type	Cost Increase %	Efficiency Improvement	
				Steady State (%)	Operating (%)
Compact Boilers	SH-WH	G-O	0-25	5-15	10-25
Pulse Combustion	SH-WH	G	25-80	10-15	15-25
Heat Pipe Heat Exchanger	SH-WH	G-O	20-25	5-10	5-20
Heat Pipe Furnace	SH	G	5-15	10	20
Heat Pump - Gas	SH	G	100	100	100
Flue Gas Heat Recovery	SH-WH	G-O	10-50	5-15	5-15
Increased Air Flow	SH	G-O	0-5	1-2	1
Heat Pump - Electric	SH-WH	E	50-150	10-100	10-100
Emulsified Fuel	SH-WH	O	15-20	5-10	7
Flue Dampers	SH-WH	G	5-15	0	5-15
Electric Ignition	SH-WH-C	G	5-15	0	1-10
Optimum Sizing	SH	G-O	-30	0	5-10
Power Combustion	SH-WH-C	G	15	10	20
Improved Evap. - Cond. Surface	AC-R	E-G	0-15	5-15	5-15
Improved Evap. - Cond. Capac.	AC-R	E-G	0-20	5-15	5-15
Reduced Storage Temp.	WH	E-G-O	20-100	0-2	5-10
Heat Pipe Water Heater	WH	G	20	10	10-20
Improved Insulation	SH-WH-R	E-G-O	1-10	0.2-10	0.1-10
Hot Gas Line Heat Recovery	WH-R	E	–	–	–
Outside Combustion Air	SH-WH-	G-O	5-10	0	0.5-8
Heat Traps	WH	E	5-10	0	0-2
Burner Modulation	SH-WH	G-O	10-80	0-10	10-20
Thermal Storage	SH-WH-AC	E-G	10-1000	–	–
Wet Condenser	AC-R	E	25	20-40	30-50
High Efficiency Compressors	AC-R	E	0-5	2-7	2-7
Evaporative Coolers	AC-R	E	–	–	–
Improved Refrigerant	AC-R	E-G	–	–	–
Improved Temp. Requirement	R	E-G	0	5-40	5-40
Improved Coatings - Fluorescent Lamps	L	E	40-50	–	7-12
Heat Pipe Oven	C	G	25	15	15
Screw in Fluorescent Lamps	L	E	200	–	150
Heat Pipe Griddle	C	G	25	100	150
Improved Coatings - Incandescent	L	E	–	–	50
Heat Pipe Fryer	C	G	25	50	50

Note 1. G - Gas, O - Oil, E - Electricity
2. SH - Space Heating, WH - Water Heating, AC - Air Conditioning, R - Refrigeration, C - Cooking, L - Lighting
3. The above is only a partial listing of improvement concepts.
4. Operating efficiency is defined as the useful energy output divided by the energy input.
5. Improvements in efficiency are defined as the change in efficiency divided by the original efficiency.

energy consumption. Development opportunities of primary interest to this study relate to the product categories of space heating, water heating, air conditioning, refrigeration, lighting, and cooking.

In general, it was relatively easy to obtain information on completed programs, particularly those under government or utility sponsorship, from published reports and trade journals. Information on current programs was more difficult to obtain and, in the area of private company development, depends on the limited degree to which disclosure is permitted from personal contacts. Information on planned development is almost impossible to obtain; however, it was reasonable to speculate that some available techniques could be applied to appliances of interest to this study.

2.6 BUYER EVALUATION AND SELECTION CRITERIA

The factors that buyers use in selecting energy-consuming equipment for application in commercial buildings is an important requisite for evaluating the sales potential of an appliance improvement opportunity. A review of several studies* together with information supplied by manufacturers and utilities on the buying process used by commercial customers of energy-related equipment led to certain conclusions regarding their selection criteria. It was found that the primary selection criteria could be divided into economic and non-economic factors. The economic factors were found, in most applications, to be the most important factors. The critical economic factors are equipment and installation first costs, and operating cost. These operating costs include preventative and repair maintenance, and fuel cost. The non-economic factors, which include the fuel type, system performance, and equipment

*References Nos. 8, 18, 19, 20, 21.

maintenance, were found to be important but not as critical as the economic factors. A tabulation of the primary selection criteria arranged in their order of importance is presented in Table 2.7. Additionally, from this study[19] of the commercial buying process, the following cost sensitivity relationship for energy-saving equipment was established:

$$MA = [1 - 0.7(PB)(CP)]\,100$$

where

MA = Market Availability, %

PB = Payback Period, years

CP = Cost Premium, (%)/100

2.7 EVALUATION OF ENERGY SAVINGS OPPORTUNITIES

Evaluation of the development opportunities was based primarily on unit energy savings and potential marketability. A development leading to a large improvement in efficiency will have no effect on a national energy savings if it cannot be sold. Conversely, a small efficiency improvement in an appliance that has a large sales potential could significantly improve the national energy utilization.

The cumulative energy savings of a particular development opportunity as it applies to a given appliance type was determined from the following:

TABLE 2.7

PRIMARY SELECTION CRITERIA

Economic Factors	Non-economic Factors
First Cost	Energy Source
• Equipment	• Availability
• Total Installation	• Restrictions
Operating Cost	System Performance
• Annual Maintenance	• Reliability
• Repair Maintenance	• Ease of Operation
• Energy (efficiency; fuel cost)	• Operational Features
	• Equipment Life
• Amortization	Maintenance
	• Ease of Maintenance
	• Service Availability
	• Availability of Parts

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$$CES = UES \sum_{t=t_i}^{t=1990} NS_{(t)}$$

where

CES	=	Cumulative energy savings through the year 1990
UES	=	Unit energy savings of a single appliance
$NS_{(t)}$	=	Market penetration (retrofit, replacement, and new market) through a given year
t_i	=	Year of market introduction $t_i = 1978 + \Delta t$
Δt	=	Time to develop the concept, years

In order to determine $NS_{(t)}$, an accepted equation[22] for market penetration was combined with the cost sensitivity relationship for energy-saving equipment and the sales potential of the conventional equipment to arrive at the following two expressions:

New and Replacement

$$NS_{(N\&R)} = (AS)\ [1 + (t+5)GR]\,[1 - 0.70(CP)\,(PB)]\,[1 - e^{-at}(1 + at)]$$

Retrofit

$$NS_{(RET)} = N_{(80)}(0.15)\ [1 - 0.70(CP)\,(PB)]\,[1 - e^{-at}(1 + at)]$$

where

CP	=	Cost premium, %/100
NS	=	Number of units sold by a given year
GR	=	Annual growth rate in appliance market

AS	=	Average annual sales of conventional equipment
t	=	Time since market introduction in years
N_{80}	=	Predicted 1980 equipment inventory
a	=	Constant = 1.683/HL
HL	=	Time required to reach a sales volume equal to 50% of the maximum potential market
PB	=	Payback Period, years

The effect of DOE's support was factored into the evaluation by estimating an acceleration of the date at which a development would first reach the market. The time required to introduce a new concept into the market, with and without DOE support, was determined by discussions with manufacturers and our engineering judgment. This created a differential in the cumulative energy savings between developments supported by DOE and those not supported by DOE. This differential in the cumulative energy savings of the various development opportunities was used in establishing the final rating for DOE program support.

In the evaluation, each of the appliance types identified in the data base was combined with applicable development opportunities, and the cumulative energy savings for each combination was computed. The results of this computation are presented in Table 9.3 of Chapter 9. To aid in the computational process, a computer program was written and can be seen with its output in Appendix C. The evaluation results of all appliance types utilizing the same development opportunity were added to arrive at the results presented in Table 2.8.

TABLE 2.8

PRIORITY RATINGS FOR POTENTIAL DOE SUPPORT OF ENERGY CONSERVATION OPPORTUNITIES

A-2233r

Concept	Application	Difference in Cumulative (1980-1990) Energy Savings (Btu x 10^{12}) Between DOE Supported and Non-DOE Supported Developments						Priority Ratings For Potential Support Based On Energy Consumption	
		Gas	Oil	Electric		Total			
				Primary	End Use	Prime	End Use	End Use	Prime
Compact Boilers	SH-	56.0	-	-	-	56.0	56.0	7	8
Pulse Combustion	SH-WH	40.3	-	-	-	40.3	40.3	10	12
Heat Pipe Exchanger	SH-WH	3.0	5.4	-	-	8.4	8.4	16	17
Flue Gas Heat Recovery	SH-WH	74.5	88.0	-	-	162.5	162.5	3	4
Heat Pump - Electric	SH-WH	-	-	6.78	2	6.78	2.0	-	19
Flue Dampers	SH-WH	82.6	56.0	-	-	138.6	138.6	4	5
Electric Ignition	SH-WH-C	45.1	-	-	-	45.1	45.1	9	12
Optimum Sizing	SH	81.4	104.0	-	-	185.4	185.4	2	3
Power Combustion	SH-WH-C	280.1	-	-	-	280.1	280.1	1	1
Improved Evap.-Cond. Surface	AC-R	2.3	-	65.4	19.3	67.7	21.6	13	7
Reduced Storage Temp.	WH	-	-	2.4	0.7	2.4	0.7	21	21
Improved Insulation	SH-WH-R	25.14	4.5	15.7	4.6	45.3	34.2	12	11
Outside Combustion Air	SH-WH	27.9	28.0	-	-	55.9	55.9	8	9
Burner Modulation	SH-WH	78.8	43.8	-	-	122.6	122.6	5	6
Wet Condenser	AC-R	-	-	194.2	57.3	194.2	57.3	6	2
High Efficiency Compressors	AC-R	-	-	27.5	8.1	27.5	8.1	17	15
Improved Refrigerant	AC-R	-	-	3.7	1.1	3.7	1.1	20	20
Heat Pipe Furnace	SH	7.0	-	-	-	7.0	7.0	18	18
Emulsified Fuel	SH-WH	-	39.1	-	-	39.1	39.1	11	13
Increased Air Flow	AC	0.54	-	30.2	8.9	30.7	9.4	15	14
Increased Evap.-Cond. Cap.	AC	1.4	-	51.7	15.3	53.1	16.7	14	10
Heat Traps	WH	-	-	2.3	0.69	2.3	0.69	22	22
Improved Coatings - Fluor	L	-	-	13.9	4.1	13.9	4.1	19	16

SH - Space Heating
WH - Water Heating
AC - Air Conditioning
C - Cooking
L - Lighting
R - Refrigeration

3. RECOMMENDATIONS

3.1 RECOMMENDED DEVELOPMENT OPPORTUNITIES

To assist DOE in planning and setting priorities for sponsoring research, development, and demonstration programs in the commercial appliance field, a data base of 45 commercial appliances was established. This data base was analyzed and evaluated to ascertain the present and future energy consumption of each appliance type. A list of the 10 groups of appliances that consume the most energy was established and is presented in Table 3.1 together with their predicted 1990 prime energy consumption. It is recommended that DOE pay particular attention to these appliance areas since they are the greatest energy consumers in the commercial sector.

Thirty-five opportunities for the development of energy-saving devices were also identified. These development opportunities were evaluated from the standpoint of probable market acceptance and areas where DOE funding could be the most effective. Nine of the most promising opportunities are presented in Table 3.2. This list indicates, in order of decreasing importance, the opportunities recommended for DOE support.

It should be recognized that the list presented in Table 3.2 is based on the 35 opportunities that we were able to identify in this study. There are probably other opportunities for development that we were not aware of or for which we could not obtain sufficient information for proper evaluation. This is particularly true in the area of lighting in which several opportunities, identified in Chapter 7 of this report, could not be evaluated due to a lack of information. Therefore, if other opportunities

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TABLE 3.1

THE MAJOR ENERGY-CONSUMING EQUIPMENT IN THE COMMERCIAL SECTOR

	Btu x 10^{12}*
Fluorescent Lamps	2850
Incandescent Lamps	958
High Intensity Discharge Lamps	781
Water Heaters - Gas Fired	774
Cast Iron Boilers - Oil Fired	714
Warm Air Furnaces - Oil Fired	617
Cast Iron Boilers - Gas Fired	613
Air Conditioners - Separate Condenser Units	534
Water Heaters - Electric	511
Steel Tube Boilers - Oil Fired	402

*Projected 1990 prime energy consumption.

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TABLE 3.2

THE MOST PROMISING DEVELOPMENT OPPORTUNITIES*

Powered Combustion - Space Heating, Water Heating, Cooking

Wet Condensers - Air Conditioning, Refrigeration

Optimum Sizing - Space Heating, Water Heating, and Air Conditioning

Flue Gas Heat Recovery - Space Heating, Water Heating, Cooking

Dampers - Space Heating, Water Heating

Burner Modulation - Space Heating, Water Heating

Improved Evaporator - Air Conditioning, Refrigeration

Compact Boilers - Space Heating

Use of Outside Combustion Air - Space Heating, Water Heating

*This list does not include improvements to lighting, the largest energy user, because information needed for evaluation of lighting improvements was not available.

are later identified, they should be evaluated by the procedure described in Chapter 9 and, if necessary, adjustments can be made to the recommended list presented in Table 3.2.

Most of the development opportunities presented in Table 3.2 have been discussed in the literature over the past few years. Still, they have received only limited use in new commercial appliances. This section reviews the approaches in the following format: first, it discusses the advantages that the concept has over conventional equipment. This will be a brief review since it is covered more extensively elsewhere in the report. Second, it discusses the reason for the approach not receiving wider acceptance. Analysis of these reasons for failure can be expected to suggest programs that will result in commercialization of the concept or product, which will then be used to recommend what program support would be desirable from DOE.

The approach then, in summary, is:

- Review what makes the concept desirable.
- Examine the reasons for it not being used extensively.
- Design a program to overcome these problems and to expedite use of the concept.

It should be noted that the development programs recommended here are only a sample of the types of programs that could be conducted. There are probably other programs that could be conducted in the nine areas covered.

3.1.1 Powered Combustion

- Advantages

Use of power combustion systems for gas-fired appliances can reduce standby losses to very low levels, since conventional vent systems are not required. The exfiltration losses common to contemporary appliances can be reduced or eliminated. Additionally, steady-state efficiency is increased because of the lower flue temperature and higher CO_2 levels obtainable with power systems. This also results in less heat-transfer surface being required and, therefore, less inertia in the system and less residual heat to be lost to ambient at the end of a burner-on cycle.

- Constraints

Power combustion systems, except for simple gun-type oil and gas burners, are not generally used in either the residential or commercial appliance markets. Industrial power burner systems are common.

Several factors have been responsible for this situation. The additional control and air-handling components required in power versus atmospheric injection burner systems created a considerable cost premium for the cost of power combustion equipment. To some degree, this situation has been alleviated by spark ignition systems, which are now receiving greater acceptance. This is the largest single factor in the cost premium of power systems.

The complexity of a power system has also created some reluctance to convert from the extremely simple and time-tested atmospheric systems. Also, the availability and reliability of controls

has been questionable. As an example, a simple power combustion system requires a zero governor to maintain a constant air/gas ratio at various external draft conditions. Until recently, only one manufacturer made a unit capable of operation at low gas flow rates. Even that unit had a tendency to drift significantly in delivery pressure. Now, at least three low-capacity zero governors are available, and reliability has been improved considerably.

Component life has been another area of concern. Power combustion systems operate at higher temperatures and with more intense combustion than do atmospheric burner systems. That, together with the number of new components involved, has raised questions concerning the life of those components. This situation has been aggravated by a lack of familiarity of service personnel with such systems.

Finally, some power combustion systems have been plagued with a number of developmental problems, varying from generation of resonant combustion noise to unexpectedly high carbon monoxide emission.

- Program Recommendations

Most of the constraints discussed suggest that some basic design information for power combustion systems is needed. Such a program would be expected to examine the effect of design parameters, such as air-gas ratio, port loading, port depth, and combustion surface type (ribbon, screen, other), on the performance and life of burners. Additionally, noise generation and emissions would be evaluated, as well as methods for assuring reliable ignition.

Essentially, the objective would be to help appliance manufacturers who have limited experience with power combustion systems to increase their confidence in designing these systems, and to assist them in avoiding pitfalls that could result in unacceptable appliance life. This program would also improve understanding of the important design parameters that could be expected to result in lower-cost design.

3.1.2 Wet Condensers

- Advantages

One of two approaches has generally been used for reducing saturation temperature in air-conditioning condenser systems: increasing heat transfer surface, or changing from dry to water-cooled condensers. The advantage of reducing the condensing temperature is, of course, the lower pressure resulting in lower compressor pumping power requirement. This can also be accompanied by longer life for the compressor.

Water-cooled condensers also have the advantage of being relatively insensitive to dry bulb ambient temperature, so that the capacity of the condensing unit is essentially a function of wet bulb temperature. This results in an air-conditioning system that is not so severely oversized at lower-than-design temperatures. It can, therefore, perform more efficiently and provide better comfort levels than can units that deliver too much capacity at off-design conditions.

- Constraints

The first problem encountered in trying to reduce condensing temperatures has generally been cost. Wet systems require more

components than do dry systems and are, therefore, more expensive. Low-temperature dry systems require more heat transfer surface, which means more cost. Additionally, dry systems are limited to condensing temperatures that provide a reasonable-temperature driving force above the standard ambient design temperature, which is usually 95°F.

Wet systems, either spray or shell and tube, are limited by the availability of water and the chemistry of the water, especially its tendency to deposit scale on heat transfer surfaces.

- Program Recommendations

What is required is a program that will result in an air-conditioning condenser system that provides significantly reduced condensing saturation temperature without severe cost penalty and without scaling problems common to wet condensers. Among the candidates that could be considered to accomplish this objective are air systems with improved heat transfer characteristics without proportional increase in pressure drop. Another approach would be to use a disposable wet filter material of the type used in humidifiers or evaporative coolers to evaporate water and thereby lower dry bulb temperature before that air makes contact with the condenser coil. Still another possibility would be to design a compound system that would spray water onto the condenser at any time the condensing temperature exceeds the design saturation temperature. This would provide some of the advantages of water-cooled systems without using as much water and without creating much liming problem.

The work should be directed to any system that could provide improved performance of air-conditioning systems by novel approaches to provide reduced condensing temperatures.

3.1.3 Optimum Sizing

- Advantages

Optimum sizing affects primarily the efficiency of heating equipment. It is, however, also significant in air conditioning and in water heating. For heating equipment located inside the heated space, optimum sizing reduces exfiltration losses from the equipment during burner-off periods. The exfiltration losses are a function of vent size, which is determined by unit capacity. Additionally, smaller units operate for longer on-cycles; thus, the amount of time during which standby losses occur is reduced. Since small units have less heat exchanger mass, the amount of residual heat lost in the exchanger at the end of a cycle is less.

For water heaters, a lower input unit has less exposed heat transfer surface. During standby operation, the losses through the flues are determined by the amount of exposed water-backed surface. Therefore, a lower input unit looses less heat. The other part of the standby loss is from the stored water through the insulation and jacket. This loss is determined by the amount of insulated surface area, which is largely a function of tank volume. A reduction in tank volume at a given firing rate will then also reduce losses.

An additional effect that optimum sizing has on heating and air-conditioning equipment is an improvement in temperature and humidity control. This permits the use of lower temperatures in winter and higher temperatues in summer, without loss of comfort.

- Constraints

Since it is apparent that optimum sizing will improve efficiency while improving comfort levels, and will also require smaller, less expensive equipment, then why are systems not sized more accurately? The reasons are many. Accurate methods for sizing frequently do not exist. Weather data is available for a large number of cities and towns, but local variations require that some safety margin by allowed. Although the ASHRAE Guide and other references publish information on the thermal conductivity of building materials, actual construction practices can result in considerable variation from these published values. These sizing limitations may require a safety factor of 30 to 50 percent.

Other factors that tend to contribute to oversizing are: the use of whatever size unit is available in the wholesaler's or distributor's warehouse; allowing excess capacity for future expansion; unavailability of the exact size required, especially when one unit serves both heating and air-conditioning functions; and, finally, the tendency to be sure that no callbacks will occur because of insufficient capacity.

- Program Recommendations

The constraints discussed suggest three program areas that would improve appliance sizing in the commercial market .

First, it is necessary to better methods for estimating the required sizes of equipment with information usable by the people who are responsible for making those calculations. This would involve weather data as well as heat loss and gain for commonly used building materials and construction methods.

The subject of modulation to match load will be discussed later, but another method for providing better optimized sizing would be to design appliances that could be safely and easily adjusted in the field to operate at a range of capacities at least 30 percent over or under the nominal capacity. The ability to reset the capacity of the unit would then permit closer matching to the actual requirement.

A more difficult program would be to devise a method to safely accomplish that same type of load matching by resetting the capacity of equipment already installed in the commercial market.

3.1.4 Dampers

- Advantages

There are two types of dampers presently being investigated - vent dampers and flue dampers. Each of these has its particular advantages. Vent dampers are located after the relief opening on a fuel-fired appliance. They serve to block the vent and eliminate the exfiltration of air from the building during the burner-off period. They are effective in increasing the efficiency of space-heating equipment, but do little to reduce the standby losses on water heaters.

Flue dampers, on the other hand, are located in the flue, ahead of the relief opening. Flue dampers can greatly reduce the standby losses and increase the efficiency in water heaters; however, they still allow building air to exfiltrate through the relief opening and are, therefore, not effective on space-heating equipment.

- Constraints

Vent dampers have been developed and are being used on approved residential furnaces. The primary reason that they have not been

employed in commercial-size equipment is the lack of availability. In most cases, present vent dampers are produced by control manufacturers since, for safety purposes, they must tie directly into the control valve. Thus far, these manufacturers have not seen a large enough potential market to develop commercial-size dampers.

Flue dampers, if improperly installed or installed without proper fail-safe devices, could pose a serious safety hazard. Therefore, the manufacturers and the gas industry have been slow to accept flue dampers. A present, the question is in an ANSI committee and final resolution is not anticipated for at least a year. Additionally, since flue dampers must act in conjunction with the controls, the control manufacturers will probably be the ultimate producer. They must, therefore, be convinced of the market potential before entering into the development.

- Program Recommendations

Safety and marketing potential are the two constraints that hamper the use of commercial-size dampers. Therefore, an education program showing the documented advantages in the savings, reliability, and safety of dampers for the commercial sector would encourage their use. To gain this documented information, DOE could sponsor demonstration programs on both vent and flue dampers in space-heating and water-heating equipment. These demonstration programs should be aimed at proving the safety of the dampers and the fuel savings obtained from their use.

3.1.5 Flue Gas Heat Recovery

- Advantages

Flue gas heat recovery systems take normally unavailable energy and transform it into useful energy in the form of air heating or water heating. Flue heat losses can, of course, be reduced in new designed equipment. The heat recovery system has the advantage of being used on new or retrofit applications. It can also be used, as a replacement item, to reduce the flue losses to the ultimate, condensing temperature, without creating a material problem in the main appliance.

- Constraints

Flue gas heat recovery systems are presently being employed on some equipment; however, they have not found general acceptance in the commercial sector, due to the uncertainty of the actual savings that can be realized. Additionally, they have not been used to lower flue temperatures into the condensing mode because of the problems caused by reducing the combustion draft in the basic equipment,

- Program Recommendations

To encourage the use of flue gas heat recovery systems, DOE could sponsor demonstration programs to accurately ascertain the savings afforded by these systems on new and existing equipment. Included in this could be the design of new heat recovery hardware for use in both space-heating and water-heating equipment.

Additionally, a program designed to study the effects of operating in the condensing mode and the resolution of any equipment problems would be of great value. This could be combined with a study to

determine the impact on piping and sewage systems and the problems involved in the disposal of large volumes of acidic condensate.

3.1.6 Burner Modulation

- Advantages

Modulation can be used to match the capacities of central-heating or water-heating systems to the imposed load. For maximum efficiency, it should be combined with a power combustion system. Full modulation could permit heating systems to operate continuously at climatic conditions as low as 10 percent of full load. The cut-off point could be selected to optimize the total saving, balancing the fuel saving against the increased electric power requirements for longer pump or fan operation. The advantages previously discussed for optimum sizing as related to firing rate also apply to modulation. Comfort is improved while energy consumption is reduced.

- Constraints

Several types of modulation were introduced to the appliance market. Their failure to be accepted was the result of several factors. Most were applied to atmospheric injection burner systems. Since only fuel input, and not combustion airflow, was regulated, the increase in excess air during modulation usually resulted in reduced steady-state efficiency. Although off-time exfiltration losses were reduced, this was not a well documented loss factor at that time. Also, because fuel was cheap and the cost of the required control system was high, the resulting payback was poor.

- Program Recommendations

Two systems components are necessary to permit appliances to be designed with a wide modulation range. A burner system is needed that will accommodate the turndown, and a low-cost control system that will provide safe and reliable modulation is required. It would be especially desirable to develop systems for both gas- and oil-fired appliances since each represents a significant portion of the commercial market. It is, therefore, recommended that a program be conducted to develop the required control and burner systems.

3.1.7 Improved Evaporators

- Advantages

Improved evaporator design can provide energy conservation in several ways. A reduction in airflow pressure drop at the same air-conditioning capacity can reduce blower motor power. The blower motor heat is frequently absorbed into the circulating air, so reduction in this power reduces both the electric power input and the load on the evaporator coil.

An improvement in the heat transfer coefficient to the coil surface can permit operation at a lower-temperature driving force between the evaporated refrigerant and the circulating air, while still accomplishing the required cooling and latent heat removal. The resulting higher suction pressure to the compressor inlet results in a reduction in the compressor power requirement.

- Constraints

It is necessary to provide a sufficiently cold evaporator surface to accomplish the necessary latent heat removal. The accepted method

for accomplishing this is to use a finned coil design with a high ratio of fin to prime surface. Although this design has been reasonably successful, it should be possible to remove the condensate from the fins more efficiently so that more bare fin surface is available for heat transfer. This must be accomplished, however, without increased pressure drop. Additionally, manufacturers currently have a considerable investment in equipment to manufacture finned coils. It would, therefore, be desirable, though not essential, to develop improved designs capable of utilizing existing production equipment.

- Program Recommendations

It is recommended that a program be undertaken to develop evaporator coils that can provide the required latent and sensible heat removal, as provided in contemporary designs, while permitting higher hot gas temperatures and compressor inlet pressures. It is anticipated that this will require improved convective heat transfer as well as a new means for removal of condensate from the evaporator coil. Furthermore, it should be accomplished without significant increase in the fluid power requirement for the air handling system. Preference should be given to design approaches that can utilize existing manufacturing equipment.

3.1.8 Compact Boilers

- Advantages

A number of highly efficient compact boilers have been developed for residential applications. Typically, these units use powered combustion with electric ignition systems to provide steady-state efficiencies of approximately 85 percent. Since these boilers contain

only small amounts of water, inertia is low and the combustion system can be actuated from a thermostat demand rather than requiring that the unit maintain water temperature during standby periods. This, of course, improves the seasonal efficiency of the system.

- Constraints

Compact boilers in the larger capacities needed for commercial applications have not been developed. Some installations in older cities presently use steam rather than hot-water heating systems. The compact boilers that have been developed for the residential market are limited to hot-water heating.

Under some conditions, for the more efficient boilers, condensation can occur during startup after long burner-off periods. Design modification is required to handle this situation. If the boiler is located outdoors, as is required in roof-top combination heating-cooling systems, it is necessary to provide for operation with antifreeze solutions.

- Program Recommendations

A program to develop compact, low-inertia boilers in sizes adequate for the commercial market would be useful. Inputs of at least 1,000,000 Btu/hr should be developed for both gas- and oil-fired designs. Additionally, the boilers should be capable of operating as hot-water or steam units. It would also be useful to study improvement beyond 85 percent efficiency by extension into the condensing regime. This poses design problems for the boiler itself, both from heat transfer and from materials compatibility aspects.

3.1.9 Outside Combustion Air

- Advantages

The use of outside combustion air in a balanced flue arrangement on fuel-fired equipment can provide savings in heating and air conditioning. The use of conditioned air for combustion, and the need to recondition this air, is eliminated. Additionally, exfiltration losses of the conditioned air during the burner-off period are also eliminated.

- Constraints

The true effects of savings using a balanced flue system are unknown. The use of outside air during the winter months causes a reduction in the steady-state efficiency of the equipment. Additionally, improper installation of a balanced flue can increase the standby losses in water heaters and boilers. For these reasons, the use of balanced flue systems has been limited.

- Program Recommendations

Since these systems are presently in use, the major roll that DOE could play is in increasing their acceptance. This could be accomplished through an education program defining the net effective savings derived from the use of this type of system. This program should be aimed at contractors and building owners.

3.2 STUDY LIMITATIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

One of the major problems encountered during our quest for relevant information was the varying definition of the commercial sector by different organizations currently compiling data, and by previous

investigators. For the purposes of this study, the commercial sector is defined in terms of the divisions prescribed in the S. I. C. Manual (1972) of the Office of Management and Budget.[1] The appliances were defined in terms of the input size normally found in commercial use, if they were not specifically defined as commercial, such as commercial cooking equipment. Both of these are reasonable definitions of the commercial sector and commercial appliances.

To avoid the confusion created by varying definitions, DOE should set up standard definitions of commercial appliances and the commercial sector and require that all future DOE-sponsored studies adhere to these definitions. Additionally, DOE could request that utilities, trade associations, and manufacturers voluntarily comply with or adapt these definitions in compiling future statistics.

Another area that was found to be lacking was a factual commercial building inventory (size, age/quantity distribution). These basic data would be required to permit appliance distribution to various building types. However, using information from a previous study,[7] we were able to produce a logical distribution of appliances to the various commercial subsectors. The lack of information on commercial building inventory can be rectified by some type of survey, either primary or secondary, to determine the trend of appliance distribution by type, size, and commercial building type. The U. S. Bureau of Census is presently contemplating a primary survey of the commercial sector. A feasibility questionnaire has been sent out to interested parties for comments. This survey is not, however, anticipated before the early part of 1980. A secondary survey could also be conducted through wholesalers/distributors who are knowledgeable

about the building-type installation of appliances. Wholesalers/distributors are emphasized since one of the facts highlighted by this study is that, in general, equipment manufacturers do not know where their equipment is being used.

Since information obtained from these types of surveys would be beneficial to energy conservation programs, DOE should extend efforts to encourage and accelerate their progress.

In spite of some missing information, we were able to piece together large amounts of disparate information in order to produce a meaningful and coherent picture of energy consumption by appliances used in the commercial sector. The following chapters of this report present the results of our study of commercial appliances.

4. ESTIMATES OF COMMERCIAL ENERGY CONSUMPTION

Estimates of end use energy consumption, based on information obtained from several agencies, were established for the commercial sector in 1975 to serve as a reference base for a later comparison of the energy information generated in the data base discussed in Section 5. Additionally, past and present trends in the commercial energy consumption were established to assist in the analysis portion of this study. These estimates of energy consumption are presented in this section together with a discussion of their limitations.

4.1 SOURCES OF INFORMATION

The estimates of energy consumption presented in this section are based on information obtained from several authoritative sources. Information on the consumption of natural gas by year, by class of service, and by geographical region was taken directly from the American Gas Association publication, Gas Facts.[2] The percentage breakdown of gas consumption by functional use was obtained from an internal document supplied by the American Gas Association. All information on electrical energy consumption was derived from the data presented in the Statistical Year Book[3] published by the Edison Electric Institute. The data presented in the Statistical Record under the categories of Small Light and Power, Highway Lighting, Public Authorities, and Interdepartmental Building were assumed collectively to constitute the commercial sector. Information on petroleum consumption was obtained from the U.S. Bureau of Mines publication, Mineral Surveys.[4] However, since neither this nor any other publication breaks down the oil consumption by sector, an assumption was made that 37 percent

of the residual and distillate fuel oil is used in the commercial sector. This assumption was based on information supplied by the New England Fuel Oil Institute concerning the breakdown between commercial and residential oil burner sales and the average size difference between a commercial and residential burner.

The functional breakdown, in percentage, of the three fuels taken collectively was obtained from the Air Conditioning, Heating and Refrigeration News, Statistical Abstract.[5] Estimates of the 1985 energy consumption were obtained by using the Reference Scenario found in the National Energy Outlook.[6]

4.2 ESTIMATED ENERGY CONSUMPTION

Information presented in this section is in the form of end-use energy consumption, except as noted. This was done to be consistent with the reference source information that is taken from metered data. Table 4.1 shows the distribution of energy among the three consuming sections. This information is presented to show the relative importance that in three energy sources have in the three consuming sectors. It will be of importance in the analysis portion of this study, and will be used as a guide in determining the relative significance of an energy-conserving measure.

The 1975 consumption of energy, based on the reference source information, was distributed throughout the nine regional divisions and is presented in Table 4.2. This information was prepared to serve as a comparison for the energy information generated by the data base presented in Section 5.

The distribution of the 1975 commercial energy consumption into the major functional uses is presented in Table 4.3. This table was also prepared as a comparison for the information

TABLE 4.1

ENERGY DISTRIBUTION BY CLASS OF SERVICE
1975
(TRILLIONS OF BTU)

Customer	Petroleum	Natural Gas	Electricity	Total
Industrial	5,635	8,991	2,828	17,454
%	50	55	42	51
Commercial	2,095	2,387	1,643	6,125
%	18.5	15	24	17
Residential	3,568	4,984	2,345	10,897
%	31.5	30	34	32
Total	11,298	16,362	6,816*	34,476

*Prime energy based on a conversion and transmission factor of 11,600 Btu/kWh would be equal to 23,152 x 10^{12} Btu.

TABLE 4.2

COMMERCIAL ENERGY CONSUMPTION
BY SOURCE AND REGION
1975

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Regional Division	Natural Gas*		Electricity**		Petroleum†		Total	% of Total
	10^{12} Btu	%	10^{12} Btu	%	10^{12} Btu	%		
New England	59.9	2.5	73.9	4.5	398.1	19	531.9	8.7
Middle Atlantic	286.4	12.0	235.9	14.4	714.4	34.1	1236.7	20.2
East North Central	744.8	31.2	281.3	17.1	215.8	10.3	1241.9	20.3
West North Central	292.5	12.2	108.9	6.6	83.8	4.0	485.2	7.9
South Atlantic	188.7	7.9	282.8	17.2	456.7	21.8	928.2	15.2
East South Central	111.5	4.7	88.4	5.3	20.9	1.0	220.8	3.6
West South Central	228.1	9.6	198.1	12.1	27.2	1.3	453.4	7.4
Mountain	179.3	7.5	104.7	6.4	25.2	1.2	309.2	5.0
Pacific	295.4	12.4	268.7	16.4	152.9	7.3	717.6	11.7
Total	2386.6		1642.7		2095.0		6124.9	

*American Gas Association

**Edison Electric Institute

†J. Faucett Association

Note: All values listed are end-use consumption for prime energy values of electricity, multiply values by 3.4.

TABLE 4.3

COMMERCIAL ENERGY CONSUMPTION
BY FUNCTION AND FUEL TYPE

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Functional Use	Natural Gas		Electricity		Petroleum		Totals	
	10^{12} Btu	% of Total	10^{12} Btu	% of Total	10^{12} Btu	% of Total	10^{12} Btu	% of Total
		1.						5.
Space Heating	1207	50.6	128	7.8	2095	100	3430	56
Air Conditioning	124	5.2	409	24.9	-	-	533	8.7
Water Heating	544	22.8	105	6.4	-	-	649	10.6
Refrigeration	-	-	221	13.4	-	-	221	3.6
Cooking	196	8.2	-	-	-	-	183	3
Lighting	-	-	612	37.2	-	-	612	10
All Other	315	13.2		10.3	-	-	497	8.1
	2.		3.		4.			
Total Energy	2387	100	1643*	100	2095	100	6125†	100
% of Total	39		26.8		34.2			

1. Private communication with AGA
2. AGA Gas Facts, 1975
3. EEI Statistical Year Book, 1975
4. Estimate Based on Information from N. E. Fuel Oil Assoc.
5. ACHV - Statistical Panorama, 1975.

*Value based on prime energy = 5581 x 10^{12} Btu

†Value based on prime energy = 10,063 x 10^{12} Btu

presented in Chapter 5. In this table it was assumed that 100 percent of the petroleum consumed in the commercial sector was in the form of space heating. Although this assumption is not entirely correct, it is close to reality and the only reasonable assumption to make in the absence of more accurate information.

Information in Table 4.3 is presented for the six functional use categories of:

- Space Heating
- Space Cooling
- Water Heating
- Refrigeration
- Cooking
- Lighting

These categories account for 87 percent of the energy consumed in the commercial sector. The remaining 13 percent of the energy consumption has been grouped into a category entitled "Other." This functional category includes equipment such as computers, business machines, commercial laundry equipment, small food service equipment, etc. Since individual information on this equipment is not available, it is included collectively. The distribution of electrical energy by functional use presented in Table 4.3 was obtained as the difference between the combined source data and that of natural gas and petroleum taken collectively.

An understanding of the historic trends in energy consumption is helpful for predicting the future patterns of energy consumption in the commercial sector. Knowledge of these future trends is useful in

estimating the market penetration and market potential of an energy-conserving appliance, which is discussed in Section 9 of this report. In Table 4.4, the consumption of the three energy sources from 1968 through 1975 is presented together with predicted values for 1985. The 1985 predictions of energy consumption are based on Reference Scenario information found in the National Energy Outlook (NEO). The Reference Scenario is a basic extrapolation of the past trends in energy consumption, which form the baseline for future predictions. Other scenarios presented in the NEO take into consideration factors such as shortage in both gas and oil supply, as well as increased use of nuclear/electric generation. However, as a reasonable approximation of future energy use, the basic extrapolation of the reference scenario was considered adequate for purposes of this study.

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TABLE 4.4

ANNUAL ENERGY CONSUMPTION
COMMERCIAL SECTOR
$\times 10^{12}$ BTU

Year	Natural Gas*	Electricity**	Petroleum	Total
1968	1705	1063	2611	5379
1969	1878	1153	2650	5681
1970	2007	1251	2671	5929
1971	2156	1332	2630	6118
1972	2276	1442	2685	6403
1973	2280	1563	2544	6387
1974	2293	1544	2430	6267
1975	2387	1642	2095	6124
1985†	2538	2175	2488	7201

* American Gas Co. – Gas Facts 1975

** Edison Electric Institute – 1975 Yearbook

† National Energy Outlook

NOTE: To convert the electrical energy consumption values from "end use" to prime energy values, multiply by 3.4.

5. 1975 APPLIANCE AND ENERGY CONSUMPTION DATA BASE

A major effort of this study program was devoted to establishing a national data base of commercial appliances, which includes an inventory of appliances in use and their corresponding energy consumption. More specifically, this inventory and energy consumption information includes the following:

- The quantities of appliances by type, size, and application used in the commercial subsector.
- The end-use unit energy consumption by energy type (gas, electricity, or oil) and by commercial subsector.
- The replacement rates of the appliances by type and size.

The inventory was established for the year 1975 since this was the latest year in which accurate appliance shipping information was available. This appliance shipping information, together with estimates of the appliance useful life and replacement rate, was used to establish the national inventory of appliances. A method, described in Section 5.1.2, was then employed to distribute the inventory among the various commercial subsectors, and estimates were established for the annual operating times by appliance functional use and commercial subsectors.

With the above information, the energy consumption (EC) for a specific appliance was determined by the relationship

$$EC = N \times C \times T$$

where

N = number of appliances in operation

C = input capacity of the appliance

T = annual operating time of appliance.

Since the appliance annual operating time, and consequently the energy consumption, for space heating and air-conditioning equipment are functions of both the building characteristics and the ambient weather conditions, the geographic location must be considered in the appliance distribution. In this study the distribution was made to the nine census divisions noted in Table 5.1.

Table 5.2 presents a summary of the material inventory of appliances and estimates their energy consumption contribution to the commercial sector for 1975. This section of the report presents the results and methods that were used to obtain the inventory and corresponding energy consumption of commercial appliances in the prescribed functional use/fuel type categories.

5.1 SPACE HEATING

5.1.1 Summary of Data

5.1.1.1 Gas Appliances

Table 5.3 lists the pertinent information on gas-fired space-heating equipment compiled for this study. The sum of the energy consumption by appliances (1103 trillion Btu) is approximately 91 percent of the total estimated to be consumed by gas-fired equipment.

Tables 5.4 through 5.9 present individual data on cast iron boilers (hot water), cast iron boilers (steam), unit heaters, duct heaters, warm-air furnaces, and steel tube boilers. These data include the inventory, average annual shipments, and replacement information of each appliance by size category.

TABLE 5.1

CENSUS DIVISIONS (9)*

1. NEW ENGLAND

CONN
ME
MASS
NH
RI
VT

2. MIDDLE ATLANTIC

NJ
NY
PA

3. SOUTH ATLANTIC

DEL
DC
FLOR
GEO
MD
N. CAR
S. CAR
VA
W. VA

4. EAST NORTH CENTRAL

ILL
IND
MICH
OHIO
WISC

5. EAST SOUTH CENTRAL

ALA
KENT
MISS
TENN

6. WEST NORTH CENTRAL

IOWA
KAN
MINN
MISSOURI
NEB
N. DAK
S. DAK

7. WEST SOUTH CENTRAL

ARK
LA
OKLA
TEX

8. MOUNTAIN

ARIZ
COLO
IDAHO
MONT
NEV
NEW MEX
UTAH
WYOM

9. PACIFIC

ALASKA
CAL
OREG
HAW
WASH

*Numerical designations correspond to census divisions in computer printouts.

TABLE 5.2

1975 APPLIANCE INVENTORY COMMERCIAL SECTOR

A-2237a r

Appliance Type	Fuel Type	Size Range ($x 10^3$ Btu/hr)	Ave. Size ($x 10^3$ Btu/hr)	Replacement Rate %	1975 Inventory ($x 10^3$)	1975 Energy Consumption ($x 10^{12}$ Btu)	
						End Use	Prime
SPACE HEATING							
1. CI Boilers (H.W. & Stm)	G	200-5500	850	42	501.0	507.2	507.2
2. Unit Heaters	G	25-500	165	63	1343.7	251.3	251.3
3. Duct Furnace	G	62-500	260	61	476.7	147.5	147.5
4. Warm Air Furnace	G	150-480	250	35	347.2	102.5	102.5
5. St'l Boilers (H.W. & Stm)	G	500-23,000	5200	42	11.5	94.6	94.6
6. CI Boilers (H.W. & Stm)	O	200-5500	840	33	466.3	504.8	504.8
7. Warm Air Furnaces	O	230-830	450	60	823.1	474.9	474.9
8. St'l Boilers (H.W. & Stm)	O	500-23,000	5000	49	37.8	324.0	324.0
9. Unit Heaters	O	100-500	250	54	89.1	22.3	22.3
10. Baseboard Heaters	E	5	5	33	380.6	1.9	6.4
11. Heat Pump (Sing. & Split)	E	54-250	40	39	127.6	5.65	19.2
12. Unit Heaters	E	10-200	70	29	409.0	28.8	97.8
AIR CONDITIONING							
13. Direct Absorption (Un.)	G	125-250	180	40	161.4	29.0	29.0
14. Direct Absorption (Built Up)	G	600	600	38	3.9	2.3	2.3
15. Indirect Fired Absorp.	G	1200-18,000	6000	23	8.6	38.7	38.7
16. A/C Year Round Unit	E	54-640	60	37	655.6	38.2	129.8
17. A/C Condenser Only	E	54-640	50	34	1751.6	86.1	292.5
18. Horizontal	E	54-640	60	37	878.6	51.1	173.6
19. Heat Pump (Sing. & Split)	E	54-250	40	39	127.6	4.8	16.3
20. Centrifugal Liq. Chill.	E	900-12,000	4000	30	37.5	34.3	116.5
21. Reciprocating Liq. Chill.	E	78-1500	240	13	67.4	15.9	54.0
WATER HEATING							
22. Water Heater	G	75-1000	250	67	805.7	536.4	536.4
23. Water Heater	O	200-700	300	33	155.7	136.1	136.1
24. Water Heater	E	150	150	40	171.0	68.5	232.0
REFRIGERATION							
25. Ref. Cent. Warehouse Stor.	E	-	-	-	-	114.8	398.9
26. Ref. Display Supermarket	E	2-40	-	-	-	96.9	329.1
27. Ref. Restaurant Stor.	E	2-8	5	53	1984.8	44.5	151.2

TABLE 5.2 (continued)

1975 APPLIANCE INVENTORY COMMERCIAL SECTOR

A-2237b

Appliance Type	Fuel Type	Size Range ($x 10^3$ Btu/hr)	Ave. Size ($x 10^3$ Btu/hr)	Replacement Rate	1975 Inventory ($x 10^3$)	1975 Energy Consumption ($x 10^{12}$ Btu)	
						End Use	Prime
COOKING							
28. Coffee Makers & Urns	G	15-25	20	65	202.0	3.7	3.7
29. Kettle, Cooker & Press. Cooker	G	100-180	140	60	167.2	21.5	21.5
30. Boilers	G	100-120	110	75	129.6	11.9	11.9
31. Fryers	G	100-120	110	71	420.8	42.5	42.5
32. Griddles & Grills	G	80-120	100	63	356.3	32.7	32.7
33. Deck & Convect. Ovens	G	80-140	110	62	429.7	35.3	35.3
34. Ranges & Braising Pans	G	110-170	140	56	392.6	50.5	50.5
35. Coffee Makers & Urns	E	5-15	10	65	360.0	3.2	10.9
36. Kettle, Cooker & Press. Cooker	E	50-90	70	60	75.8	4.7	16.0
37. Broilers	E	50-60	55	75	32.4	1.4	4.8
38. Fryers	E	50-60	55	71	105.2	5.1	17.3
39. Griddles & Grills	E	40-60	50	63	118.7	5.2	17.7
40. Deck & Convect. Ovens	E	40-70	55	62	142.6	5.6	19.0
41. Ranges & Braising Pans	E	55-85	70	56	65.4	4.0	13.6
LIGHTING							
42. Incandescent Lights	E	-	75	95	670,000	170.7	579.8
43. Fluorescent Lights	E	-	40	90	585,000	397.6	1350.0
44. Hi Intensity Disch.	E	-	400	85	20,000	110.6	375.0
45. Metal Halide	E	-	-	-	-	12.3	41.8

TABLE 5.3

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Space Heat
Fuel Type: Gas
Year: 1975

A-2238r

Appliance Type	Size Range (K-Btu/hr) (Inp. or Outp.)	Inventory (K-units)	Annual Replace. Rate, %	Useful Life (Years)	Energy Consump. (Tril. Btu)	% Total Energy Consump.
Cast Iron Boiler (Hot Water)	200-5500(O)	306.0	30	27.5	249.7	22.6
Cast Iron Boiler (Steam)	200-5500(O)	195.4	54	27.5	257.5	23.3
Unit Heaters	25-500(I)	2584.4	63	17.5	251.3	22.8
Duct Furnaces	62.5-500(I)	476.7	61	17.5	147.5	13.4
Warm Air Furnaces	200-640(O)	347.2	35	17.5	102.4	9.3
Steel Tube Boilers (Steam & Hot Water)	500-23,000(I)	11.5	42	22.5	94.6	8.6
Total					1103.1	

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TABLE 5.4

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Cast Iron Boiler (Hot Water)
Functional Use: Space Heat
Useful Life (Years): 27.5

A-1502rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
200- 250 (O)	146.6	4,710	1,375	29
250- 450	76.6	2,190	660	30
450- 950	50.4	1,050	325	31
950-1,550	17.9	440	110	25
1,550-5,500	14.5	255	105	41
Total	306.0	8,645	2,575	30

*Data obtained from GAMA "Statistical Release of Appliance Shipments" and Hydronics Institute "Ten-Year Summary of Shipments."

Thermo Electron CORPORATION

TABLE 5.5

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Cast Iron Boiler (Steam)
Functional Use: Space Heat
Useful Life (Years): 27.5

A-1503rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
200- 250 (O)	39.7	1,150	450	39
250- 450	55.7	1,140	565	50
450- 950	52.6	1,000	600	60
950-1,550	25.7	510	305	60
1,550-5,500	21.7	300	295	98
Total	195.4	4,100	2,215	54

*Data obtained from Hydronics Institute "Ten-Year Summary of Shipments" and GAMA "Statistical Release of Appliance Shipments."

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TABLE 5.6

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Unit Heater
Functional Use: Gas
Useful Life (Years): 17.5

A-1506rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
25 - 62.5	262.8	13,970	8,790	62.9
62.5-125	707.0	37,400	23,500	62.9
125 -187.2	756.6	39,090	26,000	66.5
187.5-250	432.0	22,830	13,750	60.2
250 -375	352.5	18,630	10,670	57.3
375 -500	73.4	3,970	2,360	59.5
Total	2584.3	135,890	85,070	62.6

*Data obtained from GAMA "Statistical Release of Appliance Shipments."

Thermo Electron CORPORATION

TABLE 5.7

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Warm Air Furnace
Functional Use: Space Heat
Useful Life (Years): 17.5

A-1507rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
200-240 (O)	301.2	18,370	6,470	35.2
240-640	46.0	2,890	960	33.3
Total	347.2	21,260	7,430	35.0

*Data obtained from GAMA "Statistical Release of Appliance Shipments."

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TABLE 5.8

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Duct Furnace
Functional Use: Space Heat
Useful Life (Years): 17.5

A-1508rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
62.5-125 (I)	49.4	1,800	1,225	68.1
125 -187.5	98.9	3,540	2,475	69.9
187.5-250	111.9	4,190	2,700	64.4
250 -375	118.4	6,020	2,885	47.9
375 -500	98.1	3,590	2,350	65.5
Total	476.7	19,140	11,635	61.0

*Data obtained from GAMA "Statistical Release of Appliance Shipments."

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TABLE 5.9

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Steel Tube Boiler (Steam & Hot Water)
Functional Use: Space Heating
Useful Life (Years): 22.5

A-2239r

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
503- 1,676 (O)	1.5	33	26.5	80.3
1,676- 4,190	4.5	126	76.5	61.4
4,190-10,056	4.3	182	60.5	33.3
10,056-23,464	1.2	65	7.0	10.7
Total	11.5	406	170.5	42.0

*Data obtained from American Boiler Manufacturers Association "Annual Statistical Information."

Table 5.10 distributes, as described in Section 5.1.2, the energy consumption for gas space heating among the appliance types and commercial subsectors (see Section 5.1.2).

5.1.1.2 Oil Appliances

Table 5.11 summarizes the information on oil-fired space-heating equipment. The energy consumption attributed to the appliance inventory represents approximately 63 percent of the estimated value. It is assumed that some of this difference can be attributed to duct heaters, for which shipping data could not be located, and to water heating by oil.

Tables 5.12 through 5.14 list specific information on oil-fired warm-air furnaces, cast iron boilers, and steel boilers, respectively. Table 5.15 delineates the appliance energy consumption distribution to the commercial subsectors for cast iron boilers, warm-air furnaces, and steel tube boilers (see Section 5.1.2).

5.1.1.3 Electric Appliances

Recorded in Table 5.16 is the pertinent information on electric space-heating equipment. It lists the equipment inventory and the energy consumption attributed to electric space heating. Tables 5.17 and 5.18 list the equipment and inventory, shipping and replacement information for electric heat pumps by size. Similar tables are not presented for unit heaters and baseboard heaters since these have only one size catagory. Table 5.19 lists the equipment energy consumption distribution to the commercial subsectors for heat pumps (single package), heat pumps (split system), unit heaters, and baseboard heaters, respectively (see Section 5.1.2).

TABLE 5.10

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)
1975

Functional Use: Space Heating

Fuel Type: Gas

	Cast Iron Boilers (H. W.)	Cast Iron Boilers (Steam)	Steel Boilers (Stm & H. W.)	Unit Heaters	Duct Furnaces	Warm Air Furnaces	Totals*
Commercial Subsector							
1. Communication	1.68	1.73	0.7	0.96	0.99	0.69	6.8
2. Utility	1.94	2.0	0.8	1.11	1.15	0.8	7.8
3. Wholesale	10.9	11.2	4.3	99.3	6.44	4.48	136.6
4. Retail	34.8	35.9	13.2	35.5	20.6	14.3	154.3
5. F., I., RE & Services	39.2	40.5	14.8	22.4	23.2	16.1	156.2
6. Hospital	46.1	47.5	17.4	26.3	27.2	18.9	183.4
7. School	47.4	48.9	17.9	27.1	28.0	19.4	188.7
8. Public Admin.	67.7	69.8	25.5	38.7	40.0	27.8	269.5
Total*	249.7	257.5	94.6	251.3	147.5	102.5	1103.3

*Totals may not sum due to roundoff.

5-14

TABLE 5.11

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Space Heat
Fuel Type: Oil
Year: 1975

A-1445rr

Appliance Type	Size Range (K-Btu/hr) (Input or Output)	Inventory (K-units)	Annual Replacement Rate, %	Useful Life (Years)	Energy Consumption (Trillion Btu)	% Total Energy Consumption
Warm Air Furnaces	229- 828 (I)	823.	60	17.5	474.9	35.8
Steel Tube Boilers	503-23,464 (I)	37.8	49	22.5	324.0	24.4
Cast Iron Boilers (Steam & Hot Water)	200- 5,500 (I)	466.3	33	27.5	504.8	38.1
Unit Heaters*	100- 500 (I)	89.1	54	15.0	22.3	1.7
Total					1,326.0	

*Based cn information from Powermates Inc.

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TABLE 5.12

INDIVIDUAL APPLIANCE DATA

Fuel Type: Oil
Appliance Type: Furnace
Functional Use: Space Heat
Useful Life (Years): 17.5

A-1509rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
229-276 (I)	174.6	8,570	5,325	62.2
276-414	281.6	13,670	8,650	63.3
414-828	366.9	18,830	10,915	46.2
Total	823.1	41,070	24,890	60.6

*Data obtained from GAMA "Statistical Release of Appliance Shipments" and "Fuel Oil and Oil Heat Publications" statistics.

Thermo Electron CORPORATION

TABLE 5.13

INDIVIDUAL APPLIANCE DATA

Fuel Type: Oil
Appliance Type: Cast Iron Boiler (Steam & Hot Water)
Functional Use: Space Heat
Useful Life (Years): 27.5

A-1504rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
200- 250 (O)	167.1	6,950	2,015	29.0
250- 450	154.6	5,920	2,180	36.9
450- 950	78.2	2,900	965	33.3
950-1,550	29.3	1,180	365	31.0
1,550-5,500	37.1	1,370	425	31.0
Total	466.3	18,320	5,950	33.0

*Data obtained from GAMA and Hydronics Institute Statistics of Annual Appliance Shipments.

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TABLE 5.14

INDIVIDUAL APPLIANCE DATA

Fuel Type: Oil
Appliance Type: Steel Tube Boiler (Steam & Hot Water)
Functional Use: Space Heating
Useful Life (Years): 22.5

A-224lr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
503- 1,676	4.6	99	76.5	77.25
1,676- 4,190	16.2	381	270.0	70.9
4,190-10,056	13.3	502	211.5	42.2
10,056-23,464	3.6	196	25.5	13.0
Total	37.8	1,178	583.5	49.5

*Data obtained from American Boiler Manufacturers Association "Annual Statistical Information."

TABLE 5.15

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)
1975

Functional Use: Space Heating Fuel Type: Oil

Appliance Type	Cast Iron Boiler (H. W. & Stm)	Warm Air Furnaces	Steel Boilers (H.W. & Stm)	Units Heaters	Totals*
Commercial Subsector					
1. Communication	3.61	3.39	2.4	0.2	9.6
2. Utility	2.73	2.57	1.7	0.2	7.2
3. Wholesale	20.1	18.9	12.7	0.9	52.6
4. Retail	40.1	37.7	25.7	1.8	105.3
5. F., I., RE & Services	51.3	48.3	32.7	2.2	134.5
6. Hospital	100.0	94.1	64.3	4.4	262.8
7. School	100.3	94.3	64.6	4.4	263.6
8. Public Admin.	186.6	175.6	119.9	8.2	490.3
Total*	504.8	474.9	324.0	22.3	1326.0

*Total may not sum due to roundoff.

TABLE 5.16

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Space Heat
Fuel Type: Electricity
Year: 1975

Appliance Type	Size Range (K-Btu/hr) (Inp. or Outp.)	Inventory (K-units)	Annual Replace. Rate, %	Useful Life (Years)	Energy Consum. (Tril. Btu)	% Total Energy Consum.
Heat Pump (single pack)	54 - 250 (0)	62.2	41	11	2.72	7.5
Heat Pump (split system)	54 - 250 (0)	65.4	37	11	2.95	8.1
Unit Heaters	10 - 200 (I)*	409.1	29	10	28.8	79.1
Baseboard	5.1 (I)*	380.6	33	10	1.9	5.2
Total					36.4	

*Based on information from National Electrical Manufacturers Association.

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TABLE 5.17

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Heat Pump (Single Pack)
Functional Use: Space Heat/Air Conditioning
Useful Life (Years): 11

A-1512rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
54- 66 (O)	46.3	7,900	3,470	44.0
65- 97	10.6	1,790	855	47.8
97-250	5.3	1,360	245	18.0
Total	62.2	11,050	4,570	41.3

*Data obtained from ARI - Annual Shipping Information.

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TABLE 5.18

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Heat Pump (Split)
Functional Use: Space Heat/Air Conditioning
Useful Life (Years): 11

A-1513rr

Appliance Size	1975 Inventory K-Units	Annual** No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
54- 65 (O)	48.1	9,000	3,350	37.2
65- 97	8.7	1,110	1,535	*
97-135	5.7	686	734	*
135-250	2.9	362	390	*
Total	65.4	11,158	6,009	53.9

*Shipment of Previous Periods Exceed Shipments 1974-1976.

**Data obtained from ARI Annual Shipping Information.

TABLE 5.19

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)
1975

Functional Use: Space Heat Fuel Type: Electricity

Appliance Type	Unit Heaters**	Base-Board**	Heat Pump (Single Pack)	Heat Pump (Split Sys.)	Totals*
Commercial Subsector					
1. Communication	0.19	0.015	0.022	0.024	0.25
2. Utility	0.17	0.014	0.02	0.022	0.23
3. Wholesale	12.4	0.056	0.08	0.09	15.7
4. Retail	3.98	0.82	1.18	1.28	7.26
5. F., I., RE & Services	5.43	0.45	0.64	0.69	7.21
6. Hospital	1.96	0.16	0.23	0.25	2.6
7. School	1.93	0.16	0.23	0.25	2.57
8. Public Admin.	2.74	0.22	0.32	0.35	3.63
Total*	28.8	1.9	2.72	2.95	36.4

*Total may not sum due to roundoff.

**Based on information from NEMA.

5.1.2 Method and Sources of Information

The general method to determine energy consumption is detailed in this section. The specific sources of appliance data are noted in each of the sections listed under gas, oil, or electric appliances.

As noted earlier, the energy consumption (EC) is computed by the relationship

$$EC = N \times C \times T$$

In order to apply this equation, one needs to know N, the appropriate number of units in operation, the input capacity, C, of the equipment, and annual operating time, T, for a prescribed appliance type.

The appliance operating time for space-heating equipment was assumed to be dependent upon building type (commercial subsector) and ambient weather conditions (geographical location or census division). This implied that we needed a national appliance inventory (number of units in operation) and some means of distributing the equipment to commercial subsectors and census divisions in order to apply the above relationship. Once this was done, the energy consumption values were summed over all commercial subsectors and census divisions to obtain national totals.

A meaningful appliance distribution to various business types and geographic locations was developed by using energy consumption estimates from a previous study[7] on the commercial sector. Information in this referenced study was presented for the gas, oil, and electric energy consumed by the functional use in the commercial subsectors and geographic regions. We used this information to form corresponding energy ratios. These ratios were multiplied by the individual appliance inventory to distribute the appliances into the various commercial subsectors and geographic locations.

A computer program was written to aid in the computational process. The inputs to the computer program are:

- National appliance inventory
- Appliance input size
- Appropriate energy consumption ratios
- Appliance annual operating time

The outputs from the program, which include the appliance inventory and corresponding energy consumption in the various commercial subsectors and census divisions for space heating, space cooling, and water heating, have been reproduced and are presented in Appendix A. Figure 5.1 depicts schematically the logical flow of this appliance distribution and energy consumption computational process.

The national inventory of an appliance was determined by using the annual shipment data for an appliance type and energy input size, which were available from various national trade associations. The annual shipment data were usually presented for only the more recent time interval (e.g., the past 10 years). Discussions with representatives of several leading manufacturers produced a concensus as to when, from a historical standpoint, these appliance types would have been shipped initially. Plotting the actual shipping data and projecting a curve back to the time of zero shipment produces a graphical function relating the number of units shipped annually versus calendar year. For illustration purposes, the results of the procedure are shown in Figure B.1 of Appendix B for year-round unitary air conditioners.

By an accumulation process, the gross number of appliances for any year is realized. Additional information on appliance useful life,

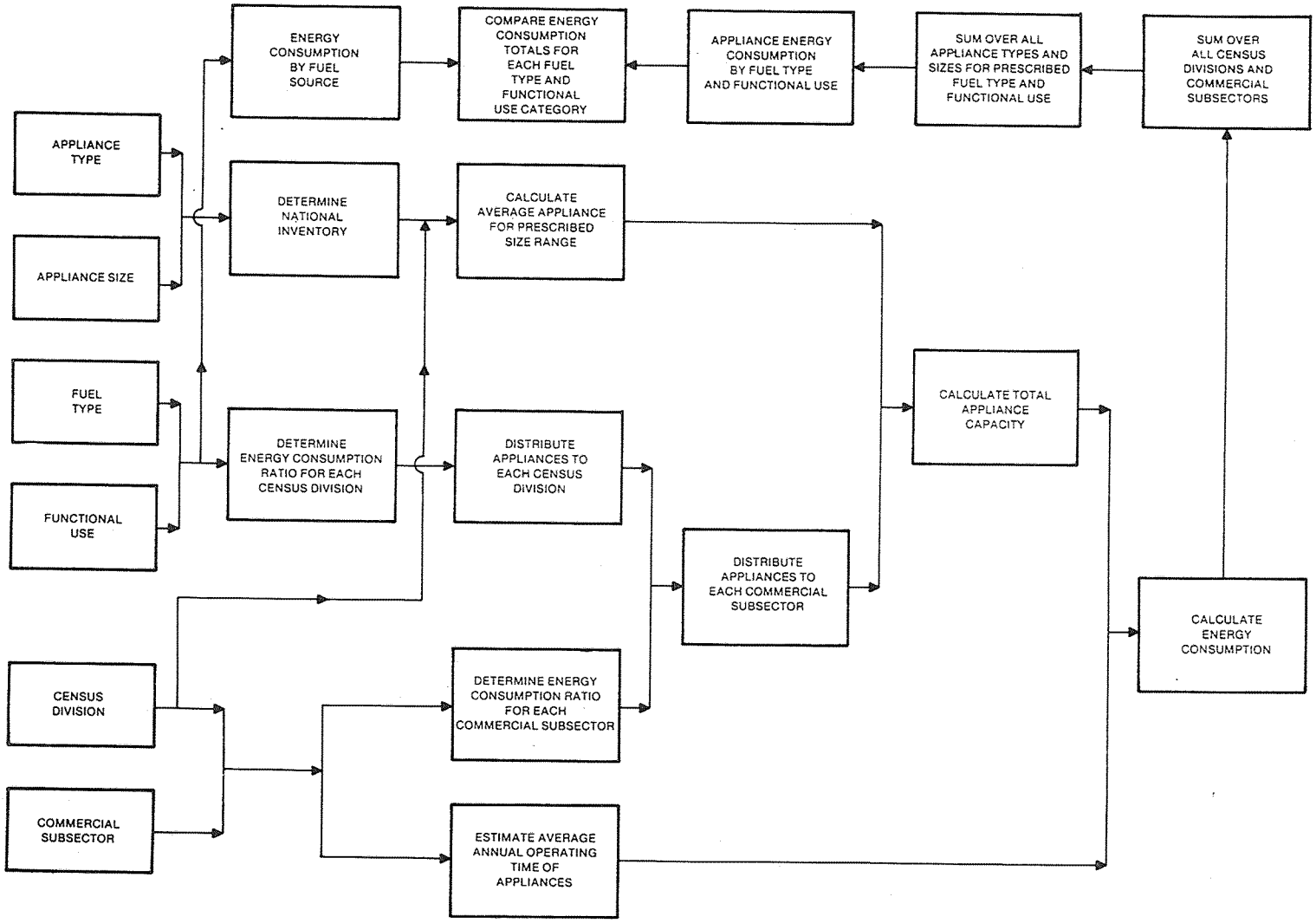

Figure 5.1 Methodology to Distribute Appliances to Commercial Subsectors and Census Division and Estimate Energy Consumption

obtained from manufacturers, was factored with the accumulation process, resulting in the net number of units in operation during any year. The results of this process are illustrated in Table B. 2 of Appendix B. The net number of units (appliance inventory) for 1975 was then used in the distribution process to estimate the energy consumption of these appliances.

The energy consumption ratios to distribute the appliances were obtained from the previously referenced report.[7] These ratios are available by functional use/fuel type combinations.

The final parameter required to estimate the energy consumption is the annual operating time. This is presumed, for all appliances, to be a function of the building type. It is additionally a function of geographic location for HVAC equipment.

The operating time of space-heating equipment for various building categories was obtained indirectly from the metered operating times of air conditioning equipment in Chicago, Illinois, and a building survey study of Baltimore, Maryland, performed by Hittman Associates,[8] which was used to estimate operating times for HVAC equipment. Since Chicago and Baltimore have the same number of cooling degree days, the operating times for the air-conditioning times for Chicago are assumed to be directly applicable to the same building types in Baltimore. Once the operating times of the air-conditioning equipment and the total operating times of the HVAC equipment in the building are established, the difference between the two becomes the operating time of the heating equipment . The operating times for the heating and air-conditioning equipment were close enough to one another that they were considered to be equal in the Baltimore region. These values

are listed in Table 5.20 along with their heating degree days for Baltimore.

The U.S. Climatic Service publishes degree-day maps of the United States; these were used to determine the weighted average degree days for the nine census divisions of this study, which are listed in Table 5.21. We adjusted the heating equipment operating time for Baltimore by the appropriate degree-day ratio to obtain the corresponding operating time of the equipment in the specified census division. The values for the different commercial subsectors and census divisions are shown in Table 5.22.

To check the operating times obtained by this methodology, we made a comparison with data published in the Handbook of Air Conditioning, Heating and Ventilation[9] on the number of hours an intermittent automatic heating plant operates in a normal year. These values are also listed in Table 5.22 and are directly applicable to the hospital heating equipment operating times, since hospitals operate on a 24-hour basis year-round. Inspection of the corresponding operating times indicates that these are comparable values.

Hence, we were able to determine the energy consumption of various equipment types by using the relationship noted previously. It is recognized that using the ratio of seasonal load factors, which are defined as the percent of time a heating plant operates during a heating season, would have been a more realistic method for determining operating times in a specified census division. However, the correlation between the degree-day method and the information presented in the Handbook of Air Conditioning, Heating and Ventilating, which uses seasonal load factors, gave sufficient credibility to justify the use of the simplified degree-day method.

TABLE 5.20

ANNUAL OPERATING TIMES OF SPACE CONDITIONING APPLIANCES FOR VARIOUS COMMERCIAL SUBSECTORS IN BALTIMORE, MARYLAND[8]

Commercial Subsector	Annual Operating Time (Thousand hrs/year)
1. Communication	0.8
2. Utility	0.8
3. Wholesale	0.8
4. Retail	0.9
5. Financial, Insurance, Real Estate & Services	0.8
6. Hospitals	1.8
7. Schools	0.8
8. Public Administration	0.9
Degree Days (Heating)	4200
Degree Days (Cooling)	1300

TABLE 5.21

NUMBER OF DEGREE DAYS FOR VARIOUS CENSUS DIVISIONS

Census Division	Degree-Days	
	Heating	Cooling
1. N. E.	7739	833
2. M. A.	6291	832
3. S. A.	2769	2387
4. ENC	6621	1210
5. ESC	2921	2298
6. WNC	7112	1226
7. WSC	2650	2615
8. MTN	6008	884
9. PAC	5495	664

TABLE 5.22

ANNUAL OPERATING TIME (Thousand hrs/year)

Fuel Type: Gas, Oil or Electricity
Functional Use: Space Heating
1975

A-1455

Census Division	1 N. E.	2 M. A.	3 S. A.	4 E. N. C.	5 E. S. C.	6 WNC	7 WSC	8 MTN	9 PAC
Commercial Subsector									
1. Communication	1.47	1.2	0.53	1.26	0.56	1.35	0.50	1.14	1.05
2. Utility	1.47	1.2	0.53	1.26	0.56	1.35	0.50	1.14	1.05
3. Wholesale	1.47	1.2	0.53	1.26	0.56	1.35	0.50	1.14	1.05
4. Retail	1.66	1.35	0.59	1.42	0.63	1.52	0.57	1.29	1.18
5. Financial, Insurance, Real Estate & Servs.	1.47	1.2	0.53	1.26	0.56	1.35	0.50	1.14	1.05
6. Hospitals	2.83	2.68	1.24	2.48	1.23	2.57	1.15	2.22	2.42
7. Schools	1.47	1.2	0.53	1.26	0.56	1.35	0.50	1.14	1.05
8. Public Administration	1.66	1.35	0.59	1.42	0.63	1.52	0.57	1.29	1.18

5.1.2.1 Gas Appliances

The appliance shipment information on cast iron boilers, unit and duct heaters, and warm-air furnaces was obtained from Gas Appliance Manufacturer Association (GAMA). In addition, the Hydronic Institute and American Boiler Manufacturers Association provided more detailed information on cast iron and steel boilers.

To determine whether the appliance distribution procedure produced results that could be confirmed by actual shipment data, we made a check on unit heaters, since there would be less distortion due to residential usage for this type of space-heating equipment. Table 5.23 presents a comparison of the distribution of gas unit heaters compiled by GAMA for 1976 and the distribution using the energy ratio technique previously described. The distribution trends are close in seven of the nine census divisions.

Discussion with various manufacturers* of unit heaters indicated that, in their opinion, the breakdown of heaters between commercial and industrial sectors is approximately 52 and 48 percent, respectively. Approximately 44 percent of the commercial sector heaters are used in warehouses, 13 percent in retail (fast food outlets), and the remaining 43 percent are scattered throughout other commercial applications. The above information was incorporated as adjustment factors to the national inventory and to the energy consumption ratios that were used to distribute the unit heaters.

5.1.2.2 Oil Appliances

The annual shipment data for cast iron boilers were provided by GAMA and the Hydronics Institute. Coresponding data for warm-air furnaces were obtained via GAMA, the Census Bureau's Current Industrial Report[10] and Fuel Oil and Oil Heat Publications.[11] No adjustment factors

*Modine Manufacturing, ITT Reznor, Lennox.

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A-1401

TABLE 5.23

COMPARISON OF DISTRIBUTION OF GAS-FIRED UNIT HEATERS

Census Division	Based on 1976 Shipment Data From G. A. M. A. % of Total	Based on Distribution by Using Energy Consumption Ratios % of Total
N. E.	3.3	0.8
M. A.	8.8	9.6
S. A.	9.1	9.5
ENC	24.6	23.2
ESC	6.8	5.0
WNC	14.8	14.6
WSC	14.1	14.0
MTN	7.8	8.4
PAC	10.8	15.0

were made to the energy consumption ratios used to distribute the oil-fired space-heating equipment.

5.1.2.3 Electric Appliances

The annual shipment information for the unitary heat pump equipment was obtained from Air Conditioning, Refrigeration Institute (ARI). The unit and baseboard heater data were made available by the National Electrical Manufacturers Assocation (NEMA). The input energy sizes of the unit and commercial baseboard heaters were not included in the NEMA data. Discussions with manufacturers and a survey of literature showed that the unit heater input capacity range varies between 10 and 200 K-Btu/hr, whereas the average input size for commercial baseboard heaters is about 4 K-Btu/hr. These values were used to calculate the electrical space-heat energy consumption.

5.2 AIR CONDITIONING

5.2.1 Summary of Data

5.2.1.1 Gas Appliances

Table 5.24 lists the relevant information on direct-fired gas and indirect-fired absorption systems. As noted in the table, these units account for 56 percent of the energy attributed to gas-fired air conditioners. Tables 5.25 and 5.26 list the equipment inventory, shipping, and replacement information for absorption air conditioners by size. Table 5.27 lists the equipment energy consumption distribution to the commercial subsectors.

5.2.1.2 Electric Appliances

Table 5.28 summarizes the relevant information on electric air-conditioning systems, which includes the inventory and energy

TABLE 5.24

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Air Conditioning
Fuel Type: Gas
Year: 1975

A-1456rr

Appliance Type	Size Range (K-Btu/hr) (Input or Output)	Inventory (K-units)	Useful Life (Years)	Energy Consumption (Trillion Btu)	% Total Energy Consumption
A/C, Direct-Fired Gas Absorption Unitary	125- 250 (I)	161.4	15	29.0	41.4
Packaged	600 (I)	3.9	15	2.3	3.3
A/C, Indirect Steam-Absorption	1,600-24,000	8.6	20	38.7	55.3
Total				70.0	

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TABLE 5.25

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Absorption A/C Direct Fired
Functional Use: Space Cooling
Useful Life (Years): 15

A-2244r

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
Unitary 125-250 (I)	161.4	14,500	5,800	40
Packaged 600 (I)	3.9	210	80	38
Total	165.3	14,710		

*Data obtained from ARKLA Industries, based on an AGA survey.

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TABLE 5.26

INDIVIDUAL APPLIANCE DATA

Fuel Type: Steam
Appliance Type: Absorption A/C Indirect Heated
Functional Use: Space Cooling
Useful Life (Years): 20

A-2245r

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
1,200-2,400 (O)	2.8	104	45	43.3
2,400-4,200	2.5	118	20	16.9
4,200-6,000	1.4	84	13	15.5
6,000-18,000	1.9	128	20	15.6
Total	8.6	434	98	22.5

*Data obtained from ARI "Report on Manufacturers Annual Shipments."

TABLE 5.27

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)
1975

Functional Use: Air Conditioning Fuel Type: Gas

Appliance Type	Unitary	Packaged	Indirect	Totals*
Commercial Subsector				
1. Communication	0.2	0.017	0.3	0.5
2. Utility	0.3	0.021	0.4	0.7
3. Wholesale	1.5	0.12	1.9	3.5
4. Retail	3.8	0.31	5.1	9.2
5. F., I., RE & Services	5.5	0.43	7.4	13.3
6. Hospital	2.9	0.23	3.9	7.1
7. School	6.4	0.5	8.5	15.4
8. Public Admin.	8.4	0.67	11.2	20.3
Total*	29.0	2.3	38.7	70.0

*Totals may not sum due to roundoff.

TABLE 5.28

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Air Conditioning
Fuel Type: Electricity
Year: 1975

A-1459rr

Appliance Type	Size Range (K-Btu/hr) (Input or Output)	Inventory (K-units)	Annual Replacement Rate, %	Useful Life (Years)	Energy Consumption (Trillion Btu)	% Total Energy Consumption
Year-Round Type	54- 640 (O)	655.6	37	10	38.2	16.6
Condenser Only	54- 640 (O)	1,751.6	34	13.5	86.1	37.4
Horizontal	54- 640 (O)	878.6	37	13.5	51.1	22.2
Heat Pump (single pack)	54- 250	62.2	41	11	2.3	1.0
Heat Pump (split)	54- 250	65.4	37	10	2.5	1.0
Liquid Chiller (Centrifugal)	900-12,000	37.5	30	20	34.3	14.9
Liquid Chiller (Reciprocating)	78- 1,500	67.4	13	20	15.9	6.9
Total					230.4	

consumption for unitary and built-up vapor compression systems as well as liquid chiller systems. The energy consumption due to the inventory accounts for 100 percent of the energy attributed to electric air conditioning. Tables 5.29 through 5.35 list the inventory, shipping, and replacement information for each type of air conditioner by size. Table 5.36 delineates the energy consumption distribution for electric air-conditioning systems.

5.2.2 Method

The method to determine the energy consumption of air-conditioning equipment was similar to that used for space-heating equipment. The following relationship was used:

$$EC = \frac{N \times C_o \times T}{COP}$$

where

EC = energy consumption

N = number of units in operation

T = operating time

C_o = output cooling load site

COP = equipment steady state coefficient of performance

Since the operating time, like that of space heating, was assumed to be dependent upon building type and weather conditions (census divisions), the energy consumption ratios were established for air conditioning, as they were for space heating, from the previously discussed report,[7] and used to distribute the equipment to the different commercial subsectors and census divisions. The number of units and cooling capacity of the equipment are realized from the annual shipping data. The Energy Efficiency Ratios (EER's) or COP's of the units are estimated values, based on discussions with manufacturers and published data from national trade associations.

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A-1499rr

TABLE 5.29

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Year Round
Functional Use: Space Cooling
Useful Life (Years): 10

Appliance Size	1975 Inventory K-Units	Annual** No. Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
54- 65 (O)	283.1	28,100	9,870	35.1
65- 97	126.9	11,900	3,875	32.6
97-135	108.7	9,500	3,805	40.1
135-185	66.5	5,500	2,520	45.8
185-250	27.8	2,770	761	27.5
250-320	20.3	2,700	270	10.0
320-640	22.3	3,670	300	8.2
Total	655.6	64,140	21,400	37.0

*Estimated number of units shipped was not significant.

**Data obtained from ARI "Report on Manufacturers Annual Shipments."

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TABLE 5.30

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Condenser Only
Functional Use: Space Cooling
Useful Life (Years): 13.5

A-1510rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
54- 65 (O)	1,058.6	96,600	25,100	26.0
65- 97	271.1	18,600	9,250	49.8
97-135	208.1	12,400	7,350	59.3
135-185	108.3	7,000	3,900	55.8
185-250	40.3	3,100	1,000	32.3
250-640	65.2	4,500	1,095	24.3
Total	1,751.6	142,200	47,695	33.5

*Data obtained from ARI "Report on Manufacturers Annual Shipments."

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TABLE 5.31

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Horizontal
Functional Use: Air Conditioning
Useful Life (Years):13.5

A-151lrr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
54- 65 (O)	365.8	30,700	11,400	37.1
65- 97	170.4	15,400	5,700	37.1
97-135	162.5	13,700	4,550	33.3
135-185	85.6	7,500	2,300	30.7
185-250	38.7	2,670	1,400	52.5
250-320	23.0	1,900	700	36.9
320-380	14.4	980	560	57.2
380-640	18.2	1,300	780	60.0
Total	878.6	74,150	27,390	36.9

*Data obtained from ARI "Report on Manufacturers Annual Shipments."

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TABLE 5.32

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Heat Pump (Single Pack)
Functional Use: Space Heat/Air Conditioning
Useful Life (Years): 11

A-1512rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
54- 66 (O)	46.3	7,900	3,470	44.0
65- 97	10.6	1,790	855	47.8
97-250	5.3	1,360	245	18.0
Total	62.2	11,050	4,570	41.4

*Data obtained from ARI "Report on Manufacturers Annual Shipments."

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TABLE 5.33

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Heat Pump (Split)
Functional Use: Space Heat/Air Conditioning
Useful Life (Years): 11

A-1513rr

Appliance Size	1975 Inventory K-Units	Annual** No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
54- 65 (O)	48.1	9,000	3,350	37.2
65- 97	8.7	1,110	1,535	*
97-135	5.7	686	734	*
135-250	2.9	362	390	*
Total	65.4	11,158	6,009	37.2

*Shipment of Previous Periods Exceed Shipments 1974-1976.

**Data obtained from ARI "Report on Manufacturers Annual Shipments."

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TABLE 5.34

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Liquid Chiller - Centrifugal
Functional Use: Space Cooling
Useful Life (Years): 20

A-2247r

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
212- 566	11.7	687	297	43.1
566- 849	9.7	746	181	24.3
849-1,132	7.1	288	107	37.2
1,132-1,415	3.2	259	61	23.6
1,415-2,830	5.8	421	80	19.0
Total	37.5	2,403	726	30.2

*Data obtained from ARI "Report on Manufacturers Annual Shipments."

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TABLE 5.35

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Liquid Chiller - Reciprocating
Functional Use: Space Cooling
Useful Life (Years): 20

A-2248r

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
78- 150 (I)	5.1	492	92	18.7
150- 432	20.9	1,797	250	13.9
432-1,200	35.5	3,263	383	11.7
1,200-1,500	5.9	600	80	13.3
Total	67.4	6,152	805	13.1

*Data obtained from ARI "Report on Manufacturers Annual Shipments."

TABLE 5.36

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)
1975

Functional Use: Air Conditioning

Fuel Type: Electricity

Appliance Type	Year Around	Condenser Only	Horizontal	Heat Pump (Single Pack)	Heat Pump (Split Sys.)	Liq. Chiller	Totals*
Commercial Subsector							
1. Communication	0.24	0.54	0.32	0.02	0.02	0.31	1.44
2. Utility	0.31	0.69	0.41	0.018	0.02	0.39	1.83
3. Wholesale	1.04	2.33	1.39	0.06	0.07	1.35	6.24
4. Retail	15.2	34.3	20.3	0.9	0.98	20.09	91.77
5. F., I., RE& Services	9.14	20.6	12.2	0.54	0.59	12.05	55.12
6. Hospital	4.13	9.3	5.52	0.24	0.26	5.32	24.77
7. School	3.06	6.89	4.09	0.18	0.2	4.01	18.43
8. Public Admin.	5.11	11.5	6.83	0.301	0.33	6.73	30.80
Total*	38.2	86.1	51.1	2.26	2.45	50.25	230.40

*Totals may not sum due to roundoff.

The annual operating time was obtained from a similar procedure developed for space-heating equipment. As noted previously, data were available to estimate the air-conditioning operating time for building types in different commercial subsectors of Baltimore, Maryland, which are shown in Table 5.20. Also included are the city's cooling degree days. Table 5.21 lists the cooling degree days that were computed for the various census divisions using data available from the National Climatic Service. Table 5.37 lists the air-conditioner operating times for the buildings in the various commercial subsectors and census divisions, determined by using the relationship:

$$T_{CD} = \frac{CDD_{CD}}{CDD_B} \times T_B$$

where

T_{CD} = operating time in prescribed census division

CDD_{CD} = cooling degree days in prescribed census divisions

CDD = cooling degree days in Baltimore, MD

T_B = operating time for commercial subsector in Baltimore, MD

As a check, the operating times for hospitals were computed using the summer 2-1/2-percent design conditions in which it is presumed the wet and dry bulb temperatures exceed the indicated design values 2-1/2 percent of the time during the summer months. The operating times were obtained by the relationship:

$$T_D = \frac{DD}{(DI - 60) \times 365} \times 8760$$

where

T_D = operating time based on summer design conditions

DD = cooling degree days

DI = discomfort index that is related to design wet and dry bulb temperature; i.e., $DI = 0.4\,(T_D + T_{WB}) + 15$

These summer design operating times are also shown in Table 5.37, and comparison with the estimated hospital times shows fairly good agreement.

Again, as in heating, it is recognized that using the ratio of cooling load factors, based on summer design conditions, would have been a more realistic approach of determining operating time. However, the close agreement between the results of the degree-day method and the method based on summer design temperatures gave sufficient justification for using the simplified degree-day method.

5.2.2.1 Gas Appliances

The data on direct-fired gas appliances were obtained from ARKLA Industries, Inc., the sole manufacturer of direct-fired gas absorption air conditioners since the early 1970's. Their estimate of unitary equipment is based on a 1972 AGA survey of the gas air-conditioning market. Based on data supplied by ARKLA, we projected the 1972 values to 1975. The COP's for absorption units ranged from 0.5 to 0.7 with the larger units tending to have the higher COP's. The replacement rate was supplied by ARKLA.

5.2.2.2 Electric Appliances

The shipment information on unitary air conditioners was obtained from ARI. The value of the COP is obtained from the EER by the relationship:

$$COP = \frac{EER}{3.413}$$

The EER values for unitary equipment ranged from 5.0* to 9.0*, depending upon both air-conditioner design and size.

The replacement rates of unitary equipment were estimated by the methodology described in Appendix B.

*Measured at a condenser temperature of 95°F db and inlet air temperature of 80°F db, 67°F wb.

TABLE 5.37

ANNUAL OPERATING TIME (Thousand hrs/year)

Fuel Type: Gas, Oil or Electricity
Functional Use: Air Conditioning

A-1465r

Census Division	1 N. E.	2 M. A.	3 S. A.	4 E. N. C.	5 E. S. C.	6 WNC	7 WSC	8 MTN	9 PAC
Commercial Subsector									
1. Communication	0.40	0.40	1.47	0.74	1.42	0.75	1.61	0.54	0.40
2. Utility	0.40	0.40	1.47	0.74	1.42	0.75	1.61	0.54	0.40
3. Wholesale	0.40	0.40	1.47	0.74	1.42	0.75	1.61	0.54	0.40
4. Retail	0.46	0.46	1.66	0.84	1.60	0.85	1.81	0.61	0.46
5. Financial, Insurance, Real Estate & Servs.	0.40	0.40	1.47	0.74	1.42	0.75	1.61	0.54	0.40
6. Hospitals	0.93	0.89	2.84	1.46	2.73	1.55	3.25	1.11	0.90
7. Schools	0.40	0.40	1.47	0.74	1.42	0.75	1.61	0.54	0.40
8. Public Administration	0.46	0.46	1.66	0.84	1.60	0.85	1.81	0.61	0.46
Thousands of Hours an Air Conditioner Operates in a year, based on 2-1/2 % Summer Design Wet and Dry Bulb Temperature for Hospitals	0.94	0.85	2.4	1.24	2.30	1.4	2.9	1.0	0.88

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5.3 WATER HEATING

5.3.1 Summary of Data

5.3.1.1 Gas Appliances

The pertinent information on gas-fired water heaters (coil and storage type) is tabulated in Table 5.38.

Table 5.39 shows the breakdown of the appliance inventory by size and the corresponding replacement rate information.

5.3.1.2 Oil Appliances

Table 5.40 lists the appropriate data for oil-fired storage heaters. Although the energy consumption estimate by reference sources (Section 4) did not consider oil-fired water heaters, it appears that their energy consumption contribution is significant. Table 5.41 shows the replacement information for oil-fired water heaters.

5.3.1.3 Electric Appliances

Table 5.42 lists the inventory and energy consumption for commercial-size electric water heaters. Table 5.43 gives the shipping and replacement information for electric water heaters.

A distribution of gas, oil, and electric water heaters, and their corresponding energy consumption to each of the commercial subsectors, is presented in Table 5.44.

TABLE 5.38

APPLIANCE INVENTORY AND
CALCULATED ENERGY CONSUMPTION

Functional Category: Water Heat
Fuel Type: Gas
Year: 1975

A-1466rr

Appliance Type	Size Range (K-Btu/hr) (Inp. or Outp.)	Inventory (K-units)	Annual Replace. Rate, %	Useful Life (Years)	Energy Consum. (Tril. Btu)	% Total Energy Consum.
Water Heater	75 - 1000 (I)	805.7	67	8.5	536.4	100

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TABLE 5.39

INDIVIDUAL APPLIANCE DATA

Fuel Type: Gas
Appliance Type: Coil and Storage
Functional Use: Water Heat
Useful Life (Years): 8.5

A-1514rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
75- 100 (I)	155.7	13,740	9,465	66.7
100- 200	286.0	25,060	16,910	67.5
200- 300	173.4	15,040	10,300	68.5
300- 500	107.5	9,490	6,310	66.5
500-1000	83.1	7,870	4,595	54.3
Total	805.7	71,200	47,580	66.8

*Data obtained from GAMA "Statistical Release of Appliance Shipment."

TABLE 5.40

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Water Heat
Fuel Type: Oil
Year: 1975

A-1468r

Appliance Type	Size Range (K-Btu/hr) (Inp. or Outp.)	Inventory (K-units)	Annual Replace. Rate, %	Useful Life (Years)	Energy Consum. (Tril. Btu)	% Total Energy Consum.
Water Heater	200 - 700 (I)	155.7	33	10	136.1	100

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TABLE 5.41

INDIVIDUAL APPLIANCE DATA

Fuel Type: Oil
Appliance Type: Direct Fired
Functional Use: Water Heater
Useful Life (Years): 10

A-1515rr

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
75-500 (I)	155.7	25,470	8,500	33.4

*Data obtained from GAMA "Statistical Release of Appliance Shipments."

TABLE 5.42

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Water Heat
Fuel Type: Electric
Year: 1975

A-1468rr

Appliance Type	Size Range (K-Btu/hr) (Input or Output)	Inventory (K-Units)	Annual Replacement Rate, %	Useful Life (Years)	Energy Consumption (Trillion Btu)	% Total Energy Consumption
Water Heater	30-185 (I)	171.0	40	10	68.5	100

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TABLE 5.43

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Appliance Type: Water Heater
Functional Use: Water Heating
Useful Life (Years): 10

A-2250r

Appliance Size	1975 Inventory K-Units	Annual* No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement
K-Btu/hr (Input or Output)				
30-185 (I)	171.0	21,000	8500	40.4

*Data obtained from GAMA "Statistical Release of Appliance Shipments" and manufacturers information supplied by R. Eckstrom ORNL.

TABLE 5.44

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)
1975
Functional Use: Water Heating

Appliance Type	Gas Fired	Oil Fired	Elec.
Commercial Subsector			
1. Communication	1.56	0.5	0.2
2. Utility	1.89	0.41	0.3
3. Wholesale	3.11	0.96	0.4
4. Retail	141.0	4.98	17.9
5. F., I., RE & Services	123.7	34.0	15.7
6. Hospital	107.5	35.4	13.6
7. School	93.5	31.8	11.8
8. Public Admin.	64.1	28.0	8.1
Total*	536.4	136.1	68.0

*Total may not sum due to roundoff.

5.3.2 Method

The energy consumption for water heaters was obtained using the relationship:

$$EC = N \times C \times T$$

The parameters N and T are defined for space-heating and air-conditioning equipment, whereas C is the input energy capacity to the water heater. The values N and C are obtained from annual shipment data.

The operating time was presumed to be dependent upon the building use characteristic and independent of the ambient conditions (geographic location), although it is realized that the difference in inlet water temperatures in various locations might introduce a slight computational error. Daily operating times for selected commercial business types were calculated from the daily water heating requirements and required water heating recovery capacity information on these business types, available in the ASHRAE Handbook.[24] The calculated values ranged from 6.7 hrs to 10.9 hrs by assuming a recovery capacity of 1.5 times the minimum requirement. Operating time for only a select number of business types, not necessarily conforming to the S.I.C. subsectors used in the study, could be calculated by this approach. Therefore, a theoretical design daily operating time of 10 hours, recommended in the Gas Engineers Handbook[12], was used to compute the annual operating time for all of the commercial subsectors. The annual operating times, presented in Table 5.45, were calculated using the following operating schedules:

- Schools - five days per week for nine months
- Hospitals - seven days per week for twelve months
- All other subsectors - five days per week for twelve months

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TABLE 5.45

ANNUAL OPERATING TIME

Fuel Type: Gas, Oil, and Electric
Functional Use: Water Heating

A-1470r

Commercial Subsector	Annual Operating Time (Thousand hrs/year)
1. Communication	2.6
2. Utility	2.6
3. Wholesale	2.6
4. Retail	2.6
5. Financial, Insurance, Real Estate & Services	2.6
6. Hospitals	3.65
7. Schools	2.0
8. Public Administration	2.6

5.3.2.1 Gas Appliances

The annual shipment of gas-fired water heaters was supplied by GAMA. The information for commercial water heaters was segregated from that for residential use and was categorized by different energy input sizes. The national inventory was obtained by the accumulation process described in Section 5.1.2 for each size.

The replacement rate was calculated using the procedure described in Appendix B.

5.3.2.2 Oil Appliances

Annual shipment data were obtained from GAMA's 10-year summary report. The report references the Commerce Department Current Industrial Reports (CIR) as the source of its information. Sizes are not listed for this equipment; however, discussion with some manufacturers indicates that 20 percent of the total could be commercial. To obtain an inventory of commercial oil-fired water heaters, the 20-percent factor was applied to the 10-year shipping data, which was then extrapolated back to 1950. The year 1950 was considered by a consensus of manufacturers to be the initial year of commercial-size water heaters (200 to 700 K-Btu/hr input). Unfortunately a size distribution could not be determined; although a 300 K-Btu/hr input size was a very popular size, this value was used in the energy consumption calculation.

The total amount of energy consumed in heating water by oil cannot be completely accounted for since much of the hot water is supplied indirectly by oil-fired boilers. Therefore, the inventory presented here accounts for only the energy consumed by direct oil-fired water heaters. The balance of this energy has been combined with the energy consumed in space heating by oil-fired boilers.

5.3.2.3 Electric Appliances

Shipping information on large electric water heaters could not be obtained directly. However, three of the larger water heater manufacturers supplied information pertaining to their split between residential and commercial water-heater sales. This information, combined with shipping information on residential electric water heaters from GAMA, allowed an inventory of the commercial-size units to be estimated.

5.4 REFRIGERATION

5.4.1 Summary of Data

Refrigeration units are essentially electric-motor-driven compressor types used for cooling space to store nondurable goods. In the commercial sector, the bulk of this equipment is uniquely placed into specific building types. These may be classified into three general categories:

- Buildings or businesses with food service capabilities (restaurants, hotels, schools, hospitals, etc.)
- Retail food establishments (supermarkets, superettes, convenience stores, etc.)
- Wholesale storage facilities (warehouses)

Table 5.46 presents information concerning the energy consumption of the different refrigeration units and Table 5.47 lists their shipping and replacement information. As suggested by the energy consumption values, the refrigeration units that are found in the various generalized categories account for most of the refrigeration energy consumption. Table 5.48 distributes the energy consumption of refrigeration among the commercial subsectors.

TABLE 5.46

APPLIANCE INVENTORY AND
CALCULATED ENERGY CONSUMPTION

Functional Category: Refrigeration
Fuel Type: Electricity
Year: 1975

A-1471r

Appliance Type	Size Range (K-Btu/hr) (Inp. or Outp.)	Inventory (K-units)	Energy Consum. (Tril. Btu)	% of Total Energy Consum.
Reach-In & Storage	2 - 5	1244	25.2	9.8
Walk-In	5 - 7.5	271	9.8	3.8
Ice Cream	2 - 5	469.8	9.5	3.7
Supermarket Compres. Units (Medium and Low Temperature)	2 - 40	-	96.9*	37.8
Central Warehouse Systems	-	-	114.8+	44.8
Total			256.2	

*Based on estimate by Commercial Refrigeration Manufacturers Association.

+Projection, using ADL report on 1972 motor inventory.

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TABLE 5.47

INDIVIDUAL APPLIANCE DATA

Fuel Type: Electric
Functional Use: Refrigeration

A-1516r

Appliance Type	1975 Inventory K-Units	Total Units Shipped in 1975	No. of Units Replaced	% Replacement
Reach-In	913.7	81,774	45,645	55.8
Storage	330.3	26,294	13,210	50.2
Walk-In	271.0	20,367	10,840	53.2
Ice Cream	469.8	42,445	23,500	55.4

TABLE 5.48

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)
1975

Functional Use: Refrigeration

Fuel Type: Electricity

Appliance Type	Central Systems	Supermarket Compressor Units	Refrig. Units in Eating Est. & Other Instit.	Totals*
Commercial Subsector				
1. Communication	--	--	--	--
2. Utility	--	--	--	--
3. Wholesale	114.8	--	--	114.8
4. Retail	--	91.6	--	91.6
5. F.,I.,RE & Services	--	--	--	--
6. Hospital	--	--	-- 44.5	--
7. School	--	--	--	--
8. Public Admin.	--	--	--	--
Totals*	114.8	91.6	44.5	250.9

*Totals may not sum due to roundoff.

5.4.2 Method

Due to a lack of annual shipping data on refrigeration equipment, an inventory of the various equipment types could not be obtained using the previously described accumulation process. An estimated inventory of reach-in, storage, walk-in, and ice cream refrigeration equipment in eating and drinking establishments was published in a report on the food service industry from a study sponsored by the market research firm of Frost and Sullivan.[13] The operating times for this equipment were determined by whether the equipment was a medium-temperature (35-40°F) or a low-temperature (30°F>) refrigerator. Discussions with various manufacturers* of refrigeration equipment indicate that 14 hours/day is typical of medium-temperature equipment, whereas 16 hours/day is usual for low-temperature equipment.

The energy consumption for the other refrigeration equipment was estimated from various sources. A report by the Commercial Refrigerator Manufacturer Association[14] estimated that, of the 200,000 grocery outlets in existence in 1975, the energy consumption used for the refrigeration display cases was approximately 96.9 trillion Btu. Discussions with representatives of local chain supermarkets indicate that the majority of the compressors can range between 0.75 and 15 hp.

Arthur D. Little, Inc.[15] estimated the energy consumption of motors used to drive compressor units in central refrigeration systems for warehouses. The value was presented for year 1972. Projection of this data based on warehouse expansion indicates that 114.8 trillion Btu was used for these motors in 1975.

*Hobart Refrigeration, Westinghouse, and Commercial Refrigeration Manufacturers Assoc.

5.5 COOKING

5.5.1 Summary of Data

5.5.1.1 Gas Appliances

Table 5.49 lists the appliances, equipment size ranges, inventories, and estimated energy consumptions for gas-fired cooking equipment. It appears that the listed equipment makes up the major share of the gas energy consumption for cooking. Table 5.50 presents the estimated number of units shipped and the replacement rate of the various gas cooking units. Table 5.51 distributes the energy consumption of gas cooking equipment to the commercial subsector.

5.5.1.2 Electric Appliances

Table 5.52 lists the data for electric cooking equipment as noted previously for the gas-fired counterparts. Although the total is somewhat higher than that estimated by fuel source, indications are that electric energy consumption was not very significant in 1975, although the growth potential is high due to anticipated gas shortages. The distribution of energy consumption of this equipment to the commercial subsectors is presented in Table 5.53.

5.5.2 Method

Annual shipment information on commercial cooking equipment was unavailable for this study due to its proprietary classification. Consequently, we had to rely substantially on a study sponsored by Frost and Sullivan on the food service industry for the appliance inventory and replacement rate of gas and electric cooking equipment. The equipment capacities were obtained by discussions with various

TABLE 5.49

APPLIANCE INVENTORY AND
CALCULATED ENERGY CONSUMPTION

Functional Category: Cooking
Fuel Type: Gas
Year: 1975

A-1472r

Appliance Type	Size Range (K-Btu/hr) (Inp. or Outp.)	Inventory (K-units)	Useful Life (Years)	Energy Consum. (Tril. Btu)	% of Total Energy Consum.
Coffee Makers & Urns	15 - 25 (I)	202	-	3.7	1.9
Steam Kettles, Cookers, & Press. Cook.	100 - 180 (I)	167.2	-	21.5	10.8
Boilers	100 - 120 (I)	129.6	-	11.9	6.0
Fryers	100 - 120 (I)	420.8	-	42.5	21.4
Griddles & Grills	80 - 120 (I)	356.3	-	32.7	16.5
Deck & Conv. Ovens	80 - 140 (I)	429.7	-	35.3	17.8
Ranges & Brais. Pans	110 - 170 (I)	392.6	-	50.5	25.5
Total				198.2	

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TABLE 5.50

APPLIANCE DATA*

Fuel Type: Gas and Electric
Functional Use: Cooking

A-1473r

Appliance Type	Total Units* Shipped in 1975	No. of Units Replaced	% Replacement
Coffee Urns	25,600	16,210	63.3
Coffee Makers	44,060	31,600	71.7
Steam Kettles	7,900	4,680	59.2
Steam Cookers	4,990	3,170	63.6
Pressure Cookers	5,175	3,070	59.3
Broilers	25,220	18,800	74.5
Fryers (floor)	38,590	27,800	72.0
Fryers (countertop)	35,100	24,720	70.0
Ranges & Braising Pans	40,470	22,900	56.6
Griddles & Grills	49,700	31,300	63.0
Deck Ovens	19,900	14,490	72.8
Convection Ovens	17,980	11,420	63.5

*Data obtained from Frost and Sullivan.[13]

TABLE 5.51

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)

Functional Use: Cooking Fuel Type: Gas

Appliance Type	Coffee Makers & Urns	Steam Kettles, Cookers & Press. Cookers	Broilers	Fryers	Griddles and Grills	Deck & Convection Ovens	Ranges & Braising Pans	Totals*
Commercial Subsector								
1. Communication	--	--	--	--	--	--	--	--
2. Utility	--	--	--	--	--	--	--	--
3. Wholesale	--	--	--	--	--	--	--	--
4. Retail	6.19	15.9	8.83	31.5	24.3	26.2	37.4	150.3
5. F., L., RE & Services	--	--	--	--	--	--	--	--
6. Hospital	2.11	5.43	3.01	10.7	8.3	8.91	12.8	51.3
7. School	--	--	--	--	--	--	--	--
8. Public Admin.	0.051	0.133	0.073	0.263	0.202	0.218	0.312	1.3
Total*	8.35	21.5	11.9	42.5	32.7	35.3	50.5	202.9

*Total may not sum due to roundoff.

TABLE 5.52

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Cooking
Fuel Type: Electricity
Year: 1975

A-1474

Appliance Type	Size Range (K-Btu/hr) (Inp. or Outp.)	Inventory (K-units)	Useful Life (Years)	Energy Consum. (Tril. Btu)	% of Total Energy Consum.
Coffee Makers & Urns	5 - 15 (I)	360	-	3.2	10.9
Steam Kettles, Cookers and Press. Cook.	50 - 90 (I)	75.8	-	4.7	16.0
Broilers	50 - 60 (I)	32.4	-	1.4	4.8
Fryers	50 - 60 (I)	105.2	-	5.1	17.4
Griddles & Grills	40 - 60 (I)	118.7	-	5.2	17.7
Deck & Conv. Ovens	40 - 70 (I)	142.6	-	5.6	19.1
Ranges & Brais. Pans	55 - 85 (I)	65.4	-	4.0	13.7
Total				29.3	

TABLE 5.53

ENERGY CONSUMPTION BY COMMERCIAL SUBSECTOR AND APPLIANCE TYPE
(TRILLION BTU)

Functional Use: Cooking Fuel Type: Electric

Appliance Type	Coffee Makers & Urns	Steam Kettles, Cookers & Press. Cookers	Broilers	Fryers	Griddles and Grills	Deck & Convection Ovens	Ranges & Braising Pans	Totals*
Commercial Subsector								
1. Communication	--	--	--	--	--	--	--	--
2. Utility	--	--	--	--	--	--	--	--
3. Wholesale	--	--	--	--	--	--	--	--
4. Retail	7.09	4.64	1.42	5.06	5.2	5.56	4.01	33.0
5. F, L, RE & Services	--	--	--	--	--	--	--	--
6. Hospital	--	--	--	--	--	--	--	--
7. School	--	--	--	--	--	--	--	--
8. Public Admin.	0.044	0.029	0.009	0.031	0.032	0.034	0.025	0.2
Totals*	7.13	4.67	1.43	5.1	5.23	5.59	4.03	33.3

*Totals may not sum due to roundoff.

equipment manufacturers, literature search, and our own experience in the cooking field. The annual operating times for the equipment were assumed to be dependent upon business type, and were estimated by using information available from AGA*, and our own experience in the cooking field. These values are listed in Table 5.54 for those commercial subsectors in which food service facilities would be found.

5.6 LIGHTING

5.6.1 Summary of Data

The energy consumption and lighting level for the four lamp types used in the commercial sector are presented in Table 5.55. Although the fluorescent, metal halide, and high-intensity discharge (HID) lamps provide approximately 91 percent of the lighting level, they account for only 75 percent of the total lighting energy consumption. This reflects the high efficiency of these lamp types compared to the incandescent type.

5.6.2 Method

We were able to obtain an energy consumption breakdown for these lamp types based on information** provided by three of the major manufacturers of lamps: General Electric, Westinghouse, and GTE Sylvania. Information on lamp sales in 1974, 1975, and 1976 supplied by the Census Bureau[23] allowed a national inventory to be estimated.

Table 5.56 presents an estimation of the breakdown of lighting energy consumption by various sectors for 1973. By applying these percentage values to the estimated total lighting consumption for 1975,

*Private communication - information from an internal document on Commercial Kitchen Appliances.

**Facts About Lighting,""Trends in Lighting Usage," and "Energy for Lighting."

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TABLE 5.54

ANNUAL OPERATING TIME

Fuel Type: Gas or Electric
Functional Use: Cooking

A-1475

Commercial Subsector	Annual Operating Time (Thousand hrs/year)
1. Communication	---
2. Utility	---
3. Wholesale	---
4. Retail	0.90
5. Financial, Insurance, Real Estate & Services	---
6. Hospitals	1.08
7. Schools	0.50
8. Public Administration	0.20

TABLE 5.55

APPLIANCE INVENTORY AND CALCULATED ENERGY CONSUMPTION

Functional Category: Lighting
Fuel Type: Electricity
Year: 1975

A-1476r

Lamp Type	Average Efficiency (Lumens/ Watt)	Energy Consumption (Trillion Btu)	% of Total Energy Consumption	Lighting Level (Trillion Lumen-Hr)	% of Total Light Level
Incandescent	20	170.7	24.7	1,000	8.8
Fluorescent	70	397.6	57.5	8,160	71.4
Metal Halide	90	12.3	1.8	315	2.8
High-Intensity Discharge	60	110.6	16.0	1,950	17.1
Total		691.1		11,425	

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A-1399r

TABLE 5.56

G.E. LIGHTING ESTIMATES FOR 1973
USED FOR PROJECTION TO 1975
(Billions kWh)

	1973	1975
Total Electrical Generation*	1960	2025
General Lighting (Est.** as 20% of Total Generation by G.E.)	392	405

Lighting Usage	Estimate for 1973**		
	Billions kWh	% of Gen. Lighting	Proj. to 1975
Residential	78.4	20	81
Industrial	78.4	20	81
Store	78.4	20	81
Street & Highway	11.8	3	12.2
Flood, Area, Signs, Sports, etc.	31.4	8	32.4
Offices	31.4	8	32.4
Schools	27.4	7	28.3
All Other Indoors	54.9	14	56.7
Total	392	100	405

*Data from E.E.I. "Statistical Year Book" multiplied by 1.15 to account for line losses.

**General Electric Estimate, "Energy for Electricity and Lighting."

the energy consumption values for these same sectors are obtained for 1975.

By adding up the energy consumption in those areas defined by the study to be the commercial sector, the lighting energy in the commercial sector is 202.5×10^9 kWh or 691.1×10^{12} Btu (i.e., 50 percent of total lighting). Table 5.57 lists the percentage of lighting that GE considers to be the breakdown of the lighting energy consumption by various lamp types totaled for the three basic sectors. Assuming* all of the residential light is incandescent, and using GE's estimate that 70 percent of the total commercial indoor lighting is fluorescent, the commercial fluorescent lighting is found by the relationship:

$$CFL = 0.7\ (\text{Store} + \text{Office} + \text{School} + 0.5\ \text{Other})$$

where

CFL = commercial fluorescent lighting

Substitution from Table 5.56 produces a value of 116.5×10^9 kWh. Assuming the metal halide units (3.6×10^9 kWh) are used in commercial staging and studio lighting, whereas the HID is all outdoor commercial lighting, then the incandescent lighting is found from:

$$CIL = \text{Total} - \text{Fluor} - \text{MH} - \text{HID}$$

where

CIL = commercial incandescent lighting

Fluor = fluorescent lighting

MH = metal halide

HID = high-intensity discharge

*Assumption made by GTE Sylvania, "Estimates of Lighting Energy Consumption from Unit Sales."

TABLE 5.57

LIGHTING ENERGY CONSUMPTION FOR 1975
(Billions kWh)

A-1400r

Sector	Incand.	Fluor.	Metal-Halide	H. I. D.	Total	%
Residential	81	--	--	--	81	20
Commercial	50	116.5	3.6	32.4	202.5	50
Industrial, Street, and Highway	35.1	61.6	--	24.8	121.5	30
Total	132.8	211.4	3.6	57.2	405	100
% of Total*	32.8	52.2	0.9	14.1	--	--

*G. E. estimates, "Trends in Lighting Usage."

Substitution produces 50 x 10^9 kWh for commercial incandescent lighting. The remaining values listed in the table are obtained by subtraction from the totals.

5.7 COMPARISON OF ENERGY CONSUMPTION ESTIMATES

A comparison of the estimated energy consumption information presented in Chapter 4 was made with the calculated energy consumption information presented in this chapter of the report. This comparison was made to verify the approach used in establishing and distributing the appliance inventory.

Table 5.58 shows the comparison between the two sets of energy consumption information for the six functional use categories. The comparison of the information is quite favorable, showing an overall agreement of better than 85 percent. The comparison of electric and gas consumption data indicates agreements of 89 percent and 92 percent, respectively. The comparison of the oil consumption data, although not as favorable, still indicates an agreement of 70 percent.

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TABLE 5.58

COMMERCIAL ENERGY CONSUMPTION COMPARISON

REFERENCE SOURCE - CALCULATED
(Trillion Btu)

A-2255r

Functional Use	Total		Nat. Gas		Electricity		Petroleum	
	Ref.	Cal.	Ref.	Cal.	Ref.	Cal.	Ref.	Cal.
Space Heating	3430	2465	1207	1103	128	36	2095	1326
A/C	533	300	124	70	409	230	-	-
Water Heating	649	740	544	536	105	68	-	136
Refrigeration	221	251	-	-	221	251	-	-
Cooking	196	236	196	203	-	33	-	-
Lighting	612	692	-	-	612	692	-	-
Total End Use	5641	4684	2071	1912	1475	1310	2095	1462
% of Total Accounted for	83		92		89		70	
Total Prime Energy	9176	7833	2071	1912	5010	4459	2095	1462
% of Total Accounted For	85		92		89		70	

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6. FUTURE PROJECTIONS OF THE DATA BASE

6.1 SUMMARY OF INFORMATION

The 1975 appliance inventory and energy consumption presented in Chapter 5 was projected to the years 1980 and 1990. The projections of the energy consumption by appliance type was performed to allow a more meaningful assessment and ranking of the major energy-consuming appliances to be made. Other information obtained from these projections, such as the 1980 appliance inventory, the average annual sales, the unit energy consumption, etc., was completed to form a baseline market potential for future energy-saving equipment. This baseline establishes the maximum potential market for both retrofit and new sale equipment that was used in evaluating the opportunities for energy-saving equipment, which is discussed in Chapter 9 of this report.

The projected information presented in Table 6.1 includes the following for each of the appliance types:

- Average Annual Sales
- Market Growth Rate
- Appliance Inventory for 1980 and 1990
- Total Sales (New and Replacement) from 1980 and 1990
- Weighted Average Input Size
- Unit Energy Consumption
- Appliance Energy Consumption in 1990

The appliance energy consumption in 1990 is separated into both end use and prime energy consumption. The difference between these values lies in the area of electrical appliances only, since the end use and prime energy consumption is considered to be the same value for gas-fired and oil-fired equipment. The end-use consumption of electrical appliance is based on a conversion factor of 3,413 Btu/kWh, whereas the prime energy consumption, which accounts for generating and transmission efficiencies, is based on a conversion factor of 11,600 Btu/kWh.

TABLE 6.1

PROJECTED DATA BASE
(1990)

A-2199

	Appliance Type	Fuel Type	Ave Annual New Sales $x10^3$	Annual Growth Rate %	Ave Size of Unit Btu/hr $x10^3$	1980 Inventory $x10^3$	Unit Energy Consumption Btu $x10^9$	Total Sales 1980 1990 $x10^3$	1990 Inventory $x10^3$	1990 Energy Consumption End Use Btu $x10^{12}$	1990 Energy Consumption Prime Btu $x10^{12}$	Ranking - Based on End Use	Ranking - Based on Prime
1	CI Boilers (HW & Stm)	G	12.8	1.34	850	536.0	1.01	128	605.1	612.7	612.7	5	7
2	Unit Heaters	G	70.7	1.96	165	1478.0	0.19	707	1740.0	326.1	326.1	7	13
3	Duct Furnace	G	19.1	1.56	260	514.9	0.31	191	589.4	182.4	182.4	11	19
4	Warm Air Furnace	G	21.3	4.0	250	423.5	0.295	213	561.5	165.7	165.7	12	21
5	St'l Boilers (HW & Stm)	G	0.4	2.0	5000	12.6	8.23	4	14.9	122.6	122.6	17	22
6	CI Boilers (HW & Stm)	O	18.3	2.6	840	531.5	1.13	183	654.1	714.4	714.4	3	5
7	Warm Air Furnaces	O	41.1	2.0	450	905.4	0.58	411	1069.8	617.3	617.3	4	6
8	St'l Boilers (HW & Stm)	O	1.2	1.6	5000	40.9	8.55	12	47.0	401.8	401.8	6	10
9	Unit Heaters	O	6.4	3.3	250	105.1	0.25	64	134.5	33.6	33.6	30	32
10	Baseboard Heaters	E	26.7	4.7	5	479.5	0.004	267	658.4	3.0	10.2	43	41
11	Heat Pump (Single & Split)	E	22.3	17.5	40	285.8	0.044	223	508.8	22.5	76.4	32	25
12	Unit Heaters	E	41.5	0.1	70	413.0	0.07	415	707.6	49.6	168.5	28	20
13	Direct Absorption (Un.)	G	14.5	5.4	180	209.8	0.18	145	296.8	53.3	53.3	26	29
14	Direct Absorption (Built Up)	G	0.21	3.3	600	4.6	0.59	2.1	6.0	3.5	3.5	42	44
15	Indirect Fired Absorption	G	0.43	4.6	6000	9.0	5.3	4.3	12.3	65.2	65.2	22	27
16	A/C Year Round Unit	E	64.1	6.2	60	885.0	0.058	641	1288.8	75.0	254.8	20	15
17	A/C Condenser Only	E	142.2	5.3	50	2259.5	0.049	1432	3198.5	157.1	533.6	13	8
18	Horizontal	E	74.2	5.3	60	1133.3	0.058	742	1600.8	93.1	316.2	18	14
19	Heat Pump (Single & Split)	E	22.2	10.7	40	211.8	0.038	222	346.8	13.0	44.2	34	31
20	Centrifugal Liquid Chiller	E	2.4	4.5	4000	46.9	0.914	24	63.7	58.0	197.0	24	18
21	Reciprocating Liquid Chiller	E	6.2	8.0	650	99.1	0.235	62	153.0	36.0	122.3	29	23
22	Water Heater	G	71.2	2.9	250	926.5	0.666	712	1161.5	773.8	773.8	2	4
23	Water Heater	O	8.0	3.4	300	183.7	0.785	80	237.3	202.6	202.6	10	16
24	Water Heater	E	23.0	7.5	150	246.2	0.40	230	375.2	150.3	510.5	16	9
25	Ref. Cent. Warehouse Stor.	E								(114.5)	388.9	14	11
26	Ref. Display Supermarket	E								(96.9)	329.1	15	12
27	Ref. Restaurant Stor.	E	107.0	2.7	5	2262.6	0.02	1270	2765.6	60.9	206.9	23	17
28	Coffee Makers & Urns	G	23.0	3.9	20	244.4	0.018	230	324.9	5.8	5.8	40	43
29	Kettle, Cooker & Pres. Ck	G	12.4	3.1	140	193.9	0.128	124	243.5	31.2	31.2	31	33
30	Broilers	G	20.1	4.2	110	159.4	0.091	200	209.6	19.2	19.2	33	39
31	Fryers	G	55.3	4.1	110	513.3	0.100	553	673.6	67.8	67.8	21	26
32	Griddles & Grills	G	37.3	4.1	100	434.6	0.091	373	572.6	52.3	52.3	27	30
33	Deck & Convect. Ovens	G	36.9	3.7	110	515.6	0.082	367	655.8	53.7	53.7	25	28
34	Ranges & Braising Pans	G	34.7	3.1	140	455.4	0.128	347	608.0	78.3	78.3	19	24
35	Coffee Makers & Urns	E	46.1	4.2	10	442.8	0.008	461	604.1	5.1	17.3	41	40
36	Kettle, Cooker & Pres. Ck	E	5.7	3.1	70	87.9	0.062	57	110.7	6.8	23.1	38	37
37	Broilers	E	5.1	4.2	55	39.8	0.043	51	52.5	2.2	7.5	44	42
38	Fryers	E	18.4	4.7	55	132.5	0.048	53	185.8	8.9	30.2	35	34
39	Griddles & Grills	E	12.4	4.1	50	144.8	0.044	124	190.6	8.3	28.2	36	35
40	Deck & Convect. Ovens	E	6.3	3.7	55	171.1	0.039	63	195.0	7.6	25.8	37	36
41	Ranges & Braising Pans	E	5.9	2.4	70	73.9	0.061	59	99.8	6.0	20.4	39	38
42	Incandescent Lights	E	455,600	3.4	75*	790,000	$0.25x10^{-3}$		1,106,000	282.0	957.9	8	2
43	Fluorescent Lights	E	298,000	5.1	40*	749,000	$0.68x10^{-3}$		1,233,000	839.0	2849.9	1	1
44	High Intensity Discharge	E	7,000	5.0	400*	25,000	5.5×10^{-3}		42,000	230.0	781.3	9	3

* Listed in watts

G = Gas
E = Electric
O = Oil

The projected information is presented for 42 of the 44 appliance types identified in the original data base. Sufficient information was not available to permit projection of warehouse and supermarket refrigeration equipment. The 1975 energy consumption information attributed to these two types of equipment was relisted in Table 6.1 for their projected 1990 energy consumption.

6.2 APPLIANCE RANKING

A ranking of the appliances in the order of their contribution to the total 1990 energy consumption is presented at the end of Table 6.1. The ranking was made on the basis of both end use and prime energy consumption. It is the latter of these two rankings that we consider to be the most important since it reflects a more accurate accounting of the energy consumption on a national level.

From this list it can be seen that the top three energy-consuming appliances are in the functional-use category of lighting. These are followed closely by gas water heaters, oil-fired boilers and furnaces, gas-fired boilers, and electric air conditioners and water heaters. It is recommended that special attention be given to these appliance types for future energy-saving developments since they will be the major energy consumers in 1990. Others that should also be given special consideration include warehouse and supermarket refrigeration equipment and oil-fired water heaters.

6.3 PROJECTION METHOD

Forecasting the sales trends of energy-consuming equipment, similar to predicting the future in any area, is full of uncertainties. Many different scenarios have been employed in attempting to predict the future national energy consumption. These scenarios use various assumptions such as:

- a rapid depletion of natural gas,
- a long-term oil embargo,

- a rapid increase in nuclear power generation,
- implementation of legislated conservation measures,
- government regulation and control of fuel prices,

to name just a few. Again, the uncertainty of these assumptions is high.

Since there is such a great uncertainty regarding the future, especially with regard to appliance sales, a simplified approach to predicting appliance sales was employed in this study. In this approach it was assumed that the sales trends and unit energy consumption of appliances in 1975 will remain constant at least for the next 15 years. This assumption may be an oversimplification of the subject; however, it offers no more uncertainty than some of the other assumptions. Additionally, it appeared to be the most reasonable assumption to use in this study of such a wide variety of equipment types. Using this assumption, the prediction of future sales and inventory of equipment became an extrapolation of previous information. In this way the normal growth in the sales and inventory of an appliance reflects the growth of the commercial sector.

The annual sales for a given appliance type was taken to be the average of the annual sales from 1974 through 1976. The growth in inventory for a particular appliance type was arrived at by combining the average annual sales, the replacement rate, and the 1975 inventory, for that appliance, in the following expression:

$$GR = \frac{(AS)(1 - RR)}{N_{75}}$$

where

GR = Inventory growth rate

AS = Average annual sales

RR = Percentage of sales used to replace existing equipment

N_{75} = 1975 appliance inventory

The growth rate in the appliance inventory is a direct reflection of the growth of the commercial sector in general. It was assumed that a constant increase in the annual sales of an appliance was also due to a constant commercial sector growth; therefore, the growth rate in the appliance sales equals the growth rate in the inventory. The replacement rate of an appliance type is the weighted average value for all sizes of that particular appliance type, based on the 1975 inventory breakdown as shown below:

$$\overline{RR} = \frac{\Sigma\,(RR \times N)_{(IS)}}{N_{75}}$$

where subscript (IS) is the input size range.

The average appliance size for a particular appliance type was similarly found:

$$IS = \frac{\Sigma\,(IS \times N)_{(IS)}}{N_{75}}$$

The projected inventory for a given appliance inventory was determined from the inventory growth rate as follows:

$$N_{(19__)} = (1 + GR)^{n}\, N_{1975}$$

where n = number of years from 1975 to the year in question.

The predicted end-use energy consumption in a given year for a particular appliance was based on the projected inventory for that year and the unit energy consumption for the appliance type. It was assumed for these projections that the seasonal or operating efficiencies of appliances would remain as they were in 1975; therefore, the unit energy consumption was determined by dividing the 1975 energy consumption of an appliance type by its 1975 inventory.

7. PRESENT AND PLANNED APPLIANCE DEVELOPMENT

The objective of this task is the identification of present or ongoing and planned commercial appliance development programs as they relate to energy conservation. Appropriate information, such as anticipated efficiencies, costs, etc., can then be applied in the evaluation of the data base.

Programs of primary interest to this study relate to the product categories of space heating, water heating, air conditioning, refrigeration, lighting, and cooking. Appliances included in these categories are listed in condensed form in Table 7. 1.

In general, it is relatively easy to obtain information on completed programs, particularly those under government or utility sponsorship, from published reports and trade journals. Information on current programs is more difficult to obtain, and, in the area of private company development, depends on the limited degree to which disclosure is permitted from personal contacts. Information on planned development is also more difficult to obtain. No one is willing to disclose his plans, but it is reasonable to speculate that some available tachniques are being applied to appliances of interest to this study.

An attempt was made, in this study, to include all energy-related developments on commercial appliances. Omission of any development from this study was due to either an oversight or a lack of information concerning the development. Several developments discussed in this chapter of the report could not be, as indicated in the tables, evaluated with regard to potential market penetration and future energy savings, since critical information concerning the development was not available.

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A-1477a

TABLE 7.1

ENERGY-RELATED EQUIPMENT
COMMERCIAL SECTOR

I. Heating Equipment

1. Boilers
2. Duct Heaters
3. Electric Resistance Heaters
4. Forced Air Furnaces
5. Heat Pumps
6. Makeup Air Heaters
7. Multizone Units
8. Radiant Heating Systems
9. Space Heaters
10. Steam Heating Apparatus
11. Unit Heaters

II. Water Heaters

1. Circulating Tank Heaters
2. Instantaneous Heaters
3. Storage Tank Heaters
4. Swimming Pool Heaters

III. Air Conditioning

1. Chillers
2. Compressors
3. Cooling Towers
4. Evaporative Condensers
5. Evaporative Coolers
6. Multizone Units
7. Packaged Terminal Air Conditioners

Thermo Electron CORPORATION

A-1477b

TABLE 7.1 (Continued)

ENERGY-RELATED EQUIPMENT
COMMERCIAL SECTOR

III. Air Conditioning (Continued)

8. Rooftop Air Conditioners
9. Room Air Conditioners
10. Self-Contained Air Conditioners
11. Split-System Air Conditioners

IV. Refrigeration

1. Coolers
2. Freezers
3. Ice Equipment
4. Refrigerators
5. Showcases

V. Lighting

1. Fluorescent
2. High Intensity
3. Incandescent

VI. Cooking

1. Broilers
2. Coffee Makers
3. Food-Warming Equipment
4. Fryers
5. Griddles
6. Ovens
7. Ranges and Stoves
8. Steam Equipment

Tables 7.2 through 7.13 list and review many of the programs related to commercial appliances of interest to this study and also review some of the approaches that are available and that are being or will be used to improve appliance efficiency. These tables identify the programs or approach, the appliances to which they apply, and the type of energy used. An estimate of the increase in cost as compared to conventional equipment is given, together with ranges of anticipated improvement in steady-state and seasonal efficiency. An estimate is included of the earliest time increment in which a reasonable volume market penetration could be reached. The various product categories are discussed in the balance of this section. Although motor energy used in air handling is appreciable, it is considered small in relation to the much larger energy consuming functions, such as space heating and air conditioning, with which it is associated. Therefore, air handling is not discussed as a separate item in this report. It is, however, included as part of some systems reviewed in this section of the report.

7.1 SPACE HEATING

Most of the heating for commercial installations is supplied by steam or hot water boilers, forced air systems, unit heaters, heat pumps, or multizone rooftop units. Energy sources are oil, gas, or electricity. As indicated in Tables 7.2 and 7.3, a wide range of programs and approaches have been applied to the heating field. They range from conventional evolutionary improvements (such as increased heat transfer surfaces and insulation through the more innovative approaches represented by compact boiler concepts, heat pipe techniques, and pulse combustion) to some imaginative but rather questionable concepts, such as an energy beam similar to a laser for space heating,[11] and a suggestion of using friction-generated heat in the annular liquid-filled space between two rotating cylinders for space heating.

Thermo Electron CORPORATION

A-1478a

TABLE 7.2

EQUIPMENT IMPROVEMENTS
SPACE HEATING

I. A. Programs

1. Liquid Heaters
2. Miniboilers
3. Instantaneous (SES) Boilers
4. Commonwealth Gas Boilers
5. European Boilers
6. Heat Pipe Furnaces
7. Rotating Heat Pipe Air Handlers/Furnaces
8. Pulse Combustion Boilers and Furnaces
9. Fuel Oil Additives
10. Heat Pumps (with ice storage)
11. Application of Vent Dampers
12. Gas-Fired Heat Pumps
13. Energy Beam
14. Friction Heaters

I. B. Approaches Available

1. Flue Gas Heat Recovery (consider final condensing stage)
2. Improved Appliance Insulation
3. Flue Dampers
4. Outside Combustion Air
5. Optimum Sizing
6. Modulation
7. Emulsified Liquid Fuel
8. Electric Ignition

TABLE 7.2 (Continued)

EQUIPMENT IMPROVEMENTS
SPACE HEATING

I. B. Approaches Available (Continued)

9. Improved Burners (power)
10. Compact Size
11. Improved Control (system adjusts capacity to outside conditions)
12. Room-Controlled Approach
13. Thermal Energy Storage (especially for heat pipes)
14. Improved Compressors
15. Improved Evaporator and Condenser Surfaces
16. Heating-Only Heat Pumps
17. New Heat Pump Working Fluids
18. District Heating
19. Improvement in Airflow and Humidity Control in Space
20. Higher Airflow Over Heat Exchangers

TABLE 7.3

PROGRAMS AND APPROACHES
SPACE HEATING

A-1479a

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
1. Compact Boiler Concepts	Boiler	G-O	0 - 25	5 - 15	10 - 25	N-I	Many compact boilers developed for the residental market can be expanded in capacity to fit commercial installations.
2. Pulse Combustion Systems	Boiler-Furnace	G	25 - 50	15	15 - 25	I	This concept has been under development for over 15 years. Problems to be overcome include reliability and noise.
3. Heat Pipe Furnaces	Furnace	G	5 - 15	10	20	I	Units have been conceptually designed, but not built. Low mass plus low pressure drop and power combustion provide improved efficiency.
4. Gas-Fired Heat Pumps	Heat Pump	G	100	100	100	I	Several gas utilities and organizations have been sponsoring programs to develop gas-fired heat pumps over the past 5 years. Primary problems tend to be cost and reliability.
5. Electric Heat Pumps	Heat Pump	E	-	10	10 - 50	N-I	Approaches include everything from nominal improvements in heat exchanger capacity and compressor efficiency to inclusion of energy storage concepts to improve temperature conditions at evaporator or to limit operation to high evaporator ambients for air source units.
6. Heat Pipe Heat Exchangers	Boiler-Furnace	G-O	25	5 - 10	5 - 10	N-I	Some heat pipe devices are in use to recover energy from flue products. Rotating heat exchangers which perform as blowers are under development.
7. Flue Gas Heat Recovery	Boiler Duct Heater Furnace Space Heater Unit Heater	G-O	10 - 30	5 - 15	5 - 15	N-I	Some units are on the market. More efficient usage will involve incorporation in the furnace or boiler design. A final low-temperature stage with suitable corrosion protection is required.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

TABLE 7.3 (continued)

PROGRAMS AND APPROACHES
SPACE HEATING

A-1479b r

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
8. Improved Insulation	Boiler Furnace	G-O-E	1 - 5	0.2	0.1	N	Jacket losses for boilers and furnaces are low. Additional insulation is being used for some models.
9. Flue Dampers	All - Except Heat Pumps	G	5 - 15	--	5 - 10	N	Flue dampers are now available for some field installations as well as appearing on some residential equipment. Reduction in exfiltration loss can reduce losses for commercial heating equipment, especially gravity vented units. Rooftop heating units which are frequently used in commercial installations eliminate the vent exfiltration loss since the entire unit is outside.
10. Outside Combustion Air	All - Except Heat Pumps	G-O	5 - 10	--	0.5 - 8	N	When combustion air is drawn from the occupied space, it must be replaced by outside air which is then heated to occupancy temperature.
11. Electric Ignition	All - Except Heat Pumps	G	5 - 15	--	2 - 10	N	Nearly all of the energy used by a constant burning pilot is lost when the main burner is not operating in a forced air furnace. Boilers are somewhat less inefficient. The percent loss is a function of appliance input and degree of oversizing.
12. Increased Air Flow	Furnace	G-O	0 - 5	1 - 2	1	N	Can provide higher heat transfer coefficient and greater temperature driving force with minimum increase in motion energy.
13. Modulation	Furnace Boiler	G-O	10 - 80	0 - 10	10 - 20	N-I	Modulation can be used for air flow or burner input for maximum efficiency. For maximum efficiency it should be combined with a powered combustion system. Full modulation would permit furnaces to operate continuously at climatic conditions down to 10 percent of full load.
14. Optimum Sizing	All	G-O	-30	--	5 - 10	I	Proper sizing of heating equipment can reduce losses caused by short cycling under part-load operation.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

TABLE 7.3 (cont'd)

PROGRAMS AND APPROACHES
SPACE HEATING

A-1479c

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
15. Emulsified Fuel	Furnace-Boiler	O	20	5 - 10	7	N-I	Oil-burning appliances suffer a decrease in efficiency due to soot formation. Blue flame or emulsified fuel burners can reduce this tendency.
16. Power Burners	All - G & O	G-O	15	10	20	N-I	Use of power burners for gas-fired appliances or improved oil power burners not requiring vent dampers can reduce standby flue losses to very low levels. Steady-state efficiency is increased by reducing flue temperature and increasing CO_2 level of flue products with improved control available with power combustion.
17. Improved Compressors	Heat Pump	E	0 - 5	2 - 5	2 - 5	N	Use of more efficient motors combined with other design changes in compressors have been steadily reducing energy requirements of heat pumps.
18. Improved Evaporator and Condenser Surfaces	Heat Pump	E-G	0 - 15	5 - 15	5 - 15	N	Increasing heat transfer surface or improving its effectiveness can reduce temperature differences between working fluid and air so that COP is increased. Several proprietary surfaces have been developed.
19.* Improved Working Fluids	Heat Pump	E-G	--	--	--	I	Several chemical companies have been investigating new fluids for use in heat pumps. In some climatic conditions different fluids would provide higher COP.
20. Heating Only Heat Pumps	Heat Pump	E	0	5 - 15	5 - 15	I	Most heat pumps are a design compromise so that they provide both heating and cooling. If heating performance is optimized in a heating-only design, higher efficiency can be provided. Longer life would also result.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

*Not evaluated.

7.1.1 Boilers

7.1.1.1 State of the Art

Boilers used for heating in the commercial sector may be either steam or hot water; construction will be cast iron or steel. Boilers are supplied as "packaged," including all pumps and controls so that they require little field installation labor, or in larger sizes as "knock down," requiring on-site assembly. Most cast iron boilers are assembled from sections with push nipples and tie rods. Capacities range from small residential sizes to units designed for over 10 million Btu/hr capability. Steel boilers cover a wider capacity range. Electric hot water boilers use immersion heaters installed into the boiler water. They may be of the storage or instantaneous type. Electric steam boilers have either electric resistance elements installed below the waterline, or electrodes immersed in the water to generate heat by the resistance of the water to the flow of electricity.

Generally, the electric boilers are small compared to gas or oil units. Electric boilers are made in sizes ranging from small residential capacities to over 3000 kW. The efficiencies of present boiler designs range from 70 to 80 percent for gas- or oil-fired units, and 90 to 99 percent for electric units at their gross output ratings. These efficiencies, however, apply only to operation under steady-state conditions and are therefore considerably higher than the seasonal efficiency actually obtained in service. The ratio of steady-state to actual year-round seasonal efficiency varies widely with operating conditions, so the test efficiency is not a reliable indication of probable fuel consumption with different types of fuel. Standby loss during light load or idle periods and recovery rate of the boiler have a material effect on the overall fuel economy.

7.1.1.2 Program Descriptions

One possibility for reducing energy losses from boilers is to design small-volume, high-efficiency boilers and to install multiple units operating in staged fashion to reduce the difference between steady-state and seasonal efficiency. A number of highly efficient compact boilers have been developed, including two approaches utilizing jet impingement, power combustion, and electric ignition to provide a steady-state efficiency of approximately 85 percent. Since small vent lines are used instead of vent hoods, service efficiency is also high. Another approach has been to combine a proprietary combustion system with an instantaneous coil-type boiler to provide high steady-state efficiency in the 85-percent range, together with high service efficiency. Compact European and Japanese boiler units have been investigated by Commonwealth Gas Company and by Southern California Gas Company for application to the residential market. Some of these may also have potential extension to the commercial field.

The application of pulse combustion to gas-fired appliances has been under investigation at the AGA Laboratories for over 15 years. This concept offers the advantage of power venting without a blower, and efficiency heat transfer due to the scrubbing of the thermal boundary layer. Outside combustion air can be used without need for a conventional vent or chimney. A traditional problem of pulse combustion systems has been noise. This can be overcome with mufflers, but generally these create size and expense problems. Applications to boilers, water heaters, and forced-air furnaces have produced

appliances with steady-state efficiencies of over 90 percent. Seasonal efficiency should also be high.

A number of flue-gas heat recovery devices have appeared on the market, many of which are applicable to boilers. There is, of course, some hazard in applying such units to conventional gravity-fired combustion units since the additional pressure drop caused by flow through the exchanger, together with the lower buoyancy force provided by lower-temperature flue products, may cause unsafe venting or combustion characteristics. Incorporation of heat recovery techniques into special final stages of new designs could overcome these limitations.

Other techniques available for improving efficiency include improved insulation, flue dampers to restrict standby losses, use of outside combustion air, elimination of continuously burning pilots, and use of power burners. These approaches are reviewed in Table 7.3.

7.1.2 Forced-Air Furnaces and Unit Heaters

7.1.2.1 State of the Art

Furnaces intended for commercial use are heavy-duty or nonresidential warm-air heaters. They may be used as large space heaters or with a duct distribution system. Sizes and styles are similar to residential units and may be gas, oil, or electric. The gas-fired designs typically use sectional heat exchangers that have air blown across the outer surface. Electric designs usually have a series of 5- to 6-kW electric elements across which the air to be heated is blown. Nominal steady-state efficiency of gas-fired or oil-fired units is 75 percent, and over 95 percent for electric units, but actual seasonal efficiencies are affected by accuracy of sizing and length of operating cycles.

Unit heaters are designed to be used without a duct system. The essential elements are a fan and motor, a heating element, and an enclosure. Unit heaters have a large heating capacity in compact sizes; they can project the heated air to a reasonable distance from the heater; and they have a low installed cost per Btu output. They are therefore usually used in cases where the heating requirement and/or the physical volume of the heated space are larger than can be handled adequately or economically by other means. Unit heaters are used principally for heating commercial or industrial structures such as garages, warehouses, showrooms, stores, and laboratories. They can use gas, oil, or electricity as an energy source. The thermal efficiency of these heaters is less affected by operating conditions than that of forced-air heaters, but they do not maintain uniform temperatures in the occupied space, so this in itself represents a different inefficiency.

Unitary rooftop units can be used to supply both the forced-air heating and air-conditioning requirements of a building. The energy source for cooling is normally electric. The heating, however, can be supplied by gas, oil, or electricity. Electric heating can be accomplished by using a reverse refrigerant cycle (heat pump), resistance elements, or a combination of these. Gas or oil heating can be accomplished with all types of air heat exchangers and with hot water or steam coils. The entire package, even in large units, can be tested prior to the arrival at the job site. Rooftop units have the advantage of being able to be applied to relatively small areas of large buildings so that desired areas can be independently controlled.

Since the air handler is always outdoors and above the conditioned space, special consideration must be given to weatherproofing. Rain

and snow, and sometimes sand, must be prevented from entering the structure. Hot water or steam lines must be protected from freezing, and fuel oil lines must be kept warm enough to provide proper oil atomization. The outside location requires good insulation of the entire structure, or heat loss from, or gain to, the components and duct work may result in poor efficiency.

7.1.2.2 Program Descriptions

Many of the design approaches discussed for boilers are also applicable to forced-air heating systems. Pulse combustion furnaces have been under development almost as long as boilers. Flue-gas heat recovery, improved insulation, flue dampers, use of outside combustion air, elimination of standing pilots, and use of power burners are also applicable to forced-air systems.

Some heat pipe approaches have been investigated for forced-air heating. A rotating heat exchanger in which the heat pipes act as blades in the air handler has been under development, and several heat pipe furnace concepts have been proposed. Both approaches are included in Table 7.3.

Modulation of burner input, together with modulation in airflow, can be effective in providing an improved seasonal efficiency of forced-air heating systems, especially if combined with the use of power burners so that high CO_2 levels can be maintained.

7.1.3 Heat Pumps

Heat pumps are becoming more popular for heating applications because of their obvious superiority in efficiency over electric resistance heating, and because of the increased cost and curtailed

availability of gas and oil. A major resistance to their use was created in the past by the traditionally poor service life of the compressor used. However, new designs are providing improved reliability. Designs are also being provided that give improved low-temperature efficiency at only slight penalty to the high-temperature performance. This has improved the seasonal efficiencies. Primary areas of development, which can be anticipated to provide further improvement, are more effective evaporator and condenser designs, working fluids, and compressor designs.

Many programs have been conducted recently on both gas- and electric-powered heat pump systems. A yet unreleased study performed by Gordian Associates, Inc. presents an evaluation of recent developments and conclusions, concerning the various systems as compared to conventional resistance electric or forced-air gas heating systems, with regard to cost and efficiency.

A significant conclusion is that currently available high-efficiency electric heat pumps show an average 18-percent COP improvement and a 9-percent seasonal performance improvement over 1975 equipment. The efficiency of commercial-size units was found to be somewhat lower than that of residential high-efficiency models.

Approaches for further improvement of electric heat pumps include improved compressors, improved evaporator and condenser surfaces, and new working fluids. Chemical companies have been conducting programs in the development of new working fluids for heat pumps. One company has directed special attention to heat-activated heat pumps.

The AGA has been sponsoring research on three approaches to gas-fired heat pumps. These are a Stirling/Rankine-cycle design for residential and commercial applications up to 10 tons capacity, a Brayton/Rankine commercial-only design for sizes over 10 tons, and an organic absorption design for residential and commercial applications. Targeted market introduction dates are 1981 for residential and 1983 for commercial designs.

From a systems approach, the greatest improvement in heat pump seasonal performance would probably be obtained by providing sufficient storage so that the compressor could be operated during periods of optimum heat availability at the evaporator, with heat being supplied from storage during the coldest periods. Heat storage in the form of water is also a potential evaporator source. Several large-volume ice/water systems have been prepared to serve both heating and cooking functions.

7.2 WATER HEATING

As indicated in Table 7.1, commercial water heating equipment can be separated into three basic types: storage tank heaters, circulating tank heaters, and instantaneous heaters. A fourth group, swimming pool heaters, is sometimes added, but it is really a special case of an instantaneous or storage heater designed for outdoor installation.

For cases where only a moderate amount of stored water is required (less than 120 gallons), a storage heater can be connected directly to the line or lines supplying the points of use. This heater is generally constructed of carbon steel with a high-temperature glass coating fired onto the inner surface. A magnesium anode is used to

prevent corrosion of bare surfaces, which occurs at sharp edges and threaded fittings. Gas- or oil-fired inputs from 100,000 to 3,000,000 Btu/hr are common. Electric heaters have typical capacities of up to 54 kW.

In cases where no storage capacity is required, an instantaneous heater may be used. These are usually gas-fired with copper-finned tubes used as the heat transfer surface. They are made with capacities up to 4,000,000 Btu/hr.

When a large storage capacity is required, either the storage tank heater or the instantaneous heater may be connected to a large tank where water is pumped from the tank to the heater, boosted in temperature, and circulated back to the storage tank.

Hot or warm water is used by most commercial establishments, including restaurants, office buildings, apartment buildings, schools, motels, hotels, dormitories, stores, laundries, swimming pools, beauty parlors, barber shops, churches, country clubs, hospitals, medical clinics, and nursing homes. The amount of water required varies with the size of the commercial establishment and the number of showers, washrooms, kitchens, etc.

7.2.1 State of the Art

Efficiencies of fuel-fired commercial water heaters are typically around 70 percent, and 80 to 90 percent for electric units. This scheduled draw efficiency is considerably greater than the overall system efficiency, which is defined as the ratio of heat in the water delivered at points of use to the heat supplied to the heater for any selected time period. This efficiency may be as low as 45 percent.

A careful design of the total system can improve the system efficiency. For fuel-fired units, it is difficult to exceed a value of 85 percent for a recovery efficiency because of condensation problems. For electric resistance heating, the theoretical maximum with perfect insulation would be 100 percent. Practical values are probably closer to 90 percent. Further improvement of electric units will require an approach such as the dedicated heat pump to exceed 100 percent.

7.2.2 Program Descriptions

As indicated in Tables 7.4 and 7.5, a number of approaches have been attempted and are available for the improvement of water-heating efficiency. A number of these approaches were described in the section on space-heating systems under the boiler subdivision, so the mechanism of operation will not be reiterated here.

A design not discussed before is the heat pipe water heater concept. This design provides a high efficiency through incorporation of a number of unique features, including a plastic tank and tank support, electric spark ignition, power combustion, elimination of conventional flue, and the use of a heat pipe heat transfer system. The present 40-gallon residential design has a service efficiency of over 68 percent. This can be increased to over 77 percent by incorporating additional insulation and more heat pipe surface. Although the present design is limited to residential load capacities, modification of the concept to commercial heater capacity is relatively straightforward.

Another approach recently started is the use of a dedicated heat pump for water heating. Again, although the program is directed toward the residential market, it may have application to commercial

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TABLE 7.4

EQUIPMENT IMPROVEMENTS
WATER HEATING

II. A. Equipment Programs

1. Liquid Heater
2. Miniboiler Plus Storage Tank
3. SES Instantaneous
4. Heat Pipe Water Heater
5. Pulse Combustion Water Heater
6. Heat Pump Water Heater
7. Hot Gas Line Water Heater

II. B. Available Approaches

1. Reduced Distribution Line Length and Size with Added Insulation
2. Lower Storage Temperature (with print of use boost)
3. Flue Gas Heat Recovery
4. Improved Insulation
5. Improved Tank Insolation
6. Heat Traps
7. Flue Dampers
8. Outside Combustion Air
9. Optimum Sizing
10. Modulation
11. Improved Burners
12. Emulsified Liquid Fuels
13. Electric Ignition
14. Power Combustion

TABLE 7.5

INFORMATION ON PROGRAMS AND APPROACHES - WATER HEATING

A-1481a

Improvement/Concept	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
1. Liquid Heater	Instantaneous	G-O	0 - 10	10	10 - 20	I	A high-efficiency heater has been developed that can be used as a booster or instantaneous heater. It uses jet impingement and powered combustion.
2. Miniboiler	Storage Tank Heater	G	0	10	10 - 20	I	The high-efficiency boiler has been developed that can be used in conjunction with a heat transfer coil to supply heat to a water storage tank.
3.* SES Heater	Instantaneous	G-O	--	10	10 - 20	I	A design has been developed that can provide high efficiency as an instantaneous or booster heater. It is a copper coil design with a proprietary burner.
4. Heat Pipe Water Heater	Storage	G	20	10	10 - 20	I	A high-efficiency water heater has been developed for the residential market. It uses powered combustion, electric ignition and heat pipe technology. The design concept can be extended to commercial units.
5. Pulse Combustion	Instantaneous Storage	G	40 - 80	10 - 15	15 - 25	I	This concept has been under development for over 15 years. Problems have been long-term reliability and noise.
6. Heat Pump	Storage	E	100 - 150	100	100	N-I	A heat-pump water heater program for residential use has recently been sponsored by DOE.
7.* Hot Gas Line Heat Recovery	Storage	E	--	--	--	N	Heat exchangers are being applied to the hot gas line ahead of the condenser on air conditioning and refrigeration systems. This has been very effective in supermarket use, sometimes eliminating the need for other water heating while improving refrigeration cycle efficiency.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

*Not evaluated.

TABLE 7.5 (cont'd)

INFORMATION ON PROGRAMS AND APPROACHES
WATER HEATING

A-1481b

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
8. Reduced Storage Temperature with Boost at Point of Use	Storage	E-G-O	20 - 100	0 - 2	5 - 10	I	Especially in the case of gas- or oil-fired heaters, the high loss through the flues on standby is a strong function of storage temperature. In some cases, point of use gas or electric heaters could reduce this loss.
9. Flue Gas Heat Recovery	Storage	G-O	25 - 50	5 - 10	5 - 10	--	The most effective way to use flue gas heat recovery for water heating would be to provide a low-temperature storage tank as a tempering stage for the primary heater.
10. Improved Insulation	Storage	G-O-E	5	0 - 0.5	0 - 5	N	Increased insulation is being used in residential heaters to reduce standby losses. For high input heaters, it is less effective on a percentage basis.
11. Heat Traps and Tank Isolation	Storage	E	5 - 10	0	0 - 2	N	These are also approaches used to reduce standby losses for residential heaters. Their effect is again marginal for high usage heaters.
12. Flue Dampers	Storage	G	5 - 10	0	5 - 15	N	Flue dampers are now available for field installation. They are most effective when applied to new designs. While they reduce the exfiltration loss, they must be applied before the vent hood to prevent loss of heat from the internal flue to the heater ambient.
13. Outside Combustion Air	All	G-O	5 - 10	--	0.5 - 5	N	This must be used in such a way that outside air cannot be gravity-pumped through the heater when the burners are not operating or losses may increase rather than decrease in winter operation.
14. Electric Ignition	All	G	5 - 10	--	1 - 5	N	The gas pilot operates at relatively low efficiency compared to the main burner. The percent loss depends on water throughput and burner capacity.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

TABLE 7.5 (cont'd)

INFORMATION ON PROGRAMS AND APPROACHES
WATER HEATING

A-1481c

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
15. Modulation	All	G-O	10 - 50	0 - 10	10	N-I	Modulation of burner rate if combined with power combustion can reduce flue temperature and provide improved recovery efficiency.
16. Emulsified Fuel	All	O	20	5	7	I	Emulsified fuel can reduce sooting and thereby reduce flue losses caused by poor heat transfer.
17. Power Burners	All	G-O	15	10	20	N-I	Use of power burners, especially for gas heaters, can reduce standby losses. Steady-state efficiency is improved by better heat transfer and higher permissable CO_2 levels.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

use. Major improvements in efficiency over conventional electric water heating is possible.

Several companies have entered the market with a heat recovery unit for heating water from the hot gas line of an air-conditioning or refrigeration compressor. A heat exchanger with a pumped water circuit is installed between the compressor and the condenser coil. This system has been particularly successful in supermarkets and in hot climates. For some supermarkets, it has eliminated the need for a conventional water heater except for standby provisions.

7.3 AIR CONDITIONING

Within the air-conditioning category, the two classifications of most interest are the chillers, which represents the cases where a cooled liquid is to be circulated to provide the air-conditioning function, and the unitary equipment, which includes both self-contained and split systems.

7.3.1 State of the Art

A liquid chilling system chills water, brine, or other secondary refrigerant liquids for air-conditioning or refrigeration purposes. The most frequent application is water chilling, for air conditioning, although brine cooling for low-temperature refrigeration is also common. For air conditioning, the chilled water typically enters the cooler at 54°F and leaves at 44°F. This provides sufficient temperature change to require only reasonable pumping rates and maintains a temperature, at the point of use, that is low enough to give good dehumidification characteristics. For capacities up to 80 tons, reciprocating compressors are generally used. From 80 to 120 tons,

reciprocal, or centrifugal compressors are used, and, from 120 to 200 tons, reciprocal, screw, or centrifugal compressors are used. The selection depends largely upon the type of anticipated load, the fluctuation rate, the available condensing conditions, and other system characteristics.

Typically, chilled water systems will provide somewhat lower overall efficiencies than those of air systems for the same condensing temperature. However, they provide the flexibility of a coolant, which is easier to circulate than air for central systems in hotels and multistory apartment buildings.

The unitary air conditioner has been defined by the Air Conditioning and Refrigeration Institute as follows: "A unitary air conditioner consists of one or more factory-made assemblies which normally include an evaporator or cooling coil, a compressor and condenser combination, and may include a heating function as well." The key part of the definition is the specification that the components are factory-made to a specific design and are matched so that the system capacity and efficiency are reproducible whenever and wherever the components comprising the system are subjected to a given condition at the condenser and evaporator locations. Matched equipment of known capacity and performance, selected with compatible accessory items, considerably lessens field design work on typical installations.

The most common unitary installation is a remote condensing unit with an evaporator coil located in a separate forced-air heating unit or in a blower-coil assembly. In the commercial market, the packaged unit, with all components located outside the building and cooled air ducted into the building, is also common.

Unitary equipment is available in a wide range of capacities and a range of efficiencies. Typical EER ratings vary from under 7 to over 10. In some cases, the higher ratings are obtained by using spray-cooled condensers; in others, simply by providing larger condenser surfaces and high airflows to give low condensing temperatures. In any case, increased condenser and evaporator areas with increased airflow will improve EER ratings, although sometimes with poor dehumidification ability.

The sensitivity to condensing temperature suggests that more attention should be given to seasonal performance of the equipment and to various methods of capacity control to assure that optimum performance is maintained under the various ambient conditions encountered throughout the air-conditioning season.

7.3.2 Program Descriptions

Some of the programs and approaches that have been directed toward the improvement in air-conditioning efficiency are listed in Tables 7.6 and 7.7.

One method for reducing condensing temperature is the use of either spray- or water-cooled condensers. This provides a unit that is not limited in capacity and efficiency by ambient dry bulb temperatures, but is controlled by wet bulb or water temperatures. If a cooling tower is used, the basic limitation is ambient wet bulb temperatures, as for spray-cooled condensers.

The use of evaporative water to reduce or eliminate the need for conventional air conditioning is a concept that has been receiving increasing attention in many countries as well as the southwestern area of the United States. Its use could be increased to other areas where the

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TABLE 7.6

EQUIPMENT IMPROVEMENTS
AIR CONDITIONING

III. A. Equipment Programs

1. Wet Condenser Units
2. High-Efficiency Compressors
3. Gas-Fired Air Conditioners
4. Evaporative Coolers
5. Control System to Switch in Outside Air When Required
6. Improved Evaporator and Condenser Surfaces
7. Cooling Tower Efficiency Improvement

III. B. Available Approaches

1. Increased Heat Exchanger Area to Increase Suction Pressure and Decrease Discharge Pressure of the Compressor
2. Improved Refrigerant
3. Increased Airflow (within humidity control limit)
4. Use of Storage to Improve Inertia and Operate at Lower Ambient Temperature
5. Combination with Ice-Producing Heat Pump
6. Indirect Evaporative Heat Exchangers Combined with ac

TABLE 7.7

INFORMATION ON PROGRAMS AND APPROACHES
AIR CONDITIONING

A-1483a

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
1. Wet Condenser Units	--	E	25	40	50	N	Spray or water cooled condensing coils can provide reduced condensing temperature and therefore reduced compressor pumping power.
2. High-Efficiency Compressors	--	E	0 - 5	2 - 5	2 - 5	N	Use of more efficient motors together with other design changes in compressors have been steadily reducing energy consumption.
3. Gas-Fired Air Conditioners	--	G	30	--	--	I	The approaches being investigated for gas-fired heat pumps also generally apply to gas-fired air conditioners. While operating at a lower COP than electric units, their efficiency compared to electric when compensated for powerplant losses can be attractive.
4.* Evaporative Coolers	--	E	--	--	--	N	In many cases, indirect evaporative coolers can be used to replace or supplement air conditioners at less than half the energy requirement. This is especially true where dew point of ambient air is low, or where a high sensible, low latent load exists.
5.* Outside Air Inlet Control	--	G-E	10	--	--	N	In some locations, the outside air temperature drops below required space dry and wet bulb levels while system inertia still calls for cooling. New control systems are automatically switching to outside air supply when this situation occurs.
6. Improved Evaporator and Condenser Surfaces	--	G-E	0 - 15	5 - 15	5 - 15	N	Several proprietary designs have been developed to improve the effectiveness of evaporators and condensers.
7. Cooling Tower Efficiency Improvement	--	G-E	0 - 20	5 - 10	5 - 10	N	Larger and more efficient cooling towers are being used to provide closer approach to wet bulb temperature in water supplied to condensers.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

*Not evaluated.

TABLE 7.7 (continued)

INFORMATION ON PROGRAMS AND APPROACHES - AIR CONDITIONING

A-1483b

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
8. Increased Evaporator and Condenser Capacity	--	G-E	0 - 20	5 - 15	5 - 15	N	Increasing heat exchanger capacity reduces compressor discharge pressure and increases suction pressure, so compressor work is reduced. Proper capacity control must, however, be maintained.
9.* Alternate Refrigerants	--	G-E	--	--	--	I	Several chemical companies are conducting searches for more efficient working fluids.
10. Increased Air Flow	--	G-E	0 - 10	5	5	N	Increased air flow at evaporator and condenser improves air to working fluid temperature difference. At the evaporator, adequate dehumidification is a limitation.
11.* Storage	--	G-E	10 - 1000	--	--	I	The use of storage in conjunction with air conditioning can provide significant improvement in efficiency levels. It permits the unit to be operated when condenser ambient is lower or when electric system load is reduced. A system combining air conditioning and heat pump operation with ice and water storage shows potential of high efficiency.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate. 5-15 years; L-long term, over 15 years.

*Not evaluated.

dew point of ambient air is low, or where a high-sensible low-latent load exists. Typically, present design units are capable of lowering the dry bulb temperature to within 80 percent of the difference between entering dry and wet bulb temperatures.

Some indirect systems have been developed to which dry bulb temperature is decreased without increasing wet bulb temperature. In these systems, air flows both inside and outside a bundle of tubes. The air flowing outside the tubes is saturated and cooled by a water spray. Air flowing inside the tubes is then cooled by the lower temperature outside air. The wet exhaust from the spray side of these systems can then be used to supply cool air to a conventional condensing unit, whereas the somewhat cool dry side is further cooled and dehumidified in a conventional air-conditioning system. The end result can represent a considerable improvement in system efficiency.

High-efficiency compressors have been in the program schedule of essentially all compressor manufacturers. In 1976 Tecumseh introduced a new AG series of three-cylinder units to replace their CL line. Average compressor efficiency improvement was 12 percent with a range from 8 to 15 percent over all sizes. The improvement was accomplished by a combination of motor design, flow path attention, and a short-stroke large-bore approach with more even flow because of the three- rather than two-piston design.

Most of the high-efficiency air-conditioning designs have incorporated an increased condenser and evaporator surface to provide lower condenser and higher evaporator temperatures so that the pressure increase across the compressor is reduced.

As previously discussed for heat pumps, the refrigerant manufacturers are actively conducting programs to develop more efficient refrigerants for air-conditioning and refrigerant systems.

More automatic control systems are also being used to improve air-conditioning system efficiency. In some commercial installations, the outside temperature, both wet and dry bulb, may drop to a level where conditioning is not necessary, but inertia in the heat load will continue to operate the air conditioner. Dilution systems are being installed that sense this condition and bring in outside air through a filtration system to reduce the air-conditioning load.

The approaches being considered for gas-fired heat pumps are also being applied to air-conditioning systems. Some appear to have attractive potential, but considerable field testing of final designs will undoubtedly be required to tempt manufacturers back into the field of gas air conditioning.

The use of storage with air conditioning, as for heat pumps, has the potential to increase efficiency by not permitting the unit to be operated when condenser ambient is excessive, at least when this condition occurs for limited time periods. Again, where sufficient storage volume is available, the proposed ice/water system for heat pump heating and air conditioning has considerable appeal.

7.4 REFRIGERATION

7.4.1 State of the Art

Refrigeration is used in the commercial sector in all food-handling businesses such as food and beverage service installations, commissaries, bakeries, candy stores, supermarkets, meat markets, and wholesale warehouses. Equipment includes food freezers, display cabinets, walk-in and reach-in cabinets, ice cream cabinets, ice makers, water coolers, meat display cases, fruit and produce cases, and dairy cases.

Almost half of the retail food sales in the United States is made up of perishable foods that require some degree of refrigeration. These products must be kept under safe temperature for their entire stay in the retail store, including storage, processing, and display-shelf life. In addition to being refrigerated, these products must be displayed as attractively as the nonperishable food items in the store. The variety of food products stored and displayed requires a selection of special evaporators, defrosting controls, and other special apparatus designs to suit the particular product being handled or displayed. Required temperatures range from medium-temperature nonfrozen to low-temperature frozen. As an example of open display-case requirements, the ideal storage temperature for meats is 40°F. An increase to 50°F will cause bacterial growth, shortening the salable life by 50 percent while also causing loss of red color. The explosion of frozen food sales has resulted in these products representing approximately 5 percent of general food sales, and up to 10 percent in some stores.

Each category of food product displayed is usually backed up by storage equipment in the back room. This typically consists of refrigerated rooms equipped with the necessary storage racks or handing rails for the particular product stored.

Food freezers and refrigerators are usually available with a great many modifications or adaptations to satisfy the various products stored. Food service applications often call for extra shelves. Retail bakeries need special conditions of humidity and temperature to retard dough so that it can be stored for the entire week. Drug stores often require special drawers for products. Florists require high humidity with a temperature of 40° to 45°F and gentle airflow.

Larger walk-in coolers and freezers are also supplied as factory-built prefabricated equipment. Large food operations usually require at least three rooms: one for fruits and vegetables, one for dairy products, and one for meats. A fourth frozen food storage room is often needed.

Closed refrigerators operate at efficiencies of about 3 Btu/watt. Open display cases are less efficient, and the efficiency drops as the operating temperature is decreased.

7.4.2 Program Descriptions

Many of the programs and approaches directed toward improvement in efficiency of refrigeration systems involve the same components and techniques as for air conditioning. Some of these are listed in Tables 7.8 and 7.9.

Many seemingly small items can contribute to inefficient refrigerator operation. Improved door seals can reduce leakage paths around gaskets. It is important to consider the deterioration of gaskets with time since many commercial outlet refrigeration units are opened and closed frequently. New control systems provide for modulated or power-pulsed operation of anticondensate heaters on refrigerant display cases. This can amount to a reduced load of over 3000 kWh/month for a six-display-case bank.

Improved insulation and methods for reducing heat losses to the ambient for supermarket display cases are areas receiving design consideration by equipment manufacturers.

Another potential area for improvement which has received more attention, but will probably see more, is the improvement of

TABLE 7.8

EQUIPMENT IMPROVEMENTS
REFRIGERATION

IV. A. Equipment Programs

1. High-Efficiency Compressor
2. Improved Temperature Requirement Range
3. Wet Condenser Units
4. Improved Cooling Tower Performance
5. Designs to Restrict Showcase Heat Pickup
6. Improved Door Seals
7. Interlocks
8. Antisweat Defeat Switch
9. Improved Evaporator and Condenser Surfaces

IV. B. Available Approaches

1. Improved Insulation
2. Improved Refrigerant
3. Multiplexing for Higher Efficiency

TABLE 7.9

INFORMATION ON PROGRAMS AND APPROACHES
REFRIGERATION

A-1485

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
1. High-Efficiency Compressors	--	E	0 - 5	2 - 7	2 - 7	N	Use of more efficient motors together with other compressor design changes have steadily reduced energy requirements.
2.* Improved Temperature Requirement Range	--	E	--	5 - 40	5 - 40	N	More accurate definition of minimum temperature required in refrigeration applications together with control systems capable of holding temperature more accurately can permit higher average temperature operation and therefore higher efficiency.
3. Wet Condensing Units and Cooling Towers	--	E	25	20 - 40	30 - 50	N	Spray- or water-cooled condensing units can provide reduced condensing temperatures and pressures and therefore reduced compressor pumping power.
4.* Improved Door Seals	--	E	--	--	--	N	Improved door seals can reduce infiltration losses. Heat leakage around gaskets and seals represents up to 20 percent off refrigerator heat loss.
5.* Antisweat Defeat Switch	--	E	--	--	--	N	Small capacity refrigerators include antisweat heaters. In low wet bulb installations, this is not needed and can be eliminated.
6. Improved Evaporator and Condenser Surfaces	--	E	0 - 15	5 - 15	5 - 15	N	Several proprietary designs have been developed to improve the effectiveness of evaporator and condenser coils.
7. Improved Insulation	--	E	0 - 10	10 - 35	10 - 35	N	Use of high-efficiency foam insulation has provided more compact, higher efficiency units.
8.* Improved Refrigerant	--	E	--	--	--	I	Several chemical companies are investigating alternate working fluids.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

*Not evaluated.

temperature control. If a given maximum temperature can be controlled more accurately, the average temperature maintained in refrigeration applications can increase and system efficiency will, therefore, increase. A decrease in the maximum temperature of a frozen food display case from 15° to 0°F can result in an increase in power requirement of over 30 percent.

7.5 LIGHTING

Some of the programs and approaches that have been directed toward the improvement in lighting efficiency are listed in Tables 7.10 and 7.11.

Lamps can be divided into the four general categories of incandescent, fluorescent, high-intensity discharge (HID) and metal halide types. The range of efficiency of these lamps is shown below:

Lamp Type	Efficacy Range[17] (Lumens/watt)
Incandescent	15-25
Fluorescent	55-85
Metal Halide	80-100
High-Intensity Discharge	50-180

The efficiency is designed as the ratio of lighting level output in lumens to the input energy in watts. The large spread in values for the HID lamps is due to the fact that they include a number of different lamp types that are used for special applications and are at the lower end of the range (e.g., mercury vapor lamps ~50 to 60 lumens/watt).

TABLE 7.10

EQUIPMENT IMPROVEMENTS
LIGHTING

V. A. Equipment Program

1. Fluorescent
2. Incandescent
3. Metal Halide
4. High-Intensity Discharge

V. B. Available Approaches

1. Improved Phosphor Coating for Fluorescent Lamps
2. Improved Coating and Optics to Use Reflective Energy to Heat Incandescent Lamp Filament
3. Develop More Efficient Lamp Ballasts by Using Solid-State Devices
4. Develop Operation of Metal Halide and High-Intensity Discharge Lamps at Lower Wattage in Order to Reduce Incandescent and Fluorescent Lamp Usage; Levels Take Advantage of Their Inherent Higher Efficiency Levels
5. Develop Screw-in Fluorescent Lamps to Replace Incandescent Lamps and Take Advantage of the Higher Efficiency Level of Fluorescent Lamps

TABLE 7.11

INFORMATION ON PROGRAMS AND APPROACHES LIGHTING

A-1487r

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	% Increased Lighting Efficacy	Time-to-Volume Usage[2]	Remarks
Improved Phosphor Coating for Fluorescent Lamps	Fluorescent Lighting	Electric	40 - 50	7 - 12	N	Lamp companies have continuous R&D effort to improve fluorescent lamp coatings.
Develop Operation of Metal Halide and High Intensity Discharge Lamps at Lower Wattage Sizes *	Metal Halide and H. I. D. Lighting	Electric	--	--	I	Lamp companies have continuous programs to develop these lamps at low wattage range to gain improved lighting levels due to their inherent high efficacy levels. A number of companies are working in this area.
Solid-State Ballasts *	H. I. D. and Fluorescent	Electric	--	--	I	To date, these devices are not economically feasible.
Development of Screw-in Fluorescent Lamps to Replace Incandescent Lamps *	Incandescent	Electric	200†	150 - 250	I	To date, lamp is not economically feasible.
Improved Coating for Incandescent Lamps *	Incandescent	Electric	--	50 - 60	N	Duco Test Corporation in association with M. I. T. is developing the coating and optics for the lamp design.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

*Not evaluated.

†Information recently supplied by ORNL.

There is presently a developmental program being pursued by a major lamp manufacturer to produce an incandescent lamp with a new chemical coating and optics that reduce energy consumption by 50 to 60 percent for the same lighting level. The principle is to focus the reflected light from the inside surface of the bulb as an aid in heating the filament.

Another manufacturer has developed a new phosphor coating for fluorescent lamps which increases its flowing properties. Furthermore, manufacturers continue to develop HID lamps at the lower end of the power input range to gain their inherently high efficiency characteristics.

In this same area, fluorescent lamps with screw-in capabilities have been proposed as replacements for incandescent lamps. However, it appears that their initial costs may prevent them from being widely utilized.

Ballasts are used in fluorescent-type and gaseous-discharge lamps that act as both an autotransformer to step up supply voltage, and a choke to limit the current through the lamp. It is estimated that the energy loss associated with the ballast can range between 10 and 20 percent of the total energy into the lamp fixture. Solid-state ballasts are being developed; however, at the present time high initial cost is the major drawback for this device.

7.6 COOKING

Commercial gas cooking equipment covers a large number of appliances, including griddles, fryers, ovens, broilers, ranges, etc. Each of these appliances is designed for a particular type of cooking.

They are manufactured in a wide variety of sizes and gas inputs. The ANSI codes covering these appliances are primarily concerned with construction and safety aspects, and pay little attention to the efficiency of their operation.

Most of these appliances have operating or cooling efficiencies (i. e., the ratio of energy into the food to the energy consumed) well below 40 percent. With the exception of the convection oven and the recent development of the isothermal griddle, heat pipe fryer, and the heat pipe oven, very little has been done to improve the operating efficiency of these appliances. Application of microwave ovens to commercial cooking has been small; however, it has been gaining increasing acceptance.

Some of the approaches previously described for other appliances are also potentially applicable to cooking equipment. The potential to use one of the compact boilers as a steam generator for steam tables, kettles, and pressure units is a distinct possibility.

The available programs and approaches are reviewed briefly in Tables 7.12 and 7.13.

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TABLE 7.12

EQUIPMENT IMPROVEMENTS
COOKING

VI. A. Improved Equipment

1. Heat Pipe Griddle
2. Heat Pipe Fryer
3. Heat Pipe Oven
4. Microwave Cooking

VI. B. Available Approaches

1. Improved Appliance Insulation
2. Modulation
3. Electric Ignition
4. Power Combustion
5. Improved Control System
6. Specialized Appliances
7. Improved Steam Generators

TABLE 7.13

INFORMATION ON PROGRAMS AND APPROACHES
COOKING

A-1489

Program/Approach	Appliance	Energy Type[1]	Cost Increase %	Efficiency Increase, %		Time-to-Volume Usage[2]	Remarks
				Steady State	Seasonal		
1. Heat Pipe Griddle	Griddle	G	25	100	150	N	This griddle uses power combustion, jet impingement heat transfer and heat pipe technology to increase efficiency and improve performance.
2. Heat Pipe Fryer	Fryer	G	25	50	50	N	This fryer uses power combustion, jet impingement heat transfer and heat pipe technology to increase efficiency and improve performance.
3. Heat Pipe Oven	Oven	G	25	15	15	N	This oven uses power combustion, jet impingement heat transfer and heat pipe technology to increase efficiency and improve performance.
4. Microwave Ovens*	Oven	E	--	--	--	N	Improvements in microwave cooking equipment permit a wider range of products to be prepared. Since the oven itself does not have to be heated, inertia and air heat losses are reduced.
5. Improved Insulation	All	G-E	2 - 5	1 - 2	1 - 2	N	Increased insulation not only reduces appliance heat losses, but also reduces the heat load applied to the kitchen, thereby reducing air conditioning requirements.
6. Modulation	All	G	10 - 25	5 - 10	5 - 10	N	Modulation of burner firing rate can permit reduced flue losses and better temperature control which eliminates unnecessary temperature overshoot.
7. Electric Ignition or Other Pilot Elimination Approach Such as Catalytic Ignition	All	G	5 - 10	--	1 - 5	N	A constant burning gas pilot represents a zero efficiency energy consumption for most cooking appliances. Electric ignition is being used in some equipment. Investigations of alternate ignition systems are being conducted.
8. Power Combustion	All	G	10	10 - 50	10 - 50	N	Power burners permit more efficient use of heat transfer surfaces with greatly reduced flue losses.
9. Improved Steam Generators	Steam Using Appliances	G	0 - 20	5 - 15	5 - 20	N-I	Some of the compact boiler concepts developed for heating applications can be extended to steam generation for cooking and warming equipment.

[1] G-gas, O-oil, E-electricity.

[2] N-near term, 0-5 years; I-intermediate, 5-15 years; L-long term, over 15 years.

*Not evaluated.

8. BUYER EVALUATION AND SELECTION CRITERIA

The preceding chapter of this report described a number of development opportunities that are aimed at improving the energy utilization of appliances used in the commercial sector. These developments vary considerably in the extent to which they will affect the design, energy utilization, and cost of contemporary equipment. Some of these developments will lead to small improvements in energy utilization with relatively small changes in the design and cost of the appliance. Other developments, which are directed toward major improvements in energy utilization, will require radical changes in the design and substantial increases in the final cost of the equipment.

A proper evaluation of these developments, with regard to energy savings on a national level, will require an estimate of their unit energy savings and their ultimate sales potential. A development leading to a large improvement in efficiency will have no effect on a national energy savings if it cannot be sold. Conversely, a small efficiency improvement in an appliance that has a large sales potential could significantly improve the national energy utilization.

Estimated efficiency improvements of many of these developments have been defined and documented. Estimates of their ultimate sales potential are not as clear. An understanding of the buying process in the commercial market is a necessary requisite in estimating the sales potential of an energy-saving product. This chapter of the report addresses itself to the buying process, which includes the characteristics of the buyers and the decisionmakers, as well as a definition of the criteria used in the selection of energy-related equipment. In this section, the primary emphasis is on heating, air conditioning,

lighting, cooking, refrigeration, and water heating, since these are the major end users of energy in the commercial sector. However, the criteria for most other functional uses of energy may be adapted from this information presented here.

Information in this chapter was obtained from various sources. The marketing departments of the Southern California Gas Company, Consolidated Gas Company, and New England Electric Company supplied information regarding commercial customers. Equipment manufacturers, such as Rheem, Lennox, Carrier, State Industries, and U.S. Range, expressed their opinions regarding the selection criteria used by their customers. Two management consultant firms, The Kearney Consultants of Cleveland[18] and Wm. Hill Associates of New York,[19] supplied information in the form of marketing reports prepared for Consolidated Gas Co. Other FEA reports prepared by Ultrasystems, Inc.,[20] Opinion Research Corp.,[21] and The Hittman Associates,[8] which are concerned with the commercialization of energy-related equipment, were employed in this study.

8.1 OWNERSHIP AND USAGE

The basic types of building owners may be identified according to the length of time they maintain control of their buildings and how that time span affects their decision to make a new building energy efficient or to retrofit an older building with energy-conserving equipment. Short-term or speculative owners generally expect to sell or lease the building within one or two years. Nonspeculative owners usually occupy or manage the building for longer periods of time.

The importance of equipment first cost varies considerably between speculative and nonspeculative buyers. The speculative buyers

are not the ultimate users of equipment. Therefore, they have less reason to consider factors other than first cost, and they tend to be price sensitive. The nonspeculative customers, particularly the owners/users, are conscious of first cost as well as other factors, such as equipment life, reliability, operating cost, and maintenance cost.

Speculative customers are not evenly distributed among the various subsectors of the commercial market. They are more involved with commercial office and retail buildings. Approximately 40 percent of these types of buildings are developed by speculative owners. Institutional buildings, in such subsectors as religion, education, health care, and public administration, have nonspeculative owners/users.

Another key factor in the selection of energy-conserving equipment is the nature of the building users; i.e., whether the building is owner- or tenant-occupied. As stated before, institutional buildings are almost exclusively owner occupied. Buildings in the services area, especially hotels and motels, are evenly divided between those that are owner occupied and those that are tenant occupied. Shopping centers are rarely owner occupied. An exception occurs when a realty trust formed by a major tenant is the developer, or if the realty trust is in a joint venture with the developer. This type of owner/tenant arrangement comprises less than 10 percent of the shopping centers.

The widest variety of usage patterns is found in office buildings. Usage varies from city to city, depending on whether the city is a recognized headquarters city.

8.2 DECISIONMAKING

The people who make the actual decisions regarding the purchase of energy-related equipment in the commercial sector are influenced by a number of issues, pressures, and priorities. Their selections must take into account cost, fuel availability, geographic location, and usage patterns. Regardless of the many factors influencing these decisionmakers, their final decisions follow a consistent pattern.

The people who are primarily involved in the decisionmaking process are:

- Owner-Developer
- Mechanical and Electrical Engineers
- Contractors
- Property Managers

The property owners were discussed previously regarding their type of ownership. Here we look at the role of the owners in the decisionmaking process. Owners are divided into two types: those owners who delegate the making of all critical decisions regarding the equipment-buying process to an architect or engineer, and the more sophisticated owners who make their own decisions. It is estimated that approximately one-third of all commercial buildings are owned by sophisticated owners. In addition, these buildings tend to be larger than those of unsophisticated owners.

When property owners do not make a direct selection of their energy-related equipment, the selection is made by either the engineers or the contractors. The engineers are both first-cost and life-cycle-cost oriented. The contractors are primarily oriented toward first cost.

Property managers influence the equipment-buying process on a retrofit, rather than on a new installation. Property managers are concerned with operating cost. However, it may be difficult for them to convince the building owners of the advantages of the life-cycle cost of retrofit equipment. The owners are expecting the retrofit equipment to pay for itself in 3 to 4 years through reduced operating cost. It is estimated that approximately 10 to 15 percent of the property owners would be willing to retrofit existing equipment if there were an operating cost advantage and a reasonable payback.

Table 8.1 is a summary of the decisionmakers involved with the selection of equipment for buildings in various subsectors and the primary criteria they used in making their selections.

8.3 EVALUATION CRITERIA

The most important criteria used in the evaluation of energy-related equipment are divided into economic and noneconomic categories. The critical economic factors are equipment and installation first cost and operating cost. Operating costs include preventive and repair maintenance and fuel costs. Other costs may or may not be important, depending upon the type of application. Noneconomic factors, such as energy source, equipment performance, equipment features, maintenance, reliability, and buyer attitude, may have a profound influence on equipment selection. In many commercial installations, for example, space heating and air conditioning are viewed as essential to the buildings' activities; therefore, the maintenance and reliability of the equipment are of prime importance. Table 8.2 lists the economic and noneconomic factors in order of their importance in the evaluation and selection of equipment.

TABLE 8.1

SUMMARY OF DECISION MAKERS AND SELECTION CRITERIA

A-1517

Building Type	Primary Decision Makers	Most Important Selection Criteria
Office Buildings, New		
- High-Rise	Engineer and Sophisticated Owner	• First Cost • Comfort of Lessees
- Low-Rise	Engineer	• First Cost • Held for Tax Reasons
Office Buildings, Retrofit		
- High-Rise	Property Manager	• Better Performance for Equal or Fewer Dollars
- Low-Rise	Property Manager	• Operating Cost • First Cost
Retail Buildings, New		
- Shopping Center	Sophisticated Owner Engineer	• First Cost • Tenants Pay Bills
- Individual Retail	Engineer	• Life Cycle Cost
- Service	Engineer/Architect	• First Cost
Retail Buildings, Retrofit		
- Shopping Center	Property Manager Owner	• Increase Owner Profit
- Individual Retail	Property Manager Owner	• Life Cycle Susceptible • Must Have at Least 4-Year Payback
- Service	Property Manager Owner	• First Cost • Tenants Pay Bills
Educational Buildings, New	Engineer Sophisticated Owner	• Life Cycle Cost
Educational Buildings, Retrofit	Property Management Group	• Life Cycle Cost with Predicted Rate of Return
Hospitals, New	Engineer Sophisticated Owner	• Life Cycle Cost
Hospitals, Retrofit	Property Management Group	• Life Cycle Cost with Predicted Rate of Return

TABLE 8.2

EQUIPMENT SELECTION FACTORS

Economic Factors

First Cost
- Equipment
- Total installation

Operating Costs
- Annual maintenance
- Repair maintenance
- Energy (efficiency; fuel costs)

Other Costs (Indirect)
- Floor or interior space -- equipment configuration, i.e., rooftop
- Loads and distribution -- sizes and complexity of equipment; i.e., ducting vs. multiples, etc.
- Interest costs/investment criteria -- funds available, required returns, etc.
- Time -- inception to occupation/operation

Noneconomic Factors

Energy Source
- Availability
- Restrictions
- System types/configurations

System Performance/Features
- Reliability
- Ease of operation
- Operational features
- Equipment life

Maintenance
- Ease of maintenance
- Service availability
- Availability of parts and replacement units

Attitudes
- System design, i.e., CE or contractor
- Equipment manufacturer
- Stability -- number of suppliers, i.e., equipment, parts service, etc.
- Prior experience with equipment, manufacturer, energy source, etc.

8.4 EQUIPMENT COST SENSITIVITY

The sales potential of commercial energy-related equipment is evaluated on the basis of both first cost and operating cost. A product that has a cost premium must possess compensating advantages, such as lower operating cost, to render it acceptable in the market. A common method of evaluating the market acceptance of such a product is to determine the time required for the operating savings to equal or pay back the first-cost premium. In this type of comparative analysis, three elements are important: the first-cost differential, the operating efficiency improvement, and the operating-cost differential. These elements and their resulting payback periods must be considered collectively rather than as separate factors. In other words, the equipment acceptance is not based solely on the payback period or on a first-cost premium.

The W. E. Hill Co.[19] has developed premium/payback - acceptance curves for commercial air conditioning, as shown in Figure 8. 1. These curves are the result of an extensive field and telephone survey and reflect the opinions of over 100 HVAC contractors with regard to the acceptability of various premium/payback period combinations.

Although these curves reflect the marketability of air-conditioning systems, they are in this report considered to represent the attitudes of the commercial market in general. The 2- and 3-year payback information has, therefore, been divided into the following general cost sensitivity relationship:

$$MA = [1 - 0.7(PB)(CP)]100$$

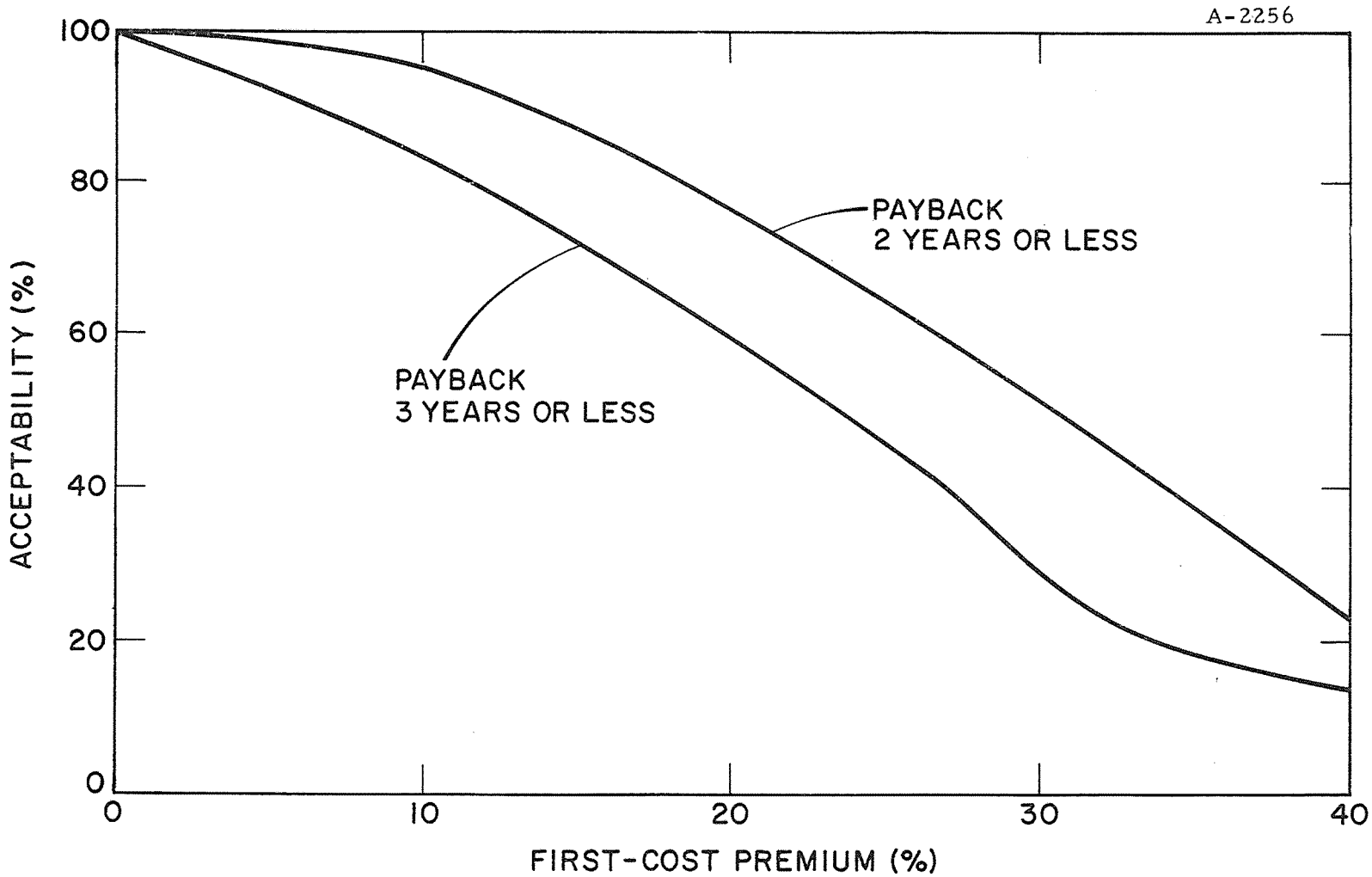

Figure 8.1 Equipment Cost Sensitivities - Premium/Payback Analysis

where

MA = Market Acceptability

PB = Payback Period

CP = Cost Premium

This linear relationship, shown in Figure 8.2 for payback periods of 2, 3, and 4 years, has been used in the market penetration calculation discussed in Chapter 9.

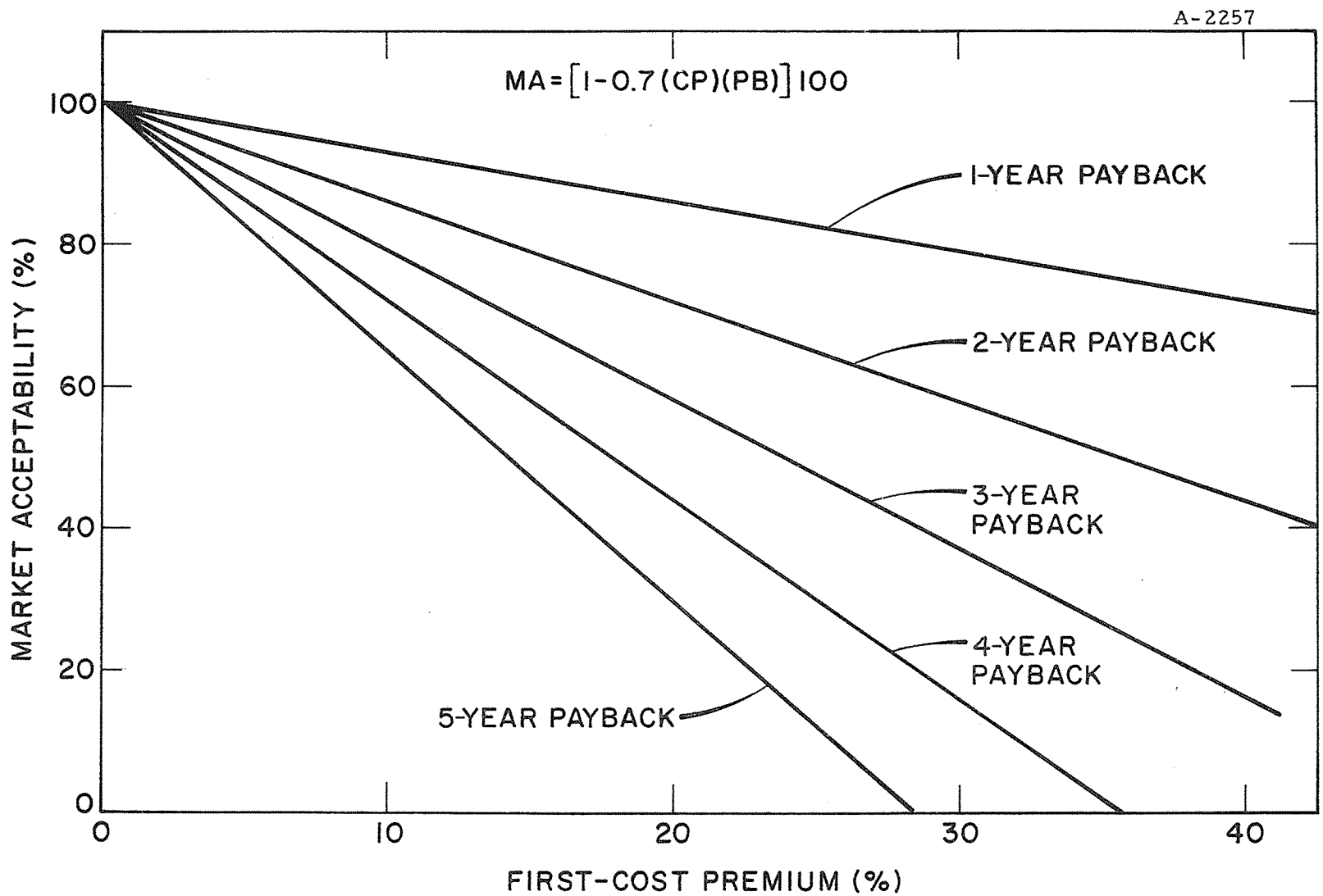

Figure 8.2 Commercial Equipment Cost Sensitivity Function

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9. ANALYSIS AND SELECTION OF ENERGY-SAVING OPPORTUNITIES

9.1 SUMMARY OF RESULTS

One of the major objectives of this study was to analyze and rank the most promising energy-saving opportunities where DOE RD&D funding could most effectively promote energy savings of national significance. To accomplish this objective, each of the specific energy-saving opportunities discussed in Chapter 7 was evaluated on a basis of unit energy savings and potential marketability. The analysis ultimately led to the potential cumulative energy savings by 1990 for each improvement combined with each of the appropriate appliance types.

It should be noted that several opportunities discussed in Section 7 could not be evaluated because critical information concerning the opportunity and required for the analysis was not available.

The effect of DOE support was factored into the analysis by assuming an acceleration of the date at which a specific development (a specific energy-saving improvement combined with a particular appliance type) would first reach the market. A differential between the cumulative energy savings of a development with DOE support and one without DOE support was thereby created. The differential in cumulative energy savings for developments utilizing the same device or improvement was totaled. The total differential in cumulative energy savings for the various improvements are presented in Table 9.1, together with the order of ranking. The ranking of the improvements was based on both end use and prime energy savings. It is, however, recommended that the final ranking be based on the prime energy savings since these values are more significant nationally.

TABLE 9.1

PRIORITY RATINGS FOR POTENTIAL DOE SUPPORT OF ENERGY CONSERVATION OPPORTUNITIES

A-2233r

Concept	Application	Difference in Cumulative (1980-1990) Energy Savings (Btu x 10^{12}) Between DOE Supported and Non-DOE Supported Developments						Priority Ratings For Potential Support Based On Energy Consumption	
		Gas	Oil	Electric		Total			
				Primary	End Use	Prime	End Use	End Use	Prime
Compact Boilers	SH-	56.0	-	-	-	56.0	56.0	7	8
Pulse Combustion	SH-WH	40.3	-	-	-	40.3	40.3	10	12
Heat Pipe Exchanger	SH-WH	3.0	5.4	-	-	8.4	8.4	16	17
Flue Gas Heat Recovery	SH-WH	74.5	88.0	-	-	162.5	162.5	3	4
Heat Pump - Electric	SH-WH	-	-	6.78	2	6.78	2.0	-	19
Flue Dampers	SH-WH	82.6	56.0	-	-	138.6	138.6	4	5
Electric Ignition	SH-WH-C	45.1	-	-	-	45.1	45.1	9	12
Optimum Sizing	SH	81.4	104.0	-	-	185.4	185.4	2	3
Power Combustion	SH-WH-C	280.1	-	-	-	280.1	280.1	1	1
Improved Evap.-Cond. Surface	AC-R	2.3		65.4	19.3	67.7	21.6	13	7
Reduced Storage Temp.	WH	-	-	2.4	0.7	2.4	0.7	21	21
Improved Insulation	SH-WH-R	25.14	4.5	15.7	4.6	45.3	34.2	12	11
Outside Combustion Air	SH-WH	27.9	28.0	-	-	55.9	55.9	8	9
Burner Modulation	SH-WH	78.8	43.8	-	-	122.6	122.6	5	6
Wet Condenser	AC-R	-	-	194.2	57.3	194.2	57.3	6	2
High Efficiency Compressors	AC-R	-	-	27.5	8.1	27.5	8.1	17	15
Improved Refrigerant	AC-R	-	-	3.7	1.1	3.7	1.1	20	20
Heat Pipe Furnace	SH	7.0	-	-	-	7.0	7.0	18	18
Emulsified Fuel	SH-WH	-	39.1	-	-	39.1	39.1	11	13
Increased Air Flow	AC	0.54	-	30.2	8.9	30.7	9.4	15	14
Increased Evap.-Cond. Cap.	AC	1.4	-	51.7	15.3	53.1	16.7	14	10
Heat Traps	WH	-	-	2.3	0.69	2.3	0.69	22	22
Improved Coatings - Fluor	L	-	-	13.9	4.1	13.9	4.1	19	16

SH - Space Heating
WH - Water Heating
AC - Air Conditioning
C - Cooking
L - Lighting
R - Refrigeration

9.2 METHOD OF ESTIMATING CUMULATIVE ENERGY SAVINGS

The evaluation and selection of the most promising development opportunities were based on the estimated cumulative energy savings for each opportunity from 1980 to 1990. To estimate these values, the following was used:

$$CES = UES \sum_{t=t_i}^{t=1990} NS_t \qquad (9.1)$$

where

CES	=	cumulative energy savings through the year 1990, Btu
UES	=	unit energy savings, Btu/unit
NS_t	=	market penetration by a particular year
t_i	=	year of market introduction $t_i = 1978 + \Delta t$
Δt	=	time to develop or improve the concept

The above equation accounts for the two important parameters that must be considered together for proper evaluation. A development leading to a large improvement in efficiency will have little effect on national energy savings if it cannot be sold. Conversely, a relatively small efficiency improvement in an appliance having a large sales potential could significantly improve the national energy utilization.

To use Equation 9.1, each specific improvement had to be applied to an appropriate appliance type, since both the unit energy savings and the number of units sold are directly associated with a particular

appliance. The unit energy savings for a particular appliance with a specific improvement was found by calculating the unit energy consumption for the appliance type of conventional design and estimating the percent improvement as follows:

$$UES = UEC \frac{Imp/100}{(Imp/100) + 1} \tag{9.2}$$

where

UEC = unit energy consumption, Btu/yr
= $(EC)_{75}/N_{75}$

$(EC)_{75}$ = total energy consumption by an appliance type in 1975

N_{75} = 1975 inventory for the appliance type

Imp = percent improvement in operative efficiency

The percent improvement in operating efficiency was taken to be the average of the range of estimated values presented in Chapter 7 for a particular appliance type and a specific improvement. It is recognized that, since the operating efficiency of a particular appliance is a function of its use (i.e., a function of the building type and, in some cases, geographic location), the improvement for each appliance will be different. The range of values presented in Chapter 7 accounts for this difference, and using the average of this range as a simplified approach for this analyses seemed justified.

The method used to estimate the sales potential for a particular development is more complex and is covered in detail in the following section.

9.3 METHOD OF MARKET PENETRATION ANALYSIS

9.3.1 Market Penetration Model

The basic model for the market penetration of an energy-saving appliance should contain three fundamental elements: the maximum sales potential (MP), the consumer acceptance or marketability (MA), and the rate of penetration (PR). The maximum sales potential (MP) is the total annual market for all appliances of a given kind, both conventional and new energy-saving appliances. The marketability factor (MA) is the fraction of that total annual market that could be captured by the new energy-saving appliance. The rate of penetration (PR) is the rate at which a new appliance can enter the market. Multiplying the (MP) by the (MA) yields the maximum sales potential for the new appliance. Multiplying again by the (PR) gives the number of new energy-saving appliances that could be sold in a given year. Therefore, the estimated number of improved appliances sold in a given year can be determined, using these three elements, as follows:

$$NS_t = (MP)(MA)(PR)$$

A mathematical model relating the three fundamental elements was established. This model takes into consideration two market areas where energy-saving appliances can be sold. One market area covers replacement rates as well as new sales due to market growth. The other is the retrofit market where useful equipment is replaced or modified to save on operating cost. An explanation of each element of the model is presented below.

9.3.1.1 Maximum Potential and Marketability

In modeling the maximum sales potential ($MP_{N\&R}$), the two markets had to be considered. The maximum potential for new and replacement sales is assumed to be the estimated average annual sales of a conventional appliance type from 1980 to 1990. This value is arrived at by taking the average sales in 1975 (AS_{75}) and applying the calculated growth

rate (GR) for that appliance type. The values were brought to a 1980 baseline by adding 5 years to the time period (t) as follows:

$$MP_{N\&R} = (AS)_{75} \left[1 + (t + 5)GR\right] \qquad (9.3)$$

The maximum sales potential for the retrofit market (MP_{Ret}), based on our findings of customer buying habits in Chapter 8, was assumed to be equal to 15 percent of the estimated 1980 inventory (N_{80}) of the appliance type. Thus, the maximum retrofit sales potential was as follows:

$$MP_{Ret} = 0.15\ N_{80} \qquad (9.4)$$

It is realized that the 1980 inventory of existing appliances will diminish over the years as conventional equipment, which has reached its useful life, is replaced by more efficient equipment. This is particularly true at the time when the more efficient equipment reaches a significant market penetration. Prior to this time, however, much of the replacement will be made with conventional equipment. To account for this change in the inventory, a more complex iterative calculation would be required. However, it was decided that the more simplified assumption was justified for the purpose of this evaluation.

The marketability or market acceptance (MA) of an energy-saving appliance was assumed to be the same for both market areas. The marketability relationship used in this analysis was discussed in Chapter 8, and relates the payback period (PB) and the appliance cost premium (CP) as shown below:

$$MA = \left[1 - 0.7\left(\frac{CP}{100}\right)(PB)\right] \qquad (9.5)$$

9.3.1.2 Market Penetration Rate

To model the rate of market penetration (PR), and "S"-curve or statistical distribution curve was followed. This is the model used by Thermo Electron in its Venture Analysis Study of Industrial

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Processes.[22] The model is based on the following second order linear differential equation:

$$\frac{1}{a^2} \frac{d^2(PR)}{dt^2} + \frac{2}{a} \frac{d(PR)}{dt} + (PR)_t = 1, t > 0 \qquad (9.6)$$

where

a = a measure of market retardation

The above equation has as its solution:

$$(PR)_t = 1 - e^{-at} \left\{ 1 + \left[a - \frac{d(PR)_o}{dt} \right] t \right\} \qquad (9.7)$$

If it is assumed that the slope of the "S"-curve $\frac{d(PR)}{dt}$ is 0 at time t = 0, Equation 9.7 becomes:

$$PR_t = 1 - e^{-at} (1 + at) \qquad (9.8)$$

The constant "a" is a function completely determined from the time at which the penetration reaches one half of the potential economic market, referred to as the half-life (HL). A fair approximation of this value may be derived by solving Equation 9.8 with PR = 0.5 and t = HL:

$$\frac{1}{2} = 1 - e^{-a(HL)} [1 + a(HL)] \qquad (9.9)$$

where the positive solution is:

$$a = 1.6783/HL \qquad (9.10)$$

The half life (HL) is considered[22] dependent on both user and producer characteristics as follows:

$$HL = \frac{B}{NPVI} + \frac{C}{P(CAP)} \qquad (9.10)$$

where

NPVI = ratio of net present value to initial cost difference

P(CAP)= manufacturer's ability to produce the product

B&C = constants

The NPVI can be related to a simple payback period as follows:

$$\text{NPVI} = \frac{\text{Net Present Value}}{\text{Initial Cost Difference}} = \frac{\text{Initial Cost Difference + Annual Savings}}{\text{Initial Cost Difference}}$$

$$= 1 + \text{Annual Savings/Initial Cost Difference}$$

$$= 1 + \frac{1}{\text{Initial Cost Difference/Annual Savings}}$$

Since

$$\frac{\text{Initial Cost Difference}}{\text{Annual Savings}} = \text{Simple Payback (PB)}$$

then

$$\text{NPVI} = (1 + \frac{1}{\text{PB}}) \qquad (9.11)$$

We additionally assumed that the manufacturer could meet any demand for a product; thus, P(CAP) = 1.

To determine the constants B and C, a knowledge between the payback period (PB) and the half life (HL) for commercial energy-saving appliances must be known. However, since there are no known data of this type, we assumed the following relationship:

HL = 4 years for PB = 1

HL = 6 years for PB = 2

By substituting the above information into Equation 9.10, the following half life relationship was determined:

$$\text{HL} = \frac{12(\text{PB})}{\text{PB} + 1} - 2 \qquad (9.12)$$

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9.3.1.3 Final Penetration Model

Using the information presented in the foregoing discussion, a mathematical model depicting the penetration of an energy-saving appliance was derived. The model is presented here for the two types of markets in a given year:

New and Replacement Sales

$$NS_{N\&R} = AS\,[1 + (t+5)GR]\left[1 - 0.7\left(\frac{CP}{100}\right)(PB)\right][1 - e^{-at}(1 + at)] \qquad (9.13)$$

Retrofit

$$NS_{Ret} = N_{80}\,(0.15)\left[1 - 0.7\left(\frac{CP}{100}\right)(PB)\right][1 - e^{-at}(1 + at)] \qquad (9.14)$$

where

AS	=	Average annual sales in 1975
N_{80}	=	Appliance inventory in 1980
NS	=	Number of units sold by a given year
CP	=	Cost premium ~ %
PB	=	Payback period ~ years
GR	=	Growth rate of appliance market
t	=	Time period from the market introduction
a	=	Characteristic constant = 1.6783/HL
HL	=	Estimated time to reach 50% of the maximum sales potential
	=	$[12(PB)/(PB + 1)] - 2$

9.3.2 Cost Premium and Payback

The previous relationship for market penetration is based primarily on two key parameters: the cost premium and the payback period. These are the parameters that determine the consumers' acceptance of an improved appliance as well as the rate at which it will be accepted.

Although the cost premium and the payback period are listed as separate factors, they are in fact closely associated. The payback period, as it is used here, is a simple payback that is related to the equipment selling price and its annual fuel savings as follows:

$$PB = \frac{\text{Initial Cost Difference of Equipment}}{\text{Annual Fuel Savings}} \qquad (9.15)$$

The initial or first cost of an improved appliance is equal to the cost of a contemporary appliance of the same type plus the incremental cost increase of the energy-saving improvement. The incremental cost increase divided by the original cost is the cost premium (CP). The cost premium used in this analysis is the average value of the range listed in Chapter 7 for a specific improvement associated with a particular appliance type. The cost of the contemporary appliance (AC) used in the analysis is based on the 1975 price of an average-size appliance of the type in question. These 1975 prices were arrived at by surveying distributers and dealers of the various appliances. These prices are listed in Table 9.2 for the weighted average-size appliances. The 1975 prices were escalated to the year 1985 for use in this analysis. The price escalation was based on the following estimated growth rate in the wholesale price index presented in the National Energy Outlook:

TABLE 9.2

1975 APPLIANCE PRICES

A-2766a

Appliance Type	Fuel Type	Ave Size (Btu/hr x10^3)	1975 Price ($)
C I Boilers (HW & STM)	G	850	4,200
Unit Heaters	G	165	400
Duct Furnace	G	260	450
Warm-Air Furnace	G	250	620
Steel Boilers (HW & STM)	G	5,000	6,000
C I Boilers (HW & STM)	O	840	3,200
Warm-Air Furnace	O	450	1,900
Steel Boiler (HW & STM)	O	5,000	6,000
Unit Heaters	O	250	1,170
Baseboard Heaters	E	5	37
Heat Pumps	E	40	1,250
Unit Heaters	E	70	430
Direct Absorp. A/C (Un)	G	180	8,000
Direct Absorp. A/C (Built)	G	600	33,000
Indirect Absorp. A/C	G	6,000	63,000
A/C Year-Round Unit	E	60	1,340
A/C Condenser Only	E	50	740
A/C Horizontal	E	60	1,400
A/C Heat Pump	E	40	1,250
Centrifugal Liq. Chiller	E	4,000	8,870
Reciprocating Liq. Chiller	E	650	3,330
Water Heater	G	250	1,400
Water Heater	O	300	1,150
Water Heater	E	150	1,200
Ref. Warehouse Storage	E	--	--
Ref. Display Supermarket	E	--	--
Ref. Restaurant Storage	E	5	2,100
Coffee Maker & Urns	G	20	385
Kettle, Cooker, Press. Ck.	G	140	2,200
Broilers	G	110	750
Fryers	G	110	400
Griddle & Grills	G	100	550
Deck & Convect. Oven	G	110	1,400
Ranges & Braising Pans	G	140	800

TABLE 9.2 (continued)

A-2766b

Appliance Type	Fuel Type	Ave Size (Btu/hr x 10^3)	1975 Price ($)
Coffee Maker & Urns	E	10	300
Kettle, Cooker, Press. Ck.	E	70	1,800
Fryers	E	55	650
Griddles & Grills	E	55	300
Deck & Convect. Oven	E	50	400
Ranges & Braising Pans	E	70	1,000
Incandescent Lights	E	0.26	1
Fluorescent Lights	E	0.14	2.5
Hi Intensity Disch.	E	1.36	15

Year	Annual Growth Rate (%)
1975-1980	5.1
1980-1985	3.4
1985-1990	2.7

This gave an overall escalation from 1975 to 1985 of 51 percent. Therefore, the price of an appliance in 1985 equals 1.51 times the 1975 price of a comparable appliance. It should be noted that the wholesale price index was used instead of the consumer price index since commercial appliances more closely follow the wholesale line.

Equation 9.15 shows that the payback period is also a function of the annual fuel cost savings that results from an appliance improvement. This savings in annual fuel cost is equal to the unit energy savings (UES) for a particular development times the unit cost of the fuel (ULC) used. In this analyses the unit cost of fuel is in dollars per therm (10^6 Btu). The specific values were based on the 1975 commercial fuel prices listed below together with their reference sources:

1975 FUEL PRICES

Fuel	Price ($\$/10^6$ Btu)	Reference Source
Natural Gas	1.68	AGA Gas Facts (1975)
Oil (No. 2 Heating)	2.60	Oil and Gas Journal (Dec. 1975)
Electricity	9.80	FPC News (Dec. 1975)

These 1975 fuel prices were inflated to 1985 prices by considering both the fuel price escalation presented in the National Energy Outlook for the reference case and a normal 4 percent annual inflation rate. The

total annual escalation rate (ER) used was as follows:

Natural Gas	6.8% + 4% = 10.8%
Petroleum	0.5% + 4% = 4.5%
Electricity	1.5% + 4% = 5.5%

The 1985 unit fuel prices were computed as follows:

$$UFC_{85} = UFC_{75} (1 + ER)^{10}$$

to the following prices:

Fuel	1985 Unit Fuel Price ($/10^6 Btu)
Natural Gas	3.24
Petroleum	2.74
Electricity	11.37

Equation 9.15 can be rewritten, using the foregoing information, in the following form:

$$PB = \frac{(AC)_{85} CP}{(UES)\ (UFC)_{85}}$$

where

PB = simple payback, years

AC_{85} = 1985 price of a conventional appliance, $

CP = cost premium for a specific improvement, %/100

UES = unit energy savings, Btu/year

$(UFC)_{85}$ = 1985 unit fuel cost for a particular fuel, $/Btu

9.3.3 The Effects of DOE Support

There are a number of ways that DOE can support the advance of energy-saving improvements in commercial appliances. The more popular methods are listed below:

- Fund Research and Development Programs
- Support Demonstration and Field Test Programs
- Develop and Implement Educational Programs
- Issue Energy-Saving Specifications for Government Purchasing

The first of these methods could be applied to radical changes in existing appliances or new appliance concepts, as well as minor modifications or adaptations of known improvements to existing appliances. In the second method, it is presumed that the improvement has been developed but DOE support could accelerate its commercialization. The third method concerns itself with programs other than hardware development, such as studies to determine methods for optimizing appliance size requirements or the effects of reduced temperature requirements in cooking and refrigeration. In the fourth method, DOE could set up more stringent energy specifications for equipment going into government installations. Since the government is a major purchaser of commercial equipment, these new specifications could increase voluntary improvement in appliance efficiency.

Regardless of the method used for a particular improvement, the net effect will be the same, i.e., an acceleration of time when the improvement will reach the market. In this analysis, the time required for a given improvement to reach the market without DOE support was found primarily by discussions with manufacturers. In cases where

information was not available, our experience in the development and commercialization of both residential and commercial appliances was used. To determine the time required for a DOE-supported improvement to reach the market, our experience and engineering judgement were again called upon.

In this analysis, the time required to first market an appliance improvement (Δt) was added to the base year 1978 to arrive at the year of first sale. Thus, a 4-year development of an improved appliance was assumed to have a market introduction in 1982.

9.4 COMPUTATION OF CUMULATIVE ENERGY SAVINGS

9.4.1 Computational Procedure

A computational procedure was established to calculate the market penetration and cumulative energy savings by 1990 of the improved appliances. The procedure utilizes information from the 1975 data base, the projected data base, and the equations presented in this section, in the manner described below:

1. Select an appliance type and extract the following information from the data base and date base projection:

   - Energy Consumption in 1975 $(EC)_{75}$
   - Average Annual Sales AS
   - The Market Growth Rate GR
   - Appliance Inventory in 1975 N_{75}
   - Appliance Inventory in 1980 N_{80}
   - Average Appliance Price 1975 $(AC)_{75}$

2. Select an energy-saving improvement that is compatible with the appliance type and, from the appropriate table in Chapter 7, extract the following:

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- Average Improvement in Operating Efficiency % (Imp)
- Average Cost Premium ~ CP

3. Using the information listed above and the equations presented in this section, compute the following:

- Unit Energy Consumption

$$UEC = (EC)_{75}/N_{75}$$

- Percent Savings

$$\% \ SAV = 1 - \frac{1}{(1 + \% \ IMP)}$$

- Unit Energy Savings

$$UES = UEC \times \% \ SAV$$

- Appliance Cost in 1985

$$(AC)_{85} = 1.51 \times (AC)_{75}$$

- Unit Fuel Cost in 1985

$$(UFC)_{85} = (UFC)_{75} \times ER$$

- Payback Period

$$PB = \frac{(AC)_{85} \times CP}{UES \times (UFC)_{85}}$$

- Half Life

$$HL = \frac{12(PB)}{PB + 1} - 2$$

4. Using the information supplied in the appropriate table in Chapter 7, estimate the time required to develop the improved appliance (Δt) with and without DOE support.

(Again, the time estimates are based on equipment manufacturers' estimates and our experience in developing and marketing efficient gas-fired appliances.) Compute the following:

- Date of Market Introduction

  $t_o = 1978 + \Delta t$

- Maximum Time Period to 1990

  $t_{max} = 1990 - t_o$

5. Using the information listed above and Equations 9.13 and 9.14, compute the number of improved appliances sold in both the new/replacement, $(NS)_{N\&R}$, and the retrofit, $(NS)_{Ret}$, markets for each year from $t = 0$ to $t = t_{max}$ assuming DOE support. Combine the $(NS)_{N\&R}$ and $(NS)_{Ret}$ to determine the total number of units sold in the prescribed year.

6. Sum the total sales from $t = 0$ to $t = t_{max}$ and use Equation 9.1 to determine the Cumulative Energy Savings (CES) of the improved appliance.

7. Repeat procedures 6 and 7 assuming no DOE support of the improved appliance.

9.4.2 Sample Calculation

A sample calculation, using the computational procedure described above, was prepared. This calculation computes market penetration and cumulative energy savings for a gas-fired cast iron boiler using a flue gas heat recovery unit.

Thermo Electron CORPORATION

SAMPLE CALCULATION FOR FLUE GAS HEAT RECOVERY IN GAS-FIRED CAST IRON BOILERS

AVG Annual Sales = 12.8×10^3

Inventory in 1975 = $N_{75} = 501 \times 10^3$

Appliance Growth Rate = GR = 1.34%

Energy Consumption in 1975 = $(EC)_{75} = 507.2 \times 10^{12}$

AVG % Improvement in Seasonal Eff = % IMP = 10%

Unit Energy Consumption = UEC = $(EC)_{75}/N_{75}$

$$UEC = 507.2 \times 10^{12}/501 \times 10^3 = 1.01 \times 10^9 \text{ Btu/yr}$$

Percent Energy Savings = % SAV = $1 - \frac{1}{(1 + \% \text{ IMP})}$

$$\% \text{ SAV} = 1 - \frac{1}{(1 + 0.1)} = 0.091\%$$

Unit Energy Savings = UES = % SAV x UEC

$$UES = 0.091 \times 1.01 \times 10^9 = 91 \times 10^6 \text{ Btu/yr}$$

Average Cost Premium = CP = 10%

Appliance Base Cost (1985) = $(AC)_{85}$ = \$5502

Unit Fuel Cost (1985) = $(UFC)_{85}$ = \$4.68/Therm

And Payback Period = $\frac{CP \times (AC)_{85}}{UES \times (UFC)_{85}}$

$$PB = \frac{0.10 \times 5502}{(91 \times 10^6)(4.68 \times 10^{-6})} = 1.29 \text{ yr}$$

Time to Develop - (based on our engineering judgment)

With DOE Support - 3 yr

Without DOE Support - 7 yr

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With DOE Support

t_o = 0 at 1978 + 3 = 1981

t_{max} = 1990 — 1981 = 9 yr

t = 1 - 9 at 1-Year Intervals

Without DOE Support

t_o = 0 at 1978 + 7 = 1985

t_{max} = 1990 — 1985 = 5 yr

t = 1 - 5

The Half Life or Time to Reach 50% of Potential

$$\text{Sales} = HL = \frac{12(PB)}{PB + 1} - 2$$

$$HL = \frac{12 \times 1.29}{1.29 + 1} - 2 = 4.76$$

$a = 1.683/HL$

$a = 1.683/4.76 = 0.354$

The Number of Units Sold From the Year $t_o = 0$ to $t = t$ is Given As:

$$(NS)_{N\&R} = AS\,[1 + (t - t_o + 5)GR]\,[1 - 0.7(PB)\,(CP)]\,[1 - e^{-at}\,(1 + at)]$$

And

$$(NS)_{Ret} = N_{80}(0.15)\,[1 - 0.7\,(PB)\,(CP)]\,[1 - e^{-at}\,(1 + at)]$$

Where

NS = Cumulative Number of Units Sold

N_{80} = 1980 Appliance Inventory = 536×10^3

AS = Average Annual Sales = 12.8×10^3

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t_o = Initial Year of Sales at 1978 + Δt_o

t = Year of Sales

Δt_o = Number of Years to Develop

GR = Growth Rate = 0.0134

$$NS = 12.8 \times 10^3 \, [1 + (t - t_o + 5)0.0134] \, [1 - 0.7(1.29)(0.1)] \, [1 - e^{-0.354t} (1 + 0.354t)]$$

$$NS = (11.64 \times 10^3) \, [1 + (t - t_o + 5)0.0134] \, [1 - e^{-0.354t}(1 + 0.354t)]$$

With DOE Support t_{max} = 9 yr

$$(NS)_{DOE} = (11.64 \times 10^3) \, [1 + (9 + 5) \, 0.0134] \, [1 - e^{-0.354(9)}(1 + 0.354(9))]$$

$$(NS)_{DOE} = 11.436 \times 10^3$$

Without DOE Support t_{max} = 3 yr

$$NS = (11.64 \times 10^3) \, [1 + (3 + 5) \, 0.0134] \, [1 - e^{-0.354(3)}(1 + 0.354(3))]$$

$$NS = 3.70 \times 10^3$$

For the Number of Retrofitted Units With DOE Support, t_{max} = 9

And

$$(NS)_{Ret} = (536 \times 10^3) \, (0.15) \, [1 - 0.7 \, (1.29) \, (0.1)] \, [1 - e^{-(0.354 \times 9)} (1 + (0.354)(9))]$$

$$(NS)_{Ret} = 60.19 \times 10^3$$

Without DOE Support, t_{max} = 5

And

$$(NS)_{Ret} = 72.78 \times 10^3 \, [1 - e^{-1.77}(2.77)]$$

$$(NS)_{Ret} = 38.5 \times 10^3$$

The Total Number of Units With Energy-Saving Devices in Use in 1990 is

$$(NS)_T = (NS)_{N\&R} + (NS)_{Ret}$$

The Total Number With DOE Support

$$(NS)_T = 11.436 \times 10^3 + 60.19 \times 10^3$$

$$(NS)_T = 71.626 \times 10^3$$

The Total Number Without DOE Support

$$(NS)_T = 6.985 \times 10^3 + 38.5 \times 10^3$$

$$(NS)_T = 45.485 \times 10^3$$

The annual market penetration and cumulative energy savings from 1980 to 1990 are shown in Figures 9.1 and 9.2, respectively.

9.4.3 Computational Results

A computer program was written to assist in the computational procedure that was applied to the large number of appliance/improvement combinations. The computer program and its total output are presented in Appendix C. The input information for the program, together with key output information, are presented here in Table 9.3.

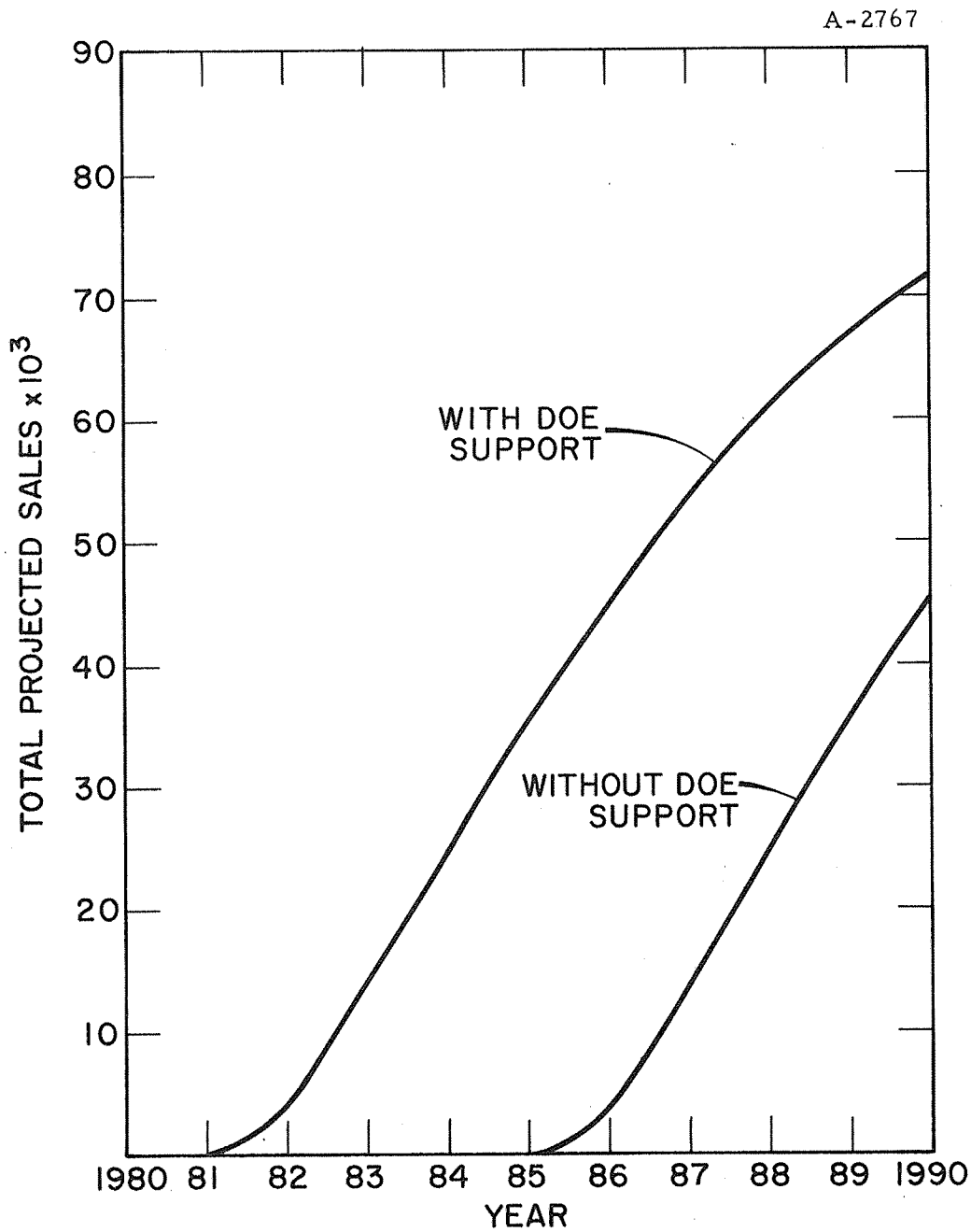

Figure 9.1 Total Projected Sales for Cast Iron Boilers with Flue Gas Heat Recovery

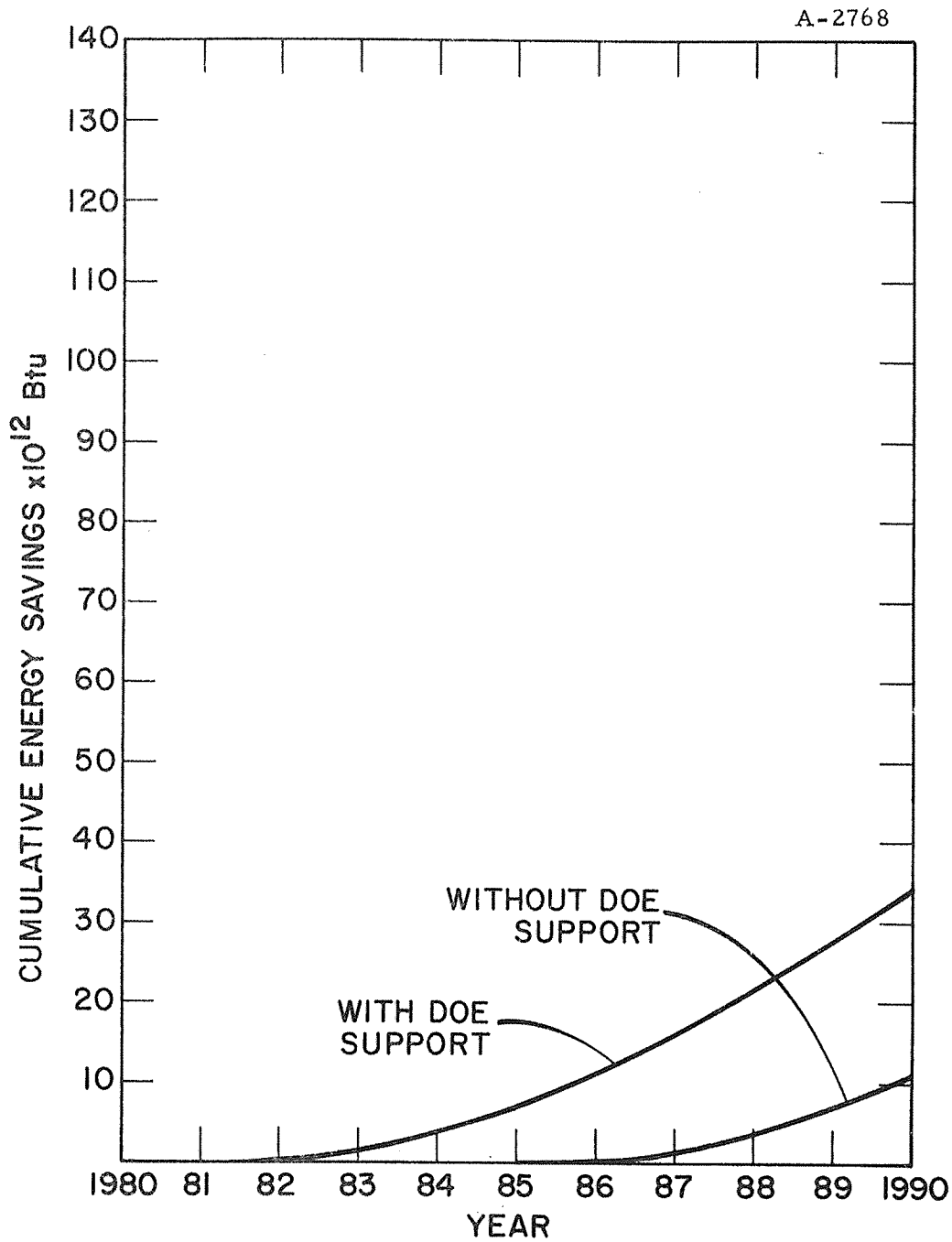

Figure 9.2 Cumulative Energy Savings for Cast Iron Boilers with Flue Gas Heat Recovery

TABLE 9.3

CUMULATIVE ENERGY SAVINGS OF POTENTIAL IMPROVED APPLIANCES

A-2773a r

No.*	Appliance	Computer Program Input									Computer Program Results		
		Proj. Annual Sales	Inventory 1980	Energy Consump. 1990	Cost Premium	Payback Period	Unit Energy Savings	Δt_o WDOE	Δt_o WODOE	Potential For Retrofit	With DOE Support: Cumulative Energy Savings 1980-1990	Without DOE Support: Cumulative Energy Savings 1980-1990	Difference in Cumulative Energy Savings 1980-1990
		x 10^3	x 10^3	Btu x 10^{12}		Years	Btu x 10^6	Years	Years		Btu x 10^{12}	Btu x 10^{12}	Btu x 10^{12}
1	CI Boiler - Gas	12.8	536.0	612.7									
	Compact Boiler	12.8	536.0	612.7	0.125	0.96	152.0	3	7	No	68.0	24.0	44.0
	Pulse Combustion	12.8	536.0	612.7	0.375	2.5	172.0	5	10	No	11.0	0.68	10.0
	Flue Heat Rec.	12.8	536.0	612.7	0.10	1.2	91.0	3	7	Yes	36.0	12.0	24.0
	Elect. Ignition	12.8	536.0	612.7	0.075	1.4	61.0	2	5	Yes	27.0	14.0	13.0
	Modulation	12.8	536.0	612.7	0.45	0.40	131.0	3	7	No	85.0	41.0	44.0
	Optimum Size	12.8	536.0	612.7	0	0	71.0	5	10	Yes	47.0	13.0	34.0
	Power Burner	12.8	536.0	612.7	0.15	1.0	172.0	3	7	No	73.0	26.0	48.0
	Flue Damper	12.8	536.0	612.7	0.10	1.6	71.0	2	5	Yes	28.0	15.0	14.0
	Outside Air	12.8	536.0	612.7	0.07	2.0	40.0	2	5	Yes	15.0	7.3	7.4
2	Unit Heaters - Gas	70.7	1478.0	326.1									
	Flue Heat Rec.	70.7	1478.0	326.1	0.10	0.6	17.1	3	7	Yes	33.0	14.0	19.0
	Flue Dampers	70.7	1478.0	326.1	0.10	0.83	13.3	2	5	Yes	25.0	14.0	11.0
	Outside Comb. Air	70.7	1478.0	326.1	0.07	1.0	7.6	2	5	Yes	13.0	7.2	6.0
	Elect. Ignition	70.7	1478.0	326.1	0.075	0.73	11.4	2	5	Yes	23.0	14.0	9.8
	Optimum Size	70.7	1478.0	326.1	0	0	13.3	5	10	Yes	28.0	7.7	20.0
	Power Burner	70.7	1478.0	326.1	0.15	0.52	32.3	3	7	No	66.0	29.0	37.0
3	Duct Furnace - Gas	19.1	514.9	182.4									
	Flue Heat Rec.	19.1	514.9	182.4	0.10	0.45	27.9	3	7	Yes	20.0	9.3	11.0
	Flue Damper	19.1	514.9	182.4	0.10	0.58	21.7	2	5	Yes	16.0	9.7	6.2
	Outside Comb. Air	19.1	514.9	182.4	0.07	0.70	12.4	2	5	Yes	8.4	4.9	3.5
	Elect. Ignition	19.1	514.9	182.4	0.075	0.50	18.6	2	5	Yes	15.0	9.2	5.4
	Optimum Size	19.1	514.9	182.4	0	0	21.7	5	10	Yes	15.0	4.1	11.0
	Power Burner	19.1	514.9	182.4	0.15	0.36	52.7	3	7	No	41.0	21.0	20.0
4	Warm Air Furnace - Gas	21.3	423.5	165.7									
	Pulse Combustion	21.3	423.5	165.7	0.375	1.3	50.1	5	10	No	8.5	0.61	7.9
	Heat Pipe Furnace	21.3	423.5	165.7	0.075	2.6	50.1	5	10	No	7.6	0.46	7.0
	Heat Pipe Heat Exch.	21.3	423.5	165.7	0.25	2.1	20.6	3	7	No	4.2	1.2	3.0
	Flue Heat Rec.	21.3	423.5	165.7	0.10	0.6	26.5	3	7	Yes	16.0	6.4	9.2
	Flue Damper	21.3	423.5	165.7	0.10	0.8	20.6	2	5	Yes	12.0	6.9	5.3
	Outside Comb. Air	21.3	423.5	165.7	0.07	1.0	11.8	2	5	Yes	6.3	3.4	2.9
	Elect. Ignition	21.3	423.5	165.7	0.075	0.72	17.7	2	5	Yes	11.0	6.5	4.7
	Modulation	21.3	423.5	165.7	0.45	2.0	38.3	3	7	No	4.7	1.4	3.3
	Optimum Size	21.3	423.5	165.7	0	0	20.6	5	10	Yes	13.0	3.6	9.6
	Power Burner	21.3	423.5	165.7	0.15	0.52	50.1	3	7	No	31.0	13.0	18.0

*Appliance numbers correspond to Table 6.1.

TABLE 9.3 (continued)

A-2773b r

No.*	Appliance	Computer Program Input									Computer Program Results		
		Proj. Annual Sales	Inventory 1980	Energy Consump. 1990	Cost Premium	Payback Period	Unit Energy Savings	Δt_o WDOE	Δt_o WODOE	Potential For Retrofit	With DOE Support: Cumulative Energy Savings 1980-1990	Without DOE Support: Cumulative Energy Savings 1980-1990	Difference in Cumulative Energy Savings 1980-1990
		x 10^3	x 10^3	Btu x 10^{12}		Years	Btu x 10^6	Years	Years		Btu x 10^{12}	Btu x 10^{12}	Btu x 10^{12}
5	St'l Boilers (H.W. & Stm)Gas	0.4	12.6	122.6									
	Compact Boiler	0.4	12.6	122.6	0.125	0.2	1234.5	3	7	No	26.0	14.0	12.0
	Pulse Combustion	0.4	12.6	122.6	0.375	0.4	1399.0	5	10	No	17.0	3.0	14.0
	Flue Heat Rec.	0.4	12.6	122.6	0.10	0.2	740.9	3	7	Yes	15.0	8.4	7.0
	Elect. Ignition	0.4	12.6	122.6	0.075	0.3	493.8	2	5	Yes	11.0	7.5	3.5
	Modulation	0.4	12.6	122.6	0.45	0.7	1069.9	3	7	No	12.0	4.7	7.3
	Optimum Size	0.4	12.6	122.6	0	0	576.1	5	10	Yes	9.4	2.6	6.8
	Power Burner	0.4	12.6	122.6	0.15	0.2	1399.0	3	7	No	29.0	16.0	13.0
	Flue Damper	0.4	12.6	122.6	0.10	0.3	576.0	2	5	Yes	13.0	8.7	4.1
	Outside Comb. Air	0.4	12.6	122.6	0.07	0.4	329.2	2	5	Yes	6.7	4.4	2.3
6	CI Boilers (H.W. & Stm) - Oil	18.3	531.5	714.4									
	Flue Heat Rec.	18.3	531.5	714.4	0.10	1.0	102.0	3	7	Yes	49.0	17.0	32.0
	Modulation	18.3	531.5	714.4	0.45	3.2	147.0	3	7	No	12.0	3.4	8.6
	Optimum Size	18.3	531.5	714.4	0	0	79.0	5	10	Yes	56.0	15.0	41.0
	Flue Damper	18.3	531.5	714.4	0.10	1.3	79.0	2	5	Yes	39.0	20.0	18.0
	Outside Comb. Air	18.3	531.5	714.4	0.07	1.6	45.0	2	5	Yes	20.0	10.0	10.0
	Emulsified Fuel	18.3	531.5	714.4	0.20	2.6	79.0	3	7	No	16.0	4.7	12.0
7	Warm Air Furnaces - Oil	41.1	905.4	617.3									
	Flue Heat Rec.	41.1	905.4	617.3	0.10	1.1	52.0	3	7	Yes	42.0	14.0	28.0
	Modulation	41.1	905.4	617.3	0.45	3.7	75.0	3	7	No	11.0	3.1	7.9
	Optimum Size	41.1	905.4	617.3	0	0	41.0	5	10	Yes	52.0	14.0	38.0
	Flue Damper	41.1	905.4	617.3	0.10	1.5	41.0	2	5	Yes	33.0	17.0	16.0
	Outside Comb Air	41.1	905.4	617.3	0.07	1.8	23.0	2	5	Yes	18.0	8.8	8.7
	Heat Pipe Heat Exch.	41.1	905.4	617.3	0.25	3.7	41.0	3	7	No	7.5	2.1	5.4
	Emulsified Fuel	41.1	905.4	617.3	0.20	3.0	41.0	3	7	No	10.0	2.9	7.4
8	St'l Boilers (H.W. & Stm)-Oil	1.2	40.9	401.8									
	Flue Heat Rec.	1.2	40.9	401.8	0.10	0.2	855.0	3	7	Yes	56.0	31.0	25.0
	Modulation	1.2	40.9	401.8	0.45	0.8	1112.0	3	7	No	35.0	13.0	22.0
	Optimum Size	1.2	40.9	401.8	0	0	598.5	5	10	Yes	31.0	8.6	23.0
	Flue Damper	1.2	40.9	401.8	0.10	0.3	598.5	2	5	Yes	42.0	29.0	13.0
	Outside Comb. Air	1.2	40.9	401.8	0.07	0.4	342.0	2	5	Yes	22.0	15.0	7.6
	Emulsified Fuel	1.2	40.9	401.8	0.20	0.7	598.5	3	7	No	25.0	9.6	15.0
9	Unit Heaters - Oil	6.4	105.1	33.6									
	Flue Heat Rec.	6.4	105.1	33.6	0.10	1.7	22.5	3	7	Yes	1.8	0.56	1.3
	Optimum Size	6.4	105.1	33.6	0	0	17.5	5	10	Yes	2.9	0.79	2.1
	Flue Damper	6.4	105.1	33.6	0.10	2.1	17.5	2	5	Yes	1.5	0.76	0.79
	Outside Comb. Air	6.4	105.1	33.6	0.07	2.6	10.0	2	5	Yes	0.83	0.40	0.43
	Emulsified Fuel	6.4	105.1	33.6	0.20	4.3	17.5	3	7	No	0.46	0.12	0.33

* Appliance numbers correspond to Table 9.1.

TABLE 9.3 (continued)

A-2773c r

No.*	Appliance	Computer Program Input: Proj. Annual Sales	Inventory 1980	Energy Consump. 1990	Cost Premium	Payback Period	Unit Energy Savings	Δt_o WDOE	Δt_o WODOE	Potential For Retrofit	Computer Program Results: With DOE Support, Cumulative Energy Savings 1980-1990	Without DOE Support, Cumulative Energy Savings 1980-1990	Difference in Cumulative Energy Savings 1980-1990
		x 10^3	x 10^3	Btu x 10^{12}		Years	Btu x 10^6	Years	Years		Btu x 10^{12}	Btu x 10^{12}	Btu x 10^{12}
11	Heat Pump (Sing. & Split)-E	22.3	285.8	22.5									
	Improved Compressor	22.3	285.8	22.5	0.025	1.8	1.3	2	5	No	0.63	0.30	0.33
	Improved Evaporator & Condenser Surface	22.3	285.8	22.5	0.075	1.8	3.9	2	5	No	1.8	0.84	0.94
	Improved Working Fluid	22.3	285.8	22.5	0	0	2.2	5	10	No	1.5	0.38	1.1
	Heat Only Heat Pump	22.3	285.8	22.5	0	0	3.9	5	10	No	2.7	0.68	2.0
13	Direct Absorption (Un.)-E	14.5	209.8	53.3									
	Improved Evaporator & Condenser Surface	14.5	209.8	53.3	0.075	10.3	16.2	2	5	No	1.2	0.52	0.64
	Improved Cooling Tower	14.5	209.8	53.3	0.10	13.7	16.2	2	5	No	1.0	0.044	0.055
	Increased Evap. & Cond. Capacity	14.5	209.8	53.3	0.10	13.7	16.2	2	5	No	1.0	0.044	0.055
	Increased Air Flow	14.5	209.8	53.3	0.05	12.5	9.0	2	5	No	0.77	0.34	0.43
14	Direct Absorption(Built Up)E	0.21	4.6	3.5									
	Improved Evaporator & Condenser Surface	0.21	4.6	3.5	0.075	13.0	53.1	2	5	No	0.045	0.02	0.025
	Improved Cooling Tower	0.21	4.6	3.5	0.10	17.4	53.1	2	5	No	0	0	0
	Increased Evap. & Cond. Capacity	0.21	4.6	3.5	0.10	17.4	53.1	2	5	No	0	0	0
	Increased Air Flow	0.21	4.6	3.5	0.05	14.6	29.5	2	5	No	0.038	0.017	0.021
15	Indirect Fired Absorp. - E	0.43	9.0	65.2									
	Improved Evaporator & Condenser Surface	0.43	9.0	65.2	0.075	2.8	477.0	2	5	No	3.1	1.5	1.6
	Improved Cooling Tower	0.43	9.0	65.2	0.10	3.7	477.0	2	5	No	2.5	1.2	1.3
	Increased Evap. & Cond. Capacity	0.43	9.0	65.2	0.10	3.7	477.0	2	5	No	2.5	1.2	1.3
	Increased Air Flow	0.43	9.0	65.2	0.05	3.3	265.0	2	5	No	1.7	0.08	0.09
16	A/C Year Round Unit - E	64.1	885.0	75.0									
	Wet Condenser	64.1	885.0	75.0	0.25	1.3	19.1	2	5	No	19.0	-	9.2
	High Eff. Compressor	64.1	885.0	75.0	0.025	1.1	2.3	2	5	No	3.1	-	1.5
	Improved Evaporator & Condenser Surface	64.1	885.0	75.0	0.075	1.5	5.2	2	5	No	5.7	-	2.8
	Increased Evap. & Cond. Capacity	64.1	885.0	75.0	0.10	2.0	5.2	2	5	No	4.7	-	2.4
	Increased Air Flow	64.1	885.0	75.0	0.05	1.8	2.9	2	5	Yes	3.0	-	1.5

*Appliance numbers correspond to Table 6.1.

TABLE 9.3 (continued)

A-2773d r

No.*	Appliance	Computer Program Input									Computer Program Results		
		Proj. Annual Sales	Inventory 1980	Energy Consump. 1990	Cost Premium	Payback Period	Unit Energy Savings	Δt_o WDOE	Δt_o WODOE	Potential For Retrofit	With DOE Support: Cumulative Energy Savings 1980-1990	Without DOE Support: Cumulative Energy Savings 1980-1990	Difference in Cumulative Energy Savings 1980-1990
		$\times 10^3$	$\times 10^3$	Btu $\times 10^{12}$		Years	Btu $\times 10^6$	Years	Years		Btu $\times 10^{12}$	Btu $\times 10^{12}$	Btu $\times 10^{12}$
17	A/C Condenser Only - E	142.2	2259.5	157.1									
	Wet Condenser	142.2	2259.5	157.1	0.25	0.89	16.1	2	5	No	49.0	27.0	22.0
	High Eff. Compressor	142.2	2259.5	157.1	0.025	0.7	1.9	2	5	No	7.5	4.3	3.2
	Improved Evap. & Cond. Surfaces	142.2	2259.5	157.1	0.075	0.98	4.4	2	5	No	14.0	7.7	6.6
	Increased Evap. & Cond. Capacity	142.2	2259.5	157.1	0.10	1.3	4.4	2	5	No	12.0	6.1	5.8
	Increased Air Flow	142.2	2259.5	157.1	0.05	1.2	2.4	2	5	Yes	4.3	2.2	2.1
18	Horizontal - Elect.	74.2	1133.3	93.1									
	Wet Condenser	74.2	1133.3	93.1	0.25	1.4	19.1	2	5	No	21.0	11.0	10.0
	High Eff. Compressor	74.2	1133.3	93.1	0.025	1.1	2.3	2	5	No	3.7	2.0	1.7
	Improved Evap. & Cond. Surfaces	74.2	1133.3	93.1	0.075	1.5	5.2	2	5	No	6.8	3.4	3.4
	Increased Evap. & Cond. Capacity	74.2	1133.3	93.1	0.10	2.1	5.2	2	5	No	5.4	2.6	2.8
	Increased Air Flow	74.2	1133.3	93.1	0.05	1.9	2.9	2	5	Yes	3.5	1.7	1.8
19	Heat Pump (Sing. & Split)-E	22.2	211.8	13.0									
	Wet Condenser	22.2	211.8	13.0	0.25	1.9	12.5	2	5	No	3.0	1.4	1.6
	High Eff. Compressor	22.2	211.8	13.0	0.025	1.6	1.5	2	5	No	0.57	0.28	0.29
	Improved Evap. & Cond. Surfaces	22.2	211.8	13.0	0.075	2.1	3.4	2	5	No	1.1	0.50	0.56
	Increased Evap. & Cond. Capacity	22.2	211.8	13.0	0.10	2.9	3.4	2	5	No	0.84	0.38	0.45
	Increased Air Flow	22.2	211.8	13.0	0.05	2.6	1.9	2	5	Yes	0.55	0.26	0.30
20	Centrifugal Liq. Chiller - E	2.4	46.9	58.0									
	Wet Condenser	2.4	46.9	58.0	0.25	0.6	302.0	2	5	No	22.0	13.0	8.7
	High Eff. Compressor	2.4	46.9	58.0	0.025	0.5	36.6	2	5	No	3.1	2.0	1.2
	Improved Evap. & Cond. Surfaces	2.4	46.9	58.0	0.075	0.6	82.3	2	5	No	6.4	3.8	2.6
	Increased Evap. & Cond. Capacity	2.4	46.9	58.0	0.10	0.8	82.3	2	5	No	5.5	3.1	2.4
	Increased Air Flow	2.4	46.9	58.0	0.05	0.8	82.3	2	5	Yes	5.6	3.2	2.5

*Appliance numbers correspond to Table 9.1.

TABLE 9.3 (continued)

A-2773e r

No.*	Appliance	Computer Program Input: Proj. Annual Sales	Inventory 1980	Energy Consump. 1990	Cost Premium	Payback Period	Unit Energy Savings	Δt_o WDOE	Δt_o WODOE	Potential For Retrofit	Computer Program Results: With DOE Support, Cumulative Energy Savings 1980-1990	Without DOE Support, Cumulative Energy Savings 1980-1990	Difference in Cumulative Energy Savings 1980-1990
		x 10^3	x 10^3	Btu x 10^{12}		Years	Btu x 10^6	Years	Years		Btu x 10^{12}	Btu x 10^{12}	Btu x 10^{12}
21	Reciprocating Liq. Chiller E	6.2	99.1	36.0									
	Wet Condenser	6.2	99.1	36.0	0.25	0.8	77.6	2	5	No	12.0	6.6	5.3
	High Eff. Compressor	6.2	99.1	36.0	0.025	0.7	9.4	2	5	No	1.7	1.0	0.75
	Improved Evap. & Cond. Surfaces	6.2	99.1	36.0	0.075	0.9	21.2	2	5	No	3.4	1.8	1.5
	Increased Evap. & Cond. Capacity	6.2	99.1	36.0	0.10	1.2	21.2	2	5	No	2.8	1.5	1.4
	Increased Air Flow	6.2	99.1	36.0	0.05	1.1	11.8	2	5	Yes	1.7	0.90	0.82
22	Water Heater - Gas	71.2	926.5	773.8									
	Liquid Heater	71.2	926.5	773.8	0.05	0.22	86.5	5	10	No	140.0	38.0	99.0
	Heat Pipe Water Heater	71.2	926.5	773.8	0.20	0.90	86.5	5	10	No	61.0	5.2	56.0
	Pulse Combustion	71.2	926.5	773.8	0.60	2.0	113.2	5	10	No	9.0	0.57	8.4
	Reduce Storage Temp. With Booster @ Point Use	71.2	926.5	773.8	0.60	5.0	46.6	5	10	No	0	0	0
	Flue Heat Recovery	71.2	926.5	773.8	0.375	3.1	46.6	3	7	Yes	6.0	1.7	4.3
	Improved Insulation	71.2	926.5	773.8	0.05	0.58	33.3	2	5	No	58.0	35.0	23.0
	Outside Comb. Air	71.2	926.5	773.8	0.075	2.2	13.3	2	5	Yes	11.0	5.6	5.8
	Elect. Ignition	71.2	926.5	773.8	0.075	2.2	13.3	2	5	Yes	11.0	5.6	5.8
	Modulation	71.2	926.5	773.8	0.30	1.9	59.9	3	7	No	30.0	9.0	21.0
	Power Burners	71.2	926.5	773.8	0.15	0.51	113.2	3	7	No	180.0	77.0	99.0
	Flue Dampers	71.2	926.5	773.8	0.075	0.48	59.9	2	5	Yes	110.0	71.0	42.0
23	Water Heater - Oil	8.0	183.7	202.6									
	Liquid Heater	8.0	183.7	202.6	0.05	0.18	102.0	5	10	No	-	-	
	Reduce Storage Temp. With Booster @ Point Use	8.0	183.7	202.6	0.60	4.1	54.9	5	10	No	0	0	0
	Flue Heat Recovery	8.0	183.7	202.6	0.375	2.5	54.9	3	7	Yes	2.3	0.67	1.7
	Improved Insulations	8.0	183.7	202.6	0.05	0.47	39.2	2	5	No	12.0	7.8	4.5
	Outside Comb. Air	8.0	183.7	202.6	0.075	1.7	15.7	2	5	Yes	2.6	1.3	1.3
	Modulation	8.0	183.7	202.6	0.30	1.5	70.6	3	7	No	7.7	2.4	5.3
	Flue Dampers	8.0	183.7	202.6	0.075	0.39	70.6	2	5	Yes	24.0	15.0	8.2
	Emulsified Fuel	8.0	183.7	202.6	0.20	1.3	54.9	5	10	No	4.7	0.34	4.4
24	Water Heater - Elect.	23.0	246.2	150.3									
	Heat Pump	23.0	246.2	150.3	1.25	0.6	200.0	3	7	No	49.0	19.0	30.0
	Reduce Storage Temp. With Booster @ Point Use	23.0	246.2	150.3	0.60	2.0	28.0	5	10	No	0.75	0.045	0.70
	Improved Insulation	23.0	246.2	150.3	0.05	0.23	20.0	2	5	No	0	0	0
	Heat Traps	23.0	246.2	150.3	0.075	1.7	4.0	2	5	No	1.4	0.66	0.69

*Appliance numbers correspond to Table 6.1.

TABLE 9.3 (continued)

A-2773f r

No.*	Appliance	Computer Program Input									Computer Program Results		
		Proj. Annual Sales	Inventory 1980	Energy Consump. 1990	Cost Premium	Payback Period	Unit Energy Savings	Δt_o WDOE	Δt_o WODOE	Potential For Retrofit	With DOE Support Cumulative Energy Savings 1980-1990	Without DOE Support Cumulative Energy Savings 1980-1990	Difference in Cumulative Energy Savings 1980-1990
		x 10^3	x 10^3	Btu x 10^{12}		Years	Btu x 10^6	Years	Years		Btu x 10^{12}	Btu x 10^{12}	Btu x 10^{12}
27	Ref. Restaurant Storage - E	107.0	2262.6	60.9									
	High Eff. Compressor	107.0	2262.6	60.9	0.025	5.1	0.8	2	5	No	1.2	0.56	0.63
	Improved Evap. & Cond. Surfaces	107.0	2262.6	60.9	0.075	6.8	1.8	2	5	No	1.7	0.76	0.90
	Improved Insulation	107.0	2262.6	60.9	0.05	1.9	4.4	2	5	No	8.7	4.3	4.3
	Wet Condensing Unit	107.0	2262.6	60.9	0.25	5.3	7.8	2	5	No	0.85	0.40	0.46
	Improved Temperature Range Requirements	107.0	2262.6	60.9	0	0	4.4	2	5	Yes			
28	Coffee Makers & Urns - Gas	23.0	244.4	5.8									
	Improved Insulation	23.0	244.4	5.8	0.003	2.0	0.3	2	5	No	0	0	0
	Modulation	23.0	244.4	5.8	0.175	14.6	1.2	2	5	No	0.0027	0.0012	0.0015
	Elect. Ignition	23.0	244.4	5.8	0.075	18.5	0.5	2	5	Yes	0.98	0.47	0.51
	Power Combustion	23.0	244.4	5.8	0.10	2.5	4.3	2	5	No	0	0	0
29	Kettle, Cooker & Pres. Ck.-G	12.4	193.9	31.2									
	Improved Insulation	12.4	193.9	31.2	0.035	8.5	2.5	2	5	No	0.26	0.12	0.14
	Modulation	12.4	193.9	31.2	0.175	12.1	8.9	2	5	No	0	0	0
	Elect. Ignition	12.4	193.9	31.2	0.075	12.2	3.8	2	5	Yes	0.17	0.078	0.095
	Power Combustion	12.4	193.9	31.2	0.10	2.0	30.7	2	5	No	5.2	2.6	2.6
	Improved Steam Generator	12.4	193.9	31.2	0.10	2.0	15.3	3	7	No	2.1	0.63	1.5
	Proper Use	12.4	193.9	31.2	0	0	21.7	2	5	Yes	9.8	6.8	3.1
30	Broilers - Gas	20.1	159.4	19.2									
	Improved Insulation	20.1	159.4	19.2	0.035	4.2	1.8	2	5	No	0.29	0.13	0.16
	Modulation	20.1	159.4	19.2	0.175	5.9	6.3	2	5	No	0.29	0.13	0.16
	Elect. Ignition	20.1	159.4	19.2	0.075	5.6	2.7	2	5	Yes	0.32	0.15	0.18
	Power Combustion	20.1	159.4	19.2	0.10	0.96	21.8	2	5	No	6.6	3.6	3.1
	Proper Use	20.1	159.4	19.2	0	0	15.4	2	5	Yes	8.1	5.5	2.6
	Heat Pipe Broiler	20.1	159.4	19.2	0.25	4.1	12.7	2	5	No	0.65	0.30	0.35
31	Fryers - Gas	55.3	513.3	67.8									
	Heat Pipe Fryer	55.3	513.3	67.8	0.25	0.82	34.0	2	5	No	30.0	17.0	13.0
	Improved Insulation	55.3	513.3	67.8	0.035	2.0	2.0	2	5	No	1.3	0.64	0.67
	Modulation	55.3	513.3	67.8	0.175	2.7	7.0	2	5	No	2.9	1.4	1.5
	Elect. Ignition	55.3	513.3	67.8	0.075	2.7	3.0	2	5	Yes	1.6	0.75	0.83
	Power Combustion	55.3	513.3	67.8	0.10	0.46	24.0	2	5	No	31.0	19.0	11.0
	Proper Use	55.3	513.3	67.8	0	0	17.0	2	5	Yes	26.0	18.0	8.4

*Appliance numbers correspond to Table 6.1.

TABLE 9.3 (continued)

A-2773g r

No.*	Appliance	Computer Program Input: Proj. Annual Sales	Inventory 1980	Energy Consump. 1990	Cost Premium	Payback Period	Unit Energy Savings	Δt_o WDOE	Δt_o WODOE	Potential For Retrofit	Computer Program Results: With DOE Support, Cumulative Energy Savings 1980-1990	Without DOE Support, Cumulative Energy Savings 1980-1990	Difference in Cumulative Energy Savings 1980-1990
		$\times 10^3$	$\times 10^3$	Btu $\times 10^{12}$		Years	Btu $\times 10^6$	Years	Years		Btu $\times 10^{12}$	Btu $\times 10^{12}$	Btu $\times 10^{12}$
32	Griddles & Grills - Gas	37.3	434.6	52.3									
	Heat Pipe Griddle	37.3	434.6	52.3	0.25	0.7	54.5	2	5	No	52.0	23.0	29.0
	Improved Insulation	37.3	434.6	52.3	0.035	3.1	1.8	2	5	No	0.73	0.35	0.39
	Modulation	37.3	434.6	52.3	0.175	4.3	6.3	2	5	No	1.2	0.55	0.64
	Elect. Ignition	37.3	434.6	52.3	0.075	4.1	2.7	2	5	Yes	0.86	0.40	0.46
	Power Combustion	37.3	434.6	52.3	0.10	0.70	21.8	2	5	No	18.0	10.0	7.4
	Proper Use	37.3	434.6	52.3	0	0	15.4	2	5	Yes	18.0	12.0	5.7
33	Deck & Convect. Ovens - G	36.9	515.6	53.7									
	Heat Pipe Oven	36.9	515.6	53.7	0.25	9.3	10.6	2	5	No	0	0	0
	Improved Insulation	36.9	515.6	53.7	0.035	9.1	1.6	2	5	No	0.46	0.21	0.25
	Modulation	36.9	515.6	53.7	0.175	12.3	5.7	2	5	No	0	0	0
	Elect. Ignition	36.9	515.6	53.7	0.075	12.4	2.4	2	5	Yes	0.30	0.13	0.17
	Power Combustion	36.9	515.6	53.7	0.10	2.0	19.6	2	5	No	26.0	15.0	11.0
	Proper Use	36.9	515.6	53.7	0	0	13.9	2	5	Yes	18.0	12.0	5.6
34	Ranges & Braising Pans - G	34.7	455.4	78.3									
	Heat Pipe Griddle	34.7	455.4	78.3	0.25	0.7	76.8	2	5	No	56.0	32.0	24.0
	Improved Insulation	34.7	455.4	78.3	0.035	3.0	2.5	2	5	No	1.0	0.48	0.53
	Modulation	34.7	455.4	78.3	0.175	4.3	8.9	2	5	No	1.7	0.77	0.89
	Elect. Ignition	34.7	455.4	78.3	0.075	4.3	3.8	2	5	Yes	1.2	0.53	0.62
	Power Combustion	34.7	455.4	78.3	0.10	0.72	30.7	2	5	No	24.0	14.0	10.0
	Proper Use	34.7	455.4	78.3	0	0	21.7	2	5	Yes	25.0	17.0	7.9
35	Coffee Makers & Urns - E	46.1	442.8	5.1									
	Improved Insulation	46.1	442.8	5.1	0.035	7.0	0.1	2	5	No	0.033	0.015	0.018
36	Kettle, Cooker & Pres. Ck.-E	5.7	87.9	6.8									
	Improved Insulation	5.7	87.9	6.8	0.035	4.1	1.2	2	5	No	0.076	0.035	0.040
37	Broilers - E	5.1	39.8	2.2									
	Improved Insulation	5.1	39.8	2.2	0.035	2.3	0.8	2	5	No	0.042	0.020	0.022
38	Fryers - E	18.4	132.5	8.9									
	Improved Insulation	18.4	132.5	8.9	0.035	0.93	0.9	2	5	No	0.26	0.14	0.12
39	Griddles & Grills - E	12.4	144.8	8.3									
	Improved Insulation	12.4	144.8	8.3	0.035	1.3	0.8	2	5	No	0.16	0.084	0.079
40	Deck & Convect. Ovens - E	6.3	171.1	7.6									
	Improved Insulation	6.3	171.1	7.6	0.035	46.0	0.7	2	5	No	0	0	0
41	Ranges & Braising Pans - E	5.9	73.9	6.0									
	Improved Insulation	5.9	73.9	6.0	0.035	1.3	1.2	2	5	No	0.11	0.059	0.054
43	Fluorescent Lights - E	30×10^4	75×10^4	839.0									
	Improved Coating	30×10^4	75×10^4	839.0	45.0	1.88		2	5	Yes	8.0	4.0	4.1

*Appliance numbers correspond to Table 6.1.

The information presented in the last column of Table 9.3 shows the difference in cumulative energy savings between a development supported by DOE and one not supported. This difference in the cumulative energy savings was totaled for all improvements of the same type. These totals, from which the final ranking of the most promising opportunities for energy savings were made, are presented in Table 9.1.

Thermo Electron CORPORATION

APPENDIX A

DISTRIBUTION OF APPLIANCE INVENTORY

A computer program was written to assist in the computational process of distributing the appliance inventory and energy consumption to the commercial subsectors and census divisions (geographic locations). The output from this computer program for the major space heating, space cooling, and water heating equipment is presented in this section.

The numerical designations for the census divisions and commercial subsectors that appear in the tables of this section correspond to the following:

COMMERCIAL SUBSECTORS

1. Communications
2. Utilities
3. Wholesale
4. Retail
5. Finance, Insurance, Real Estate, Services
6. Hospitals
7. Schools
8. Public Administration

CENSUS DIVISIONS

1. New England
2. Middle Atlantic
3. South Atlantic
4. East North Central
5. East South Central
6. West North Central
7. West South Central
8. Mountain
9. Pacific

A-1440

TABLE A.1

Fuel Type: Gas

Appliance Type:

Cast Iron Boiler (Hot Water)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.071	72.342
2	0.062	62.550
3	0.146	147.482
4	1.046	1195.823
5	0.475	480.615
6	0.190	370.491
7	0.136	138.089
8	0.290	331.508
Totals	2.417	2798.900
	Census Division 2	
1	0.172	142.253
2	0.274	226.105
3	1.118	923.994
4	3.653	3395.789
5	1.996	1649.127
7	4.413	8143.591
4	7.727	6384.761
8	9.983	9279.462
Totals	29.335	30145.083
	Census Division 3	
1	0.118	43.087
2	0.335	122.199
3	1.917	699.760
4	2.251	914.289
5	7.899	2882.693
6	2.416	2062.989
7	5.319	1941.201
8	8.950	3635.982
Totals	29.205	12302.199
	Census Division 4	
1	0.614	533.059
2	0.737	639.430
3	4.263	3698.351
4	13.033	12743.127
5	11.328	9828.353
6	7.025	11996.286
7	16.809	14583.571
8	17.128	16746.830
Totals	70.937	70769.007
	Census Division 5	
1	0.076	29.234
2	0.104	39.968
3	0.988	380.876
4	1.288	558.667
5	2.175	838.566
6	1.496	1267.140
7	3.789	1460.848
8	5.368	2328.448
Totals	15.282	6903.747

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.292	271.619
2	0.392	364.300
3	2.083	1936.754
4	5.688	5953.422
5	8.356	7767.204
6	5.698	10083.104
7	10.277	9553.650
8	11.807	12357.521
Totals	44.594	48287.575
	Census Division 7	
1	0.330	113.582
2	0.469	161.299
3	1.701	585.517
4	4.093	1606.423
5	7.942	2734.475
6	3.881	3073.435
7	9.084	3127.630
8	15.188	5961.145
Totals	42.688	17363.508
	Census Division 8	
1	0.261	205.036
2	0.209	164.277
3	0.854	670.279
4	4.166	3700.651
5	5.559	4363.866
6	1.891	2891.234
7	4.684	3676.540
8	8.141	7231.719
Totals	25.766	22903.602
	Census Division 9	
1	0.367	265.359
2	0.221	159.872
3	2.574	1861.080
4	5.813	4723.439
5	12.012	8684.755
6	3.699	6163.591
7	8.986	6497.079
8	12.103	9833.481
Totals	45.775	38188.657
	U. S. Totals	
1	2.302	1675.570
2	2.802	1939.999
3	15.644	10904.093
4	41.031	34791.630
5	57.742	39229 655
6	30.710	46051.861
7	66.812	47363.370
8	88.957	67706.097
Totals	306.000	249662.277

TABLE A.2

Fuel Type: Gas

Appliance Type:

Cast Iron Boiler (Steam)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.046	74.618
2	0.039	64.518
3	0.093	152.121
4	0.668	1233.440
5	0.303	495.734
6	0.121	382.145
7	0.087	142.433
8	0.185	341.937
Totals	1.543	2886.945
	Census Division 2	
1	0.110	146.728
2	0.175	233.217
3	0.714	953.061
4	2.333	3502.611
5	1.274	1701.004
6	2.818	8399.766
7	4.934	6585.608
8	6.374	9571.367
Totals	18.733	31093.362
	Census Division 3	
1	0.075	44.442
2	0.214	126.043
3	1.224	721.773
4	1.437	943.050
5	5.044	2973.374
6	1.543	2127.885
7	3.397	2002.266
8	5.715	3750.359
Totals	18.649	12689.191
	Census Division 4	
1	0.392	549.827
2	0.471	659.545
3	2.722	3814.690
4	8.322	13143.990
5	7.234	10137.525
6	4.486	12373.655
7	10.734	15042.328
8	10.937	17273.638
Totals	45.298	72995.200
	Census Division 5	
1	0.048	30.153
2	0.066	41.225
3	0.631	392.857
4	0.822	576.241
5	1.389	864.945
7	0.955	1307.000
7	2.419	1506.803
8	3.428	2401.695
Totals	9.758	7120.919

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.187	280.163
2	0.250	375.760
3	1.330	1997.679
4	3.632	6140.700
5	5.336	8011.539
6	3.638	10400.289
7	6.563	9854.181
8	7.539	12746.253
Totals	28.476	49806.565
	Census Division 7	
1	0.211	117.155
2	0.299	166.373
3	1.086	603.936
4	2.614	1656.956
5	5.072	2820.494
6	2.478	3170.117
7	5.801	3226.016
8	9.699	6148.666
Totals	27.259	17909.715
	Census Division 8	
1	0.167	211.486
2	0.134	169.444
3	0.545	691.364
4	2.660	3817.063
5	3.550	4501.141
6	1.208	2982.184
7	2.991	3792.193
8	5.199	7459.209
Totals	16.453	23624.084
	Census Division 9	
1	0.234	273.706
2	0.141	164.901
3	1.644	1919.624
4	3.712	4872.025
5	7.670	8957.953
6	2.362	6357.481
7	5.738	6701.459
8	7.728	10142.814
Totals	29.230	39389.963
	U. S. Totals	
1	1.470	1728.279
2	1.789	2001.026
3	9.990	11247.105
4	26.201	35886.077
5	36.872	40463.709
6	19.610	47500.522
7	42.664	48853.287
8	56.804	69835.938
Totals	195.400	257515.945

TABLE A.3

Fuel Type: Gas

Appliance Type: Unit Heaters

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.168	41.406
2	0.145	35.644
3	5.457	1343.357
4	4.385	1219.086
5	1.116	274.690
6	0.447	211.612
7	0.321	78.971
8	0.681	189.443
Totals	12.720	3394.210
	Census Division 2	
1	0.405	81.366
2	0.643	129.280
3	41.880	8416.118
4	15.314	3462.149
5	4.689	942.248
6	10.368	4653.083
7	18.155	3648.251
8	23.454	5302.304
Totals	114.908	26634.800
	Census Division 3	
1	0.277	24.625
2	0.787	69.873
3	71.812	6373.677
4	9.434	932.112
5	18.559	1647.171
6	5.676	1178.722
7	12.497	1109.195
8	21.028	2077.615
Totals	140.070	13412.990
	Census Division 4	
1	1.444	304.602
2	1.734	365.888
3	159.647	33686.017
4	54.635	12992.113
5	26.615	5615.830
6	16.505	6854.486
7	39.492	8332.914
8	40.240	9568.990
Totals	340.311	77720.840
	Census Division 5	
1	0.178	16.668
2	0.244	22.848
3	36.993	3469.186
4	5.399	569.596
5	5.109	479.151
6	3.515	723.996
7	8.901	834.712
8	12.611	1330.460
Totals	72.949	7446.617

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.687	155.241
2	0.921	208.164
3	78.030	17640.631
4	23.846	6069.755
5	19.631	4438.089
6	13.387	5761.398
7	24.146	5458.917
8	27.740	7061.113
Totals	188.388	46793.309
	Census Division 7	
1	0.775	64.902
2	1.101	92.198
3	63.693	5333.106
4	17.158	1637.827
5	18.661	1562.501
6	9.119	1756.218
7	21.343	1787.116
8	35.684	3406.168
Totals	167.535	15640.036
	Census Division 8	
1	0.614	117.189
2	0.492	93.850
3	31.979	6105.066
4	17.465	3772.966
5	13.062	2493.570
6	4.443	1651.940
7	11.004	2100.789
8	19.128	4132.207
Totals	98.187	20467.577
	Census Division 9	
1	0.863	151.691
2	0.519	91.320
3	96.405	16951.433
4	24.370	4815.700
5	28.221	4962.354
6	8.690	3521.767
7	21.113	3712.390
8	28.435	5618.888
Totals	208.616	39825.543
	U. S. Totals	
1	5.410	957.690
2	6.586	1109.064
3	585.896	99318.593
4	172.007	35471.305
5	135.662	22415.604
6	72.150	26313.224
7	156.972	27063.253
8	209.001	38687.188
Totals	1343.684	251335.924

TABLE A.4

Fuel Type: Gas

Appliance Type: Duct Furnaces

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.111	42.739
2	0.096	36.954
3	0.227	87.131
4	1.630	706.480
5	0.740	283.942
6	0.296	218.882
7	0.213	81.582
8	0.452	195.852
Totals	3.765	1653.561
	Census Division 2	
1	0.268	84.042
2	0.426	133.580
3	1.742	545.886
4	5.691	2006.197
5	3.109	974.288
6	6.875	4811.150
7	12.038	3772.052
8	15.551	5482.211
Totals	45.700	17809.406
	Census Division 3	
1	0.184	25.455
2	0.522	72.194
3	2.987	413.411
4	3.506	540.153
5	12.305	1703.065
6	3.764	1218.793
7	8.286	1146.842
8	13.943	2148.101
Totals	45.497	7268.013
	Census Division 4	
1	0.957	314.926
2	1.148	377.769
3	6.641	2184.948
4	20.303	7528.509
5	17.648	5806.490
6	10.944	7087.283
7	26.186	8615.824
8	26.682	9893.856
Totals	110.508	41809.605
	Census Division 5	
1	0.118	17.271
2	0.161	23.613
3	1.539	225.017
4	2.006	330.055
5	3.388	495.416
6	2.331	748.613
7	5.902	863.054
8	8.362	1375.623
Totals	23.807	4078.663

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.455	160.470
2	0.611	215.225
3	3.246	1144.214
4	8.861	3517.221
5	13.017	4588.785
6	8.876	5956.994
7	16.011	5644.199
8	18.393	7300.697
Totals	69.470	28527.805
	Census Division 7	
1	0.514	67.103
2	0.730	95.294
3	2.649	345.918
4	6.376	949.058
5	12.373	1615.500
6	6.046	1815.754
7	14.152	1847.772
8	23.661	3521.784
Totals	66.502	10258.183
	Census Division 8	
1	0.407	121.133
2	0.326	97.053
3	1.330	395.994
4	6.490	2186.307
5	8.660	2578.128
6	2.946	1708.112
7	7.296	2172.062
8	12.683	4272.426
Totals	40.140	13531.213
	Census Division 9	
1	0.572	156.771
2	0.344	94.451
3	4.010	1099.507
4	9.056	2790.560
5	18.713	5130.864
6	5.762	3641.387
7	13.999	3838.408
8	18.854	5809.520
Totals	71.311	22561.467
	U. S. Totals	
1	3.587	989.910
2	4.365	1146.132
3	24.371	6442.027
4	63.920	20554.539
5	89.953	23176.479
6	47.841	27206.968
7	104.083	27981.794
8	138.581	40000.068
Totals	476.699	147497.916

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TABLE A.5

Fuel Type: Gas

Appliance Type: Warm Air Furnace

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.081	29.700
2	0.070	25.680
3	0.165	60.549
4	1.187	490.944
5	0.539	197.316
6	0.216	152.105
7	0.155	56.692
8	0.329	136.101
Totals	2.742	1149.086
	Census Division 2	
1	0.195	58.402
2	0.310	92.827
3	1.269	379.345
4	4.145	1394.138
5	2.265	677.048
6	5.007	3343.345
7	8.767	2621.259
8	11.327	3809.676
Totals	33.285	12376.040
	Census Division 3	
1	0.134	17.689
2	0.380	50.169
3	2.176	287.286
4	2.554	375.361
5	8.963	1183.487
6	2.741	846.958
7	6.035	796.958
8	10.155	1492.749
Totals	33.137	5050.658
	Census Division 4	
1	0.697	218.847
2	0.836	262.518
3	4.837	1518.355
4	14.788	5231.681
5	12.853	4035.022
6	7.971	4925.066
7	19.072	5987.273
8	19.434	6875.398
Totals	80.488	29054.159
	Census Division 5	
1	0.086	12.002
2	0.118	16.409
3	1.121	156.368
4	1.461	229.360
5	2.468	344.273
6	1.698	520.223
7	4.299	599.750
8	6.090	955.943
Totals	17.340	2834.328

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.332	111.513
2	0.445	149.563
3	2.364	795.133
4	6.454	2444.173
5	9.481	3188.820
6	6.465	4139.610
7	11.661	3922.244
8	13.397	5073.370
Totals	50.598	19824.425
	Census Division 7	
1	0.374	46.631
2	0.532	66.221
3	1.930	240.384
4	4.644	659.516
5	9.012	1122.637
6	4.404	1261.796
7	10.308	1284.046
8	17.233	2447.344
Totals	48.436	7128.574
	Census Division 8	
1	0.296	84.177
2	0.237	67.444
3	0.969	275.183
4	4.727	1519.299
5	6.308	1791.582
6	2.146	1186.994
7	5.314	1509.400
8	9.238	2968.977
Totals	29.236	9403.055
	Census Division 9	
1	0.416	108.943
2	0.251	65.635
3	2.921	764.065
4	6.596	1939.204
5	13.629	3565.519
6	4.197	2530.458
7	10.196	2667.371
8	13.732	4037.128
Totals	51.939	15678.322
	U. S. Totals	
1	2.612	687.904
	3.179	796.465
	17.750	4476.667
	46.556	14283.676
	65.516	16105.703
	34.845	18906.555
	75.808	19444.993
8	100.934	27796.684
Totals	347.200	102498.647

TABLE A.6

Fuel Type: Oil

Appliance Type: Warm Air Furnace

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	1.139	750.970
2	0.810	534.081
3	5.918	3900.745
4	13.191	9818.954
5	19.268	12700.704
6	24.069	30543.708
7	39.063	25748.562
8	51.620	38423.369
Totals	155.078	122421.092
	Census Division 2	
1	3.183	1712.568
2	2.474	1331.348
3	17.509	9421.517
4	28.353	17163.297
5	31.248	16814.111
6	25.906	31132.229
7	69.695	37502.103
8	107.028	64789.144
Totals	285.396	179866.318
	Census Division 3	
1	0.624	148.412
2	0.870	206.650
3	6.491	1542.592
4	2.159	571.188
5	26.740	6354.943
6	12.821	7128.611
7	33.403	7938.394
8	96.106	25425.853
Totals	179.214	49316.643
	Census Division 4	
1	0.894	505.237
2	0.445	251.223
3	3.432	1938.881
4	8.785	5593.902
5	9.119	5152.299
6	8.724	9701.504
7	25.164	14217.531
8	29.938	19062.426
Totals	86.501	56423.003
	Census Division 5	
1	0.021	5.211
2	0.074	18.609
3	0.970	243.655
4	0.762	215.214
5	2.140	537.431
6	0.748	412.550
7	1.052	264.249
8	1.791	506.074
Totals	7.559	2202.993
	Census Division 6	
1	0.213	129.200
2	0.184	111.256
3	1.411	854.157
4	3.180	2167.232
5	3.007	1820.168
6	5.535	6378.992
7	6.197	3751.593
8	10.844	7391.354
Totals	30.572	22603.953
	Census Division 7	
1	0.086	19.274
2	0.182	40.763
3	1.113	249.450
4	2.004	512.175
5	5.198	1165.505
6	0.257	132.479
7	0.674	151.088
8	1.816	464.190
Totals	11.330	2734.925
	Census Division 8	
1	0.055	28.286
2	0.064	32.832
3	0.330	168.705
4	1.151	665.873
5	2.147	1097.591
6	0.582	579.354
7	0.784	400.547
8	4.164	2408.575
Totals	9.277	5381.762
	Census Division 9	
1	0.197	92.580
2	0.085	40.010
3	1.210	569.903
4	1.930	1021.081
5	5.647	2658.774
6	7.475	8111.481
7	9.283	4370.810
8	32.346	17114.737
Totals	58.173	33979.375
	U. S. Totals	
1	6.413	3391.737
2	5.188	2566.770
3	38.384	18889.605
4	61.515	37728.917
5	104.515	48301.526
6	86.117	94120.909
7	185.316	94344.878
8	335.653	175585.723
Totals	823.100	474930.066

TABLE A.7

Fuel Type: Oil

Appliance Type: Cast Iron Boiler (Steam and Hot Water)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.645	798.234
2	0.459	567.694
3	3.353	4146.247
4	7.473	10436.932
5	10.916	13500.052
6	13.636	32466.045
7	22.130	27369.105
8	29.243	40841.630
Totals	87.855	130125.940
	Census Division 2	
1	1.803	1820.352
2	1.402	1415.139
3	9.919	10014.481
4	16.062	18243.508
5	17.702	17872.345
6	14.676	33091.606
7	39.483	39862.383
8	60.633	68866.796
Totals	161.682	191186.613
	Census Division 3	
1	0.354	157.753
2	0.493	219.655
3	3.677	1639.678
4	1.223	607.137
5	15.149	6754.905
6	7.263	7577.266
7	18.923	8438.015
8	54.446	27026.087
Totals	101.528	52420.497
	Census Division 4	
1	0.507	537.035
2	0.252	267.034
3	1.944	2060.909
4	4.977	5945.966
5	5.166	5476.571
6	4.942	10312.090
7	14.256	15112.344
8	16.960	20262.163
Totals	49.004	59974.112
	Census Division 5	
1	0.012	5.538
2	0.042	19.780
3	0.550	258.990
4	0.432	228.759
5	1.212	571.255
6	0.424	438.515
7	0.596	280.880
8	1.015	537.925
Totals	4.282	2341.643

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.121	137.332
2	0.104	118.258
3	0.799	907.916
4	1.801	2303.632
5	1.703	1934.725
6	3.136	6780.469
7	3.511	3987.708
8	6.144	7856.545
Totals	17.320	24026.584
	Census Division 7	
1	0.049	20.487
2	0.103	43.328
3	0.630	265.150
4	1.135	544.410
5	2.945	1238.859
6	0.146	140.817
7	0.382	160.597
8	1.029	493.405
Totals	6.418	2907.054
	Census Division 8	
1	0.031	30.066
2	0.036	34.898
3	0.187	179.323
4	0.652	707.781
5	1.216	1166.670
6	0.330	615.817
7	0.444	425.757
8	2.359	2560.164
Totals	5.256	5720.476
	Census Division 9	
1	0.111	98.407
2	0.048	42.528
3	0.686	605.772
4	1.093	1085.345
5	3.199	2826.110
6	4.235	8621.995
7	5.259	4645.897
8	18.324	18191.891
Totals	32.956	36117.944
	U. S. Totals	
1	3.633	3605.204
2	2.939	2728.315
3	21.745	20078.465
4	34.849	40103.472
5	59.210	51341.492
6	48.787	100044.620
7	104.984	100282.687
8	190.153	186636.607
Totals	466.300	504820.867

TABLE A.8

Fuel Type: Elect.

Appliance Type: Heat Pump (Single Pack)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.037	2.201
2	0.027	1.585
3	0.106	6.300
4	1.537	103.404
5	0.707	42.143
6	0.088	10.102
7	0.343	20.451
8	0.319	21.490
Totals	3.164	207.677
	Census Division 2	
1	0.110	5.346
2	0.086	4.206
3	0.424	20.630
4	4.025	220.261
5	2.195	106.777
6	0.215	23.306
7	0.996	48.460
8	1.045	57.202
Totals	9.097	486.188
	Census Division 3	
1	0.056	1.201
2	0.114	2.457
3	0.262	5.624
4	3.945	94.329
5	4.247	91.227
6	0.691	34.751
7	1.006	21.608
8	2.012	48.123
Totals	12.333	299.320
	Census Division 4	
1	0.035	1.780
2	0.083	4.249
3	0.408	20.840
4	4.307	247.865
5	1.761	89.937
6	0.242	24.312
7	0.862	44.018
8	0.844	48.573
Totals	8.541	481.573
	Census Division 5	
1	0.015	0.338
2	0.033	0.757
3	0.068	1.550
4	1.366	34.888
5	0.954	21.648
6	0.274	13.667
7	0.334	7.574
8	0.556	14.185
Totals	3.600	94.608

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.089	4.862
2	0.032	1.738
3	0.226	12.376
4	2.274	140.101
5	0.722	39.480
6	0.167	17.386
7	0.276	15.109
8	0.404	24.871
Totals	4.189	255.923
	Census Division 7	
1	0.050	1.006
2	0.065	1.318
3	0.234	4.751
4	2.571	59.394
5	1.158	23.459
6	0.720	33.566
7	0.629	12.739
8	0.763	17.635
Totals	6.189	153.869
	Census Division 8	
1	0.043	2.005
2	0.034	1.551
3	0.105	4.845
4	2.272	118.782
5	0.944	43.633
6	0.059	5.280
7	0.267	12.327
8	0.503	26.310
Totals	4.226	214.732
	Census Division 9	
1	0.071	3.009
2	0.057	2.413
3	0.160	6.790
4	3.317	158.624
5	4.206	179.013
6	0.691	67.821
7	1.050	44.672
8	1.309	62.567
Totals	10.859	524.927
	U. S. Totals	
1	0.505	21.747
2	0.531	20.275
3	1.993	83.707
4	25.613	1177.649
5	16.894	637.317
6	3.147	230.190
7	5.762	226.957
8	7.755	320.976
Totals	62.200	2718.818

TABLE A.9

Fuel Type: Elect.

Appliance Type: Heat Pump (Split System)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.039	2.399
2	0.028	1.730
3	0.111	6.807
4	1.616	112.218
5	0.744	45.753
6	0.093	10.957
7	0.361	22.207
8	0.336	23.213
Totals	3.327	225.384
	Census Division 2	
1	0.115	5.785
2	0.091	4.555
3	0.445	22.364
4	4.232	239.043
5	2.308	115.875
6	0.226	25.329
7	1.048	52.608
8	1.100	62.105
Totals	9.566	527.664
	Census Division 3	
1	0.059	1.308
2	0.121	2.676
3	0.275	6.095
4	4.147	102.366
5	4.465	98.996
6	0.727	37.700
7	1.058	23.457
8	2.116	52.224
Totals	12.967	324.822
	Census Division 4	
1	0.036	1.913
2	0.087	4.591
3	0.429	22.622
4	4.528	269.009
5	1.852	97.612
6	0.254	26.357
7	0.906	47.778
8	0.887	52.713
Totals	8.980	522.595
	Census Division 5	
1	0.015	0.361
2	0.035	0.829
3	0.072	1.679
4	1.436	37.854
5	1.003	23.488
6	0.289	14.846
7	0.351	8.226
8	0.584	15.400
Totals	3.785	102.684
	Census Division 6	
1	0.093	5.278
2	0.034	1.896
3	0.238	13.425
4	2.391	152.025
5	0.758	42.838
6	0.175	18.827
7	0.290	16.397
8	0.425	27.001
Totals	4.404	277.688
	Census Division 7	
1	0.052	1.082
2	0.068	1.423
3	0.247	5.162
4	2.703	64.452
5	1.217	25.450
6	0.758	36.448
7	0.661	13.835
8	0.803	19.147
Totals	6.508	167.000
	Census Division 8	
1	0.045	2.164
2	0.035	1.688
3	0.110	5.236
4	2.388	128.874
5	0.993	47.338
6	0.062	5.730
7	0.280	13.371
8	0.529	28.546
Totals	4.442	232.946
	Census Division 9	
1	0.074	3.268
2	0.060	2.630
3	0.168	7.373
4	3.487	172.125
5	4.423	194.292
6	0.727	73.576
7	1.103	48.463
8	1.376	67.945
Totals	11.418	569.673
	U. S. Totals	
1	0.530	23.557
2	0.559	22.018
3	2.094	90.764
4	26.928	1277.965
5	17.762	691.642
6	3.309	249.771
7	6.060	246.342
8	8.156	348.395
Totals	65.397	2950.454

TABLE A.10

Fuel Type: Electricity

Appliance Type: Unit Heaters

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.193	19.002
2	0.136	13.413
3	9.423	927.749
4	3.145	349.641
5	3.650	359.363
6	0.454	86.076
7	1.771	174.372
8	1.646	183.025
Totals	20.419	2112.641
	Census Division 2	
1	0.568	45.623
2	0.443	35.586
3	37.921	3047.632
4	8.231	744.229
5	11.320	909.727
6	1.107	198.689
7	5.143	413.347
8	5.393	487.598
Totals	70.125	5882.432
	Census Division 3	
1	0.290	10.277
2	0.590	20.956
3	23.400	830.594
4	8.067	318.751
5	21.901	777.397
6	3.565	296.064
7	5.189	184.173
8	10.377	410.046
Totals	73.378	2848.259
	Census Division 4	
1	0.176	14.850
2	0.426	35.928
3	36.530	3082.648
4	8.810	837.886
5	9.083	766.470
6	1.249	207.434
7	4.445	375.091
8	4.354	414.084
Totals	65.073	5734.393
	Census Division 5	
1	0.074	2.768
2	0.176	6.600
3	6.103	228.877
4	2.793	117.845
5	4.916	184.379
6	1.414	116.442
7	1.720	64.511
8	2.867	120.959
Totals	20.062	842.380
	Census Division 6	
1	0.460	41.574
2	0.165	14.885
3	20.238	1829.777
4	4.649	473.295
5	3.718	336.186
6	0.857	147.542
7	1.425	128.829
8	2.083	212.087
Totals	33.595	3184.175
	Census Division 7	
1	0.255	8.554
2	0.335	11.216
3	21.010	703.548
4	5.257	200.674
5	5.966	199.792
6	3.718	286.381
7	3.247	108.735
8	3.940	150.397
Totals	43.728	1669.297
	Census Division 8	
1	0.221	16.903
2	0.176	13.436
3	9.344	713.411
4	4.644	401.188
5	4.871	371.875
6	0.301	44.734
7	1.374	104.888
8	2.594	224.136
Totals	23.525	1890.570
	Census Division 9	
1	0.363	25.549
2	0.295	20.759
3	14.288	1004.795
5	6.784	536.111
5	21.697	1525.755
6	3.565	577.803
7	5.410	380.441
8	6.750	533.419
Totals	59.152	4604.632
	U. S. Totals	
1	2.600	185.101
2	2.742	172.779
3	178.257	12369.031
4	52.380	3979.620
5	87.122	5430.945
6	16.230	1961.164
7	29.724	1934.387
8	40.004	2735.752
Totals	409.058	28768.780

TABLE A.11

Fuel Type: Electric

Appliance Type: Baseboard Heater

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.227	1.702
2	0.164	1.227
3	0.644	4.829
4	9.404	79.612
5	4.330	32.459
6	0.539	7.773
7	2.101	15.755
8	1.954	16.539
Totals	19.362	159.897
	Census Division 2	
1	0.671	4.104
2	0.528	3.231
3	2.592	15.866
4	24.631	169.587
5	13.432	82.206
6	1.315	17.970
7	6.098	37.322
8	6.399	44.060
Totals	55.667	374.346
	Census Division 3	
1	0.343	0.928
2	0.702	1.898
3	1.600	4.324
4	24.135	72.622
5	25.983	70.232
6	4.229	26.746
7	6.157	16.641
8	12.313	37.050
Totals	75.462	230.441
	Census Division 4	
1	0.211	1.357
2	0.507	3.257
3	2.497	16.049
4	26.353	190.846
5	10.777	69.250
6	1.478	18.699
7	5.275	33.896
8	5.164	37.397
Totals	52.262	370.750
	Census Division 5	
1	0.090	0.256
2	0.206	0.588
3	0.417	1.191
4	8.358	26.855
5	5.834	16.663
6	1.679	10.533
7	2.043	5.836
8	3.400	10.925
Totals	22.028	72.848

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.544	3.744
2	0.195	1.345
3	1.383	9.524
4	13.913	107.853
5	4.414	30.391
6	1.019	13.357
7	1.690	11.633
8	2.471	19.156
Totals	25.629	197.003
	Census Division 7	
1	0.301	0.767
2	0.396	1.010
3	1.436	3.662
4	15.729	45.725
5	7.081	18.055
6	4.409	25.858
7	3.849	9.815
8	4.673	13.584
Totals	37.874	118.476
	Census Division 8	
1	0.264	1.535
2	0.206	1.197
3	0.639	3.714
4	13.897	91.429
5	5.776	33.584
6	0.359	4.065
7	1.632	9.486
8	3.078	20.252
Totals	25.851	165.261
	Census Division 9	
1	0.433	2.319
2	0.348	1.866
3	0.977	5.231
4	20.291	122.112
5	25.740	137.838
6	4.229	52.198
7	6.421	34.382
8	8.010	48.203
Totals	66.449	404.149
	U. S. Totals	
1	3.084	16.712
2	3.252	15.620
3	12.186	64.392
4	156.711	906.639
5	103.367	490.679
6	19.256	177.198
7	35.265	174.765
8	47.462	247.165
Totals	380.584	2093.171

TABLE A.12

Fuel Type: Gas

Appliance Type: Direct-Fired Absorption (Unitary)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.001	0.163
2	0.001	0.141
3	0.002	0.335
4	0.013	2.761
5	0.006	1.090
6	0.002	1.016
7	0.002	0.313
8	0.004	0.766
Totals	0.031	6.587
	Census Division 2	
1	0.002	0.397
2	0.003	0.627
3	0.014	2.564
4	0.047	9.639
5	0.025	4.577
6	0.056	22.529
7	0.098	17.726
8	0.127	26.334
Totals	0.374	84.395
	Census Division 3	
1	0.001	0.989
2	0.004	2.822
3	0.024	16.172
4	0.029	21.432
5	0.101	66.604
6	0.031	39.361
7	0.068	44.851
8	0.114	85.214
Totals	0.372	277.446
	Census Division 4	
1	0.008	2.605
2	0.009	3.127
3	0.054	18.087
4	0.166	62.790
5	0.144	48.080
6	0.090	58.820
7	0.214	71.336
8	0.218	82.514
Totals	0.904	347.359
	Census Division 5	
1	0.001	0.611
2	0.001	0.846
3	0.013	8.038
4	0.016	11.812
5	0.028	17.706
6	0.019	23.437
7	0.048	30.853
8	0.068	49.259
Totals	0.195	142.563
	Census Division 6	
1	0.004	1.258
2	0.005	1.688
3	0.027	8.963
4	0.072	27.726
5	0.106	35.943
6	0.073	50.662
7	0.131	44.211
8	0.150	57.562
Totals	0.568	228.013
	Census Division 7	
1	0.004	3.056
2	0.006	4.335
3	0.022	15.705
4	0.052	42.482
5	0.101	73.338
6	0.049	72.336
7	0.116	83.891
8	0.194	157.666
Totals	0.544	452.808
	Census Division 8	
1	0.003	0.810
2	0.003	0.650
3	0.011	2.646
4	0.053	14.573
5	0.071	17.215
6	0.024	12.040
7	0.060	14.504
8	0.104	28.480
Totals	0.328	90.917
	Census Division 9	
1	0.005	0.843
2	0.003	0.508
3	0.033	5.906
4	0.074	15.340
5	0.153	27.556
6	0.047	19.088
7	0.115	20.617
8	0.154	31.928
Totals	0.583	121.785
	U. S. Totals	
1	0.029	10.733
2	0.036	14.744
3	0.199	78.417
4	0.523	208.554
5	0.736	292.109
6	0.391	299.290
7	0.852	328.302
8	1.134	519.724
Totals	3.900	1751.874

TABLE A.13

Fuel Type: Gas

Appliance Type: Direct-Fired Gas Absorption (Built Up)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.038	2.703
2	0.032	2.338
3	0.077	5.553
4	0.552	45.711
5	0.251	18.048
6	0.100	16.818
7	0.072	5.188
8	0.153	12.688
Totals	1.276	109.047
	Census Division 2	
1	0.091	6.576
2	0.144	10.376
3	0.590	42.452
4	1.927	159.567
5	1.052	75.771
6	2.328	372.945
7	4.076	293.437
8	5.265	435.933
Totals	15.473	1397.056
	Census Division 3	
1	0.062	16.380
2	0.177	46.723
3	1.012	267.716
4	1.187	354.777
5	4.167	1102.549
6	1.275	651.583
7	2.806	742.462
8	4.721	1410.618
Totals	15.406	4592.806
	Census Division 4	
1	0.324	43.121
2	0.389	51.772
3	2.248	299.410
4	6.874	1039.408
5	5.975	795.905
6	3.705	973.702
7	8.865	1180.880
8	9.034	1365.930
Totals	37.414	5750.127
	Census Division 5	
1	0.040	10.116
2	0.055	14.007
3	0.521	133.066
4	0.679	195.527
5	1.147	293.108
6	0.790	387.975
7	1.998	510.735
8	2.831	815.428
Totals	8.060	2359.963
	Census Division 6	
1	0.154	20.824
2	0.207	27.948
3	1.099	148.372
4	3.000	458.971
5	4.407	594.994
6	3.006	838.645
7	5.421	731.858
8	6.228	952.876
Totals	23.523	3774.488
	Census Division 7	
1	0.175	50.584
2	0.248	71.759
3	0.897	259.980
4	2.159	703.246
5	4.189	1214.023
6	2.047	1197.432
7	4.792	1388.716
8	8.011	2609.980
Totals	22.517	7495.720
	Census Division 8	
1	0.138	13.415
2	0.111	10.752
3	0.451	43.796
4	2.197	241.240
5	2.932	284.972
6	0.998	199.314
7	2.470	240.091
8	4.294	471.449
Totals	13.589	1505.029
	Census Division 9	
1	0.194	13.956
2	0.117	8.403
3	1.358	97.764
4	3.067	253.930
5	6.336	456.157
6	1.950	315.978
7	4.740	341.296
8	6.383	528.530
Totals	24.145	2016.014
	U. S. Totals	
1	1.215	177.675
2	1.479	244.077
3	8.252	1298.109
4	21.642	3452.377
5	30.456	4835.527
6	16.199	4954.392
7	35.241	5434.662
8	46.920	8603.431
Totals	161.402	29000.251

TABLE A.14

Fuel Type: Elect.

Appliance Type: Air Conditioning - Year Round

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.389	9.209
2	0.280	6.634
3	1.115	26.364
4	16.199	440.657
5	7.455	176.354
6	0.928	51.051
7	3.618	85.578
8	3.367	91.582
Totals	33.351	887.428
	Census Division 2	
1	1.158	27.404
2	0.911	21.561
3	4.471	105.753
4	42.428	1154.181
5	23.139	547.354
6	2.261	119.027
7	10.502	248.415
8	11.018	299.740
Totals	95.889	2523.436
	Census Division 3	
1	0.589	51.218
2	1.206	104.802
3	2.760	239.899
4	41.576	4081.464
5	44.760	3891.143
6	7.288	1223.989
7	10.602	921.658
8	21.210	2082.185
Totals	129.991	12596.358
	Census Division 4	
1	0.367	16.075
2	0.877	38.377
3	4.301	188.223
4	45.391	2254.857
5	18.562	812.292
6	2.549	220.105
7	9.085	397.559
8	8.895	441.874
Totals	90.027	4369.363
	Census Division 5	
1	0.157	13.182
2	0.352	29.528
3	0.720	60.461
4	14.401	1362.606
5	10.053	844.173
6	2.889	466.476
7	3.517	295.364
8	5.855	554.013
Totals	37.944	3625.802

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.937	41.542
2	0.335	14.853
3	2.384	105.734
4	23.969	1204.843
5	7.605	337.300
6	1.759	161.250
7	2.910	129.081
8	4.255	213.888
Totals	44.153	2208.491
	Census Division 7	
1	0.523	49.819
2	0.685	65.263
3	2.471	235.246
4	27.097	2900.422
5	12.201	1161.683
6	7.590	1458.819
7	6.625	630.810
8	8.045	861.177
Totals	65.238	7363.238
	Census Division 8	
1	0.457	14.604
2	0.354	11.296
3	1.105	35.291
4	23.945	863.784
5	9.953	317.849
6	0.618	40.599
7	2.812	89.797
8	5.304	191.323
Totals	44.548	1564.541
	Census Division 9	
1	0.745	17.625
2	0.598	14.135
3	1.682	39.781
4	34.957	950.948
5	44.334	1048.739
6	7.288	387.884
7	11.063	261.708
8	13.793	375.209
Totals	114.460	3096.029
	U. S. Totals	
1	5.323	240.678
2	5.598	306.450
3	21.007	1036.752
4	269.962	15213.763
5	178.062	9136.886
6	33.172	4129.199
7	60.734	3059.970
8	81.742	5110.991
Totals	655.600	38234.687

TABLE A.15

Fuel Type: Elect.

Appliance Type: A/C-Condenser Only

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	1.040	20.739
2	0.749	14.941
3	2.978	59.375
4	43.279	992.417
5	19.918	397.171
6	2.480	114.974
7	9.666	192.731
8	8.995	206.254
Totals	89.104	1998.603
	Census Division 2	
1	3.095	61.716
2	2.435	48.559
3	11.944	238.169
4	113.356	2599.364
5	61.821	1232.712
6	6.042	268.064
7	28.057	559.462
8	29.439	675.054
Totals	256.191	5683.100
	Census Division 3	
1	1.574	115.350
2	3.221	236.028
3	7.373	540.282
4	111.081	9191.979
5	119.589	8763.351
6	19.471	2756.579
7	28.326	2075.692
8	56.668	4689.346
Totals	347.303	28368.609
	Census Division 4	
1	0.981	36.202
2	2.343	86.431
3	11.491	423.903
4	121.275	5078.227
5	49.592	1829.385
6	6.811	495.705
7	24.272	895.354
8	23.766	995.157
Totals	240.531	9840.365
	Census Division 5	
1	0.419	29.687
2	0.939	66.500
3	1.924	136.166
4	38.475	3068.763
5	26.858	1901.184
6	7.720	1050.564
7	9.397	665.197
8	15.643	1247.709
Totals	101.376	8165.771
	Census Division 6	
1	2.502	93.557
2	0.895	33.451
3	6.369	238.127
4	64.039	2713.461
5	20.318	759.643
6	4.700	363.156
7	7.776	290.707
8	11.368	481.703
Totals	117.967	4973.805
	Census Division 7	
1	1.398	112.199
2	1.831	146.981
3	6.601	529.804
4	72.396	6532.122
5	32.598	2616.258
6	20.279	3285.446
7	17.701	1420.664
8	21.495	1939.480
Totals	174.300	16582.954
	Census Division 8	
1	1.222	32.890
2	0.945	25.439
3	2.953	79.479
4	63.974	1945.352
5	26.592	715.836
6	1.652	91.433
7	7.513	202.234
8	14.170	430.883
Totals	119.021	3523.547
	Census Division 9	
1	1.991	39.695
2	1.596	31.834
3	4.493	89.592
4	93.396	2141.656
5	118.451	2361.895
6	19.471	873.564
7	29.559	589.400
8	36.851	845.019
Totals	305.808	6972.654
	U. S. Totals	
1	14.223	542.037
2	14.956	690.164
3	56.126	2334.897
4	721.270	34263.340
5	475.738	20577.435
6	88.626	9299.484
7	162.266	6891.443
8	218.395	11510.606
Totals	1751.600	86109.407

TABLE A.16

Fuel Type: Elect.

Appliance Type: A/C-Horizontal and Others

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.522	12.303
2	0.376	8.863
3	1.494	35.222
4	21.708	588.717
5	9.991	235.608
6	1.244	68.204
7	4.848	114.331
8	4.512	122.353
Totals	44.695	1185.602
	Census Division 2	
1	1.553	36.611
2	1.222	28.806
3	5.991	141.285
4	56.859	1541.983
5	31.010	731.264
6	3.031	159.020
7	14.074	331.882
8	14.766	400.452
Totals	128.505	3371.303
	Census Division 3	
1	0.790	68.428
2	1.616	140.015
3	3.698	320.504
4	55.718	5452.825
5	59.986	5198.556
6	9.767	1635.245
7	14.208	1231.333
8	28.425	2781.793
Totals	174.206	16828.699
	Census Division 4	
1	0.492	21.476
2	1.175	51.272
3	5.764	251.466
4	60.831	3012.483
5	24.875	1085.220
6	3.416	294.060
7	12.175	531.138
8	11.921	590.342
Totals	120.650	5837.457
	Census Division 5	
1	0.210	17.611
2	0.471	39.449
3	0.965	80.776
4	19.299	1820.438
5	13.472	1127.812
6	3.872	623.211
7	4.714	394.605
8	7.847	740.161
Totals	50.850	4844.062

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	1.255	55.500
2	0.449	19.843
3	3.195	141.261
4	32.122	1609.667
5	10.192	450.632
6	2.358	215.430
7	3.900	172.452
8	5.702	285.754
Totals	59.172	2950.538
	Census Division 7	
1	0.701	66.558
2	0.919	87.191
3	3.311	314.288
4	36.314	3874.956
5	16.351	1552.005
6	10.172	1948.978
7	8.879	842.760
8	10.782	1150.530
Totals	87.429	9837.266
	Census Division 8	
1	0.613	19.511
2	0.474	15.091
3	1.481	47.148
4	32.089	1154.013
5	13.339	424.645
6	0.829	54.240
7	3.768	119.969
8	7.108	255.607
Totals	59.701	2090.223
	Census Division 9	
1	0.999	23.548
2	0.801	18.884
3	2.254	53.147
4	46.847	1270.463
5	59.415	1401.113
6	9.767	518.212
7	14.827	349.642
8	18.484	501.278
Totals	153.393	4136.287
	U. S. Totals	
1	7.134	321.545
2	7.502	409.416
3	28.153	1385.097
4	361.788	20325.545
5	238.629	12206.854
6	44.455	5516.598
7	81.392	4088.111
8	109.547	6828.270
Totals	878.600	51081.437

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TABLE A.17

Fuel Type: Elect.

Appliance Type: Heat Pump (Single Pack)

Subsector	Inventory K-Units	Energy Consumption Billions Btu	Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1			Census Division 6	
1	0.037	0.544	1	0.089	2.454
2	0.027	0.392	2	0.032	0.877
3	0.106	1.557	3	0.226	6.246
4	1.537	26.031	4	2.274	71.173
5	0.707	10.418	5	0.722	19.925
6	0.088	3.016	6	0.167	9.525
7	0.343	5.055	7	0.276	7.625
8	0.319	5.410	8	0.404	12.635
Totals	3.164	52.422	Totals	4.189	130.460
	Census Division 2			Census Division 7	
1	0.110	1.619	1	0.050	2.943
2	0.086	1.274	2	0.065	3.855
3	0.424	6.247	3	0.234	13.896
4	4.025	68.180	4	2.571	171.334
5	2.195	32.333	5	1.158	68.623
6	0.215	7.031	6	0.720	86.175
7	0.996	14.674	7	0.629	37.263
8	1.045	17.706	8	0.763	50.871
Totals	9.097	149.064	Totals	6.189	434.961
	Census Division 3			Census Division 8	
1	0.056	3.026	1	0.043	0.863
2	0.114	6.191	2	0.034	0.667
3	0.262	14.171	3	0.105	2.085
4	3.945	241.100	4	2.272	51.025
5	4.247	229.858	5	0.944	18.776
6	0.691	72.304	6	0.059	2.398
7	1.006	54.444	7	0.267	5.304
8	2.012	122.999	8	0.503	11.302
Totals	12.333	744.093	Totals	4.226	92.421
	Census Division 4			Census Division 9	
1	0.035	0.950	1	0.071	1.041
2	0.083	2.267	2	0.057	0.835
3	0.408	11.119	3	0.160	2.350
4	4.307	133.199	4	3.317	56.174
5	1.761	47.984	5	4.206	61.951
6	0.242	13.002	6	0.691	22.913
7	0.862	23.485	7	1.050	15.460
8	0.844	26.102	8	1.309	22.164
Totals	8.541	258.107	Totals	10.859	182.889
	Census Division 5			U. S. Totals	
1	0.015	0.779	1	0.505	14.217
2	0.033	1.744	2	0.531	18.103
3	0.068	3.572	3	1.993	61.243
4	1.366	80.492	4	25.613	898.708
5	0.954	49.867	5	16.894	539.734
6	0.274	27.556	6	3.147	243.920
7	0.334	17.448	7	5.762	180.759
8	0.556	32.727	8	7.755	301.917
Totals	3.600	214.184	Totals	62.200	2258.601

TABLE A.18

Fuel Type: Elect.

Appliance Type: Heat Pump (Split System)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.039	0.590
2	0.028	0.425
3	0.111	1.690
4	1.616	28.251
5	0.744	11.306
6	0.093	3.273
7	0.361	5.486
8	0.336	5.871
Totals	3.327	56.893
	Census Division 2	
1	0.116	1.757
2	0.091	1.382
3	0.446	6.780
4	4.232	73.995
5	2.308	35.091
6	0.226	7.631
7	1.048	15.926
8	1.099	19.216
Totals	9.565	161.777
	Census Division 3	
1	0.059	3.284
2	0.120	6.719
3	0.275	15.380
4	4.147	261.663
5	4.465	249.461
6	0.727	78.470
7	1.058	59.087
8	2.116	133.489
Totals	12.967	807.552
	Census Division 4	
1	0.037	1.031
2	0.087	2.460
3	0.429	12.067
4	4.528	144.559
5	1.852	52.076
6	0.254	14.111
7	0.906	25.488
8	0.887	28.329
Totals	8.981	280.120
	Census Division 5	
1	0.016	0.845
2	0.035	1.893
3	0.072	3.876
4	1.437	87.357
5	1.003	54.120
6	0.288	29.906
7	0.351	18.936
8	0.584	35.518
Totals	3.785	232.450
	Census Division 6	
1	0.093	2.663
2	0.033	0.952
3	0.238	6.779
4	2.391	77.242
5	0.759	21.624
6	0.175	10.338
7	0.290	8.275
8	0.424	13.712
Totals	4.405	141.586
	Census Division 7	
1	0.052	3.194
2	0.068	4.184
3	0.246	15.082
4	2.703	185.946
5	1.217	74.475
6	0.757	93.525
7	0.661	40.441
8	0.803	55.210
Totals	6.508	472.057
	Census Division 8	
1	0.046	0.936
2	0.035	0.724
3	0.110	2.262
4	2.389	55.377
5	0.993	20.377
6	0.062	2.603
7	0.281	5.757
8	0.529	12.266
Totals	4.444	100.303
	Census Division 9	
1	0.074	1.130
2	0.060	0.906
3	0.168	2.550
4	3.487	60.965
5	4.423	67.235
6	0.727	24.867
7	1.104	16.778
8	1.376	24.055
Totals	11.418	198.486
	U. S. Totals	
1	0.531	15.430
2	0.558	19.646
3	2.096	66.466
4	26.930	975.354
5	17.763	585.766
6	3.309	264.723
7	6.059	196.175
8	8.154	327.666
Totals	65.400	2451.225

TABLE A.19

Fuel Type: Gas

Appliance Type: Water Heater (Coil and Storage)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.077	50.793
2	0.065	43.174
3	0.042	27.936
4	12.054	7982.155
5	1.711	1132.689
6	0.591	549.055
7	0.219	111.354
8	0.330	218.411
Totals	15.088	10115.568
	Census Division 2	
1	0.180	119.364
2	0.288	190.475
3	0.353	233.649
4	32.190	21315.375
5	9.558	6328.835
6	13.707	12742.359
7	23.418	11928.593
8	10.616	7029.782
Totals	90.310	59888.432
	Census Division 3	
1	0.134	88.888
2	0.376	248.887
3	1.013	670.471
4	27.238	18036.673
5	31.078	20578.874
6	20.089	18675.007
7	14.586	7429.485
8	10.754	7121.210
Totals	105.268	72849.494
	Census Division 4	
1	0.548	363.172
2	0.660	436.822
3	0.798	528.250
4	46.170	30572.440
5	40.225	26635.965
6	21.823	20286.520
7	42.350	21571.490
8	15.506	10267.849
Totals	168.079	110662.507
	Census Division 5	
1	0.084	55.873
2	0.119	78.729
3	0.387	256.506
4	9.496	6288.201
5	12.937	8566.277
6	12.442	11565.812
7	13.109	6677.355
8	6.374	4220.917
Totals	54.949	37709.668
	Census Division 6	
1	0.261	172.697
2	0.349	231.109
3	0.330	218.411
4	21.163	14013.850
5	17.723	11735.774
6	17.700	16453.829
7	27.564	14040.418
8	10.850	7184.701
Totals	95.940	64050.789
	Census Division 7	
1	0.372	246.347
2	0.529	350.473
3	0.729	482.536
4	22.057	14605.591
5	24.818	16434.146
6	11.970	11127.281
7	28.331	14431.136
8	18.417	12195.452
Totals	107.224	69872.962
	Census Division 8	
1	0.288	190.475
2	0.230	152.380
3	0.311	205.713
4	10.290	6813.911
5	13.163	8716.117
6	5.876	5462.030
7	14.705	7490.047
8	9.542	6318.677
Totals	54.404	35349.347
	Census Division 9	
1	0.407	269.204
2	0.245	162.538
3	0.736	487.615
4	32.336	21411.882
5	35.626	23590.911
6	11.410	10606.748
7	19.284	9822.627
8	14.394	9531.348
Totals	114.438	75882.874
	U. S. Totals	
1	2.351	1556.812
2	2.861	1894.587
3	4.698	3111.085
4	212.994	141040.076
5	186.837	123719.588
6	115.608	107468.639
7	183.566	93502.507
8	96.784	64088.347
Totals	805.700	536381.641

TABLE A.20

Fuel Type: Oil

Appliance Type: Water Heater (Storage)

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 1	
1	0.103	80.640
2	0.074	58.004
3	0.149	116.008
4	1.210	943.624
5	5.953	4643.141
6	6.406	7014.771
7	9.896	5937.509
8	4.776	3724.982
Totals	28.567	22518.678
	Census Division 2	
1	0.288	224.942
2	0.225	175.426
3	0.473	369.244
4	2.581	2013.159
5	12.821	10000.720
6	6.896	7551.007
7	17.918	10750.853
8	9.930	7745.642
Totals	51.133	38830.993
	Census Division 3	
1	0.060	46.686
2	0.078	60.833
3	0.294	229.186
4	0.205	159.864
5	9.014	7031.203
6	9.136	10003.794
7	9.582	5749.241
8	10.054	7841.843
Totals	38.423	31122.652
	Census Division 4	
1	0.069	53.760
2	0.040	31.124
3	0.054	42.442
4	0.816	636.628
5	2.775	2164.535
6	2.323	2544.145
7	5.485	3290.877
8	2.365	1844.807
Totals	13.928	10608.319
	Census Division 5	
1	0.002	1.415
2	0.007	5.659
3	0.033	25.465
4	0.102	79.225
5	1.086	847.423
6	0.533	583.902
7	0.230	138.208
8	0.187	145.717
Totals	2.180	1827.014

Subsector	Inventory K-Units	Energy Consumption Billions Btu
	Census Division 6	
1	0.016	12.733
2	0.016	12.733
3	0.020	15.562
4	0.296	230.601
5	4.195	3272.268
6	1.473	1612.682
7	1.571	942.427
8	0.898	700.291
Totals	8.485	6799.297
	Census Division 7	
1	0.009	7.074
2	0.016	12.733
3	0.042	32.539
4	0.290	226.357
5	1.391	1085.097
6	0.069	75.470
7	0.093	55.501
8	0.180	140.058
Totals	2.089	1634.828
	Census Division 8	
1	0.005	4.244
2	0.005	4.244
3	0.011	8.488
4	0.085	66.492
5	0.435	339.535
6	0.156	170.801
7	0.225	134.943
8	0.448	349.438
Totals	1.371	1078.187
	Census Division 9	
1	0.018	14.147
2	0.011	8.488
3	0.029	22.636
4	0.136	106.105
5	1.435	1119.051
6	1.975	2162.821
7	2.568	1540.966
8	3.355	2617.249
Totals	9.528	7591.463
	U. S. Totals	
1	0.571	445.640
2	0.473	369.244
3	1.105	861.570
4	5.721	4462.055
5	39.106	30502.973
6	28.967	31719.396
7	47.568	28540.526
8	32.192	25110.026
Totals	155.704	122011.430

Thermo Electron CORPORATION

APPENDIX B

METHODOLOGY TO DETERMINE APPLIANCE REPLACEMENT RATE

In the absence of explicit appliance replacement rate data, it was necessary to estimate these rates based on available annual shipping information and knowledge of the average useful life. The following methodology was used to determine replacement rates of all appliances included in this study, except those in the cooking functional-use category. Values for cooking appliances were obtained from a national study of the food service industry, which was sponsored by the marketing research firm of Frost and Sullivan. Data from an independent source, which estimated replacement rates in a western state, tend to verify these high replacement levels (>50 percent). The replacement rate in this report is defined as the percentage of annual sales that is used to replace wornout equipment.

As an example, the replacement rate of year-round unitary air conditioners was calculated to demonstrate the methodology employed to estimate the replacement rate. Figure B. 1 plots the annual shipment data (both actual and interpolated) for the type of air conditioner and a prescribed size. Based on manufacturers' estimates, the appliance useful life or range of useful life is established. The replacement rate (RR) of an appliance can then be calculated from the ratio:

$$RR = \frac{A_i}{A_p} \times 100$$

where

A_i = units shipped in year i

i = prescribed year minus useful life

p = units shipped in prescribed year

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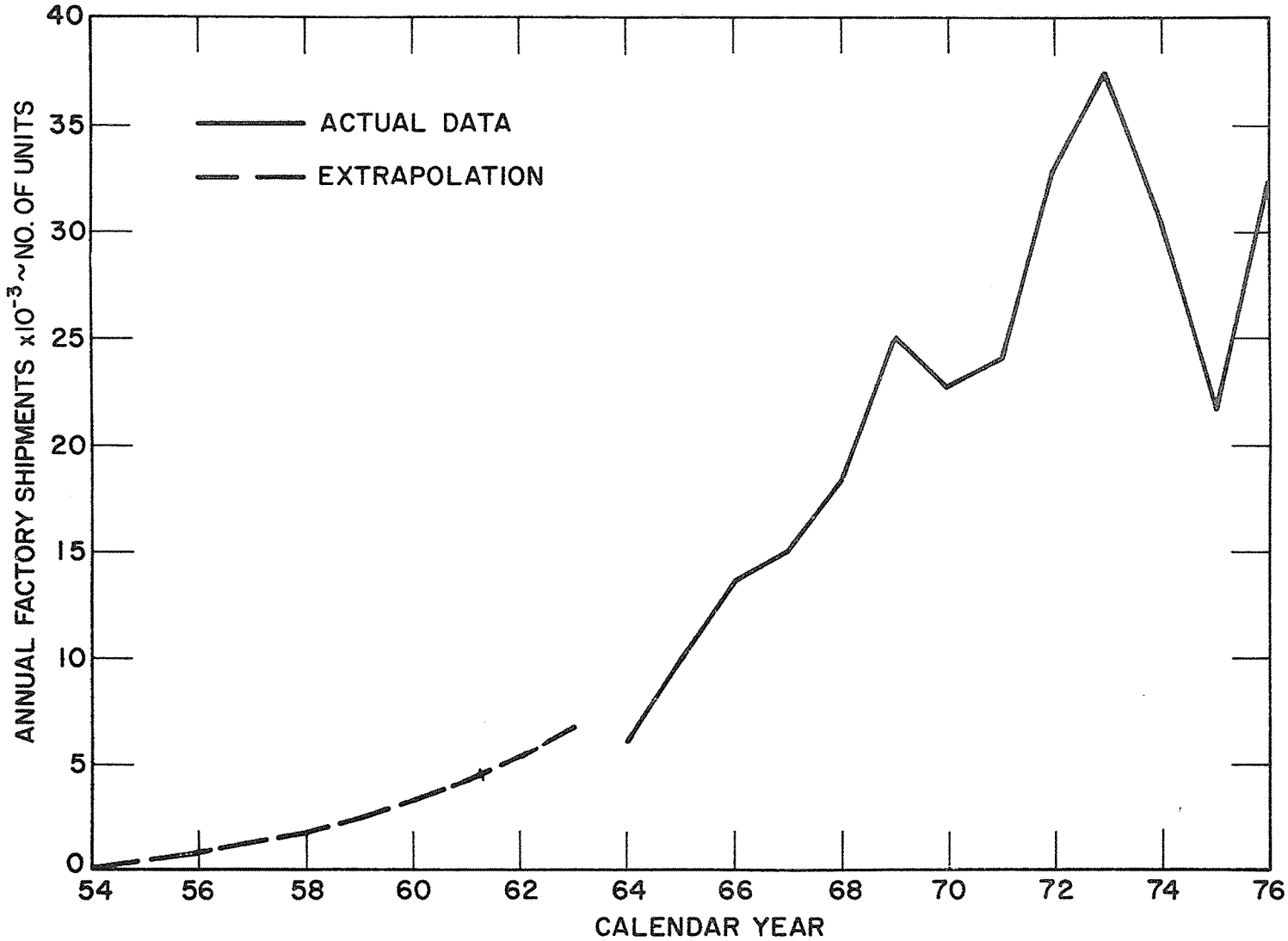

Figure B. 1 Appliance: Air Conditioner (Year-Round Type)
(Cooling Capacity Range: 54-65 K-Btu/Hour)

Inspection of the actual shipment data indicates that this ratio is very sensitive to the prescribed year and useful life selected. To reduce the effect of a prescribed year selection, the average annual shipment of the past 3 years was used in the above relationship. Table B.1 shows the appropriate numbers for three different values of average useful life (10, 12, and 15 years) resulting in a calculated annual replacement rate of 37, 21.4, and 13 percent, respectively.

A detailed report on year-round air conditioners, performed by the marketing research form of William E. Hill, lists the estimated failure rate of this equipment; see Table B. 2. Using this failure rate and the known shipment information, we calculated the replacement rate; see Table B. 3. Comparison of these replacement rate values with those of Table B. 1 shows that the listed values for a 10-year useful life closely approach these values. Hence, it is presumed that this methodology will produce a close approximation of the actual replacement rate, once the average useful life is known. However, to truly reflect the actual replacement rate, a failure rate table or curve must be used for each appliance. Because this type of information was not available, the preceding methodology was used to obtain the replacement rate for a range of average useful lives. The final replacement rate value was then taken to be the average of the two values. The new installation rate is presumed to be equal to 1 - RR. This assumes that the units replaced are within the same category (e. g., cast iron boilers replace cast iron boilers rather than warm air furnaces).

It should be noted that the method described here accounts for the replacement of equipment that is worn out only. Replacement of equipment due to obsolescence or its inability to fulfill newer requirements is not accounted for.

Thermo Electron CORPORATION

TABLE B. 1

ESTIMATE OF APPLIANCE REPLACEMENT RATE

Fuel Type: Electric
Appliance Type: Year Round
Functional Use: Air Conditioning
Useful Life (years): 15

A-1499

Appliance Size	Annual No. Units Ship. 1974-1976	Annual No. of Units Replaced for Useful Life			% Replacement for Useful Life		
		10 yrs.	12 yrs.	15 yrs.	10 yrs.	12 yrs.	15 yrs.
K-Btu/Hour (Input or Output)							
54 - 65.0 (0)	28,100	9,870	6,000	3,400	35.1	21.4	12.1
65.0 - 97	11,900	3,875	2,550	1,500	32.6	21.4	12.6
97 - 135	9,500	3,805	2,200	1,050	40.1	23.2	11.1
135 - 185	5,500	2,520	1,370	720	45.8	24.9	13.1
185 - 250	2,770	761	520	260	27.5	18.8	9.4
250 - 320	2,700	270	*	*	10.0	-	-
320 - 640	3,670	300	*	*	8.2	-	-
Total	64,140	21,400	12,640	6,930	37.0	21.9	13.0

*Estimated number of units shipped was not significant.

Thermo Electron CORPORATION

A-1500

TABLE B.2

ESTIMATED REPLACEMENT SCHEDULE*
YEAR-ROUND UNITARY AIR CONDITIONERS

Age (Years)	Percent of Units Replaced
1-5	2
6	6
7	6
8	6
9	6
10	11
11	12
12	11
13	10
14	10
15	10
16	10

*Source: William E. Hill and Co., Inc. report on Gas-Fired Heat Pump performed under ERDA Contract No. E4-76-C-02-2883.000.

Thermo Electron CORPORATION

TABLE B.3

ESTIMATE OF APPLIANCE REPLACEMENT RATE*

Fuel Type: Electricity
Appliance Type: Year Round
Functional Use: Air Conditioning

A-1501

Appliance Size	Annual No. of Units Shipped 1974-1976	Annual No. of Units Replaced	% Replacement Rate
K-Btu/hr (Input or Output)			
54 - 65 (0)	28,100	10,020	35.6
65 - 97	11,900	4,440	37.3
97 - 135	9,500	4,050	42.6
135 - 185	5,500	2,560	46.5
185 - 250	2,770	900	32.3
250 - 320	2,700	380	14.0
320 - 640	3,670	330	9.0
Total	64,140	22,680	35.4

*Based on William E. Hill and Co., Inc. replacement-age distribution.

Thermo Electron CORPORATION

APPENDIX C

COMPUTER PROGRAM
MARKET PENETRATION AND PREDICTED ENERGY SAVINGS

A computer program shown in Table C. 1 was written to assist in the computational process of predicting the market penetration and future energy savings of a development opportunity as discussed in Chapter 9. Table C.2 presents the output or results of the computer program. The format titles on these output tables correspond to the following definitions:

TEC90	- Projected appliance energy consumption in the year 1990 for conventional appliances.
BNT(LTF)	- The number of energy-saving appliances to be sold in 1990 if no DOE support is given.
ANT (LTFS)	- The number of energy-saving appliances to be sold in 1990 if DOE support is given.
ES	- The energy savings in 1990 for a nonsupported appliance development.
ESS	- The energy savings in 1990 for a DOE-supported appliance development.
ESA	- The cumulative energy savings from 1980 to 1990 for a nonsupported appliance development.
ESAS	- The cumulative energy savings from 1980 to 1990 for a DOE-supported appliance development.
DES	- The difference in cumulative energy savings for an appliance development that has DOE support and one that does not have DOE support.
APN	- The number of the appliance being studied corresponding to the numbers listed in Table 9.3.

A-2769

TABLE C.1

```
JHPR          13:56EDT     08/18/78

8 DIMENSION BMP(20),BNN(20),BNR(20),BNT(20),BNTA(20)
9 DIMENSION BMPS(20),BNNS(20),BNRS(20),ANTS(20),ANTSA(20)
10 OPEN FILE "JHDFA"
20 REWIND "JHDFA"
30 55 READ ("JHDFA",1) AS,GR,AI80,EC90,CP,PB,UES,DTS,DT,R
40 1 FORMAT (V)
50 HL=(12.0*PB/(PB+1.))-2.0
60 A=1.678/HL
70 TOS=1978.+DTS
80 TO=1978.+DT
90 LTFS=1990.-TOS
100 LTF=1990.-TO
105 ANTSA(1)=0.0
110 DO 2 I=1,LTFS
120 BMPS(I)=(1-0.7*PB*CP)*(1.-(EXP(-A*I))*(1.+A*I))
130 BNNS(I)=AS*1000.*BMPS(I)*(1.+(I+5.)*GR)
140 BNRS(I)=AI80*1000.*0.15*BMPS(I)
150 ANTS(I)=BNNS(I)+BNRS(I)
160 ANTSA(I+1.)=ANTSA(I)+ANTS(I)
165 2 CONTINUE
170 ESS=UES*(10.**6.0)*ANTS(LTFS)
180 ESAS=UES*(10.**6.0)*ANTSA(LTFS+1.)
190 BNTA(1)=0.0
200 DO 3 J=1,LTF
210 BMP(J)=(1.-0.7*PB*CP)*(1.-(EXP(-A*J))*(1.+A*J))
220 BNN(J)=AS*1000.*BMP(J)*(1.+(J+5.)*GR)
230 BNR(J)=AI80*1000.*0.15*BMP(J)
240 BNT(J)=BNN(J)+BNR(J)
250 BNTA(J+1.)=BNTA(J)+BNT(J)
255 3 CONTINUE
260 ES=UES*(10.**6.0)*BNT(LTF)
270 ESA=UES*(10.**6.0)*BNTA(LTF+1.)
280 DES=ESAS-ESA
290 TEC90=EC90*(10.**12.)
300 PRINT 10,TEC90,BNT(LTF),ANTS(LTFS),ES,ESS,ESA,ESAS,DES
310 10 FORMAT(8E10.2,//)
320 GO TO 55
330 90 STOP
350 END
```

TABLE C.2

APN	TEC 90	(BNT)LFT	ANT(LTFS)	ES	ESS	ESA	ESAS	DES
	0.61E+15	0.55E+05	0.79E+05	0.84E+13	0.12E+14	0.24E+14	0.68E+14	0.44E+14
	0.61E+15	0.30E+04	0.17E+05	0.52E+12	0.30E+13	0.68E+12	0.11E+14	0.10E+14
	0.61E+15	0.48E+05	0.74E+05	0.44E+13	0.67E+13	0.12E+14	0.36E+14	0.24E+14
	0.61E+15	0.60E+05	0.75E+05	0.67E+13	0.46E+13	0.14E+14	0.27E+14	0.13E+14
1	0.61E+15	0.81E+05	0.94E+05	0.11E+14	0.11E+14	0.41E+14	0.85E+14	0.44E+14
	0.61E+15	0.94E+05	0.95E+05	0.67E+13	0.68E+13	0.13E+14	0.47E+14	0.34E+14
	0.61E+15	0.53E+05	0.76E+05	0.91E+13	0.13E+14	0.26E+14	0.73E+14	0.48E+14
	0.61E+15	0.54E+05	0.70E+05	0.38E+13	0.49E+13	0.15E+14	0.28E+14	0.14E+14
	0.61E+15	0.50E+05	0.66E+05	0.20E+13	0.27E+13	0.72E+13	0.15E+14	0.74E+13
	0.33E+15	0.25E+06	0.29E+06	0.43E+13	0.50E+13	0.14E+14	0.33E+14	0.19E+14
	0.33E+15	0.25E+06	0.28E+06	0.33E+13	0.37E+13	0.14E+14	0.25E+14	0.11E+14
2	0.33E+15	0.23E+06	0.27E+06	0.18E+13	0.21E+13	0.72E+13	0.13E+14	0.60E+13
	0.33E+15	0.27E+06	0.29E+06	0.30E+13	0.33E+13	0.14E+14	0.23E+14	0.98E+13
	0.33E+15	0.30E+06	0.31E+06	0.40E+13	0.41E+13	0.77E+13	0.28E+14	0.20E+14
	0.33E+15	0.26E+06	0.29E+06	0.85E+13	0.95E+13	0.29E+14	0.66E+14	0.37E+14
	0.18E+15	0.92E+05	0.97E+05	0.26E+13	0.27E+13	0.93E+13	0.20E+14	0.11E+14
	0.18E+15	0.92E+05	0.96E+05	0.20E+13	0.21E+13	0.97E+13	0.16E+14	0.62E+13
	0.18E+15	0.88E+05	0.95E+05	0.11E+13	0.12E+13	0.49E+13	0.84E+13	0.35E+13
3	0.18E+15	0.95E+05	0.98E+05	0.18E+13	0.18E+13	0.92E+13	0.15E+14	0.54E+13
	0.18E+15	0.98E+05	0.10E+06	0.21E+13	0.22E+13	0.41E+13	0.15E+14	0.11E+14
	0.18E+15	0.95E+05	0.97E+05	0.50E+13	0.51E+13	0.21E+14	0.41E+14	0.20E+14
	0.17E+15	0.94E+04	0.44E+05	0.47E+12	0.22E+13	0.61E+12	0.85E+13	0.79E+13
	0.17E+15	0.72E+04	0.43E+05	0.36E+12	0.22E+13	0.46E+12	0.76E+13	0.7 E+13
	0.17E+15	0.23E+05	0.43E+05	0.48E+12	0.89E+12	0.12E+13	0.42E+13	0.30E+13
4	0.17E+15	0.76E+05	0.91E+05	0.20E+13	0.24E+13	0.64E+13	0.16E+14	0.92E+13
	0.17E+15	0.78E+05	0.89E+05	0.16E+13	0.18E+13	0.69E+13	0.12E+14	0.53E+13
	0.17E+15	0.72E+05	0.86E+05	0.84E+12	0.10E+13	0.34E+13	0.63E+13	0.29E+13
	0.17E+15	0.82E+05	0.92E+05	0.15E+13	0.16E+13	0.65E+13	0.11E+14	0.47E+13

TABLE C.2 (continued)

APN	TEC 90	BNT(LFT)	ANT(LTFS)	ES	ESS	ESA	ESAS	DES
	0.17E+15	0.14E+05	0.26E+05	0.54E+12	0.98E+12	0.14E+13	0.47E+13	0.33E+13
4	0.17E+15	0.91E+05	0.95E+05	0.19E+13	0.20E+13	0.36E+13	0.13E+14	0.96E+13
	0.17E+15	0.80E+05	0.91E+05	0.40E+13	0.46E+13	0.13E+14	0.31E+14	0.19E+14
	0.12E+15	0.23E+04	0.23E+04	0.29E+13	0.29E+13	0.14E+14	0.26E+14	0.12E+14
	0.12E+15	0.14E+04	0.21E+04	0.20E+13	0.30E+13	0.30E+13	0.17E+14	0.14E+14
	0.12E+15	0.23E+04	0.24E+04	0.17E+13	0.17E+13	0.84E+13	0.15E+14	0.70E+13
	0.12E+15	0.23E+04	0.24E+04	0.12E+13	0.12E+13	0.75E+13	0.11E+14	0.35E+13
5	0.12E+15	0.14E+04	0.18E+04	0.15E+13	0.19E+13	0.47E+13	0.12E+14	0.73E+13
	0.12E+15	0.23E+04	0.24E+04	0.13E+13	0.14E+13	0.26E+13	0.94E+13	0.68E+13
	0.12E+15	0.23E+04	0.23E+04	0.32E+13	0.33E+13	0.16E+14	0.29E+14	0.13E+14
	0.12E+15	0.23E+04	0.24E+04	0.13E+13	0.14E+13	0.87E+13	0.13E+14	0.41E+13
	0.12E+15	0.23E+04	0.24E+04	0.77E+12	0.78E+12	0.44E+13	0.67E+13	0.23E+13
	0.71E+15	0.59E+05	0.87E+05	0.60E+13	0.68E+13	0.17E+14	0.49E+14	0.32E+14
	0.71E+15	0.92E+04	0.18E+05	0.13E+13	0.26E+13	34E+13	0.12E+14	0.68E+13
6	0.71E+15	0.10E+06	0.10E+06	0.80E+13	0.82E+13	0.15E+14	0.58E+14	0.41E+14
	0.71E+15	0.66E+05	0.83E+05	0.52E+13	0.65E+13	0.20E+14	0.39E+14	0.18E+14
	0.71E+15	0.61E+05	0.79E+05	0.28E+13	0.36E+13	0.10E+14	0.20E+14	0.19E+14
	0.71E+15	0.23E+05	0.44E+05	0.19E+13	0.35E+13	0.47E+13	0.16E+14	0.12E+14
	0.62E+15	0.10E+06	0.15E+06	0.52E+13	0.78E+13	0.14E+14	0.42E+14	[illegible]9E+14
	0.62E+15	0.17E+05	0.32E+05	0.12E+13	0.24E+13	0.31E+13	0.11E+14	[illegible]79E+13
	0.62E+15	0.18E+06	0.19E+06	0.75E+13	0.77E+13	0.14E+14	0.52E+14	0.38E+14
7	0.62E+15	0.11E+06	0.14E+06	0.45E+13	0.58E+13	0.17E+14	0.33E+14	0.16E+14
	0.62E+15	0.10E+06	0.14E+06	0.24E+13	0.31E+13	0.88E+13	0.19E+14	0.87E+13
	0.62E+15	0.20E+05	0.40E+05	0.83E+12	0.16E+13	0.21E+13	0.75E+13	0.54E+13
	0.62E+15	0.28E+05	0.55E+05	0.11E+13	0.22E+13	0.29E+13	0.10E+14	0.74E+13
	0.40E+15	0.74E+04	0.75E+04	0.63E+13	0.64E+13	0.31E+14	0.56E+14	0.25E+14
8	0.40E+15	0.40E+04	0.53E+04	0.45E+13	0.59E+13	0.13E+14	0.35E+14	0.22E+14
	0.40E+15	0.75E+04	0.76E+04	0.45E+13	0.45E+13	0.86E+13	0.31E+14	0.23E+14

TABLE C.2 (continued)

APN	TEC 90	BNT(LFT)	ANT(LTFS)	ES	ESS	ESA	ESAS	DES
	0.40E+15	0.74E+04	0.75E+04	0.44E+13	0.45E+13	0.29E+14	0.42E+14	0.13E+14
8	0.40E+15	0.74E+04	0.75E+04	0.25E+13	0.26E+13	0.15E+14	0.22E+14	0.76E+13
	0.40E+15	0.53E+04	0.66E+04	0.32E+13	0.40E+13	0.96E+13	0.25E+14	0.15E+14
	0.34E+14	0.95E+04	0.17E+05	0.21E+12	0.38E+12	0.56E+12	0.18E+13	0.13E+13
	0.34E+14	0.24E+05	0.25E+05	0.41E+12	0.43E+12	0.79E+12	0.29E+13	0.21E+13
9	0.34E+14	0.12E+05	0.16E+05	0.21E+12	0.29E+12	0.76E+12	0.15E+13	0.79E+12
	0.34E+14	0.11E+05	0.16E+05	0.11E+12	0.16E+12	0.40E+12	0.83E+12	0.43E+12
	0.34E+14	0.29E+04	0.58E+04	0.50E+11	0.10E+12	0.12E+12	0.46E+12	0.33E+12
	0.22E+14	0.66E+05	0.95E+05	0.86E+11	0.12E+12	0.30E+12	0.63E+12	0.33E+12
11	0.22E+14	0.62E+05	0.89E+05	0.24E+12	0.35E+12	0.84E+12	0.18E+13	0.94E+12
	0.22E+14	0.92E+05	0.11E+06	0.20E+12	0.25E+12	0.38E+12	0.15E+13	0.11E+13
	0.22E+14	0.92E+05	0.11E+06	0.36E+12	0.44E+12	0.68E+12	0.27E+13	0.20E+13
	0.53E+14	0.96E+04	0.15E+05	0.16E+12	0.24E+12	0.52E+12	0.12E+13	0.64E+12
13	0.53E+14	0.83E+03	0.13E+04	0.13E+11	0.21E+11	0.44E+11	0.10E+12	0.55E+11
	0.53E+14	0.83E+03	0.13E+04	0.13E+11	0.21E+11	0.44E+11	0.10E+12	0.55E+11
	0.53E+14	0.12E+05	0.18E+05	0.10E+12	0.16E+12	0.34E+12	0.77E+12	0.43E+12
	0.35E+13	0.11E+03	0.17E+03	0.61E+10	0.93E+10	0.20E+11	0.45E+11	0.25E+11
14	0.35E+13	-0.77E+02	-0.12E+03	-0.41E+10	-0.62E+10	-0.14E+11	-0.30E+11	-0.17E+11
	0.35E+13	-0.77E+02	-0.12E+03	-0.41E+10	-0.62E+10	-0.14E+11	-0.30E+11	-0.17E+11
	0.35E+13	0.17E+03	0.27E+03	0.52E+10	0.79E+10	0.17E+11	0.38E+11	0.21E+11
	0.65E+14	0.88E+03	0.12E+04	0.42E+12	0.59E+12	0.15E+13	0.31E+13	0.16E+13
15	0.65E+14	0.70E+03	0.10E+04	0.33E+12	0.48E+12	0.12E+13	0.25E+13	0.13E+13
	0.65E+14	0.70E+03	0.10E+04	0.33E+12	0.48E+12	0.12E+13	0.25E+13	0.13E+13
	0.65E+14	0.86E+03	0.12E+04	0.23E+12	0.33E+12	0.80E+12	0.17E+13	0.89E+12
	0.75E+14	0.13E+06	0.17E+06	0.25E+13	0.33E+13	0.96E+13	0.19E+14	0.92E+13
16	0.75E+14	0.18E+06	0.23E+06	0.42E+12	0.52E+12	0.16E+13	0.31E+13	0.15E+13
	0.75E+14	0.15E+06	0.20E+06	0.77E+12	0.10E+13	0.29E+13	0.57E+13	0.28E+13
	0.75E+14	0.12E+06	0.17E+06	0.64E+12	0.88E+12	0.23E+13	0.47E+13	0.24E+13

A-2770d

TABLE C.2 (continued)

APN	TEC 90	BNT(LFT)	ANT(LTFS)	ES	ESS	ESA	ESAS	DES
16	0.75E+14	0.14E+06	0.19E+06	0.40E+12	0.55E+12	0.15E+13	0.30E+13	0.15E+13
	0.16E+15	0.40E+06	0.47E+06	0.65E+13	0.76E+13	0.27E+14	0.49E+14	0.22E+14
	0.16E+15	0.51E+06	0.57E+06	0.97E+12	0.11E+13	0.43E+13	0.75E+13	0.32E+13
17	0.16E+15	0.43E+06	0.52E+06	0.19E+13	0.23E+13	0.77E+13	0.14E+14	0.66E+13
	0.16E+15	0.37E+06	0.47E+06	0.16E+13	0.21E+13	0.61E+13	0.12E+14	0.58E+13
	0.16E+15	0.24E+06	0.30E+06	0.58E+12	0.73E+12	0.22E+13	0.43E+13	0.21E+13
	0.93E+14	0.15E+06	0.19E+06	0.29E+13	0.37E+13	0.11E+14	0.21E+14	0.1[illegible]E+14
	0.93E+14	0.22E+06	0.27E+06	0.50E+12	0.62E+12	0.20E+13	0.37E+13	0.17E+13
18	0.93E+14	0.18E+06	0.23E+06	0.92E+12	0.12E+13	0.34E+13	0.68E+13	0.34E+13
	0.93E+14	0.14E+06	0.20E+06	0.74E+12	0.16E+13	0.26E+13	0.54E+13	0.28E+13
	0.93E+14	0.16E+06	0.22E+06	0.47E+12	0.64E+12	0.17E+13	0.35E+13	0.18E+13
	0.13E+14	0.33E+05	0.47E+05	0.41E+12	0.58E+12	0.14E+13	0.30E+13	0.16E+13
	0.13E+14	0.51E+05	0.71E+05	0.77E+11	0.11E+12	0.28E+12	0.57E+12	0.29E+12
19	0.13E+14	0.42E+05	0.60E+05	0.14E+12	0.21E+12	0.50E+12	0.11E+13	0.56E+12
	0.13E+14	0.33E+05	0.50E+05	0.11E+12	0.1[illegible]E+12	0.38E+12	0.84E+12	0.45E+12
	0.13E+14	0.39E+05	0.58E+05	0.75E+11	0.11E+12	0.26E+12	0.55E+12	0.30E+12
	0.58E+14	0.91E+04	0.98E+04	0.27E+13	0.30E+13	0.13E+14	0.22E+14	0.87E+13
	0.58E+14	0.10E+05	0.11E+05	0.38E+12	0.40E+12	0.20E+13	0.31E+13	0.12E+13
20	0.58E+14	0.99E+04	0.11E+05	0.81E+12	0.87E+12	0.38E+13	0.64E+13	0.26E+13
	0.58E+14	0.88E+04	0.10E+05	0.72E+12	0.83E+12	0.31E+13	0.55E+13	0.24E+13
	0.58E+14	0.90E+04	0.10E+05	0.74E+12	0.85E+12	0.32E+13	0.56E+13	0.25E+13
	0.36E+14	0.20E+05	0.24E+05	0.16E+13	0.18E+13	0.66E+13	0.12E+14	0.53E+13
	0.36E+14	0.24E+05	0.28E+05	0.23E+12	0.26E+12	0.10E+13	0.17E+13	0.75E+12
21	0.36E+14	0.21E+05	0.26E+05	0.45E+12	0.54E+12	0.18E+13	0.34E+13	0.15E+13
	0.36E+14	0.18E+05	0.23E+05	0.38E+12	0.49E+12	0.15E+13	0.28E+13	0.14E+13
	0.36E+14	0.20E+05	0.25E+05	0.23E+12	0.29E+12	0.90E+12	0.17E+13	0.82E+12
	0.77E+15	0.22E+06	0.23E+06	0.19E+14	0.20E+14	0.38E+14	0.14E+15	0.99E+14
22	0.77E+15	0.45E+05	0.17E+06	0.39E+13	0.15E+14	0.52E+13	0.61E+14	0.56E+14
	0.77E+15	0.39E+04	0.22E+05	0.44E+12	0.25E+13	0.57E+12	0.90E+13	0.84E+13

TABLE C.2 (continued)

APN	TEC 90	BNT(LFT)	ANT(LTFS)	ES	ESS	ESA	ESAS	DES
	0.77E+15	-0.17E+05	-0.11E+06	-0.77E+12	-0.52E+13	-0.99E+12	-0.18E+14	-0.17E+14
	0.77E+15	0.14E+05	0.28E+05	0.67E+12	0.13E+13	0.17E+13	0.60E+13	0.43E+13
	0.77E+15	0.22E+06	0.23E+06	0.73E+13	0.78E+13	0.35E+14	0.58E+14	0.23E+14
22	0.77E+15	0.12E+06	0.16E+06	0.15E+13	0.21E+13	0.56E+13	0.11E+14	0.58E+13
	0.77E+15	0.12E+06	0.16E+06	0.15E+13	0.21E+13	0.56E+13	0.11E+14	0.58E+13
	0.77E+15	0.58E+05	0.10E+06	0.35E+13	0.63E+13	0.90E+13	0.30E+14	0.21E+14
	0.77E+15	0.20E+06	0.23E+06	0.23E+14	0.25E+14	0.77E+14	0.18E+15	0.99E+14
	0.77E+15	0.23E+06	0.23E+06	0.14E+14	0.14E+14	0.71E+14	0.11E+15	0.42E+14
	0.20E+15	0.28E+15	0.33E+37	0.28E+23	0.17E+39	0.28E+23	0.17E+39	0.17E+39
	0.20E+15	-0.20E+04	-0.13E+05	-0.11E+12	-0.70E+12	-0.14E+12	-0.24E+13	-0.23E+13
	0.20E+15	0.48E+04	0.90E+04	0.26E+12	0.50E+12	0.67E+12	0.23E+13	0.17E+13
23	0.20E+15	0.38E+05	0.39E+05	0.15E+13	0.15E+13	0.78E+13	0.12E+14	0.45E+13
	0.20E+15	0.22E+05	0.29E+05	0.35E+12	0.46E+12	0.13E+13	0.26E+13	0.13E+13
	0.20E+15	0.13E+05	0.22E+05	0.90E+12	0.15E+13	0.24E+13	0.77E+13	0.53E+13
	0.20E+15	0.38E+05	0.39E+05	0.27E+13	0.27E+13	0.15E+14	0.24E+14	0.82E+13
	0.20E+15	0.48E+04	0.22E+05	0.26E+12	0.12E+13	0.34E+12	0.47E+13	0.44E+13
	0.15E+15	0.31E+05	0.39E+05	0.62E+13	0.79E+13	0.19E+14	0.49E+14	0.30E+14
24	0.15E+15	0.13E+04	0.75E+04	0.35E+11	0.21E+12	0.45E+11	0.75E+12	0.70E+12
	0.15E+15	0.48E+05	0.63E+05	0.18E+12	0.25E+12	0.66E+12	0.14E+13	0.69E+12
	0.61E+14	0.20E+06	0.29E+06	0.16E+12	0.23E+12	0.56E+12	0.12E+13	0.63E+12
	0.61E+14	0.12E+06	0.19E+06	0.22E+12	0.33E+12	0.76E+12	0.17E+13	0.90E+12
27	0.61E+14	0.27E+06	0.36E+06	0.12E+13	0.16E+13	0.43E+13	0.87E+13	0.43E+13
	0.61E+14	0.15E+05	0.22E+05	0.12E+12	0.17E+12	0.40E+12	0.85E+12	0.46E+12
	0.61E+14	0.78E+05	0.49E+05	0.16E+12	0.99E+11	0.88E+12	0.34E+12	-0.54E+12
28	0.58E+13	-0.20E+05	-0.31E+05	-0.24E+11	-0.38E+11	-0.80E+11	-0.18E+12	-0.10E+12
	0.58E+13	0.72E+03	0.11E+04	0.36E+09	0.56E+09	0.12E+10	0.27E+10	0.15E+10

TABLE C.2 (continued)

APN	TEC 90	BNT(LFT)	ANT(LTFS)	ES	ESS	ESA	ESAS	DES
28	0.58E+13	0.31E+05	0.44E+05	0.13E+12	0.19E+12	0.47E+12	0.98E+12	0.51E+12
	0.31E+14	0.14E+05	0.21E+05	0.35E+11	0.54E+11	0.12E+12	0.26E+12	0.14E+12
	0.31E+14	-0.82E+04	-0.13E+05	-0.73E+11	-0.11E+12	-0.25E+12	-0.54E+12	-0.30E+12
29	0.31E+14	0.61E+04	0.94E+04	0.23E+11	0.36E+11	0.78E+11	0.17E+12	0.95E+11
	0.31E+14	0.23E+05	0.31E+05	0.71E+12	0.96E+12	0.26E+13	0.52E+13	0.26E+13
	0.31E+14	0.16E+05	0.29E+05	0.24E+12	0.44E+12	0.63E+12	0.21E+13	0.15E+13
	0.31E+14	0.46E+05	0.47E+05	0.10E+13	0.10E+13	0.68E+13	0.98E+13	0.31E+13
	0.19E+14	0.22E+05	0.33E+05	0.39E+11	0.59E+11	0.13E+12	0.29E+12	0.16E+12
	0.19E+14	0.62E+04	0.95E+04	0.39E+11	0.60E+11	0.13E+12	0.29E+12	0.16E+12
30	0.19E+14	0.16E+05	0.24E+05	0.43E+11	0.66E+11	0.15E+12	0.32E+12	0.18E+12
	0.19E+14	0.41E+05	0.49E+05	0.89E+12	0.11E+13	0.36E+13	0.66E+13	0.31E+13
	0.19E+14	0.54E+05	0.57E+05	0.83E+12	0.87E+12	0.55E+13	0.81E+13	0.26E+13
	0.19E+14	0.69E+04	0.10E+05	0.88E+11	0.13E+12	0.30E+12	0.65E+12	0.35E+12
	0.68E+14	0.12E+06	0.14E+06	0.40E+13	0.47E+13	0.17E+14	0.30E+14	0.13E+14
	0.68E+14	0.89E+05	0.12E+06	0.18E+12	0.24E+12	0.64E+12	0.13E+13	0.67E+12
31	0.68E+14	0.56E+05	0.79E+05	0.39E+12	0.56E+12	0.14E+13	0.29E+13	0.15E+13
	0.68E+14	0.71E+05	0.10E+06	0.21E+12	0.31E+12	0.75E+12	0.16E+13	0.83E+12
	0.68E+14	0.15E+06	0.16E+06	0.37E+13	0.39E+13	0.19E+14	0.31E+14	0.11E+14
	0.68E+14	0.16E+06	0.17E+06	0.27E+13	0.28E+13	0.18E+14	0.26E+14	0.84E+13
	0.52E+14	0.96E+05	0.11E+06	0.52E+13	0.61E+13	0.23E+14	0.52E+14	0.29E+14
	0.52E+14	0.55E+05	0.79E+05	0.99E+11	0.14E+12	0.35E+12	0.73E+12	0.39E+12
32	0.52E+14	0.26E+05	0.38E+05	0.16E+12	0.24E+12	0.55E+12	0.12E+13	0.64E+12
	0.52E+14	0.43E+05	0.63E+05	0.12E+12	0.17E+12	0.40E+12	0.86E+12	0.46E+12
	0.52E+14	0.10E+06	0.12E+06	0.23E+13	0.25E+13	0.10E+14	0.18E+14	0.74E+13
	0.52E+14	0.12E+06	0.13E+06	0.19E+13	0.19E+13	0.12E+14	0.18E+14	0.57E+13
	0.54E+14	-0.31E+05	-0.48E+05	-0.33E+12	-0.51E+12	-0.11E+13	-0.25E+13	-0.14E+13
33	0.54E+14	0.39E+05	0.59E+05	0.62E+11	0.95E+11	0.21E+12	0.46E+12	0.25E+12
	0.54E+14	-0.24E+05	-0.38E+05	-0.14E+12	-0.21E+12	-0.46E+12	-0.10E+13	-0.57E+12

TABLE C.2 (continued)

APN	TEC 90	BNT(LFT)	ANT(LTFS)	ES	ESS	ESA	ESAS	DES
	0.54E+14	0.17E+05	0.26E+05	0.40E+11	0.62E+11	0.13E+12	0.30E+12	0.17E+12
33	0.54E+14	0.11E+06	0.12E+06	0.34E+13	0.38E+13	0.15E+14	0.26E+14	0.11E+14
	0.54E+14	0.13E+06	0.13E+06	0.18E+13	0.19E+13	0.12E+14	0.18E+14	0.56E+13
	0.78E+14	0.94E+05	0.10E+06	0.72E+13	0.81E+13	0.32E+14	0.56E+14	0.24E+14
	0.78E+14	0.55E+05	0.78E+05	0.14E+12	0.20E+12	0.48E+12	0.10E+13	0.53E+12
34	0.78E+14	0.25E+05	0.37E+05	0.22E+12	0.33E+12	0.77E+12	0.17E+13	0.89E+12
	0.78E+14	0.41E+05	0.60E+05	0.16E+12	0.23E+12	0.53E+12	0.12E+13	0.62E+12
	0.78E+14	0.10E+06	0.11E+06	0.31E+13	0.35E+13	0.14E+14	0.24E+14	0.10E+14
	0.78E+14	0.12E+06	0.12E+06	0.26E+13	0.27E+13	0.17E+14	0.25E+14	0.79E+13
35	0.51E+13	0.45E+05	0.69E+05	0.45E+10	0.69E+10	0.15E+11	0.33E+11	0.18E+11
36	0.68E+13	0.86E+04	0.12E+05	0.10E+11	0.15E+11	0.35E+11	0.76E+11	0.40E+11
37	0.22E+13	0.71E+04	0.10E+05	0.57E+10	0.80E+10	0.20E+11	0.42E+11	0.22E+11
38	0.89E+13	0.39E+05	0.47E+05	0.35E+11	0.42E+11	0.14E+12	0.26E+12	0.12E+12
39	0.83E+13	0.27E+05	0.35E+05	0.22E+11	0.28E+11	0.84E+11	0.16E+12	0.79E+11
40	0.76E+13	-0.15E+04	-0.23E+04	-0.10E+10	-0.16E+10	-0.35E+10	-0.78E+10	-0.43E+10
41	0.60E+13	0.13E+05	0.16E+05	0.15E+11	0.19E+11	0.59E+11	0.11E+12	0.54E+11
43	0.84E+15	0.20E+09	0.27E+09	0.11E+14	0.15E+14	0.40E+14	0.80E+14	0.41E+14

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APPENDIX D
COMPANIES CONTACTED DURING COURSE OF STUDY PROGRAM

	ORGANIZATION	NAME	POSITION
1.	American Gas Association	Robert L. Himmel	Senior Research Engineer
2.	American Gas Association	Mark Menzer	Manager, Solar Energy Systems
3.	American Hotel & Motel Assoc.	Jack Wolfe	Director, Energy Technical Center
4.	Berko	Dennis Pickrel	Service Manager
5.	Carrier	Van B. Smith, Jr.	Marketing Manager
6.	Census Bureau	Dave I. Siskind	Assistant Division Chief
7.	Cleaver Brooks	David DeLiagnese	Engineering Manager
8.	Cleveland Stove	Elmer Vegh	Chief Engineer
9.	Commerce Department	Charles Pitcher	Commodity Industry Specialist
10.	Data Resources, Inc.	Gale Blattenburg	Senior Energy Economist
11.	Department of Energy	Dr. Peter Back	Acting Chief of Planning Analysis & Evaluation Branch
12.	Department of Energy	Chris Bourdeaux	Program Analyst
13.	Edison Electric Institute	J. Dudley Waldner	Director, Commercial & Industrial Programs
14.	Edison Electric Institute	Francis Harvey	Statiscian
15.	Exxon	Jim Percival	Marketing Technical Services
16.	F. W. Dodge	G. Gieber	Economist

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APPENDIX D (Cont.)

ORGANIZATION	NAME	POSITION
17. Frost & Sullivan	Bud Anderson	Consultant
18. Fuel Oil & Oil Heat	Mr. Dunphy	
19. Gas Appliance Mfg. Assoc.	Margaret McDonald	Manager, Market Statistics
20. General Electric	R. D. Roley	Commercial & O. E. M. Sales
21. Heating, Piping & A/C Magazine	Robert Osborn	Publisher
22. Hittman Assoc.	Dr. T. Alereza	Program Manager
23. Hydrotherm	C. Chadwick	Vice President-Engineering
24. Illuminating Engineering Soc.	F. Coda	Executive Vice President
25. Lennox	R. K. Casey	Commercial Sales Manager
26. Modine Mfg.	Derald Welles	Product Manager, Thermal Transfer
27. National Bureau of Standards	Dr. J. Snell	Director, Office of Energy Programs
28. National Fuel Oil Inst.	Bert Weller	Engineer
29. Pope, Evans & Robbins	Norman Diamond	Vice President
30. Powermatic	Mel Anderson	Sales Engineer
31. Rheem	Paul Daugirda	Manager
32. Rheem	Robert Newell	Vice President-Engineering
33. Syska & Hennesey	Irving Silverman	Associate

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APPENDIX D (Cont.)

ORGANIZATION	NAME	POSITION
34. Tyler Refrigerator Corp.	Faez Abraham	Vice President-Engineering
35. Veterans Administration Hospital	John Sisky	Energy Coordinator
36. Weil-McLain	Fred Shaffer	Manager, Technical Services
37. Westinghouse Corp.	Hunter Childs	Manager, Market Research & Analysis
38. York-Borg-Warner	Lynn Stump	Product Manager
39. York-Borg-Warner	Paul H. Elslager	Commercial Marketing Manager

ENCLOSURE IV

APPENDIX E

SCOPE OF WORK

Union Carbide Corporation, Nuclear Division, in fulfillment of responsibilities to the Energy Research and Development Administration (ERDA), requires information that will assist in planning and setting priorities for research, development, and demonstration activities of commercial appliances. Specifically, a comprehensive data base of the appliances used in the commercial sector is required along with an evaluation of that data base to determine present and future energy consumption, to identify opportunities and estimate the potential for saving energy used by the appliances, and to identify where ERDA-RD & D funding would promote use of commercial appliances resulting in a significant national energy savings. The work will be monitored by an Oak Ridge National Laboratory Technical Manager (ORNL TM).

Commercial appliances are defined as those devices that consume gas, oil, or electrical energy while providing building services and amenities to the occupants.

The commercial sector is defined in terms of divisions of the Standard Industrial Classification Manual. These divisions are F, G, H, I, J, K, and part of division E. That part of E not included in the definition is all forms of transportation. Subgroups of these divisions should be used as necessary to segregate the use of appliances in the commercial sector. The following building types represent a large portion of the energy used in the commercial sector and are suggested as the likeliest areas where significant energy conservation can be achieved:

Stores	Offices
Schools	Hotels
Colleges	Restaurants
Supermarkets	Theaters
Motels	Churches
Hospitals	

The above definition would exclude residential buildings; however our interest here is on the appliance, regardless of the sector in which it is used. Thus, when the appliances are used in the residential sector also, they should be included and quantified separately.

Although the tasks and schedule given in this Scope of Work describe the work we anticipate to accomplish the project objectives, you should not let them unduly limit your proposal, especially if you believe that you may propose work or a schedule which would accomplish the project objectives more effectively. Variations and the reasons for them should be detailed with proposals.

The contractor shall accomplish the following tasks:

Task 1

Deliverable 1D. Submit a detailed project plan for review and approval by the ORNL TM. This plan shall indicate, in more detail than the proposal program plan, final allocation of financial and personnel resources, timing of principal events that are to occur during execution of the project, decision points and progress milestones, technical approach, and other items of direct relevance to timely and successful accomplishment of the project objectives.

Deliverable 1F. Submit a final project plan reflecting resolution of comments from the ORNL TM review of Deliverable ID.

The Contractor shall not proceed with Task 2 or beyond until this plan is approved by the ORNL TM. No changes shall be made to the approved plan without approval of the ORNL TM.

Schedule and Distribution

Deliverable	Schedule	No. of Copies to ORNL TM
1D	Within 15 days of signing the contract.	3
1F	Within 10 days after the ORNL review. Allow 10 days for the ORNL review.	8

Task 2

Conduct studies and investigations necessary to establish a data base for appliances used in the commercial sector. Specifically,

1. identify types, sizes, quantities by building type and application of appliances in use;
2. determine end use unit energy consumption by type – gas, oil, electricity – and use pattern;
3. determine commonality of appliances between commercial building types and between commercial and residential sectors;

4. determine replacement and new installation rates by appliance type, size, and application;

5. determine appliance development now being conducted or planned;

6. determine buyer evaluation and selection criteria.

The Contractor should collect additional information he feels is necessary to support the evaluation portion of this project. Establish contacts in government, commerce, industry, and educational institutions to provide information useful to the project.

Deliverable 2. Submit, for review by the ORNL TM, an interim report documenting the basic information, methodology, criteria, other pertinent information, and results of the Task 2 study. Three copies of this report are due within five months of signing the contract.

Task 3

Evaluate and analyze the information and data assembled in Task 2 to:

1. identify appliances where the significant national energy savings are possible and estimate potential energy savings by appliance and application;

2. estimate what energy savings will occur without ERDA-RD & D funding;

3. evaluate buyer acceptance of energy-saving appliances and recommend methods for overcoming possible buyer resistance to initial cost increase (assumed) of energy-saving appliances;

4. identify opportunities for significant energy conservation in commercial appliances, rank according to an approved methodology, and suggest implementation plans;

5. identify possible barriers to implementation of energy-saving appliances such as capital costs, material availability, manufacturability, and adverse life cycle costs. Complete ERDA Project Evaluation Data form (enclosure VII) for each significant energy-saving appliance identified;

6. identify opportunities for significant energy conservation in commercial appliances, and from an implementation standpoint, that will benefit from ERDA-RD & D funding.

Deliverable 3D. Submit, for review by the ORNL TM, a report documenting the data, assumptions, information, and methodology used to support the conclusions and recommendations resulting from this project.

Deliverable 3F. Submit a final report for the project reflecting resolution of comments from the ORNL TM review of Deliverable 3D.

Schedule and Distribution

Deliverable	Schedule	No. of Copies to ORNL TM
3D	Within 7 months of signing the contract.	8
3F	Within 1 month after the ORNL review. Allow 2 weeks for ORNL review.	200 and camera ready copy

ENCLOSURE V

TECHNICAL EVALUATION CRITERIA

The evaluation criteria, and their importance, are the following:

Criteria	Importance (%)
Merit of the proposed approach, with respect to management plan, allocation of personnel and resources, and task organization.	35
Familiarity with and access to information and data.	25
Qualifications of staff and organization with respect to technical and economic basis of the work to be undertaken, as well as ability to perform the analysis required.	20
Participation of essential expert organizations or individuals in the proposed project.	20

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