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Characterization of Commercial Building Appliances

Final Report

Prepared by
Arthur D. Little, Inc.

for

Building Equipment Division
Office of Building Technologies
U.S. Department of Energy

August 1993

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**CHARACTERIZATION OF COMMERCIAL BUILDING
APPLIANCES**

Prepared by

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ADL Reference No. 42520

for

**Building Equipment Division
Office of Building Technologies
U.S. Department of Energy
Project Manager: Dr. James R. Brodrick and Mr. John Ryan
Contract No. DE-AC01-90CE23821**

August, 1993

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Rusi F. Patel, P.E.
Program Manager

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1.0 Introduction

In the commercial sector, lighting, heating, ventilating, and air conditioning (HVAC) end-uses have been emphasized in energy conservation programs, since these end-uses account for the highest consumption of energy in this sector. Lighting and HVAC together account for 78% of the commercial sector energy use. The remaining end-uses are often bundled together as "other" end-uses. This study focuses on this "other" end-uses category.

The purpose of this study was to determine the relative importance of energy end-use functions other than HVAC and lighting for commercial buildings, and to identify general avenues and approaches for energy use reduction. Specific energy consuming technologies addressed include non-HVAC and lighting technologies in commercial buildings with significant energy use to warrant detailed analyses. The end-uses include office equipment, refrigeration, water heating, cooking, vending machines, water coolers, laundry equipment and electronics other than office equipment. The building types include offices, retail, restaurants, schools, hospitals, hotels/motels, grocery stores, and warehouses.

The emphasis in the study was to establish a documented, soundly-based estimate of current energy consumption for these end-use functions. Secondary emphasis of the study was on estimating the maximum possible/probable energy savings potential for each of these end-uses. The purpose of these savings estimates was to determine the first order, relative importance of the end-uses to the U.S. Department of Energy (DOE). Therefore, an evaluation of technical options was needed to support the energy savings estimates and identify general technical opportunities rather than one which would select or prioritize specific technical options which warrant DOE support. Market penetration was considered, although examination of the probable cost of technologies was left for more detailed technical/economic studies to be performed in subsequent task efforts.

DOE programs encompass a wide range of activities including research and development to develop new technologies and programs on standards, incentives, and technology transfer. The potential for energy savings is therefore differentiated by:

- Current technologies that are available in the marketplace but may not be in widespread use due to a variety of cost and/or industry structure reasons.
- New technologies that are available but not yet utilized in commercially available equipment.
- Advanced technologies that need research and development to establish technical and commercial viability.

2.0 Scope of Work

2.1 Scope of Work

A two-phase approach was planned for this project:

Phase 1: Characterization of Commercial Building Appliances

Phase 2: Comparative economic and institutional analyses for energy saving technologies identified in Phase 1

The scope of work for this Phase 1 effort was comprised of five tasks:

Task 1: Conduct Literature Search and Assessment

Task 2: Establish Baseline Estimates of Energy Consumption

Task 3: Characterize Existing Equipment

Task 4: Identify and Characterize Technical Options

Task 5: Determine National Energy Consumption and Savings Potential

The above tasks were performed for the following end uses:

- Refrigeration including unit coolers, central refrigeration and ice makers;
- Cooking including broilers, fryers, griddles, ovens, ranges, and steamers;
- Office equipment including computers, typewriters, copiers, printers, facsimile machines;
- Water heating;
- Vending machines and water coolers;
- Laundry equipment including washers, dryers and dry cleaning equipment; and
- Electronics including electromedical equipment, telephone equipment, automated teller machines, point-of-sale terminals and cash registers.

Vertical transportation (escalators and elevators) were also examined but not analyzed in detail due to its low energy consumption. In a study for the Bonneville Power

Administration (BPA) by Battelle Pacific Northwest Laboratory (Ref. 1), vertical transportation showed the lowest energy consumption out of seventeen electric equipment categories, as shown in Table 2-1. In this table, percentages are shown merely to point out relative importance of the various categories.

Though vertical transportation energy use is rather small when the commercial sector as a whole is considered, it is 3.7% of large office, 2.9% of large dry goods retail and 2.3% of hotel/motel, total building energy consumption (Ref. 1); showing that as a percentage of the energy use of these three building types, it is still small but not negligible. In keeping with the purpose of this study, vertical transportation is not analyzed in detail due to the overall size of this load relative to commercial sector energy use.

Table 2-1: Estimated average Megawatts of Electricity Consumption by Equipment Category

Equipment Type	Average Annual Loads (MWa)	% of Total of 17 Categories
1. Office Equipment	77.22	7.0
2. Personal Computers	49.47	4.5
3. Large Computers	63.47	5.7
4. Task Lights	34.18	3.1
5. Laboratory	5.70	0.5
6. Vertical Transport - Continuous	0.08	0
7. Vertical Transport - Intermittent	4.03	0.4
8. Shop	20.71	1.9
9. Miscellaneous - Continuous	13.67	1.2
10. Miscellaneous - Intermittent	51.55	4.7
11. Material Handling	20.07	1.8
12. Food Preparation - Continuous	110.65	10.0
13. Food Preparation - Intermittent	21.58	2.0
14. Refrigeration - Unitary	161.58	14.6
15. Refrigeration - Central	220.40	19.9
16. Sanitation	36.90	3.3
17. Hot Water	214.08	19.4
Total	1105.44	100.0

[Source: Pratt, R.G., Williamson, M.A., Richman, E.E., Miller, N.E., "Commercial Equipment Loads, End-Use Load and Consumer Assessment Program (ELCAP)." Prepared for U.S. Department of Energy by Battelle PNW Laboratory, July 1990.]

2.2 References

1. Miller, N.E., R.G. Pratt, and M.A. Williamson. Commercial Equipment Loads, End-Use Load and Consumer Assessment Program (ELCAP). DE-AC06-76RLO. Battelle Pacific Northwest Laboratory, for Bonneville Power Administration (BPA), July, 1990.

3.0 Summary of Results and Recommendations

3.1 Introduction

The National Energy Strategy report by U.S. DOE (Ref. 8) states that the commercial sector accounts for more than 13 quads* (15%) of the Nation's annual primary energy use. Analyses performed in this report show that more than 2.9 quads of this commercial sector energy use is in end-uses other than HVAC and lighting. This effort focuses on the development of this baseline energy use of 2.9 quads and the potential for energy savings in these end-uses.

A database of appliance and equipment inventory, U.S. baseline energy consumption and energy savings potential (from current, new and advanced conservation technologies) is developed for eight end-uses. Current, new, and advanced technologies, were defined in Section 1 of this report. The end-uses covered here are refrigeration, cooking, office equipment, water heating, vending machines, water coolers, laundry equipment, and electronics other than office equipment. Based on specialists' opinions, both Arthur D. Little and industry specialists, and the database developed herein, we have identified energy savings opportunities and general approaches to energy use reduction for these end-uses.

3.2 Relative Importance of End-Uses

The relative importance of end-uses mentioned above can be determined by comparing the baseline energy use for each of these end-uses. Table 3-1 summarizes this data. For the end-uses (water heating, cooking, and laundry) where more than one fuel type applies, the data is shown separately by fuel type. All of the data is in primary energy terms in Btu's at the power plant in case of electricity and Btu's on-site for gas and oil. For electricity generation the conversion factor used is 11,200 Btu's of primary energy for 1 Kwh delivered at the building. (The average generation plus transmission efficiency of U.S. power plants is implicitly assumed to be 30%.) For gas-based and oil-fired equipment, the energy input to the equipment is directly used as the primary energy Btu's.

Figure 3-1 illustrates the relative share of the total 2.9 quads of energy used for these end-uses. A relative comparison of the end-uses shows that water heating consumes 1/3 the total energy for end-uses other than HVAC and lighting if swimming pool water heating is included. Refrigeration is next with 26%, cooking is next with 19% of the total for "other" end-uses. Office equipment accounts for 12% and laundry accounts for 5% of the total for "other" end-uses. Vending machines and water coolers account for 3% and 1%, respectively, and other electronics (non-office) is the remaining 1%.

* Quad = Quadrillion Btu's = 10^{15} Btu's

Table 3-1: U.S. Commercial Sector Primary Energy Use for Year 1990

End-Use	Primary* Energy Use x 10 ¹² Btu/Year			Total	Energy Use (% of Total)	Ranking	Comments
	Gas	Oil	Electric				
Refrigeration	-	-	744	744	26	2	
Cooking	289	-	251	540	19	3	
Office Equipment	-	-	335	335	12	4	Growth mode
Water Heating	519	147	132	798	28	1	Could be combined with Pool Heating
Pool Heaters	135	-	-	135	5	6	Commercial Pools Only
Vending Machines	-	-	108	108	3	7	Low eff. at present - Potential savings high
Water Coolers	-	-	44	44	1	8	Drinking Water only
Laundry+	122	-	24	146	5	5	
Electronics (excl. office equipment)	-	-	43	43	1	9	Incl. telephone, medical and banking
Total	1065	147	1681	2893	100		

+Laundry energy excludes hot water heating energy use in laundries since this is included under water heating. Dry cleaning energy use of 3x10¹² Btu/yr is included.

*Primary energy use for electricity is converted using 1kWh = 11,200 Btu's.

Figure 3-1: Relative Energy Use by End-Uses

Hot water used in washers consumes 47×10^{12} Btu/yr. This energy use is included under the hot water heating end-use and excluded from laundry to avoid double counting.

3.3 Relative Importance of Equipment Types Within Each End-Use

To understand the relative significance of various equipment types, each of the nine end-uses discussed above are further subdivided into logical equipment types. In case of refrigeration, office equipment, vending machines, water coolers, and electronics, electricity is the only fuel type. For cooking, water heating, and laundry more than one fuel type applies. In these cases, the baseline energy use is further subdivided by the type of fuel used.

Table 3-2 shows energy use by equipment type within each end-use. Each end-use is briefly discussed below. Figure 3-2 is an illustration of the data provided, in the form of pie charts.

Table 3-2: Primary Energy Use in the USA in 1990 by Equipment Type

End Uses	Primary Energy Use (x 10 ¹² Btu/yr)		
	Electric	Gas	Oil
Refrigeration			
Ice Makers	105		
Commercial	490		
Unit Coolers	149		
Sub-Total	744	N/A	
Cooking			
Broiler-Gas		28	
Broiler-Electric	4		
Fryer-Gas		27	
Fryer-Electric	33		
Griddle-Gas		14	
Griddle-Electric	25		
Oven-Gas		123	
Oven-Electric	140		
Range-Gas		80	
Range-Electric	10		
Steamer-Gas		17	
Steamer-Electric	39		
Sub-Total	251	289	
Office Equipment			
Mainframe & Mini computers	83		
Desktop Computers	53		
Workstations	7		
Laptops	1		
Printers	50		
Copiers	123		
Typewriters	14		
Facsimile	4		
Sub-Total	335	N/A	
Commercial Water Heating (excl. swimming pools)			
Gas		519	
Oil			147
Electric	132		
Sub-Total	132	519	147
Commercial Pool Water Heating (gas)		135	
Vending Machines			
Beverage	72		
Food	14		
Other	22		
Sub-Total	108	N/A	
Water Coolers	44	N/A	
Laundry Machines (C&R* and OPL*)			
Washers++	7 (motors)		
Dryers (Total = 136 x 10 ¹² Btu/yr)*	14 (motors)	122 (heat)	
Dry Cleaning	3		
Sub-Total	24	122	
/Electronics (Non-office)			
Electromedical--			
Ultrasound	2		
MRI	1		
X-ray Diagnostics	8		
Computed Tomography	2		
Cash Registers & POS Terminals	17		
Automated Teller Machines	8		
Telephone Equipment	5		
Sub-Total	43	N/A	
Total	1681	1065	147

+C&R = Coin and route operations, OPL = On-Premise Laundry

++47 x 10¹² Btu/yr is for water heating and 7 x 10¹² for motors. Water heating for washers is included under water heating.

*Commercial dryers are predominantly gas-fired.

Figure 3-2: Appliance Energy Use by Equipment Type (1990)

3.3.1 Refrigeration

The refrigeration equipment is divided into three categories:

- Unit coolers which are free standing units often placed in the aisles in supermarkets and commonly used in convenience stores and restaurants;
- Ice-makers; and
- Commercial refrigeration referring to central systems as found in supermarket applications and large walk-in refrigerators and freezers found in restaurants and institutional kitchens.

Central refrigeration systems consume 66% of the refrigeration baseline energy use, unit coolers account for 20% and ice-makers consume the remaining 14% of the refrigeration energy use.

3.3.2 Cooking

The cooking end-use is rather diverse in equipment types - broilers, fryers, griddles, ovens, ranges, steamers are the major ones from an energy viewpoint. Toasters, melters, and microwave ovens, though substantial in numbers of units, are relatively less significant from an energy use point of view due to their low power levels and operating hours. Each of the six major cooking equipment types mentioned above are widely used in both gas-fired and electrically operated equipment. Electric and gas energy use for cooking is roughly split 46% and 54% respectively between electricity and gas. Ovens, both electric and gas, represent the most significant energy user with 26% for the electric cooking energy and 23% for the gas cooking energy use. Thus, ovens represent 49% of the total cooking energy use.

3.3.3 Office Equipment

Office equipment may be divided into the following categories:

- Computers - Desktop and Workstations
- Computers - Mainframes and Minis
- Printers
- Copiers
- Typewriters, and
- Facsimile.

The office equipment energy use is the highest for copiers (37%) with mainframes and minis at 25% and PCs and workstations at 18%. Printers represent 15% of the office equipment energy use. Typewriters and facsimile machines are 4% and 1% respectively of the total office equipment energy use.

3.3.4 Water Heaters

Commercial water heaters are divided into gas, oil, and electric water heaters. The gas-fired water heaters' total energy use is roughly 65% of the total water heater energy use excluding swimming pool water heaters. Electric water heaters account

for 17% and oil-based water heaters energy use is 18% of the total.

Commercial pool water heaters, which are predominantly gas-fired, have an estimated energy use of an additional 135×10^{12} Btu/year, which is roughly equal to the total electric water heating in the commercial sector. If swimming pool water heating is included, the total water heating energy use = 933×10^{12} Btu/yr with gas-fired water heating accounting for 70% of this total, electric 14%, and oil 16% of the water heating energy use.

3.3.5 Vending Machines

Vending machine designs have to date emphasized displays and sale of products rather than energy use especially since energy bills are not paid by the vending machine operating companies, but by the owner or lessee of the real estate on which the vending machines are located. Often refrigerated vending machines that are energy inefficient are located outdoors, such as outside auto service stations with substantial solar and conduction cooling loads imposed on them. These vending machines, therefore, have a relatively high baseline energy use.

Vending machines may be divided into three categories: beverage, food and confectionery, and other. Beverage vending machines consume 67%, food and confectionery 13%, and other 20% of the total vending machine energy use.

3.3.6 Water Coolers

Water coolers are a relatively small energy user and are not divided further into different equipment types.

3.3.7 Laundry

Commercial laundries include coin and route operations, and on-premise laundries in hospitals and nursing homes. Dry cleaners are also included in this category. Laundry equipment includes washers, dryers and dry cleaning equipment. Washers and dry cleaning equipment are electric and dryers are predominantly gas-fired. If we include water heating energy required for washers in the washer baseline energy use, dryer energy use is roughly two-and-a-half times that of washers while dry cleaning equipment energy use is five percent that of washers. If water heating energy for washers is excluded from laundry, dryers account for 93% of the laundry energy use.

3.3.8 Electronics

This category includes major electronics equipment other than office equipment discussed earlier. Specifically electromedical equipment, telephone equipment, and cash handling equipment are included. The electromedical equipment may be divided into:

- Ultrasound;
- Magnetic Resonance Imaging (MRI);
- Radiographic or X-ray equipment; and
- Computed Tomography (CT).

The four categories of imaging systems have national energy consumption ranging from one to eight trillion Btu/year each, with x-ray equipment consuming 62%, ultrasound and CAT equipment 15% each, and MRI remaining 1% of the electromedical equipment energy use. This equipment sector is growing in spite of the constraints on health care costs. MRI is relatively new to the imaging technologies but is growing. Most of the electromedical equipment is high value delivered and high capital cost equipment and, therefore, energy conservation for this equipment is de-emphasized by the users and manufacturers.

Telephone equipment includes both telephone instruments as well as central switching systems.

The cash handling equipment includes cash registers, point-of-sale terminals and automated teller machines. This category accounts for more than half the consumption of non-office electronics.

3.4 Comparison of Baseline Energy Use with Other Sources of Data

Baseline energy use data for the U.S. was independently estimated by Arthur D. Little for each of the end-uses by fuel type. In order to check for reasonableness of these estimates, we compared similar data from other sources obtained through literature assessment and telephone interviews. No data was found at the national level for laundry equipment and electronics (non-office).

Figure 3-3 shows this comparison for electric end-uses. Sources of data include References 1, 3, 4, 5, and 6. Generally, all of the estimates compared well with the other sources as levels of agreement were generally within 10 to 15% for most categories. Observations on differences among the sources follow:

- The BPA electric appliance data (Ref. 5) was extrapolated from the Pacific Northwest (PNW) region to the whole country and therefore may be substantially higher than anticipated. Electricity in the Pacific Northwest (PNW) region is less expensive than in the rest of the country so that electricity is preferred over other fuel types. This, when extrapolated to the U.S., inflates the electric baseline energy use above the estimates from other sources. This effect applies only when there is a choice for other fuels available to the specific end-use, such as for water heating.
- Relative to office equipment, BPA 1988 estimates were based on circuit breaker level measurements which tended to include other pieces of equipment that were plugged into the same circuits. Also, there was a lag in time between when instrumentation was done and data was collected, so that the plug-in loads could have changed during that time. However, BR Associates reported office equipment energy use was closer to the Arthur D. Little estimates.

Figure 3-3: Commercial Electrical Appliance Comparison of ADL Results with Other Sources

Figure 3-4 shows the comparison of Arthur D. Little estimates of baseline annual energy consumption with other sources for gas-fired equipment. With the exception of LBL data (Ref. 2) which is substantially out of line relative to all other sources, the data compare well, are within a reasonable range, and also show an increasing trend with time.

TECO 1982 data for water heating includes all residential and commercial swimming pool heaters, which are predominantly gas-fired. TECO 1989 data excludes the swimming pool heaters and is, therefore, in line with the ADL estimates for the same.

Figure 3-5 shows the comparison for oil-fired water heaters baseline energy use. ADL estimate is lower than TECO's by about 30%. This is attributed to a lower usage level estimated by ADL specialists relative to the usage estimated by TECO.

3.5 Energy Conservation Potential

In this section, we have summarized the energy conservation technologies, and their potential. Section 5 of this report provides the detailed analyses of energy savings and the technologies involved. The potential energy savings identified in this report can be achieved by applying the approaches shown below based on the status of the technology, -- current, new, and advanced.

Technology Status	Example Approaches for Achieving Savings
Current	Standards, R&D for Cost Engineering, Cost Incentives, Demand Side Management, Field Demonstrations
New	Technology Transfer, Cost Engineering R&D, Standards
Advanced	R&D

*TECO 1975, TECO 1982 include swimming pool water heating;
TECO 1989 does not include pool water heating.
ADL 1990 is shown with and without pool heating.

Figure 3-4: Commercial Gas Appliance Energy Use Comparison of ADL Results with Other Sources

The basis for recommendations are the analysis performed in this study, our knowledge of the key issues involved and the status of each technology. Before implementation of these technologies, an important first step is the evaluation of each of these technologies from an economic cost/benefit standpoint and an analysis of institutional and other issues. This essential second phase of this study will provide a broader perspective of each technology option and a means to prioritize the various technologies involved.

3.5.1 Energy Conservation Potential by End-Use

A relative comparison of baseline energy consumption by end-use was provided in Section 3.2. A similar comparison of the potential energy savings by end-use is presented in this section.

Figure 3-5: Commercial Oil-Fired Water Heaters Energy-Use-ADL vs. TECO Estimates

Table 3-3 shows the energy savings potential of current, new, and advanced technologies. This is summarized from Section 5 which provided details on these technologies and savings potential. For the purposes of this report, current technologies are those that are available in the marketplace today for the specific product; new technologies are those that are transferable from other products, and advanced technologies are those that are in need of R&D before they can be commercialized.

The last column in Table 3-3 is calculated by taking the highest of the three savings values (current, new or advanced technologies) for a given end-use and dividing it by the sum of these highest values across end-uses. The sum of the maximum values is 1446×10^{12} Btu/yr.

This table shows the technical potential for energy savings for the various end-uses and provides another measure of the relative importance of the end-uses. It is important to note that small differences, between end-uses are not significant since the savings estimates are first-order estimates.

Figure 3-6 shows the relative energy savings potential by end use. Again, water heating and refrigeration show the highest potential savings accounting for 37% and 25%, respectively, of the savings potential for all end-uses under consideration.

Table 3-3: Energy Savings Potential by End-Use

End-Use	1990 Baseline Energy Use (x 10 ¹² Btu)	Energy Savings Potential (x 10 ¹² Btu/yr)			
		CT Current Technology	NT New Technology	AT Advanced Technology	Max. of CT, NT, AT as % of Total of Maximums+
Refrigeration	744	91	179	373	26
Cooking	540	143	71	117	10
Office Equipment	335	95	93	98	7
Water Heating	798	238	88	534	37
Pool Heaters	135	49	--	86	6
Vending Machines & Water Coolers	152	--	59	65	4
Laundry	146* (Excl. hot water) 190 (total)	73	102 +39 (hot water)	109	10
Electronics - Non-office	43 (incl. tel.)	4	6	1	0
Total	2893	693	637**	1383	100

*Laundry hot water included under water heating baseline energy use.

**Hot water savings due to heat recovery dryer included.

+Total of maximums (CT, NT, or AT) across end-uses = 1446 x 10¹² Btu/yr

Based on this analyses, water heating has the highest potential for savings followed by refrigeration, cooking, and laundry. Office equipment and pool heaters are next, followed by vending machines and water coolers. Non-office electronics has the lowest energy savings potential. Each of these end-uses' energy savings potential is broken down by equipment type and by technologies in the next section.

3.5.2 Energy Conservation Potential by Equipment Type by Technology

Various types of equipment are used to accomplish any given end-use. Energy can be conserved by increasing the market penetration of currently available technologies through standards, cost engineering R&D or cost incentives, or by improving the equipment design incorporating transferable technologies from other products, cost engineering R&D, or by performing R&D in advanced technologies.

Note: Non-office electronics saving of 6×10^{12} Btu/yr not displayed.

Annual Energy Savings Potential for Commercial Building Appliances =
 1446×10^{12} Btu/yr

Figure 3-6: Energy Savings Potential by End-Uses

Table 3-4 summarizes the various technologies for refrigeration by type of equipment. Detailed discussions of the technologies and the calculations for the potential savings are provided in Section 5 of this report. Current, new and advanced technologies as defined earlier are kept separated in the summary table. Since many of the current technologies would be replaced by new or advanced technologies, the savings from the three types of groupings cannot be added together.

Table 3-5 summarizes the cooking end-use, Table 3-6 office equipment, Table 3-7 water heating, Table 3-8 vending machines and water coolers, Table 3-9 laundry equipment and Table 3-10 non-office electronics. Energy savings technologies and their potential are discussed in detail in Section 5 of this report.

Table 3-4: Annual Energy Savings Potential in Refrigeration - Base Year 1990

			Energy Savings Potential (x 10 ¹² Btu/yr)		
Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Current Tech.	New Tech.	Advanced Tech.
Unit Coolers	149	New Technologies		79	
		- high efficiency compressors			
		- higher insulation levels			
		- increased face area of evaporator and cond.			
		- water cooled condensers			
		Advanced technologies:			
		- advanced vapor cycle with multi-stage mechanical cooling and high-efficiency refrigerants (propane/ammonia)			35
		- reverse Stirling Cycle			25
		- advanced absorption cycle			75
Unit Coolers Subtotal			-	79	75
Ice Makers	105	Current Technologies:	15		
		- water cooled condensers			
		- harvest assist mechanism			
		- improved evaporator designs			
		New Technologies		28	
		- high efficiency compressors			
		- increased insulation			
		Advanced Technologies:			
		- advanced vapor cycle with multi-stage mechanical cooling and high-efficiency refrigerants			26
		- reverse Stirling Cycle			18
		- advanced absorption cycle (double effect)			52
Ice Makers Subtotal			15	28	52*

*In case of mutually exclusive technologies, include only the technology with the highest potential savings in the subtotals and totals.

Table 3-4: Annual Energy Savings Potential in Refrigeration - Base Year 1990 (continued)

			Energy Savings Potential (x 10 ¹² Btu/yr)		
Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Current Tech.	New Tech.	Advanced Tech.
Commercial Refrigeration	490	Current Technologies:	76		
		- variable capacity			
		- floating head pressure control			
		- water cooled condensers			
		- mechanical subcooling			
		Improved design (new technologies):		72	
		- fully floating head pressure control			
		- two-stage R22 with intercooling and subcooling			
		Advanced Technologies:			
		- advanced vapor cycle with multi-stage mechanical cooling and high-efficiency refrigerants			110
		- reverse Stirling Cycle			141
		- advanced absorption cycle			246
Central Refrigeration Subtotal			76	72	246*
Refrigeration Total	744		91	179	373

*In case of mutually exclusive technologies, include only the technology with the highest potential savings in the subtotals and totals.

+Excluded from total since it is mutually exclusive with inductive cooking.

Table 3-5: Annual Energy Savings Potential in Cooking - Base Year 1990

			Energy Savings Potential (x 10 ¹² Btu/yr)		
Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Current Tech.	New Tech.	Advanced Tech.
Electric Cooking Equipment	251	Current Electric Technologies:	70		
		- zone control/modularity			
		- efficient resistive element configurations			
		- air impingement technology			
		- higher insulation/sealing			
		Reduced thermal mass griddles, double-sided griddles & conveyorized broilers			
		New & Advanced Elec. Technologies*:			
		- life and reliability improvement of reduced diameter heating elements			50
		- development of oil-less fryer technology			10
		- microwave combined with other cooking modes			18+
		- inductive cooking			43
		- energy management system		30	
Electric Cooking Subtotal	251		70	30	103
Gas Cooking Equipment	289	Current Gas Technologies:	73		
		- zone control/modularity			
		- power and infrared burners			
		- air impingement technology			
		- electronic ignition			
		- insulation/gaskets & seals			
		Reduced thermal mass griddles, double-sided griddles and conveyorized broilers			
		New & Advanced Gas Technologies*:			
		- oil less fryers			11
		- energy management system		41	
		- steam combination			3
Gas Cooking Subtotal	289		73	41	14
Integrated Restaurant** (Involves savings in HVAC Systems - Excluded here)					
Total (cooking)	540		143	71	117

*Integrated restaurant would use integrated appliances, recover waste heat for water, space heating, space cooling, and ventilation systems. Total savings of 70 x 10¹² to 100 x 10¹² Btu/yr are estimated.

Table 3-6: Annual Energy Savings Potential in Office Equipment - Base Year 1990

			Energy Savings Potential (x 10 ¹² Btu/yr)		
Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Current Tech.	New Tech.	Advanced Tech.
All Office Equipment	335	Combination of power management software, awareness programs, rapid turn-on equipment	38		
Computers (PC's and Workstations)	61	Current Technologies:	14		
		- replace NMOS with CMOS	12		
		- replace linear with switching power supplies	2		
Copiers & Printers	173	Current Technologies:	53		
		- digital copiers (multiple* copies from memory)	10*		
		- lower wattage exposure lamp and lower power laser	15		
		- reduced temperature fusing for copiers and printers	34		
		Reduced Power Laser	4		
		Direct electronic* information transfer	62*		
All Office Equipment	335	Lower voltage chips 3V instead of 5V (New Tech.)		20	
Computers (PC's and Workstations)	61	Flat panel displays such as LCD, plasma (New Tech.)		5	
Copiers, Printers	173	New Technologies		83	
		• cold fusing technology		57	
		• efficiently focused exposure light		26	
Copiers, Printers & Facsimile	177	High resolution inkjet* technology		62*	
All Office Equipment (except Mainframes and Minis)	252	Advanced Technologies:			14
		- high efficiency motors			8
		- "Microtips" CRT's			6
Printers & Copiers	173	Advanced Technologies:			87
		- ion deposition			87
		- magnetostatic			25*
Total**	335		95**	93**	98**

*For mutually exclusive technologies, highest savings potential used in total.

**For derivation of totals see relevant tables in Section 5.

+Savings reported here are those based on energy use reduced by savings for other measures.

E

Table 3-7: Annual Energy Savings Potential in Water Heating - Base Year 1990

			Energy Savings Potential (x 10 ¹² Btu/yr)		
Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Current Tech.	New Tech.	Advanced Tech.
Gas-Fired Water Heaters	519	Current Gas Technologies:	187		
		- condensing combustion			
		- spark ignition			
		- active flue damper			
		- higher insulation level			
		Advanced Gas Technologies:			
		- gas-fired absorption heat pump water heater with heat recovery			311
		- gas-engine driven heat pump water heater with heat recovery			311
		- gas-based multi-pressure heat pump water heater			332
		- Duplex Stirling or Vuilleumier Cycle			311
Electric Water Heaters	132	Displace resistance water heaters with heat pump		88	
		Advanced Electric Technologies:			
		- multi-pressure heat pump water heater			94
		- advanced multi-pressure heat pump water heater			108
Oil-Fired Water Heaters	147	Current Technologies: (Same as gas except lower impact)	51		
		Advanced Technologies: (Same as gas)			94
Total (Gas)			187	---	332
Total (Electric)				88	108
Total (Oil)			51		94
Water Heating Total	798		238	88	534

Swimming Pool Water Heating:

Note that savings for swimming pool water heating is the same percent of baseline savings as for any gas-fired water heaters. For current technologies the savings = 49×10^{12} Btu/yr and for advanced technologies the savings = 86×10^{12} Btu/yr for swimming pool water heaters. These savings are not included in the above table.

Total savings potential including swimming pool water heating:

- Current Technologies = 287×10^{12} Btu/Yr
- New Technologies = 88×10^{12} Btu/Yr
- Advanced Technologies = 620×10^{12} Btu/Yr

Table 3-8: Annual Energy Savings Potential in Vending Machines and Water Coolers - Base Year 1990

			Energy Savings Potential (x 10 ¹² Btu/yr)		
Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Current Tech.	New Tech.	Advanced Tech.
Vending Machines	108	Improved design: (New Technologies)		44	
		- thicker insulation (food & beverage)			
		- high eff. Motor and compressor (food & beverage)			
		- zone control (food & beverage)			
		- off-peak control (food & beverage)			
		- high efficiency lighting (all)			
		- improve dispense mechanism (all)			
Vending Machines	108	Advanced Technologies			43
		- advanced vapor cycle (multistage mech. subcooling and higher efficiency refrigerants)			
		- reverse stirling cycle			
		- advanced absorption cycle			
Water Coolers	44	Improved design:		15	
		- higher insulation level			
		- high eff. compressors & motors			
		- improved bonding between coil and evaporator			
		- storage coil redesign			
Water Coolers	44	Advanced Technologies			22
		- advanced vapor cycle			
		- reverse stirling			
		- adv. absorption cycle			
Vending Machines and Water Coolers Total	152			59	65

E

Table 3-9: Annual Energy Savings Potential in Laundry Equipment - Base Year 1990

			Energy Savings Potential (x 10 ¹² Btu/yr)		
Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Current Tech.	New Tech.	Advanced Tech.
Washers	54	Current Technologies:	31		
		- horizontal axis design			
		- higher spin speeds (spin speed conserves dryer energy—see dryers)			
		Improved design:		15+	
		- fill level switch			
		- high efficiency motors			
		- eliminate warm rinse			
		All Cold Wash		47	
		Advanced Technologies:			
		- ozone washing			48
		- ultrasonic washing			39++
Washers Subtotal	54		31	47	48
Dryers	136	- high recycle/high airflow dryers	42		
		- high efficiency motors		1	
		- higher spin speed washers		54	
		Improved design: (New Technologies)		39*	
		- heat recovery dryers to save water heating energy for washers			
		Advanced Technologies:			
		- desiccant-based dryer			61
Dryers Subtotal			42	55 (+39*)	61
Laundry Equipment Total	143 (excludes water heating) 190 (with laundry hot water)		73	102 39*	109

+Mutually exclusive relative to "All Cold Wash".

*Savings in water heater energy.

WH = water heating.

++Mutually exclusive relative to ozone washing.

**Dry cleaning equipment was considered but the baseline energy use was too small to carry further into technology analyses.

Table 3-10: Annual Energy Savings Potential in Non-Office Electronics - Base Year 1990

Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	Technology Options	Energy Savings Potential (x 10 ¹² Btu/yr)		
			Current Tech.	New Tech.	Advanced Tech.
Electromedical	13	New Technologies		3.4	
		- power management			
		- switching power supplies			
		- low energy displays			
		Hi-Eff. Motors			0.7
		Room temperature superconductors to reduce cryogenics in MRI			0.2
Sub-total	13			3	1
Cash Handling Machines	25	Current Technologies:	4		
		- NMOS to CMOS conversion			
		- linear to switching power supplies			
		Power management (new)		3	
Subtotal	25		4	3	
Total	38*		4	6	1

*Telephone equipment baseline energy use of 5 x 10¹² Btu/yr brings the total for non-office electronics to 43 x 10¹² Btu/yr.

3.6 Recommendations

As seen in Section 3.5, for each of the end-uses, a substantial number of technologies were evaluated, and the savings potential of each of these technologies was estimated. We have selected some of these technical options and suggested some of key program elements for DOE's consideration.

Water Heating: Heat pump water heaters and high efficiency water heaters for both gas and electric are available in the market place today. The Comprehensive National Energy Policy Act incorporating the ASHRAE Standard 90.1b has been signed into law. This will increase the market penetration of higher efficiency equipment. However, the ASHRAE 90.1b standard does not go as far as the current

technologies would permit, especially condensing combustion for gas and heat pumps for electric water heaters. For these current technologies, we suggest an economic/market assessment followed by implementation of the recommendations that result from such an assessment. The assessment would include an understanding of the market motivators and recommend ways to accelerate market penetration of these technologies. The savings potential is 0.3 quad per year.

Advanced technologies such as direct-fired double-effect absorption technology with heat recovery has the potential for savings of 0.3 quad per year. Suggested program elements include economic/market assessment and R&D possibly in cooperation with the Gas Research Institute (GRI).

On the electric side, multi-pressure electric heat pump water heaters have the potential for savings in the order of 0.1 quad per year. Suggested avenues are economic/market assessment followed by R&D possibly in cooperation with the Electric Power Research Institute (EPRI).

Advanced electric vapor compression cycle with multi-stage mechanical subcooling and use of inherently higher efficiency refrigerants such as ammonia, propane, etc. could provide savings of 0.17 quad per year (savings potential not additive with absorption cycle potential). Economic/market assessment followed by required R&D possibly conducted in cooperation with EPRI are suggested.

Cooking: All commercial food service equipment is represented in both gas-fired and electric models. The efficiency of commercially available gas-fired cooking equipment varies significantly depending on the specific manufacturer and model. There are no mandated minimum efficiency standards in this industry, and uniform test procedures for measuring actual cooking efficiency are in the process of being developed. The largest impact on the future efficiency of the installed base of cooking equipment will depend more on factors that influence the purchase decision criteria for this equipment than on technology developments. Quite simply, the installed base of commercial gas-fired cooking equipment efficiencies could be significantly increased if customers purchased more efficient models. However, the cost premium associated with the high efficiency cooking equipment does not always justify the resultant savings.

Cost reduction R&D possibly in cooperation with GRI and EPRI could increase the market penetration of high efficiency models. An alternative approach is setting up guidelines and standards. The savings potential is 0.14 quad per year.

Refrigeration: Residential refrigeration standards have been effective in substantially improving refrigeration efficiency in the residential sector. Transferring these technologies to the commercial sector with additional technical measures could significantly reduce commercial refrigeration energy use. Savings potential of 0.18 quad per year is estimated through application of high efficiency compressors, increased face area of evaporator and condenser, higher insulation levels, use of water loop for water cooled condensers, and two-stage refrigeration.

Advanced technologies such as direct-fired, double-effect absorption cycle refrigeration could be developed possibly in cooperation with GRI. An economic/market assessment is recommended as the first step. Savings potential of 0.37 quad per year is estimated. Advanced electric vapor compression cycle with multi-stage mechanical subcooling and use of inherently higher efficiency refrigerants such as ammonia, propane, etc. could provide savings of 0.17 quad per year (savings potential not additive with absorption cycle potential). Economic/market assessment followed by required R&D possibly conducted in cooperation with EPRI are suggested.

Cooking: All commercial food service equipment is represented in both gas-fired and electric models. The efficiency of commercially available gas-fired cooking equipment varies significantly depending on the specific manufacturer and model. There are no mandated minimum efficiency standards in this industry, and uniform test procedures for measuring actual cooking efficiency are in the process of being developed. The largest impact on the future efficiency of the installed base of cooking equipment will depend more on factors that influence the purchase decision criteria for this equipment than on technology developments. Quite simply, the installed base of commercial gas-fired cooking equipment efficiencies could be significantly increased if customers purchased more efficient models. However, the cost premium associated with the high efficiency cooking equipment does not always justify the resultant savings.

Cost reduction R&D possibly in cooperation with GRI and EPRI could increase the market penetration of high efficiency models. An alternative approach is setting up guidelines and standards. The savings potential is 0.14 quad per year.

Advanced technologies involve the integrated restaurant concept where the kitchen is optimized to reduce overall energy use including HVAC. Reduction in the heat generated by cooking equipment directly translates to reduction in kitchen ventilation requirements. Though HVAC is not a part of this study, the savings potential of 0.1 quad per year, from an integrated restaurant concept cannot be ignored.

Office Equipment: A wide range of energy efficiency in the currently available models indicates a need for an economic/market assessment to understand the market drivers and to develop ways to accelerate penetration of higher efficiency models. R&D possibly in cooperation with EPRI and utilities to help energy efficient equipment in the marketplace is suggested. The savings potential is estimated at close to 0.1 quad per year.

Of all the energy end-uses discussed in this study, the energy use literature and data on this end-use is the least developed. A field data collection effort to better estimate the inventories, the operational characteristics, and the energy use is necessary. Joint efforts with utilities and EPRI could make for a significant contribution to the database and literature for this growth sector.

Laundry: Laundry equipment shows significant energy savings potential with many technologies available today as well as with advanced technologies where R&D could significantly reduce energy use.

All cold wash would require consumer acceptance and a study of the detergent chemistry. Eliminating the need for hot water could result in savings of 47×10^{12} Btu/yr. Higher spin speed washers could save drying energy. This combined with high efficiency dryers could potentially save 55×10^{12} Btu/yr. Economic/market assessment and accelerating market penetration based on this assessment would result in savings of this magnitude.

Desiccant based dryers require R&D to provide potential savings of 61×10^{12} Btu/yr. This R&D could possibly be conducted in cooperation with GRI and industry.

3.7 References

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4.0 Baseline Energy Consumption Estimates

For the commercial and institutional sectors, end-uses other than lighting and HVAC are analyzed. These end-uses include refrigeration, cooking, office equipment, water heaters, vending machines, water coolers, laundry, and non-office electronics.

4.1 Methodology Overview

In this section we have described the methodology in general terms as it applies to all of the above end-uses. In the subsequent sections, we have indicated the data sources and the steps specific to each end-use.

Baseline energy consumption estimates were developed using two different methods. Initially, a detailed literature search and interviews were conducted to establish energy use estimates in each of the end-uses as derived by various organizations such as Electric Power Research Institute (EPRI), California Energy Commission (CEC), Bonneville Power Authority (BPA), Southern California Edison (SCE), Pacific Gas & Electric (PG&E), Thermo-Electron Corporation (TECO) and Lawrence Berkeley Labs (LBL). Their estimates of end-use energy consumption were primarily derived from engineering analyses to estimate energy utilization index (EUI) data by building type and end-use. BPA used metered data to establish their baseline energy use estimates.

The EUI data from the above studies were typically provided for the following commercial building types: offices, schools, hospitals, hotels, retail stores, grocery stores, restaurants, and warehouses. Total square footage for each of these building types was obtained from the US Department of Energy May 1989 report "Nonresidential Buildings Energy Consumption Survey: Commercial Buildings Consumption and Expenditures 1986" (NBECS) (REF 1) by Energy Information Administration. This report provided 1986 building inventory data. We multiplied this times the EUI to derive estimates of the energy consumption by end-use by building type and aggregated the energy use across building types to calculate the total annual energy use at the national level. This was done for each end use except laundry and non-office electronics. Other sources of data for these two end-uses were not found in the literature.

We also estimated the baseline energy use independently using an appliance inventory based methodology and compared the results with the EUI based energy use numbers. The methodology based on inventory estimates by equipment type by type of establishment is discussed below. By contacting specialists in the field and at Arthur D. Little, and reviewing recent reports, estimates of hours of on-time, utilization factors and typical rated capacity (BTU/hr) by type of establishment were obtained. The utilization factor incorporates both the percent of peak capacity and the standby mode of operation. The equation below shows how these data were used to calculate the annual energy use in the U.S. by type of establishment.

$$\text{Energy Use/Yr} = (\text{Installed Inventory}) (\text{Typical Operating Hours/Yr}) (\text{Utilization Factor}) (\text{Rated Capacity})$$

The energy use was then aggregated across all types of establishments for each end-use.

For the commercial laundry equipment, energy use per pound of clothes was derived based on a detailed analysis of the washing and drying cycles. This is a significant departure from the general methodology described above.

For the non-office electronics end-use, electromedical, telephone, point-of-sale terminals and automated teller machines were analyzed. Methodology was similar to the one described above.

Figure 4-1 shows a flowchart of the methodology used for estimating the baseline energy use for each of the end-uses.

Annual shipments of end-use appliance for the latest 15 to 20 years are obtained from various sources. (References 2, 3, 4, 5, 6, 7, 8). Current Industrial Reports by the Department of Commerce, Gas-Appliance Manufacturer's Association were the original sources for some of the data obtained from the magazines and trade publications. This shipment data and estimated mean life of the appliance are provided as inputs to an Arthur D. Little-Appliance Age Distribution model (ADLAAD). The model assumes the lifetime of a particular piece of end-use equipment is a random variable with a Weibull distribution and then calculates the amount of shipments in year X that will be in service in year X+1, X+2, X+3, etc. It does this for each year in which shipment data is entered. The inventory in year N is then determined by summing the amount of shipment that are still in service in year N from each of the previous years shipments.

Table 4-1 is an example of the output of the ADLAAD model, showing the number of appliances in service in a given year from shipments in all prior years. The inventory for 1990 is 2,099,474 units. The number of years for which shipment data is provided should substantially exceed the mean life span of the appliance for the decay function to work accurately. The output of the ADLAAD model is the total U.S. inventory of the appliance in the latest year (1989-90 for this study).

The next step is to distribute the total appliance inventory over different building types to obtain inventory by type of establishment. Establishments in the commercial/institutional sector include offices, schools, hospitals, hotels/motels, retail stores, grocery stores, restaurants, and warehouses. The need for inventory by type of establishment arises from the fact that appliance use varies considerably from one type of establishment to another. This necessitates energy use calculations by type of establishment before aggregated baseline energy use for a given end-use can be estimated.

*Arthur D. Little Appliance Age Distribution Model

**Non-residential Buildings Energy Consumption Survey 1989.

Figure 4-1: Flowchart for Estimating U.S. Baseline Energy Use

The inventory allocation by establishment type is based on number of appliances per establishment as estimated by specialists, and the number of establishments by building type obtained from the 1986 (Ref. 1) Non-residential Buildings Energy Consumption Survey (NBECS), by U.S. DOE (1989). Since the number of appliances per establishment is based on subjective judgement, we use only the relative ratios among building types and allocate the total inventory obtained from shipment data to the various types of establishments.

Besides the appliance inventory by building type, we need to estimate the operating hours, typical size and utilization factors to obtain energy use. Operating hours per year are the hours for which the equipment is powered on. Operating hours for appliances by building type are estimated by specialists in each end-use, typical rated capacities are obtained from manufacturers catalogs as well as the sales data and utilization factors are obtained from survey data or specialists estimates. Utilization factors account for percent of peak capacity and the ratio of actual on-time to total operating hours. Data sources are discussed in greater detail within the Section on each end-use.

Energy Use (annual) is calculated as the product of inventory, operating hours, typical capacity, and utilization factor. The energy use is then aggregated across all building types to obtain a baseline national energy use.

The energy use estimated above is compared with similar estimates by other organizations. Most of the results compare well with other sources. Wherever differences exist among the various sources, we have attempted to find the rationale for those differences.

4.2 Refrigeration

4.2.1 Refrigeration Inventory Data

The 1990 inventory data for refrigeration were developed using annual shipment data and mean equipment life as inputs to the Arthur D. Little Appliance Age Distribution Model (ADLAAD). The shipment data for refrigeration equipment were obtained from "The Air Conditioning, Heating and Refrigeration News" for the years 1967 to 1990. (Ref. 2) Every year this publication provides a statistical panorama of Heating, Ventilating, and Air Conditioning (HVAC) and refrigeration equipment including statistics on shipments, trends in the industry and discussion of key issues. Past copies of this publication were obtained for this data. Mean equipment life was obtained from a book, Life Spans Products of Man. (Ref. 10)

The Arthur D. Little inventory data were cross-checked using two sources. The refrigeration data were checked against a 1989 Arthur D. Little report to DOE, "Impact of a CFC Ban on the Cost and Performance of Household Refrigerators, Centrifugal Chillers, and Commercial/Industrial Refrigeration Systems" (Ref. 11) and a 1978 TECO report to DOE "Energy Conservation Opportunities in Commercial Appliances". (Ref. 12) The different sources showed results within close range of the Arthur D. Little estimates.

Table 4-1: Output of ADLAAD Model

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4.2.2 Refrigeration Baseline Energy Consumption

Energy use data for refrigeration was developed using the following methodology. The refrigeration sector was divided into three categories: unit coolers, ice makers and commercial refrigeration. Each of these subsectors were evaluated by building type; office, retail, restaurant, grocery, schools, hotel, hospital and warehouse.

"Unit Coolers," for the purposes of this report, are the free standing refrigerated display cases commonly used in commercial and institutional kitchens, convenience stores, and aisle locations in supermarkets to hold and display frozen foods, cold beverages, and fresh foods. The unit cooler is self-contained, with the refrigerating system built in and heat is rejected from the refrigeration cycle to the building interior air. The mean life of unit coolers is estimated at fifteen years. The total inventory for ice makers was obtained through our contacts with this industry, based on estimates made by key manufacturers of ice makers.

"Commercial Refrigeration Systems," as used in this report are the refrigerated display cases used in supermarkets to hold and display frozen foods, cold beverages and fresh foods. The refrigeration systems are located remotely from the display cases, interconnected by long runs of liquid and suction tubing. The compressor units can consist of a single compressor, or multiple, rack mounted, parallel compressors. The mean life of commercial refrigeration systems is estimated at fifteen years.

Spreadsheets were set up to calculate energy use data for each subsector by building type. The Arthur D. Little energy use per year was estimated by multiplying the end use inventory times appliance operating hours times rated capacity times utilization factor, by building type and for each type of refrigeration system.

Appliance operating hours, utilization factors, and efficiency data were estimated by Arthur D. Little specialists in refrigeration and through discussions with manufacturers and review of product literature. The Coefficients of Performance (COP) have been estimated for use in calculating potential energy savings, but were not used for calculating the baseline energy consumption. The COP has already been accounted for in the rated capacity and hours of operation. In Tables 4-2, 4-3, and 4-4, we present the input data and the estimated baseline energy use by building type for unit coolers, ice makers and central commercial refrigeration systems respectively.

Refrigeration systems in all buildings are powered on 8760 hours/year. However, the utilization factor accounts for the percent of peak capacity the unit is operating at, on an average, during the year as well as the percent of operating time relative to total time.

Operating time is when the compressor is in operation. Utilization factor takes into account both the standby mode of operation, as well as, the percent of peak capacity when in the operating mode. Based on product literature and discussions with manufacturers, Arthur D. Little specialists estimated the typical rated capacities and utilization factors for the various equipment types.

Tables 4-2, 4-3, and 4-4 follow the same calculation logic. A column by column explanation is provided here. As mentioned earlier, the number of buildings by type are obtained from the NBECS survey by the U.S. DOE (Ref. 1). Number of units per establishment were estimated by ADL specialists in refrigeration markets. A fractional number of units such as 0.5 means that one in every two establishments contains one unit of this appliance. The next column in these tables "ADL inventory for distribution" is the product of the estimated number of units per establishment times the number of buildings. This column is summed up and the ratio of the appliance inventory for each building type to the total is used to apportion the total U.S. inventory arrived at from the shipment data. The apportioned inventory is shown in column headed "1990 estimated inventory". In case of the unit coolers, for example, total inventory for 1990 was 2,099,474 from the ADLAAD model. The ratio for office buildings' unit coolers to the total is $307,000/2,341,500$ or 13.11%. Applying this ratio to the total unit cooler inventory of 2,099,474, we obtained 275,267 units for offices. The total inventory for the ice makers was obtained from ADL's contacts with key manufacturers of this equipment.

The next three columns operating hours/year, utilization factor and typical rated capacity have been explained earlier. The COP though not used in the energy calculations is shown here for the typical piece of equipment in that class to provide a basis for the current energy use calculations and to allow projections of energy use as efficiency is improved.

The U.S. electricity use in Kwh/year is the product of the inventory times the operating hours/year times the utilization factor times the rated capacity in Kw. This is converted to primary energy input at the power plant using a conversion factor of 11,200 Btu per Kwh.

Arthur D. Little's energy use estimate of 744 trillion Btu's for the refrigeration end use was compared with Bonneville Power Administration (BPA) and Electric Power Research Institute (EPRI) values for the same. BPA energy use values were given as Energy Use Intensities (EUI's), which we multiplied by average square footages for each building type. The comparisons were within a reasonable range as shown in Figure 4-2.

Table 4-2: Unit Coolers Energy Use Estimates by Building Type

1990 ADL Inventory = 2,099,474 unit coolers based on shipment data and ADLAAD Model.

Building Type	1986 NBECS Number of Buildings	ADL Estimate #Units/ Building	Inventory for Distribution Ratios (Col. 1 x Col. 2)	1990 Estimated Inventory	Operating Hrs/Yr	Utilization Factor	Typical Rated Cap (kW)	Typical COP	1990 ADL Energy/yr (kWh)	U.S. Annual Energy Use* (Btu/yr)
Office	614,000	0.5	307,000	275,267	8,760	0.5	1.4	1.5	1.69E+09	1.89E+13
Retail	1,287,000	0.5	643,500	576,985	8,760	0.5	1.4	1.5	3.54E+09	3.96E+13
Restaurant	201,000	3	603,000	540,672	8,760	0.5	1.4	1.5	3.32E+09	3.71E+13
Grocery	102,000	3	306,000	274,371	8,760	0.7	1.4	1.5	2.36E+09	2.64E+13
Schools	241,000	1	241,000	216,089	8,760	0.4	1.4	1.5	1.06E+09	1.19E+13
Hotel	137,000	1	137,000	122,839	8,760	0.5	1.4	1.5	7.53E+09	8.44E+12
Hospitals	52,000	2	104,000	93,250	8,760	0.5	1.4	1.5	5.72E+08	6.40E+12
Warehouse	549,000	0	0	0	8,760	0.5	1.4	1.5	0.00E+00	0
Total	3,183,000		2,341,500	2,099,474					1.33E+10	1.49E+14

*Primary Electric Conversion 11,200 Btu/kWh

Notes:

- Inventory obtained from shipment data and ADLAAD Model. Shipment data from Air Conditioning, Heating and Refrigeration News - Statistical Panorama, April issues, 1967 to 1991.
- # units/building, operating hours, utilization factor, rated capacity and COPs obtained from product literature, vendor interviews, and ADL specialists.

Table 4-3: Ice Maker Energy Use Estimates by Building Type

1990 ADL Inventory = 1,200,000 ice makers based on contacts with key manufacturers.

Building Type	1986 NECS Number of Buildings	ADL Estimate #Units/ Building	Inventory for Distribution Ratios (Col. 1 x Col. 2)	1990 Estimated Inventory	Operating Hrs/Yr	Utilization Factor	Typical Rated Cap (kW)	Typical COP	1990 ADL Energy Use (x10 ³ kWh/yr)	U.S. Annual Energy Use* (x 10 ³ Btu/yr)
Office	614,000	0.1	61,400	33,581	8,760	0.45	3	0.76	3.97	4.45
Retail	1,287,000	0.1	128,700	70,388	8,760	0.45	3	0.76	8.33	9.32
Restaurant	201,000	1.5	301,500	164,898	8,760	0.45	2	0.76	13.0	14.50
Grocery	102,000	0.5	51,000	27,893	8,760	0.45	3	0.76	3.3	3.70
Schools	241,000	0.5	120,500	65,904	8,760	0.45	3	0.76	7.80	8.73
Hotel	137,000	7	959,000	524,497	8,760	0.30	1.5	0.76	20.7	23.1
Hospitals	52,000	11	572,000	312,839	8,760	0.45	3	0.76	37.0	41.4
Warehouse	549,000	0	0	0	0	0	0	0	0	0
Total	3,183,000		2,194,100	1,200,000					94.1	105.2

*Primary Electric Conversion 11,200 Btu/KWh

Notes:

1. Utilization Factor reflects a 30% shut-off when on and 70-100% of peak capacity when making ice. Rated Capacity assumes a 1200lb/day ice machine which is the most common unit in use in 1990. Efficiency assumes a 1200lb/day ice machine. Four manufacturers products had an average efficiency of 6.6 kWh/100lbs of ice which is equivalent to 76% efficiency.
2. Total inventory obtained from contacts with key manufacturers of this equipment.
3. Number of units per building operating hours, utilization factor, rated capacity and COPs obtained from product literature, vendor interviews, and ADL specialists.
4. Efficiency for ice makers is defined as the ratio of the theoretical amount of energy required to make a given quantity of ice to the actual energy consumption to make the same quantity of ice.

Table 4-4: Commercial Refrigeration (Centralized) Systems Energy Use by Building Type

1990 ADL Inventory = 1,372,685 commercial refrigeration systems based on shipment data and ADLAAD Model.

Building Type	1986 NBES Number of Buildings	ADL Estimate #Units/ Building	Inventory for Distribution Ratios (Col. 1 x Col. 2)	1990 Estimated Inventory	Operating Hrs/Yr	Utilization Factor	Typical Rated Cap (kW)	Typical COP	1990 ADL Energy Use (kWh/yr)	U.S. Annual Energy Use* (Btu/yr)
Office	614,000	0	0	0	0	0	0	0	0.00E+00	0
Retail	1,287,000	0	0	0	0	0	0	0	0.00E+00	0
Restaurant	201,000	0.5	100,500	125,280	8,760	0.5	3	1.6	1.65E+09	1.84E+13
Supermarket	30,000	5	150,000	187,000	8,760	0.70	25	1.5	2.86E+10	3.20E+14
Convenience	72,000	1	72,000	90,000	8,760	.70	5	1.8	5.5E+9	6.16E+13
Schools	241,000	0	0	0	0	0	0	0	0.00E+00	0
Hotel	137,000	1.5	205,500	256,170	8,760	0.5	2.5	1.8	2.81E+09	3.14E+13
Hospitals	52,000	2	104,000	129,643	8,760	0.5	3	1.6	1.70E+09	1.91E+13
Warehouse	549,000	0.33	181,170	225,841	8,760	0.5	3.5	1.3	3.46E+09	3.88E+13
Total	3,183,000		1,101,170	1,372,685					4.37E+10	4.90E+14

*Primary Electric Conversion 11,200 Btu/KWh

Notes:

1. Inventory obtained from shipment data and ADLAAD Model. Shipment data from Air Conditioning, Heating and Refrigeration News, Statistical Panorama, April issues, 1967 to 1991.
2. Number of units per building operating hours, utilization factor, rated capacity and COPs obtained from product literature, vendor interviews, and ADL specialists.

Figure 4-2: Comparison of Arthur D. Little Baseline Refrigeration Energy Use with Estimates from Other Sources

Sources:

EPRI: "Efficient Electricity Use: Estimates of Maximum Energy Savings," EPRI CV-6746, Project 2788, March 1990. (Ref. 23)

BPA: Taylor Z.T., R.G. Pratt "Description of Electric End Use in Commercial Buildings in the Pacific Northwest, End-Use Load and Consumer Assessment Program (ELCAP), prepared by Battelle, PNWL, April 1989. (Ref. 18)

4.3 Cooking Equipment

4.3.1 Cooking Inventory Data

We identified six major types of cooking equipment and analyzed them in detail. These are broilers, fryers, griddles, ovens, ranges and steamers. In each case these were further subdivided by gas and electric fuel. Microwave ovens and toasters and melters were screened out due to their very low energy use.

The cooking equipment inventory was obtained from two sources:

- Data on commercial establishments was obtained from "The NAFEM Equipment and Supply Study, Volume C: Cooking and Reconstituting Equipment," (Ref. 3). This source provides the number of establishments and the total number of units by equipment type.
- Data on institutional cooking equipment was obtained from "1989 Equipment and

Supplies Census, Section 1: Food Preparation Equipment," (Ref. 13). This source provides the same data as NAFEM for the institutional sector.

- For cooking equipment inventory, we did not need to use the ADLAAD model since inventory data was already available from the above sources. Shipment data and life span were therefore not required for cooking equipment.

Table 4-5 shows the inventory by type of equipment and by fuel.

The first column of numbers in Table 4-5 shows the percentage of total establishments that have one or more units of a specific equipment type. For example, 9% of all establishments have one or more overfired broiler, 8.2% have the salamander type and 16% have underfired or charboilers. As shown in Column 2, the total number of commercial establishments is 240,000 and the number of institutional establishments is 87,000. Commercial establishments include restaurants, grocery stores, office cafeterias, etc. Institutional establishments include hospitals, universities, schools, etc. The average number of units of an equipment type per establishment is shown in Column 3. The total number of units by equipment type is obtained by multiplying Column 1 x Column 2 x Column 3, and is shown in Column 4. The percent split between gas and electric and, therefore, the number of gas units and electric units are obtained in the last four columns. Data obtained from the above two sources is shown in Table 4-5.

Since equipment utilization varies by building types, inventory needs to be allocated by building type before energy use can be estimated. Percentage distribution of each type of equipment over various building types was made using NBECS (Ref. 1) data for the number of establishments and Arthur D. Little specialists' judgement on the number of units per establishment. The total inventory of each type of cooking equipment obtained from NAFEM (Ref. 3) and Food Management Equipment Census* (Ref. 4) was distributed over types of establishments using these percentages. Table 4-6 shows the distributed inventory by type of equipment, type of fuel, and type of establishment.

We should note that the total number of establishment in the NBECS data (Column 1 in the tables) is substantially higher than the number of establishments shown in NAFEM and Food Management magazine. This is due to NAFEM excluding small restaurants and other establishments which generally do not have commercial cooking equipment. The number of broilers/establishment (Column 2 in the table, for example) is based on judgement of professionals with many years of experience with cooking equipment, markets, and technologies.

Column 3 is the relative distribution of broilers by building type based on number of buildings (Column 1) and number of broilers per establishment (Column 2). Percent of total inventory in Column 4 is based on the relative distribution of equipment such as in Column 3 and represents the percentage of total number of broilers in Column 3. The total broiler inventory in 1990 obtained from NAFEM and Food Management Magazine is then distributed by building type (Column 5) using the percentages in Column 4. The gas to electric broilers are maintained in the same

Table 4-5: Inventory of Commercial/Institutional Cooking Equipment by Type and by Fuel

Equipment Class	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8
	% Establishments with one or more	Total # Establishments*	Avg. # per Establishment	Total	%Gas	%Elec	#Gas	#Elec
Broilers—Commercial								
Overfired	9.00%	240,000	1.3	28,080				
Salamander	8.20%	240,000	1.2	23,616				
Underfired/Charbroilers	16.00%	240,000	1.2	46,080				
Total Broilers—Commercial				97,776				
Broilers—Institutional								
Overfired	13.00%	87,000	2.12	23,977				
Salamander	13.40%	87,000	2.03	23,666				
Conveyorized	2.30%	87,000	1.63	3,262				
Underfired/Charbroilers	14.60%	87,000	1.92	24,388				
Total Broilers—Institutional				75,292				
Total Broilers				173,068	91%	9%	157,492	15,576
Fryers—Commercial								
Pressure	12.40%	240,000	2.2	65,472				
Floor Mounted	52.10%	240,000	2.3	287,592				
Countertop	37.80%	240,000	1.7	125,664				
Total Fryers—Commercial				478,728				
Fryers—Institutional								
Pressure	4.80%	87,000	2.97	12,403				
Floor Mounted	74.00%	87,000	6.51	419,114				
Countertop	25.90%	87,000	2.38	53,629				
Continuous	1.30%	87,000	1.8	2,036				
Total Fryers—Institutional				487,181				
Total Fryers				965,909	56%	42%	560,227	405,682

Table 4-5: Inventory of Commercial/Institutional Cooking Equipment by Type and by Fuel (Continued)

Equipment Class	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8
	% Establishments with one or more	Total # Establishments*	Avg. # per Establishment	Total	% Gas	% Elec	# Gas	# Elec
Griddles—Commercial								
Griddles & Grills	61.70%	240,000	1.4	207,312				
Sandwich Grills	6.75%	240,000	1.4	22,680				
Total Griddles—Commercial				229,992				
Griddles—Institutional								
Griddles & Grills	65.80%	87,000	3.75	213,694				
Hot Dog Grills	14.00%	87,000	2.44	29,719				
Sandwich Grills	13.50%	87,000	2.73	32,064				
Total Griddles—Institutional				275,477				
Total Griddles				505,469	50%	50%	252,734	252,734
Ovens—Commercial								
Deck	27.80%	240,000	1.9	126,768				
Convection (1/2)	12.10%	240,000	1.2	34,848				
Convection (Full)	31.80%	240,000	1.6	122,112				
Combination	4.70%	240,000	1.6	18,048				
Rotary Rack	2.10%	240,000	1.1	5,544				
Rotary	1.80%	240,000	1.1	4,752				
Cook & Hold	14.50%	240,000	1.6	55,680				
Conveyor	3.90%	240,000	1.4	13,104				
Dough Proofer	11.20%	240,000	1.2	32,256				
Total Ovens—Commercial				286,344				
Ovens—Institutional								
Deck	52.30%	87,000	6.91	314,412				
Convection (1/2 + Full + Combi)	86.60%	87,000	10.51	791,844				
Rotary	18.20%	87,000	2.29	36,260				
Cook & Hold	11.00%	87,000	2.25	21,533				
Conveyor (Compact)	1.00%	87,000	1.86	1,618				
Conveyor (Full Size)	2.20%	87,000	2	3,828				
Total Ovens—Institutional				1,169,495				
Total Ovens				1,455,839	55%	45%	800,711	655,128

Table 4-5: Inventory of Commercial/Institutional Cooking Equipment by Type and by Fuel (Continued)

Equipment Class	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8
	% Establishments with one or more	Total # Establishments*	Avg. # per Establishment	Total	%Gas	%Elec	#Gas	#Elec
Ranges - Commercial								
Light Duty	17.40%	240,000	1.2	50,112				
Heavy Duty	35.60%	240,000	1.6	136,704				
Total Ranges—Commercial				186,816				
Ranges—Institutional								
Light Duty	12.60%	87,000	7.24	79,365				
Heavy Duty	75.60%	87,000	6.75	443,961				
Total Ranges—Institutional				523,326				
Total Ranges				710,142	91%	9%	646,229	63,913
Steamers—Commercial								
Atmospheric	7.20%	240,000	1.5	25,920				
Low Pressure	7.10%	240,000	1.2	20,448				
High Pressure	6.60%	240,000	1.5	23,760				
Total Steamer—Commercial				70,128				
Steamers—Institutional								
Conv. (Pressureless)	16.10	87,000	2.78	38,939				
Conv. (Pressureless)	31.20%	87,000	4.06	110,205				
Low Pressure	23.70%	87,000	5.84	120,415				
High Pressure	40.500%	87,000	4.84	170,537				
Total Steamers—Institutional				440,096				
Total Steamers				510,224	33%	67%	166,374	341,850

Sources:
Food Management Equipment and Supplies Census, 1987 (Ref. 4)
NAFEM Equipment and Supply Study, 1989 (Ref. 3)
Restaurant and Institutions: Bureau of Foodservice Research
Arthur D. Little, Inc.

*Total # Establishments = Eating & Drinking Places with sales of \$100,000 or more

Table 4-6: Distribution of Cooking Equipment Inventory by Type of Establishment

Building Type	1986 NBECs Number of Buildings	Relative # Broil Per Establishment	Relative Distribution of Broilers	% of Total Inventory	1990 Broiler Inventory	Fryers 1990 Inventory	Griddles 1990 Inventory
Restaurant	186,000	1.0	186,000	52	81,616(G) 8,072(E)		
Hotels	38,000	1.0	38,000	12	18,238(G) 1,808(E)		
Hospitals	12,000	1.0	12,000	4	6,282(G) 621(E)		
Schools	67,000	0.5	33,500	9	14,313(G) 1,416(E)		
Grocery	45,000	0.0	0	0	0		
Retail	73,000	1.0	73,000	20	32,032(G) 3,168(E)		
Offices	20,000	0.5	10,000	3	4,965(G) 491(E)		
Gas Total					157,491(G)		
Elec. Total					15,576(E)		
Total					173,067		
					0.91	0.58	0.50
					0.09	0.42	0.50

Building Type	1986 NBECs Number of Buildings	Broilers				Fryers				Griddles			
		Relative # Broil Per Establishment	Relative Distribution of Broilers	% of Total Inventory	1990 Broiler Inventory	Relative # Fryers Per Establishment	Relative Distribution of Fryers	% of Total Inventory	1990 Fryer Inventory	Relative # Griddle Per Establishment	Relative Distribution of Griddles	% of Total Inventory	1990 Griddle Inventory
Restaurant	186,000	1.0	186,000	52	81,616(G) 8,072(E)	2	372,000	50	278,423(G) 201,617(E)	1	186,000	46	116,690(G) 116,690(E)
Hotels	38,000	1.0	38,000	12	18,238(G) 1,808(E)	2	76,000	11	62,371(G) 45,165(E)	1	38,000	10	26,140(G) 26,140(E)
Hospitals	12,000	1.0	12,000	4	6,282(G) 621(E)	1	12,000	2	10,715(G) 7,759(E)	1	12,000	4	8,981(G) 8,981(E)
Schools	67,000	0.5	33,500	9	14,313(G) 1,416(E)	1	67,000	9	48,826(G) 35,357(E)	1	67,000	16	40,927(G) 40,927(E)
Grocery	45,000	0.0	0	0	0	1	45,000	6	33,680(G) 24,389(E)	0	0	0	0
Retail	73,000	1.0	73,000	20	32,032(G) 3,168(E)	2	146,000	20	109,274(G) 79,129(E)	1	73,000	18	45,798(G) 45,798(E)
Offices	20,000	0.5	10,000	3	4,965(G) 491(E)	1	20,000	3	16,939(G) 12,266(E)	1	20,000	16	14,198(G) 14,198(E)
Gas Total					157,491(G)				560,227(G) 405,682(E)				252,734(G) 252,734(E)
Elec. Total					15,576(E)				965,909				505,468

Notes:

1. Inventory data from NAFEM and Food Management (Ref. 3&4)
2. Distribution of inventory by building type based on NBECs data (Ref. 1) and ADL estimates of relative number of units per establishment.
3. G = gas fuel type and E = electric fuel type.

Table 4-6: Distribution of Cooking Equipment Inventory by Type of Establishment (continued)

		Ovens 1990 Inventory		Ranges 1990 Inventory		Steamers 1990 Inventory
	Gas	800,711	Gas	642,229	Gas	168,374
	Electric	655,128	Electric	63,913	Electric	341,850
	Total	1,455,839	Total	710,142	Total	510,224
		0.55 0.45		0.91 0.09		0.33 0.67

Building Type	1986 NBECS Number of Buildings	Ovens			Ranges			Steamers					
		Relative # Ovens Per Establishment	Relative Distribution of Ovens	% of Total Inventory	1990 Oven Inventory	Relative # Ranges Per Establishment	Relative Distribution of Ranges	% of Total Inventory	1990 Ranges Inventory	Relative # Steamers Per Establishment	Relative Distribution of Steamers	% of Total Inventory	1990 Steamers Inventory
Restaurant	186,000	1.0	186,000	29	229,946(G) 188,138(E)	1	186,000	37	238,568(G) 23,595(E)	1	186,000	42	70,453(G) 143,041(E)
Hotels	38,000	3.0	114,000	19	154,533(G) 126,437(E)	2	76,000	17	106,885(G) 10,571(E)	2	76,000	19	31,565(G) 64,086(E)
Hospitals	12,000	3.0	36,000	7	53,094(G) 43,441(E)	2	24,000	6	36,724(G) 3,632(E)	1	12,000	3	5,423(G) 11,009(E)
Schools	67,000	2.0	134,000	20	161,300(G) 131,973(E)	1	67,000	13	83,674(G) 8,276(E)	1	67,000	15	24,710(G) 50,169(E)
Grocery	45,000	1.0	45,000	7	55,632(G) 45,517(E)	1	45,000	9	57,718(G) 5,708(E)	0	0	0	0
Retail	73,000	1.0	73,000	11	90,248(G) 73,839(E)	1	73,000	14	93,632(G) 9,260(E)	1	73,000	16	27,651(G) 56,140(E)
Offices	20,000	2.0	40,000	7	55,957(G) 45,783(E)	1	20,000	4	29,028(G) 2,871(E)	1	20,000	5	8,572(G) 17,404(E)
Gas Total Elec. Total					800,711(G) 655,128(E)				646,229(G) 63,913(E)				168,374(G) 341,850(E)
Total					1,455,839				710,142				510,224

Notes:

1. Inventory data from NAFEM and Food Management
2. Distribution of inventory by building type based on NBECS data and ADL estimates of relative number of units per establishment.
3. G = gas fuel type and E = electric fuel type.

proportion as total gas and electric broilers. The mix of gas to electric is not varied by building type.

The same process as discussed above is repeated in Table 4-6 for fryers, griddles, ovens, ranges, and steamers.

4.3.2 Cooking Baseline Energy Consumption

Energy use data for cooking were developed using the following methodology. Cooking equipment was subdivided into griddles, ovens, ranges, fryers, broilers, and steamers by gas and electric fuel type. Each of these equipment types were evaluated by building type: office, retail, restaurant, grocery, schools, hotel, hospital and warehouse.

The cooking inventory data estimated, as discussed above, were entered into spreadsheets which calculated energy use data for each subsector by building type. The energy use per year estimate was calculated by multiplying the end use inventory, times appliance operating hours, times rated capacity, times a utilization factor. The utilization factor incorporates the average percent of peak capacity for the equipment when it is operating, as well as the standby mode of operation.

Cooking operating hours data were obtained from cooking equipment specialist Charlie Claar at Penn State University and Arthur D. Little specialists in this area. As an example of the methodology used to estimate operating hours per year, restaurants were assumed to be open 7 days/week with fryers, griddles, and broilers operating on average for 10 hours/day. This resulted in annual operating hours for this equipment in restaurants of 3650 hours/year. Schools, for comparison, were assumed to be open 180 days/year with fryers, griddles, and broilers operating on average for 3 hours/day during lunch. This resulted in operating hours for this same equipment in schools of 540 hours/year. This methodology was applied to all the buildings and cooking equipment types, to estimate the operating hours per year.

Utilization factors, rated capacities, and efficiency data were obtained from discussions with Arthur D. Little specialists; Charlie Claar, Penn State University; Don Fisher, PG&E; Bettie Ferlin, PG&E; and Jim Hurley, TECO. In addition, product literature was reviewed and equipment manufacturers interviewed. The efficiency or COP numbers have been provided in the tables for use in the upcoming tasks, but were not incorporated into the calculations for the baseline energy consumption. The efficiency numbers are implicitly taken into account in the rated capacity value and the operating hours. The utilization factor data were derived from actual performance data at the Test Kitchen at PG&E and estimates by Arthur D. Little cooking specialists. Rated capacity values were obtained from product literature and manufacturers by Arthur D. Little as a range, but the most typical size was assumed in the calculations for each type of cooking equipment. In restaurants, for example, the total rated capacity of gas-fired broilers range from 60,000 - 110,000 Btu/hr and electric broilers range from 40,000-60,000 Btu/hr. For the broilers, 90,000 Btu/hr was assumed for gas and 45,000 for electric equipment. These are the

sizes that are assumed to be most typical. This methodology was used for all cooking equipment types, and reviewed by each of the specialists for their inputs. The data and the estimated energy use are shown in Tables 4-7 to 4-13. Each table represents a specific building type. Table 4-14 shows aggregated energy use over all building types by equipment type.

Arthur D. Little's aggregated energy use values were compared with Bonneville Power Administration (BPA), Electric Power Research Institute (EPRI), TECO, and LBL values. BPA energy use values were given as EUI's which we multiplied by average square footage for each building type.

Figure 4-3 shows the comparison of electric and gas cooking equipment baseline energy use from different sources. Our estimates of 1990 electric cooking energy is 251×10^{12} Btu's using a conversion factor of 11,200 Btu/Kwh. Bonneville Power Administration (BPA) data from ELCAP study (Ref. 14) shows 212×10^{12} Btu's for 1988 data when extrapolated from the Pacific Northwest (PNW) region to the U.S.A. EPRI 1987 (Ref. 15) study shows an estimate of 164×10^{12} Btu's, while 1982 TECO (Ref. 16) data shows an even lower estimate of 83×10^{12} Btu's. One trend that can be seen here is the growth in the electric cooking energy use over the years.

For gas cooking energy use, the Arthur D. Little Estimate of 289.6×10^{12} Btu's compares well with 1989 TECO estimate of 263, 1982 TECO estimate of 241×10^{12} Btu's and 1975 TECO (Ref. 12) estimate of 214×10^{12} Btu's. The LBL (Ref. 17) estimate of 641×10^{12} Btu's is considered out of reasonable range. The gas cooking baseline estimates also indicate some growth over the years.

Table 4-7: Cooking Equipment Energy Use in Office Buildings

Cooking Equipment	Fuel	1990			Rated Cap (Btu/hr)	Eff.	1990 ADL	US Annual
		Office Inventory	Operating Hrs/Yr	Utilization Factor			Energy/yr (kWh)	Energy Use* (Btu/yr)
Broilers	Gas	4,965	1260	0.6	90000	0.25	9.90E+07	3.38E+11
	Electric	491	1260	0.6	45000	0.5	4.90E+06	5.48E+10
Fryers	Gas	16,939	1260	0.15	100000	0.35	9.38E+07	3.20E+11
	Electric	12,266	1260	0.15	50000	0.6	3.40E+07	3.80E+11
Griddles	Gas	14,198	1260	0.2	90000	0.4	9.44E+07	3.22E+11
	Electric	14,198	1260	0.2	50000	0.58	5.24E+07	5.87E+11
Ovens	Gas	55,957	1260	0.75	85000	0.4	1.32E+09	4.50E+12
	Electric	45,783	1260	0.5	50000	0.68	4.23E+08	4.73E+12
Ranges	Gas	29,028	1260	0.2	160000	0.45	3.43E+08	1.17E+12
	Electric	2,871	1260	0.2	60000	0.7	1.27E+07	1.42E+11
Steamer	Gas	8,572	1260	0.2	160000	0.5	1.01E+08	3.46E+11
	Electric	17,404	1260	0.2	90000	0.65	1.16E+08	1.30E+12
Total		222,672				Gas	2.05E+09	6.99E+12
						Elect.	6.42E+08	7.19E+12
						Total	2.69E+09	1.42E+13

* Gas Conversion 3,413 Btu/kWh and Electric Conversion 11,200 Btu/kWh

Notes: 1. Rated capacities obtained from product literature and manufacturers.

2. Utilization factors from PG&E Kitchen data, ADL specialists, and other experts.

3. Operating hrs/yr estimates made by ADL specialists and outside experts.

Table 4-8: Cooking Equipment Energy Use in Retail Establishments

Cooking Equipment	Fuel	1990			Rated Cap (Btu/hr)	Eff.	1990 ADL	US Annual
		Retail Inventory	Operating Hrs/Yr	Utilization Factor			Energy/yr (kWh)	Energy Use* (Btu/yr)
Broilers	Gas	32,032	3650	0.6	90000	0.25	1.85E+09	6.32E+12
	Electric	3,168	3650	0.6	45000	0.5	9.15E+07	1.02E+12
Fryers	Gas	109,274	3650	0.15	100000	0.35	1.75E+09	5.98E+12
	Electric	79,129	3650	0.15	50000	0.6	6.35E+08	7.11E+12
Griddles	Gas	45,798	3650	0.2	90000	0.4	8.82E+08	3.01E+12
	Electric	45,798	3650	0.2	50000	0.58	4.90E+08	5.49E+12
Ovens	Gas	90,248	2920	0.75	85000	0.4	4.92E+09	1.68E+13
	Electric	73,839	2920	0.5	50000	0.68	1.58E+09	1.77E+13
Ranges	Gas	93,632	4015	0.2	160000	0.45	3.53E+09	1.20E+13
	Electric	9,260	4015	0.2	60000	0.7	1.31E+08	1.46E+12
Steamer	Gas	27,651	3650	0.2	160000	0.5	9.47E+08	3.23E+12
	Electric	56,140	2190	0.2	90000	0.65	6.49E+08	7.26E+12
Total		665,969				Gas	1.39E+10	4.74E+13
						Elect.	3.58E+09	4.00E+13
						Total	1.75E+10	8.74E+13

* Gas Conversion 3,413 Btu/kWh and Electric Conversion 11,200 Btu/kWh

Notes: 1. Rated capacities obtained from product literature and manufacturers.

2. Utilization factors from PG&E Kitchen data, ADL specialists, and other experts.

3. Operating hrs/yr estimates made by ADL specialists and outside experts.

Table 4-9: Cooking Equipment Energy Use in Restaurants

Cooking Equipment	Fuel	1990 Restaurant Inventory	Operating Hrs/Yr	Utilization Factor	Rated Cap (Btu/hr)	Eff.	1990 ADL Energy/yr (kWh)	US Annual Energy Use* (Btu/yr)
Broilers	Gas	81,616	3650	0.6	90000	0.25	4.71E+09	1.61E+13
	Electric	8,072	3650	0.6	45000	0.5	2.33E+08	2.61E+12
Fryers	Gas	278,423	3650	0.15	100000	0.35	4.47E+09	1.52E+13
	Electric	201,617	3650	0.15	50000	0.6	1.62E+09	1.81E+13
Griddles	Gas	116,690	3650	0.2	90000	0.4	2.25E+09	7.67E+12
	Electric	116,690	3650	0.2	50000	0.58	1.25E+09	1.40E+13
Ovens	Gas	229,946	2920	0.75	85000	0.4	1.25E+10	4.28E+13
	Electric	229,946	2920	0.5	50000	0.68	4.92E+09	5.51E+13
Ranges	Gas	238,568	4380	0.2	160000	0.45	9.80E+09	3.34E+13
	Electric	23,595	4380	0.2	60000	0.7	3.63E+08	4.07E+12
Steamer	Gas	70,453	3650	0.2	160000	0.5	2.41E+09	8.23E+12
	Electric	143,041	2190	0.2	90000	0.65	1.65E+09	1.85E+13
Total		1,738,657				Gas	3.62E+10	1.24E+14
						Elec.	1.00E+10	1.12E+14
						Total	4.62E+10	2.36E+14

* Gas Conversion 3,413 Btu/kWh and Electric Conversion 11,200 Btu/kWh

- Notes: 1. Rated capacities obtained from product literature and manufacturers.
 2. Utilization factors from PG&E Kitchen data, ADL specialists, and other experts.
 3. Operating hrs/yr estimates made by ADL specialists and outside experts.

Table 4-10: Cooking Equipment Energy Use in Grocery Stores

Cooking Equipment	Fuel	1990 Inventory	Operating Hrs/Yr	Utilization Factor	Rated Cap (Btu/hr)	Eff.	1990 ADL Energy/yr (kWh)	US Annual Energy Use* (Btu/yr)
Broilers	Gas	0	0	0.6	90000	0.25	0.00E+00	0
	Electric	0	0	0.6	45000	0.5	0.00E+00	0
Fryers	Gas	33,680	3508	0.15	100000	0.35	5.19E+08	1.77E+12
	Electric	24,389	3508	0.15	50000	0.6	1.88E+08	2.11E+12
Griddles	Gas	0	0	0.2	90000	0.4	0.00E+00	0
	Electric	0	0	0.2	50000	0.58	0.00E+00	0
Ovens	Gas	55,632	3508	0.75	85000	0.4	3.65E+09	1.24E+13
	Electric	45,517	3508	0.5	50000	0.68	1.17E+09	1.31E+13
Ranges	Gas	57,718	6570	0.2	160000	0.45	3.56E+09	1.21E+13
	Electric	5,708	6570	0.2	60000	0.7	1.32E+08	1.48E+12
Steamer	Gas	0	0	0.2	160000	0.5	0.00E+00	0
	Electric	0	0	0.2	90000	0.65	0.00E+00	0
Total		222,644				Gas	7.72E+09	2.63E+13
						Elec.	1.49E+09	1.67E+13
						Total	9.21E+09	4.30E+13

* Gas Conversion 3413 Btu/kWh and Electric Conversion 11,200 Btu/kWh

- Notes: 1. Rated capacities obtained from product literature and manufacturers.
 2. Utilization factors from PG&E Kitchen data, ADL specialists, and other experts.
 3. Operating hrs/yr estimates made by ADL specialists, and outside experts.

Table 4-11: Cooking Equipment Energy Use in Schools

Cooking Equipment	Fuel	1990 Schools Inventory	Operating Hrs/Yr	Utilization Factor	Rated Cap (Btu/hr)	Eff.	1990 ADL Energy/yr (kWh)	US Annual Energy Use* (Btu/yr)
Broilers	Gas	14,313	540	0.60	90,000	0.25	1.22E+08	4.17E+11
	Electric	1,416	540	0.60	45,000	0.50	6.05E+06	6.78E+10
Fryers	Gas	48,826	540	0.15	100,000	0.35	1.16E+08	3.96E+11
	Electric	35,357	540	0.15	50,000	0.60	4.20E+07	4.70E+11
Griddles	Gas	40,927	540	0.20	90,000	0.40	1.17E+08	3.98E+11
	Electric	40,927	540	0.20	50,000	0.58	6.48E+07	7.25E+11
Ovens	Gas	161,300	540	0.75	85,000	0.40	1.63E+09	5.55E+12
	Electric	131,973	540	0.50	50,000	0.68	5.22E+08	5.85E+12
Ranges	Gas	83,674	540	0.20	160,000	0.45	4.24E+08	1.45E+12
	Electric	8,276	540	0.20	60,000	0.70	1.57E+07	1.76E+11
Steamer	Gas	24,710	540	0.20	160,000	0.50	1.25E+08	4.27E+11
	Electric	50,169	540	0.20	90,000	0.65	1.43E+08	1.60E+12
Total		641,868				Gas	2.53E+09	8.64E+12
						Elect.	7.94E+08	8.89E+12
						Total	3.32E+09	1.75E+13

* Gas Conversion 3,413 Btu/kWh and Electric Conversion 11,200 Btu/kWh

- Notes: 1. Rated capacities obtained from product literature and manufacturers.
 2. Utilization factors from PG&E Kitchen data, ADL specialists, and other experts.
 3. Operating hrs/yr estimates made by ADL specialists, and outside experts.

Table 4-12: Cooking Equipment Energy Use in Hotels

Cooking Equipment	Fuel	1990 Hotel Inventory	Operating Hrs/Yr	Utilization Factor	Rated Cap (Btu/hr)	Eff.	1990 ADL Energy/yr (kWh)	US Annual Energy Use* (Btu/yr)
Broilers	Gas	18,283	3650	0.6	90000	0.25	1.06E+09	3.60E+12
	Electric	1,808	3650	0.6	45000	0.5	5.22E+07	5.85E+11
Fryers	Gas	62,371	3650	0.15	100000	0.35	1.00E+09	3.42E+12
	Electric	45,165	3650	0.15	50000	0.6	3.62E+08	4.06E+12
Griddles	Gas	26,140	3650	0.2	90000	0.4	5.03E+08	1.72E+12
	Electric	26,140	3650	0.2	50000	0.58	2.80E+08	3.13E+12
Ovens	Gas	154,533	2920	0.75	85000	0.4	8.43E+09	2.88E+13
	Electric	126,437	2920	0.5	50000	0.68	2.71E+09	3.03E+13
Ranges	Gas	106,885	4380	0.2	160000	0.45	4.39E+09	1.50E+13
	Electric	10,571	4380	0.2	60000	0.7	1.63E+08	1.82E+12
Steamer	Gas	31,565	3650	0.2	160000	0.5	1.08E+09	3.69E+12
	Electric	64,086	2190	0.2	90000	0.65	7.40E+08	8.29E+12
Total		673,984				Gas	1.65E+10	5.62E+13
						Elect.	4.30E+09	4.82E+13
						Total	2.08E+10	1.04E+14

* Gas Conversion 3,413 Btu/kWh and Electric Conversion 11,200 Btu/kWh

- Notes: 1. Rated capacities obtained from product literature and manufacturers.
 2. Utilization factors from PG&E Kitchen data, ADL specialists, and other experts.
 3. Operating hrs/yr estimates made by ADL specialists and outside experts.

Table 4-13: Cooking Equipment Energy Use In Hospitals

Cooking Equipment	Fuel	1990 Hospital Inventory	Operating Hrs/Yr	Utilization Factor	Rated Cap (Btu/hr)	Eff.	1990 ADL Energy/yr (kWh)	US Annual Energy Use* (Btu/yr)
Broiler	Gas	6,282	3650	0.6	90000	0.25	3.63E+08	1.24E+12
	Electric	621	3650	0.6	45000	0.5	1.79E+07	2.01E+11
Fryer	Gas	10,715	2190	0.15	100000	0.35	1.03E+08	3.52E+11
	Electric	7,759	2190	0.15	50000	0.6	3.74E+07	4.18E+11
Griddles	Gas	8,981	3650	0.2	90000	0.4	1.73E+08	5.90E+11
	Electric	8,981	3650	0.2	50000	0.58	9.61E+07	1.08E+12
Ovens	Gas	53,094	3650	0.75	85000	0.4	3.62E+08	1.24E+13
	Electric	43,441	3650	0.5	50000	0.68	1.16E+09	1.30E+13
Ranges	Gas	36,724	4380	0.2	160000	0.45	1.51E+09	5.15E+12
	Electric	3,632	4380	0.2	60000	0.7	5.59E+07	6.27E+11
Steamers	Gas	5,423	3650	0.2	160000	0.5	1.86E+08	6.34E+11
	Electric	11,009	3650	0.2	90000	0.65	2.12E+08	2.37E+12
Total		196,662				Gas	5.95E+09	2.03E+13
						Elect.	1.58E+09	1.77E+13
						Total	7.54E+09	3.80E+13

* Gas Conversion 3413 Btu/kWh and Electric Conversion 11,200 Btu/kWh

- Notes: 1. Rated capacities obtained from product literature and manufacturers.
 2. Utilization factors from PG&E Kitchen data, ADL specialists, and other experts.
 3. Operating hrs/yr estimates made by ADL specialists and outside experts.

Table 4-14 National Cooking Energy Use by Type of Equipment

Equipment Type	Fuel Type	Energy Use* (x 10 ¹² Btu/yr)
Broilers	Gas	28.0
	Electric	4.5
Fryers	Gas	27.5
	Electric	32.7
Griddles	Gas	13.7
	Electric	25.0
Ovens	Gas	123.1
	Electric	139.8
Ranges	Gas	80.4
	Electric	9.8
Steamers	Gas	16.6
	Electric	39.3
Total	Gas	289.3
	Electric	251.1
Total	All	540.4

* Conversion for gas-3413 Btu/Kwh, electricity - 11,200 Btu/Kwh

Figure 4-3: Comparison of Arthur D. Little Baseline Cooking Energy Use with Estimates from Other Sources

Sources:

- BPA - "Description of Electric End-Use in Commercial Buildings in the Pacific Northwest, End-Use Load and Consumer Assessment Program (ELCAP), by Battelle, PNW Labs, April 1989. (Ref. 18)
- EPRI - "Efficient Electricity Use: Estimates of Maximum Energy Savings," EPRI CV6746, March 1990. (Ref. 23)
- 1982 TECO - "Commercial Appliance Energy Use Update" for GRI/Rpl No. PB86-243730, by Thermo Electron, May 1986. (Ref. 35)
- 1975 TECO - "Energy Conservation Opportunities in Commercial Appliances," for DOE, by Thermo Electron. (Ref. 12)
- LBL - "Integrated Estimation of Commercial Sector End-Use Load Shapes and Energy Use Intensities" by LBL for U.S. DOE. (Ref. 17)
- 1989 TECO - "Commercial Appliance Energy Use Update - 1989", by Tecogen, Inc., for Gas Research Institute, February 19, 1992. (Ref. 35) (Electric adjusted from this source by 11200/3413, to convert to primary energy).

4.4 Office Equipment

The office equipment energy end-use has only recently begun to be studied by a few professionals and organizations including Lawrence Berkeley Laboratories (J. Harris, M. Piette, J. H. et.al), American Council for an Energy Efficient Economy (ACEEE) (M. Ledbetter, L. Smith et.al.), Massachusetts Institute of Technology (MIT) (Les Norford et.al.) and Canada NRC. The results of work being performed by these organizations is only partially available at this time and represents the first attempts at establishing equipment utilization, actual power levels and energy use for office equipment. (References 40, 41)

All indications are that to date very little attention has been paid to energy issues in office equipment. A thorough examination of the major office equipment technologies and their current and potential efficiencies is necessary. Considerably more work on data development and analysis is needed both in characterizing current stock as well as in realizing the potential energy savings in this end use. Such a detailed data development and analysis is beyond the scope of this study.

We used the available data from these and other sources. We attempted to perform some limited data development by measuring power levels for equipment in-house. Based on this, we developed the energy use estimates that compare reasonably well with other sources.

4.4.1 Office Equipment Inventory Data

The 1990 inventory data for office equipment were developed using the Arthur D. Little Appliance Age Distribution Model (ADLAAD). Lifetimes in the case of office equipment were time to obsolescence rather than actual life spans. These were estimated by ADL's in-house specialists in office products. The lifetimes used in the analyses are shown in Table 4-15. The office equipment annual shipment data for computers (main frame, PC, and work station); copiers; fax machines; and electric typewriters were obtained from "Appliance" magazine (Ref. 5). The Appliance magazine obtains this data from "The Computer and Business Equipment Industry Marketing Data Book," (Ref. 6). The shipment data from 1975 to 1990 was used to estimate the 1990 inventory by type of equipment.

4.4.2 Office Equipment Energy Use Data

Office equipment energy use for each type of equipment needs to be differentiated by operating and standby modes. For some of the copiers and printers available today, an energy saver mode is presently providing an even lower level standby mode. Since this represents a negligible fraction of the equipment in the current inventory, this has not been considered here. In addition to the data available (Ref. 6, 9, 17, 34, 40, 41 and other ongoing work), our approach to estimating the energy use was to actually measure the power levels for different office equipment for a small sample of typical equipment, both in the operating and standby modes. The purpose of measuring the power levels was to enhance the existing data. The ADL measured power levels as well as those obtained from other sources, are shown in Table 4-15. In both cases, the actual energy use data was found to be significantly lower than the nameplate rating of the equipment.

Table 4-15: Office Equipment - Power Data

	Life	Features	Power (VA)		
	(Years)		Rated	Active	Standby
PC Compaq 386/20MHZ NEC 19" Color Monitor	5	130MHD,2FD	252	146	143
IBM PC CGA Monitor	5		230 440 210	62 122 60	Not Available
Laptop Toshiba 1200	5	20 Meg HD	40	12	12
Typewriter IBM Selectric II	5		150	120	115
Copiers • Canon NP270 • Canon NP 8580 • Canon NP 271 • Minolta S10 11	5		1400 1600 1600 1680	1100 1520 1240 1350	36 170 54 149
Laser Printer HP Laser Series II	5		900	575	31
Dot Matrix Printers Star LC 20 Star NL 10 IBM PC Printer	5		65 65 100	28 34 27	7 14 17
Facsimile Canon Fax 270	5		276	100	12
Workstation Sparcstation-I	7		210	130	127
Nokia AIDesktop WS386, b/w 19" monitor			430 606 176	84 169 85	Not Available

Sources:

1. "Technology Assessment: Electronic Office Equipment," by J. Harris, et al, LBL, for U.S. DOE, Nov. 88. (Ref. 9)
2. "Electricity-Saving Office Equipment," by A.B. Lovins, and M.R. Meede, Competitek, Rocky Mountain Institute, 1990 Edition. (Ref. 17)
3. Actual Power Measurements by Arthur D. Little on a small sample of office equipment.
4. "Analysis of Office Equipment Load Factors" by C.K. Wilkins, R. Kosonen, T. Laine, ASHRAE Journal, September 1991. (Ref. 34)

Using Arthur D. Little specialists' judgement on the operating hours per year in the standby and operating modes, in conjunction with the measured power levels in both these modes, we estimated the energy use by type of equipment using inventory estimates obtained as described earlier.

The inventory, the power levels and the operating hours per year estimates used in calculating the energy use, as well as, the resulting energy use by equipment type are shown in Table 4-16. The first column shows the type of equipment. The second column in this table is the inventory, calculated as discussed above. The rated, active and standby power in Columns 3, 4 and 5 were estimated based on comparing such data from various sources (References 40, 41), and those shown in Table 4-15.

Since there are a large number of different models within each category such as desktop PC's, it is difficult to define the typical equipment in the appliance stock. A large sample of power measurements and shipment data analyses by models within each category would provide a more accurate picture. However, for the purposes of this report we have used judgement of specialists who know the office equipment markets and technologies. Utilization estimates in the active and standby modes are based on the ELCAP study by Battelle PNW Laboratories for the Bonneville Power Administration (BPA) (Ref. 14). The "standby utilization" as defined in this table is the total time that equipment is turned on, but is not active. "Active utilization" is the time that the equipment is performing its functions. Both active and standby utilizations are expressed in hours per year. The total energy consumption is obtained by:

$$\text{Inventory} \times [\text{Active Power} \times \text{Active Utilization} + \text{Standby Power} \times \text{Standby Utilization}]$$

We compared our national energy consumption results to a study by BR Associates for Bonneville Power Administration (BPA), (Ref. 19). We found ADL energy use estimates to be about the same for computers about twice for printers, copiers and facsimile machines. Our total energy use estimates were at the higher end of Norford/Harris range of estimates for office equipment.

A more detailed study of the office equipment energy use including actual measurements over an extended period of time is warranted due to lack of data in this important and continually growing end-use.

Table 4-16: Office Equipment Energy Usage

Type of Equipment	1990 Inventory (million units)	Typical Rated Power (watts)	Actual Power (watts)			Power on (Hr/Yr)	Active Utilization (Hr/Yr)	Standby Utilization (Hr/Yr)	US Energy Usage (GWh)			BPA/BR (GWh) (Ref. 19)	US Annual Energy Use ($\times 10^{12}$ Btu/Yr)
			Typical Active	Typical Standby	Active Range				Typical Active	Typical Standby	Total		
Computers													
Mainframe	0.095	30000	10000	7000	10k-150k	8760	5700	3060	5415	2035	7450	6981.9	83.4
Workstation	0.65	160	117	114	50-200	8760	2190	6570	166	487	653		7.3
Desktop	21	360	110	106	25-250	2100	500	1600	1155	3562	4717	4937.65	52.8
Laptop	2.5	36	10	9	5-40	2190	420	1770	11	40	51		0.6
Printers													
Impact	33	365	115	35	10-600	2000	800	1200	3036	1386	4422	1968.77	49.5
Non-impact	14	700	230	60									
Typewriter	11.1	140	118	50	50-200	1300	650	650	851	361	1212	1918.45	13.6
Copier**	5.8	1311	650	150	162-2400	6000	2000	4000	7540	3480	11020	6069.85	123.4
Facsimile	3.7	216	80	9.6	50-200	8760	260	8500	77	302	379	163.54	4.2
TOTAL									18251	11652	29903	22040	334.9

Notes:

1. Useful life assumption for estimation of inventory is 5 years for PC's, copiers, printers and facsimile machines, 7 years for workstations and 10 years for mainframes.
2. Utilization estimates base on "Commercial Equipment Loads, ELCAP", by Battelle PNW for BPA (Ref. 14) and Arthur D. Little estimates.
3. Data from BPA/BR Associates, September, 1989, study (Ref. 19) was extrapolated from the PNW region to the USA level.
4. Rated, active and standby power levels from various sources (see Table 4-15) were compared. The values used in this table are based on ADL specialists' judgement as to the typical equipment in the U.S. appliance stock. For printers and typewriters data used from LBL report (Ref. 40). Copiers data source is ACEEE (Ref. 41).

4.5 Water Heaters

Two very different methodologies were used to arrive at the baseline water heater energy use in the U.S. The first method is based on the hot water usage by different building types and the second method is based on the equipment inventory - same as the method employed for other end-uses in this report.

4.5.1 Water Heater Baseline Energy Consumption - Water Usage Based Method

This method is based on the average hot water consumption figures for different types of buildings, as shown in Table 4-17. The first column gives the building type. Space functions within a building type are shown separately. For example, since a cafeteria in an office and office space have significantly different energy use profiles for hot water, these space functions are separated. Similarly, colleges (classrooms) are separated from dormitories, since hot water usage is significantly different in the two space functions. Double counting is avoided by using hot water usage by space function. The second column gives the unit (for example; meal, bed or person), on which the average hot water consumption is based. The third column gives hot water use per average day per unit. Most of the values are taken from the ASHRAE Handbook, 1991 HVAC Applications, Chapter 44, Table 7. (Ref. 28) Wherever data is not available from ASHRAE it is estimated based on ADL judgement and usage for comparable applications in ASHRAE handbook. Wherever the ASHRAE recommendations for average daily hot water consumption do not agree with other studies (Ref. 29) modified figures are used. The fourth column gives the hot water temperature, water heater output temperature based on ASHRAE Handbook (Ref. 28) recommendations (Chapter 44, Table 3). The average water inlet temperature is calculated to be 55°F. The fifth column gives the average efficiency of the water heater. This efficiency includes distribution losses. The sixth column gives the energy required to heat one gallon of water for each application in Btu/gal. The seventh column is a multiplication of columns three and six to get the energy consumed per average day per unit (Btu/unit/day). The eighth column gives the number of days in a year over which the average usage is based. Note at this point that wherever the hot water consumption given in column three is based on the actual days of operation in a year then the number of days of operation is given instead. The ninth column gives the number of units in the U.S. Most of the information is taken from the U.S. Bureau of the Census, Statistical Abstract of the United States, 1991 (111th Edition), (Ref. 33). Information with respect to the average number of meals served in a day derives from NAFEM figures (Ref. 3). The tenth column gives the total energy used in a year (Btu/yr) for water heating by straight multiplication of columns seven, eight, and nine. The eleventh column gives the energy used in a year for water heating for each building category aggregated to all uses within a building type. The total energy use for commercial water heating in the U.S. (excluding swimming pools) is estimated at 708×10^{12} Btu/yr by this methodology.

Table 4-17: U.S. Energy Consumption for Water Heating - Water Usage Based Method.

1	2	3	4	5	6	7	8	9	10	11
Type of Building	Unit	Hot Water Use Average Day (gal/unit/d) *	Hot Water Temperature (°F)	Efficiency [†]	Energy Use per gal (Btu/gal)	Energy Use per unit day (Btu/unit/d)	Number of Days (d/yr)	Daily Number of Units in the USA	Total Energy Used (Btu/yr)	Total Energy Use (Btu/yr)
Office building (##)	person	2.5	120	0.55	984.5	2461.1	365	5500000	4.94E+13	5.80E+13
Office - Restaurants (##)	avg meal	3.8	160	0.55	1590.3	6043.0	260	5500000	8.64E+12	
Mercantile/Service (a)	person	3.9	120	0.55	984.5	3856.2	365	16323477	2.30E+13	
Mercantile Restaurants (##)	avg meal	3.8	160	0.55	1590.3	6043.0	365	3650000	8.05E+12	
Gymnasiums/Stadiums (#)	establ	6000.0	140	0.55	1287.4	7724181.8	365	3001	8.46E+12	
Physical Fitness facilities (#)	establ	5000.0	120	0.55	984.5	4922272.7	365	8014	1.44E+13	
Laundry/cleaning services (#)	wash mach	75.0	140	0.55	1287.4	96552.3	365	1527390	5.38E+13	
Beauty and Barber shops (#)	customer	2.5	120	0.55	984.5	2461.1	300	3209920	2.37E+12	
Other facilities (b) (#)	establ	4000.0	120	0.55	984.5	3837818.2	300	10024	1.18E+13	1.22E+14
Food Service (full meal) (##)	avg meal	3.8	160	0.55	1590.3	6043.0	365	38955901	8.59E+13	
Food Service (fast food) (##)	avg meal	3.1	160	0.55	1590.3	4929.8	365	52722604	9.49E+13	
Food Service (other) (##)	avg meal	1.9	160	0.55	1590.3	3021.5	365	18324316	6.02E+13	2.01E+14
Food Sales (c)	person	6.2	140	0.55	1287.4	7942.5	365	3011686	8.73E+12	
Food Sales - Restaurants (##)	avg meal	3.8	160	0.55	1590.3	6043.0	365	2850000	6.29E+12	1.50E+13
Colleges (d)	student	0.6	110	0.55	833.0	499.8	365	13419000	2.45E+12	
Elementary schools	student	0.6	110	0.55	833.0	499.8	180	33309000	3.00E+12	
Jr/Sr High Schools	student	1.8	110	0.55	833.0	1499.4	180	12654000	3.42E+12	
Gymnasiums/Stadiums (#)	establ	3000.0	140	0.55	1287.4	3862090.9	365	36245	5.11E+13	
Educational foodservice (##)	avg meal	3.8	160	0.55	1590.3	6043.0	365	14000000	3.09E+13	9.08E+13
Men's dormitories **	student	13.1	115	0.55	908.7	11904.3	365	1001600	4.35E+12	
Women's dormitories **	student	12.3	115	0.55	908.7	11177.3	365	1145440	4.67E+12	
Hotels-Motels (20 or less units)	room	20.0	140	0.55	1287.4	25747.3	365	300000	2.82E+12	
Hotels-Motels (60 units)	room	14.0	140	0.55	1287.4	18023.1	365	800000	5.26E+12	
Hotels-Motels (100 or more)	room	10.0	140	0.55	1287.4	12873.6	365	2000000	9.40E+12	
Hotel/Motel restaurants (##)	avg meal	3.8	160	0.55	1590.3	6043.0	365	10000000	2.21E+13	
Hotel/Motel Laundry (#)	room	40.0	140	0.55	1287.4	51494.5	365	1887900	3.55E+13	
Nursing homes	bed	18.4	140	0.55	1287.4	23687.5	365	1709000	1.48E+13	
Nursing homes - Restaurants (##)	avg meal	3.8	160	0.55	1590.3	6043.0	365	4614300	1.02E+13	
Nursing homes - Laundry (#)	bed	20.0	140	0.55	1287.4	25747.3	365	219729	2.06E+12	1.11E+14
Health Care (Hospitals) (e)	bed	55.2	160	0.55	1590.3	87783.1	365	1241000	3.98E+13	
Clinics (#)	person	18.5	140	0.55	1287.4	23816.2	365	2185360	1.90E+13	
Hospitals - Restaurants (##)	avg meal	3.8	160	0.55	1590.3	6043.0	365	6000000	1.32E+13	
Hospitals - Laundry (#)	bed	40.0	180	0.55	1893.2	75727.3	365	868700	2.40E+13	9.60E+13
Warehouse (f)	person	5.4	140	0.55	1287.4	6986.5	365	5500000	1.40E+13	1.40E+13
Total									7.08E+14	7.08E+14

Average Inlet Water Temp. (°F): 55
 * ASHRAE Handbook, 1991 HVAC Applications, Chapter 44.

This data already accounts for the occupancy and diversity factors.

(#) Estimated values - data not available from ASHRAE

(##) Modified ASHRAE data

** 16% of college enrollment

Hospital Occupancy rate : 70%

Nursing Homes Occupancy rate : 90%

Hotel Occupancy rate : 60.9%

+Distribution losses included

(a) estimated from usage from office buildings multiplied by the ratio of energy consumed per worker (Mercantile & Service Office)

(b) Bowling centers, dance studios

(c) estimated from usage from office buildings multiplied by the ratio of energy consumed per worker (Food Sales/Office)

(d) same usage as for elementary schools

(e) three times the usage of nursing homes

(f) estimated from usage from office buildings multiplied by the ratio of energy consumed per worker (Warehouse/Office)

4.5.2 Water Heater Baseline Energy Use - Inventory Based Method

The water heater baseline energy use estimates based on shipment data and inventory of water heaters is similar to the method used in previous analyses. Since the rated capacity, and operating hours vary by building type, the total inventory has to be allocated by building type. This allocation is done by using NBECS data (Ref. 1) for number of establishments by building type and by fuel used for water heating. For example, the number of office buildings using gas for water heating is 225,000 according to NBECS data. The absolute values of this NBECS data are not used in the final inventory estimates, but the relative percentages over building and fuel type are utilized from NBECS. The total inventory obtained from shipment data and ADLAAD model are more reliable estimates of the inventory and these are used as the total inventory levels by fuel type.

The 1990 inventory data for gas and electric water heaters were developed using the Arthur D. Little Appliance Age Distribution Model (ADLAAD). Water heater shipment data were obtained from Appliance magazine (Ref. 5) and average life was assumed to be ten years, based on the book "Life Spans - The Products of Man". (Ref. 10) Appliance magazine obtains their data from the Department of Commerce and Gas Appliance Manufacturers Association (GAMA). The shipment data for gas equipment includes integral tank type, copper tube or coil type commercial gas water heaters and gas swimming pool heaters.

Inventory of swimming pool heaters was estimated based on the number of hotel/motels, sports and recreation clubs, schools and colleges, and municipal pool as shown in Table 4-18.

Table 4-18: Estimated Number of Commercial Swimming Pools in the USA

Type of Establishment	Number of Establishment*	Percent of Establishments with Pools**	Number of Pools (Rounded)
Lodging	117,000	15	18,000
Sports/Recr. Club	13,000	30	4,000
School/College	195,000	20	39,000
Municipal	80,000	25	20,000
TOTAL			80,000

* Number of establishments obtained from References 1, 31, 1, and 33 respectively for lodging Sports/Rec. Clubs, education, and municipal.

** ADL Estimates

Oil-fired water heaters inventory was obtained by assuming the growth rate to be the same as for electric water heaters starting with the 1982 inventory based on shipments shown in GAMA data. GAMA stopped collecting oil-fired water heater data in 1982.

Energy use data for water heaters was developed using the following methodology. Water heaters were divided by fuel type into gas, oil and electric. Each of these

subsets were evaluated by building type; office, retail, restaurant, grocery, schools, hotel, hospital and warehouse. Water heating had an additional pool heating application, which represents a significant part of the inventory and the energy use. This was not included in the baseline energy use estimates for water heating, but is provided separately for commercial swimming pools.

The total inventory of water heaters by fuel type was distributed over the various building types. The swimming pool application was treated separately. The Arthur D. Little energy use per year estimate was calculated by multiplying the end use inventory times appliance operating hours times rated capacity times utilization factor. Utilization factor is the ratio of average operating capacity to rated capacity which is one in this case. These parameters were estimated by building type. Energy use was calculated for each building type by fuel type and then aggregated across building types for each fuel.

Appliance operating hours, utilization factor, and efficiency data were estimated by Arthur D. Little specialists in water heating based on product literature, vendor interviews and engineering judgement. Natural gas, oil, and electric powered water heaters are used in all commercial building types including schools, hotels, office buildings laundries and laundromats, restaurants, and hospitals. Rated capacity data was obtained from manufacturer's product literature and popular models information obtained through interviews. Commercial electric water heaters range in size from small booster models with 6 kW of heating and six gallon capacity to units with over 800 kW of load and 2,500 gallons of storage capacity. Commercial gas heaters vary in size from small tank type with 50 gallon storage or tankless with 55,000 Btu/hr inputs to large units with over 3,000,000 Btu/hr input. Commercial oil-fired water heaters range in size from 75,000 Btu/hr to 500,000 Btu/hr input.

Our estimates of the energy use for water heaters by building and fuel type along with the values of the various parameters used to calculate energy use are shown in Table 4-19. The total 1990 inventory by fuel type was obtained as discussed above. To allocate this total inventory by building type we used the following methodology as shown in Table 4-19.

The second column in this table shows the total number of buildings or establishments that heat water. These are obtained from the "Non-residential Buildings Energy Consumption Survey" conducted by USDOE (Ref. 1). The same source also provides a breakdown of these establishments by type of fuel used for hot water heating. This breakdown is shown in Column 3 - "NBECS Inventory" and represents the 1986 U.S. building stock. This data in Column 3 is used strictly to allocate the inventory by building type. The actual total inventory of water heaters by fuel type in 1990 was obtained by using the annual shipment data and the ADLAAD model as previously described. This is shown as totals in Column 4 by fuel type. This total 1990 inventory by fuel type was distributed by types of buildings using the same ratios as shown in the "NBECS Inventory" column. The resulting inventory distribution is shown in Column 4 - "1990 Ratio Inventory". This inventory of water heaters is used in the energy use estimates.

Table 4-19: Commercial Sector Water Heating Energy Use By Building Type and By Fuel Type.

Building Type	1	Number of Buildings	2	3		4	5	6	7	8	9	10	11
				NBECS Fuel Type	Inventory								
Office		540,000		Gas	225,000	270,606	1100	1	125,000	0.60	3.72E+13		
				Oil	29,000	71,537	1100	1	125,000	0.60	9.84E+12		
				Electric	286,000	57,546	1700	1	50,000	0.98	1.61E+13	6.31E+13	5.80E+13
Mercantile & Service		834,000		Gas	350,000	420,943	1100	1	160,000	0.60	7.41E+13		
				Oil	34,000	83,671	1100	1	160,000	0.60	1.46E+13		
				Electric	450,000	90,544	1700	1	65,000	0.98	3.26E+13	1.22E+14	1.22E+14
Food Service		199,000		Gas	120,000	144,323	3200	1	375,000	0.60	1.73E+14		
				Oil	20,000	49,336	3200	1	375,000	0.60	5.92E+13		
				Electric	59,000	11,671	4900	1	150,000	0.98	2.86E+13	2.61E+14	2.01E+14
Food Sales		98,000		Gas	43,000	51,716	1400	1	125,000	0.60	9.05E+12		
				Oil	10,000	24,668	1400	1	125,000	0.60	4.32E+12		
				Electric	45,000	9,054	2150	1	50,000	0.98	3.19E+12	1.66E+13	1.50E+13
Education		195,000		Gas	115,000	138,310	1600	1	325,000	0.60	7.18E+13		
				Oil	16,000	39,469	1600	1	325,000	0.60	2.05E+13		
				Electric	64,000	12,677	2200	1	125,000	0.98	1.16E+13	1.04E+14	9.08E+13
Lodging		117,000		Gas	63,000	75,770	2100	1	450,000	0.60	7.16E+13		
				Oil	10,000	24,668	2100	1	450,000	0.60	2.33E+13		
				Electric	44,000	8,853	3200	1	175,000	0.98	1.63E+13	1.11E+14	1.11E+14
Health Care		48,000		Gas	26,000	31,270	3650	1	650,000	0.60	7.42E+13		
				Oil	2,000	4,934	3650	1	650,000	0.60	1.17E+13		
				Electric	20,000	4,024	5550	1	260,000	0.98	1.91E+13	1.05E+14	9.60E+13
Warehouse		232,000		Gas	83,000	99,824	600	1	125,000	0.60	7.40E+12		
				Oil	20,000	49,336	600	1	125,000	0.60	3.70E+12		
				Electric	129,000	25,958	920	1	50,000	0.98	3.92E+12	1.51E+13	1.40E+13
Total		2,263,000		Gas	1,025,000	1,232,761			221,951				
				Oil	141,000	347,820			222,092				
				Electric	1,097,000	220,726			74,749				
				Total	2,263,000	1,801,307						7.98E+14	7.08E+14

* Energy required at the power plant

Operating hours/year, (Column 5), utilization factor (Column 6), rated capacity, (Column 7), baseline efficiency data (Column 8) were obtained by interviews with ADL specialists. Energy use is calculated and shown in Column 9 and summed over fuel types in Column 10. A comparison of these totals with totals obtained based on water usage (Column 11) is also presented in this table. As can be seen by comparing Columns 10 and 11, the estimates from the two methods match fairly well.

Commercial swimming pool water heaters are typically sized based on raising the temperature of the entire pool by 45°F in a 48 hour period. A typical 80,000 gallon pool would require a 625,000 Btu/hr. water heater. The average operating hours for a commercial pool heater are estimated at 3650 hrs/yr for pools operating all year and 1825 hrs/yr for pools operating six months/yr. We have used 2700 hrs/yr as an average, assuming 50% of the pools are open all year and 50% operate six months per year. For an inventory of 80,000 pools as estimated earlier in Table 4-18, the energy use is calculated by:

$$80,000 \text{ pools} \times 625,000 \frac{\text{Btu}}{\text{hr.}} \times 2700 \frac{\text{hrs}}{\text{yr.}}$$

$$= 1.35 \times 10^{14} \text{ Btu/year}$$

Therefore, commercial swimming pool water heating energy use in the U.S.A. is estimated at 135×10^{12} Btu/year.

Total Commercial Sector water heating energy including swimming pools is estimated at 933×10^{12} Btu/year (798 + 135 trillion).

Arthur D. Little's energy use values were compared with Electric Power Research Institute (EPRI) and TECO estimates. These comparisons are shown in Figure 4-4 and fall within a reasonable range of each other. TECO 1978 and 1982 include swimming pool water heaters. ADL 1990 and TECO 1989 exclude swimming pool heaters.

4.6 Vending Machines and Water Coolers

4.6.1 Vending Machines and Water Coolers Inventory

The 1990 inventory of vending machines and water coolers was estimated using the ADLAAD Model. The shipment data was obtained from the Air Conditioning, Heating and Refrigeration News, (Ref.2). The original source of data used by this magazine is the Bureau of Census, Current Industrial Reports MA-35M. Vending machines were divided into 3 categories - beverage, food and confectioneries, and other. Water coolers were treated as a single category.

Figure 4-4: Comparison of Arthur D. Little Baseline Water Heating Energy Use with Estimates from Other Sources

Sources: References 15, 12, 35, 36.

4.6.2 Vending Machines and Water Coolers Baseline Energy Use

Energy use was estimated by multiplying the inventory by the operating hours per year, utilization factor and rated capacity. The annual operating hours, rated capacities, and utilization factors were estimated using product literature and extensive telephone interviews with vendors. The estimates of energy use and the typical values of the input parameters are shown in Table 4-20.

Table 4-20: Commercial Sector Water Coolers and Vending Machines - Energy Use

End Use	Arthur D. Little Inventory	Operating Hrs./Yr.	Utilization Factor	Rated Capacity (kW)	1990 Arthur D. Little Energy/Yr (kWh)	Source Energy (Btu/Yr)*
Water Coolers	6,030,502	8760	0.15	0.500	3.96E+09	44.35E+12
Vending Machine (Beverage)	2,270,359	8760	0.30	1.080	6.44E+09	72.13E+12
Vending Machine (Food)	1,501,157	8760	1.00	0.096	1.26E+09	14.11E+12
Vending Machine (Other)	2,358,744	8760	1.00	0.096	1.98E+09	22.18E+12
Total Vending	6,130,260				9.69E+09	108.42E+12
Total Vending & Water Cooler)	12,160,762				13.64E+09	152.77E+12

*Conversion factor 11,200 Btu = 1 kWh.

The energy use by refrigerated vending machines turned out to be very significant. Very little, if any, attention is paid to the energy use of vending machines. Design of vending machines is focused on displays and selling attributes. These machines are often located outside gas stations with high solar loads. Insulation level is rather small and the display lights often inefficient and left on 24 hours a day. The refrigeration system is also not geared towards high efficiency. The vending machine company generally is not responsible for the electricity bills, which is a disincentive to make vending machines more energy efficient. The inventory of vending machines is also very large. The combination of these factors results in the high energy use for this equipment type.

4.7 Laundry

4.7.1 Laundry Inventory Data

The market for the commercial laundry can be divided into the following three segments:

- Coin-operations--commercial enterprises which make coin-operated laundry equipment available to the public.
- Route operations--coin laundry equipment installed in apartments by route operators (equipment owners) on speculation. Revenue from these machines is generally shared by the operators and the apartment owners.
- On-premise laundry (OPL)--owner-operated facilities for institutional laundry such as in nursing homes, hospitals, hotels/motels, etc.

The coin-operated and route laundry represents an unusual operating environment in that the buyer and the user of the machine are generally not the same person. Although the buyer/operator is likely to place a significant priority on equipment energy efficiency the user controls many of the important aspects that determine how much energy is consumed during a laundry cycle.

The main data sources used for laundry equipment are:

- U. S. Department of Energy, "Technical Support Document: Energy Conservation Standards for Consumer Products: Dishwashers, Clothes Washers, and Clothes Dryers" DOE/CE-0299P December 1990. (Ref. 20)
- Jakobi, G. A. Lohr, "Detergents and Textile Washing" Principles and Practice, ISBN 0-89573-6861 (VCH Publishers) VCH Verlagsgesellschaft mbH, D-6940 Weinheim (Federal Republic of Germany), 1987. (Ref. 21)
- Topping, Richard F., "Advanced Technology Gas-Fired Commercial Clothes Dryer", Final Report (April 1985-December 1988) for Gas Research Institute, Prepared by Arthur D. Little, Inc., March 1989. (Ref. 22)
- Report to the Gas Research Institute and Speed Queen by Arthur D. Little, Inc., "Coin Laundry Description and Market Study", June 1987. (Ref. 7)

The major energy consuming equipment currently installed in commercial laundries includes:

- Vertical axis, top-loading washers, typically of 15 lb to 30 lb capacity and similar in design and construction to standard size residential washers. Data from the study (Ref. 20) showed that the average life of a coin-store washer was eight years. The installed base in coin and route operations is estimated to be 1.3 million washers.
- Tumble dryers, almost universally natural gas fired and typically with larger capacity (up to 30 lbs of dry clothes) than residential dryers. The average life of a tumble dryer was found to be 15 years. The installed base is estimated to be 1.7 million units.
- Spin extractors, installed in perhaps 30% of locations, providing the function of extracting additional water from clothes by mechanical spinning after the wash cycle and before the dry cycle. The extractor function is being offered in many new washer designs. Since extractors are not a major energy consumer, discussion of this function is included in the washer section.
- Hot water heaters supply heated water to the washers. Although water heating has been addressed in a separate analysis, reduction in the amount and temperature of the wash/rinse water represents a potential energy savings which goes beyond improvements in water heating efficiency and is specific to laundry operations. Baseline water heating energy calculations shown below assume gas water heaters operating at 60% efficiency. Hot water temperature setpoint is at an average of 130°F. (Ref. 7)

4.7.2 Laundry Baseline Energy Consumption

The Baseline energy consumption was estimated using the inventory data, the utilization data (Ref. 7) and an analysis of the energy consuming steps in a typical laundry cycle.

4.7.2.1 Washers Figure 4-5 show the important energy consuming steps in a typical laundry cycle using the equipment described above. The calculations and data used to estimate energy consumption are discussed below.

Almost all washers allow the user to select the wash and rinse temperatures. Usually the wash temperature includes at least three selections: hot (all hot water), warm (approximately a 50/50 blend of hot and cold), and cool (typically at normal delivery temperatures without any heating regardless of the season). Over the last decade, there has been a definite trend in home and coin-store laundry toward cooler wash temperatures due to improvements in detergent chemistry, concerns regarding delicate fabricates, and recognition of the potential energy savings by the consumer. Table 4-21 shows data from three sources for the percentage of wash loads done at each setting. The first two data sets are for home use, while the third data set from GRI was determined by actual observation in coin-stores. One explanation for the higher

Figure 4-5: Typical Wash Cycle

"Typical" Wash Cycle

percentage of "hot" washes found in the GRI study (Ref. 7) is the lack of economic incentive for the coin store user to select a cooler temperature. Using this data, the hot water accounts for 62% $[(100\% \times 39\%) + (50\% \times 46\%)]$ of the total wash water used.

Table 4-21: Percentage of Wash Loads By Temperature Setting

Wash Setting	Proctor and Gamble (home)	Jakobi and Lohr (home)	Gas Research Institute (coin store)
Hot (130°F)	20%	10%	39%
Warm (100°F)	50%	50%	46%
Cool (65°F)	30%	30%	15%

Sources: 1. Lebot, B. et al "Horizontal Axis Domestic Clothes Washers: An Alternative Technology that Can Reduce Residential Energy and Water Use," 1987 (Ref. 42).
2. Jakobi and Lohr, "Detergents and Textile Washing," 1987. (Ref. 21)

Rinse temperatures are generally established by the operator's choice of wash cycle. "Regular" cycles typically use a warm (50/50) rinse while "delicate" and "permanent press" use cool water (no heat). Available data for rinse temperature distribution are shown in Table 4-22. Based on the data from the report (Ref. 7), 12% $(50\% \times 24\%)$ of the rinse water utilization will be hot water.

Table 4-22: Percentage of Wash Loads By Temperature Setting During Rinse Cycle

Rinse Setting	Proctor and Gamble	Gas Research Institute
Hot (130°F)	0%	0%
Warm (100°F)	26%	24%
Cool (65°F)	74%	76%

All current and most new design vertical axis machines require at least enough water to "float" the clothes for washing and agitation. Unlike home washers, coin store washers do not provide switch selections to determine the amount or level of water for the wash and rinse steps based on the size of the load. For the baseline energy calculations presented here, it is assumed that both the wash and the rinse steps use a "regular" or large setting which corresponds to about 16.5 gallons of water for each fill.

There are two spin steps in the wash cycle which remove water by centrifugal force. For the intermediate spin, it is desirable to remove as much "dirty" water as possible from the clothes to decrease the dirt load on the rinse step that follows. For the final spin, removal of water by spinning reduces the amount of drying energy required and is a much more energy efficient method of water removal compared with evaporative drying. Typical washers currently in use spin at around 560 RPM generating about 60 g's. The water removed during spinning depends on the g level, type of fabric, weave, and even the age of the clothes. Following a 60 g spin, heavily needed, all cotton towels will retain up to 120% water (i.e., 1.2 lb of water per lb of dry clothes), cotton/polyester blend shirts will retain 80% to 100% water, and nylon or polypropylene materials as little as 50%. Since most laundry consists of all cotton and cotton/polyester blends, this analysis is based on 100% water retention (1 lb water per lb of dry clothes).

Columns A, B, D and E of Table 4-23 show additional data on average washer utilization, load size, and throughput taken from the coin store survey conducted as part of the GRI study, (Ref. 7). From this data, we have derived an estimate of 3×10^{10} lbs of clothes per year washed in coin and route operations.

Table 4-23: Washer Utilization and Annual Throughput - Coin and Route Operations

	A	B	C	D	E	F	G	H
	Facility Operating Hrs/Day	Washer Utilization	Washer Operating (AxB) Hrs./Day	Washer Cycle Time (Loads/Hr)	Average Load Size (lbs dry clothes equiv)	Average Washer Throughput (lbs clothes/washer/yr) (C x D x E x 365)	Installed Base (# machines)	Total Lbs/Yr Washed (F x G)
Washer	15	20%	3	2	10.7	23,400	1,300,000	3×10^{10}

Using the energy data (1180 Btu/lb) from Figure 4-5, the baseline annual washer primary energy consumption for coin store and route operations is estimated to be 35×10^{12} Btu/yr. This energy is consumed by wash and rinse water heating and motors.

Energy use estimate for On-Premise Laundries (OPL's) is shown in Table 4-24. We have assumed that medical offices and out-patient services would not have on-premise laundries but hospitals and nursing homes do. Hospital laundry cleaning protocols are diverse since state health boards regulate the wash temperatures. These are generally higher than normal washing. The total energy for water heating and motors for OPL's is estimated at 18.5×10^{12} Btu/yr.

Table 4-24: Washer Energy Use Estimates for On-Premise Laundries

Hospitals		Source
Hot water lbs at 180°F per lb of clothes	10 to 30	Blaser, 1984
Water heating energy Btu/lb of clothes	1300 to 3300	Smith, 1987
Drive motor (electricity) Btu/lb of clothes	120	
Total energy use Btu/lb of clothes	1420 to 3420	
Laundry processed lbs/bed/year	4500 to 7000	
No. of hospitals in the U.S.	7000	
No. of beds in the U.S.	1,400,000	AHA - Hospital Statistics
Energy required for washing (Btu/yr)	12.6×10^{12}	
$\frac{4500 \text{ lbs}}{\text{bed-Yr}} \times \frac{2000 \text{ Btu}}{\text{lb}} \times 1.4 \times 10^6 \text{ beds}$		
Nursing Homes		
Total number of nursing homes	15,000	Dept. of HEW
Total number of beds	1,100,000	Dept. of HEW
Occupancy rate (%)	90	Dept. of HEW
No. of occupied beds	990,000	Arthur D. Little
Laundry processed lbs/bed/year	3000	
Energy required for washing (Btu/yr)	5.9×10^{12}	
$\frac{3000 \text{ lbs}}{\text{bed/yr}} \times \frac{2000 \text{ Btu}}{\text{lb}} \times 990,000 \text{ beds}$		
Total Energy Use (Btu/yr)	18.5×10^{12}	

Sources:

1. Blaser, M.J., et al, "Killing of Fabric Associated Bacteria in Hospital Laundry by Low Temperature Washing," Journal of Infectious Diseases, 149, 48-57. (Ref. 13)
2. Smith, J., et al, "Effect of Water Temperature on Bacterial Killing in Laundry," 1987. (Ref. 37)
3. Hospital Statistics - American Hospital Association, 1978. (Ref. 38)
4. U.S. Department of Health, Education & Welfare, "A County and Metropolitan Area Data Book", 1977. (Ref. 39)

4.7.2.2 Dryers Commercial dryers are predominantly gas-fired. Number of commercial electric dryers are negligible in quantity (Ref. 7). Figure 4-6 shows the change in clothing moisture content during an idealized drying cycle. The "useful" Drying Phase begins with a short period during which the clothes, drum and cabinet warm up, and there is very little change in clothing moisture content. Following this period, the clothing moisture content falls nearly linearly until it is very near the normal equilibrium moisture content (4% to 6%). The balance of the moisture is driven off very slowly during the "Continued" Drying Phase. Typical coin-op dryers work on a timed basis depending on how many coins are inserted and will run until the time expires or the door is opened.

Figure 4-7 shows the distribution of energy during both drying phases. Based on test data from DOE (December, 1990), using a dryer typical of those currently installed, the drying average efficiency for the useful phase is 36% based on the theoretical energy required to evaporate the moisture load. Air heating and cabinet losses are approximately 700 Btu/min (based on 180°F outlet air and 370 cfm air flow) with cabinet losses making up less than 5% of the total loss.

Figure 4-6: Clothing Moisture Content Reduction with Time-Drying Cycle

Figure 4-7: Energy Partitioning for the Drying Cycle

During the "Continued" Drying Phase, the efficiency (as measured by change in moisture content) is close to zero. The burner output is reduced, and air/cabinet losses account for all of the energy usage. No data were found on the duration of the continued drying phase, so we have assumed that the average dry cycle extends five minutes beyond the end of the useful drying period.

Figure 4-8 shows the complete energy use for a typical dryer cycle. The average load size was determined in the GRI survey (Ref. 7). Estimation of the moisture content of the clothes entering the dryer was described in the Washer section.

During the useful drying phase 36% of the input heat goes into the evaporative load and the balance is consumed by heating of the air and cabinet losses. The installed base of dryers in coin stores and route operations is estimated to be 1.7 million units (Ref. 7) with a throughput of 3×10^{10} lbs of dry clothes per year as calculated in the washer analysis. The total baseline dryer energy utilization is 104×10^{12} Btu for Coin & Route operations.

For the OPL's, the drying energy in Btu/lb is the same as for coin operations laundry.

The total energy use for hospitals drying operation:

$$= 3460 \text{ Btu/lb} \times \frac{4500 \text{ lb}}{\text{bed-yr}} \times 1.4 \times 10^6 \text{ beds}$$

$$= 21.8 \times 10^{12} \text{ Btu/yr}$$

Similarly total energy use for nursing homes drying operation:

$$\frac{3460 \text{ Btu}}{\text{lb}} \times \frac{3000 \text{ lb}}{\text{bed - yr}} \times 990,000 \text{ beds}$$

$$= 10.3 \times 10^{12} \text{ Btu/yr}$$

Total energy use in drying for OPL's = 32.1×10^{12} Btu/yr.

Figure 4-8: Energy Consumption by Steps in a Dryer Cycle

"Typical" Dryer Cycle

*Electric converted a 11,200 Btu/Kwh

**Total Energy = 40,900 Btu
(3,460 Btu/lbm)**

Total Time = 35 minutes

4.7.3 Dry Cleaning Process Energy Use

The major process used for dry cleaning in the U.S. today is based on perchlorethylene as a cleaning solvent with limited use of naptha in the Southwest. Older perchlorethylene systems are based on the so called "cold process" that vents vapor from the drum to the atmosphere during the final solvent removal and cooldown phases of the cycle. OSHA and EPA regulations are forcing most new equipment installations to utilize the "dry-to-dry" process which uses a closed loop system with a heat pump to condense and reclaim solvent vapors prior to removal of the clothing. This is a more energy intensive process but is much more representative of the trends in the industry today. We have developed a simple model of a typical dry-to-dry process below to determine if sufficient energy savings potential exists in this commercial area.

Process Model: Dry-cleaning units used in commercial establishments range in capacity from approximately 25 to 75 pounds of clothes per manufacturer's catalogs. The process steps in a typical cycle for a 40 lb cleaning unit (including off-line regeneration of the used solvent) are shown in Table 4-25 along with the energy requirement for each process step.

Table 4-25: Energy Use in Dry Cleaning Process

Step	Power Kw	Time	KwH Load (40 lbs)	KwH per lb of clothes
1. Load clothes and inject solvent	0.75 Kw	5 min.	0.063	.0016
2. Tumble Wash	1.0 Kw	15 min.	0.25	.0063
3. Spin extraction	3 Kw	5 min.	0.25	.0063
4. Heat drum to 160°F with heat pump and electrical assist; recover solvent in evaporator section	11 Kw	15 min.	2.75	.07
5. Cool down drum and remove clothes	4 Kw	5 min.	0.332	.008
6. Regenerate solvent	9 Kw	*	1.08	.027
Total			4.72	.119

Source: Personal Communications with Solver Institute (K. Faig).

*1.5 hours every 500 lbs of laundry.

Annual Volume: The International Solver Institute estimates that there are 1.8×10^9 pounds of clothes per year processed by dry cleaning establishments. As a separate check, the 1990 Statistical Abstracts of the U.S. lists 46,000 establishments under SIC code 721 (laundry, cleaning and garment services). Assuming a volume of 50,000 pounds of clothes per year (1000 lbs/week) for a typical facility, the annual volume of dry cleaning would be 2.3×10^9 (about nine pounds per person per year).

Annual Energy Consumption: Using the higher estimate for dry cleaning volume, the annual energy consumption from this sector would be approximately 0.27×10^9 kwh or 3×10^{12} Btu/year.

This baseline energy use is well below that for "other" end-uses considered in this report, and does not appear to warrant energy conservation programs at the national level. Hence, dry cleaning is not pursued further in this report.

4.8 Electronics Excluding Office Equipment

Office equipment such as computers, copiers, printers, facsimile and typewriters were covered earlier in Section 4.4. The category of "Electronics" in this section includes:

- Electromedical imaging equipment such as radiography, computed tomography (CAT), magnetic resonance imaging (MRI), and ultrasonic scanners;
- Cash registers, point-of-sale terminals and automated teller machines (ATM); and
- Telephone equipment including switching equipment.

4.8.1 Inventory Data

Sources for inventory data as well as utilization and power levels used for estimating energy use for this equipment are:

- Current industrial reports by the U.S. Department of Commerce (DOC) on medical diagnostics, MRI, ultrasonic scanning, pacemakers and defibrillators and cash registers/POS terminals.
- Clinica Factbook, 1991, Pharmabooks, Ltd.; (Ref. 24)
- World Medical Electronics Market, 1987, Market Intelligence Research Corporation; (Ref. 25)
- Preston et al, "Medical Imaging Techniques, A Comparison", Plenum Publishing, 1979; (Ref. 26)
- Webster, J., "Encyclopedia of Medical Devices and Instrumentation", John Wiley and Sons, 1988; (Ref. 27)
- Manufacturers interviews by Arthur D. Little including Siemens, G.E. Medical Systems, Hewlett Packard, and others.
- Hospital equipment users telephone interviews by Arthur D. Little, mainly in Boston and Philadelphia.

The shipment data from current industrial reports (CIR) were used as inputs to the Arthur D. Little Appliance Age Distribution (ADLAAD) model to estimate the current inventory of the various equipment types mentioned above.

A check for reasonableness revealed that the inventory obtained for point-of-sale terminals and cash registers seemed rather low based on the number of establishments in the U.S. where these would be used. The inventory data for these were revised using an average number of units per establishment and the number of establishments. We think the discrepancy may have resulted from the fact that DOC did not report shipment numbers for some years where there was a single dominant manufacturer. The inventory data used for this class of equipment is, therefore, based on number of establishments obtained from NBECS - Nonresidential Buildings

Energy Consumption Survey, 1986. Inventories estimated by type of equipment are shown in subsequent tables.

The life span of a telephone instrument is about 25 years. However, due to the progress of technology, the telephone instrument is generally obsolete in about 10 years.

The inventory data obtained for telephones based on shipment data from the CIR's (Department of Commerce) and ADLAAD model using 10-years as life span was an aggregate of 129.8 million telephones for all sectors (residential, commercial, institutional) combined. Since there are 95.3 million residential units in the U.S. with an average of one telephone per unit, the commercial/industrial sector inventory of telephone instruments is 34.5 million units.

The total inventories in the U.S. by equipment type are shown in tables for baseline energy consumption in the following sections. The life spans used for this equipment are 7-years for medical diagnostics and MRI, 12-years for cash registers, 7-years for ATMs, 12-years for POS terminals and 10-years for telephone sets.

4.8.2 Electronics (Non-Office) Baseline Energy Consumption

4.8.2.1 Electromedical Equipment Baseline Energy Consumption:

Electromedical equipment energy consumption data is not easily available. Most users are reluctant to allow energy consumption or power level measurements, while the information from manufacturers contacted was rated (nameplate) power data. Most of the relevant (substantial energy using) equipment delivers high value services and are high capital and operating cost products. Energy use is, therefore, of relatively low significance. Our approach to estimating the energy use for the electromedical products was to use engineering judgment based on information received from product designers where possible and manufacturers' catalog data. The equipment in this category includes radiographic, computed axial tomography (CAT), magnetic resonance imaging (MRI) and ultrasonic scanners.

Radiographic Equipment

Radiographic systems are used in numerous applications in addition to medical diagnostics, including inspection and analysis of food and materials. While these non-medical systems are numerous, these systems are typically much smaller and consume a fraction of the power of medical systems. In addition, dental applications for X-ray equipment accounts for a reasonable percentage of inventory. These dental units consume approximately 1500 watts peak and less than 300 watts in standby. The utilization factors for dental units is considered very low. This analysis does not address non-diagnostic or dental X-ray systems.

The usage profiles for radiographic equipment used in hospitals and large clinics varies by location but are generally used 12 to 16 hours per day with varying number of patients and exposures per hour. Each exposure requires less than one second of active power per required view. The radiographic equipment is left on in the standby mode most of the time during the daytime hours due to warm-up and stabilization concerns.

Computed Tomography (CAT) CAT equipment is found in large hospitals and several large clinics. This equipment typically has a higher active utilization factor than standard X-ray due to its high cost. Usage is 8 to 10 hours per day. CAT requires thousands of brief exposures which can accumulate to two or more seconds per view.

Magnetic Resonance Imaging (MRI) MRI is a new diagnostic tool used by radiologists to produce cross-sectional pictures of a patient's anatomy. It is most useful in visualizing changes in soft tissue characteristics by means of video display and hard copy outputs. Initially patented in 1972, MRI is now available in many clinics across the country.

MRI has a high utilization profile due to its high cost and limited availability. Many of the MRI machines are operated 24 hours a day, seven days a week, average usage is about 16 hours a day.

Ultrasonic Scanners Ultrasonic scanners are widely used for medical diagnostic purposes. Diagnostic scanners are found in hospitals, clinics and physicians' offices. Usage profiles vary significantly from heavy usage in hospitals to moderate in physicians' offices. The equipment requires minimal warm-up time and is typically turned off when not in use.

Table 4-26 shows the inventory, the power levels, the utilization, and the energy use by active and standby modes as well as the total energy use in the U.S. for each of the four equipment types discussed above. The first column shows the type of equipment. The second column is the 1990 inventory based on shipments from current Industrial Reports CIR and life spans based on interviews with hospital staff members. The third column shows the rated power for a typical system; for example, a 50 Kw X-ray system is typical of X-ray equipment. The fourth column shows the power draw when the equipment is in active mode or in use. The fifth column shows the power draw when the equipment is in standby or idling. The range of power for equipment available in the marketplace is shown in the sixth column; for example, X-ray diagnostic equipment is available in the 30 Kw to 150 Kw range. Numbers in the seventh column are the percentage of total time that the equipment is powered on. The eighth column shows the hours/year that the equipment is in active mode. The ninth column shows the hours per year that the equipment is in a standby mode. The energy use is the product of utilization factors, power levels and inventory.

The baseline energy use of 13×10^{12} Btu/yr for electro-medical equipment may not be significant for a national program on conservation.

4.8.2.2 Cash Registers/POS Terminals and Automated Teller Machines Baseline Energy Consumption Point-of-sale terminals and cash registers are used in a broad range of retail establishments and personal service businesses.

This includes a wide range of equipment from smart terminals that communicate with a central host computer in a department store to a cash register at a local convenience store.

POS Terminals Usage of POS terminals is dependent on the operating hours of the retail establishment and the sales volume. Daily operating time typically ranges from 10 to 16 hours. Transactions per hour range from one in a slow period to 30-40 per hour during high volume sales and rush periods. Standby requirements are the key to analysis of power consumption of POS terminals. The active or peak power consumption occurs at relatively low frequency. However, POS terminals are powered throughout the entire business day. This scenario is very similar to the usage profile for personal computers.

Automated Teller Machine (ATM's) While ATM's have been part of retail banking for twenty years, it is over the last decade that usage of this equipment has greatly expanded. The Bank Administration Institute estimates that 93,000 ATM's were installed in 1990 alone with a significant percentage being upgrades.

Utilization of ATM's is 24 hours a day, seven days a week. The ATM's are, therefore, always on standby or active except during downtime due to a failure.

Baseline energy use is calculated as shown in Table 4-27 for both POS terminals/cash registers and ATM's. The baseline energy use of 8×10^{12} Btu/yr for ATM's does not seem to warrant national programs in conservation and is, therefore, not analyzed further in Section 5.

4.8.2.3 Telephone Equipment Telecommunications technology has undergone a major change from the electromechanical relay switching where power consumption was 6 watts per telephone instrument to the current electronic switching systems with a power consumption of 2.5 watts/telephone. The change in technology has, therefore, reduced the baseline energy consumption to about one-third that of the older systems. It is estimated that the total U.S. inventory of telephones in the residential/commercial and industrial sectors is about 130 million telephone instruments of which roughly 95 million are used in residences and 35 million in the commercial/industrial sectors. If we assume that 60-70% of these are used in the commercial sector, we can obtain an estimate of baseline energy use.

2 of 3

Baseline Energy Use =

$$\frac{2.5 \text{ watts}}{\text{unit}} \times \frac{8760 \text{ hours}}{\text{year}} \times 34.5 \times 0.6 \text{ million units}$$

$$= 453 \times 10^6 \text{ Kwh/year}$$

$$= 5.08 \times 10^{12} \text{ Btu/year for the 60\% of the units that are in the commercial sector.}$$

If we assume 75% of the units in the commercial sector - Energy Use =
 $6.3 \times 10^{12} \text{ Btu/year.}$

Both of these baseline energy use numbers are too small for national programs on conservation. Hence, this equipment is not pursued in the analysis of Section 5. The baseline energy use is included in the summary table in Section 3 though no conservation technologies are pursued.

Table 4-26: Electromedical Equipment Energy Usage Analysis

Medical Imaging	1990 Inventory (000 units)	Typical Rated Power (watts)	Actual Power (watts)			Power On (%)	Opn Active (Hrs/Yr)	Opn Standby (Hrs/Yr)	U.S. Energy Usage (GWHr)			U.S. Energy Use ($\times 10^{12}$ Btu/yr)
			Typical Active	Typical Standby	Rated Power Range				Active	Standby	Total	
Ultrasound	50	1800**	1440	1152	1-2K	34	2000	1000	144	58	202	2.3
MRI	1.2*		45000	15000	30-80K	55	60	4800	3.2	86	89	1.0
X-ray Diag.	59.5*	50,000	40000	2400	30-150K	51	8	4500	19.0	643	662	7.4
CT	5.25		52000	12500	40-80K	34	30	3000	8.2	197	205	2.3
Total									174	984	1158	13.0

Notes:

Ultrasound—assume 10 hr per day service, two 20-minute sessions per hour, 300 days per year.

MRI—assume 16 hr per day service, continuous service, scanning 75% of the time 300 day per year assumes hospital and clinic use differences average out.

X-ray—assume 15 hr per day service, 6 patients per hour scanning, 1 sec per patient, 300 days per year.

CAT—assume 10 hr per day, 300 days per year, 2 secs/view, 10 views per patient, 2 patients/hr

*Source: Clinica Factbook, 1991, Pharmabooks Ltd. (Ref. 24)

**Hewlett Packard HP SONOS 1000 used as typical based on telephone interviews.

Table 4-27: Cash Registers and Automated Teller Machines Energy Usage Analysis

Computer Terminals	1990 Inventory (000 units)	Typical Rated Power (watts)	Actual Power (watts)			Power On (%)	Opn Active (Hrs/Yr)	Opn Standby (Hrs/Yr)	U.S. Energy Usage (GWHr)			U.S. Energy Use (x 10 ¹² Btu/yr)
			Typical Active	Typical Standby	Active Range				Typical Active	Typical Standby	Total	
ATM	256	1430	350	300	250-2500	90	790	7880	71	605	676	7.6
POS Register	2051	330	180	162	75-400	50	175	4380	65	1456	1521	17.0
Total									136	2061	2197	24.6

Notes:

ATM assumes 90% availability to customers and 10% of this time in an active mode.

POS Register is assumed to be powered on 50% of the time and 4% of this time is in active mode.

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5.0 Energy Conservation Opportunities and Potential

5.1 Introduction

In this section, we discuss the characteristics of currently available equipment, first principles analyses, the key issues related to their energy efficiency, energy conservation opportunities and their potential, their impact at the national level and recommended development opportunities as well as further study options.

Current technologies, new technologies, and advanced technologies are addressed separately. Current technologies for the purposes of this report are those technologies that are currently applied to the product being discussed and are available in the marketplace today. New technologies are defined as those that cannot be bought in the marketplace today for the product or equipment being discussed but are available for other applications. This means that even though a technology may be mature, it is considered "new" to a product if the technology has not been specifically applied to it. For example, vending machines with high efficiency compressors are not available in the marketplace today. High efficiency compressor technology would, therefore, be considered "new" as it relates to vending machines. Advanced technologies are those that require R&D and could not be incorporated into current products due to the need for technology development.

Energy savings potential for current, new, and advanced technologies cannot be added together since several of the new technologies are replacements for current ones, and advanced technologies may result in radical changes in product design. For the current technologies, we have estimated the current market penetration (Arthur D. Little estimates - subjective) levels to calculate the remaining energy savings potential, since in many cases the technologies have achieved significant penetration in the market.

An example will show how energy savings potential is aggregated. Assume baseline energy use is 100×10^{12} Btu/yr, and the first applied technology has a 10% savings and a 5% current market penetration; then the remaining savings (not taken yet) from this technology is $(100 \times 10^{12} \text{ Btu/yr} \times 0.10 \times 0.95 =) 9.5 \times 10^{12}$.

If a second technology, for example, has a savings of 15% and has a current market penetration of 10%, then the energy savings estimated from this second technology is:

$$\begin{aligned} \text{Potential savings} &= (100 \times 10^{12} - 9.5 \times 10^{12}) (0.15 \times 0.90) \\ &= 12.22 \times 10^{12} \text{ Btu/yr.} \end{aligned}$$

This process is continued so that for the third technology the savings are based on a reduced baseline of $(100 - 9.5 - 12.22) \times 10^{12}$ Btu/yr.

If market penetration is zero, the total potential energy savings can also be calculated

as percent savings using the expression: Total Percent Savings = $1 - (1-PS_1)(1-PS_2)(1-PS_3)\dots$ where $PS_1, PS_2, PS_3, \dots$ are percent savings for each technology in a group of non-mutually exclusive technologies. Since the order of the technologies is random, only the summation of savings from all of the technologies is of real significance.

The same method can be applied to new and advanced technologies. Since the market penetration for these technologies is zero, the aggregate can be calculated as:

Potential Savings = Baseline Energy Use $[1-(1-0.1)(1-.15)(1-.3)]$ for three non mutually exclusive technologies that have 10, 15, and 30% savings respectively.

Whenever, any two technologies within a given set of technologies are mutually exclusive, we have included the technology with the highest savings potential in the aggregated savings.

5.2 Refrigeration

5.2.1 Unitary Systems - Unit Coolers

5.2.1.1 System Description Unit coolers are the free standing refrigerated display cases commonly used in convenience stores to hold and display frozen foods, cold beverages, and fresh foods. The unit cooler is self contained, with the refrigerating system built in and heat rejected from the refrigeration cycle to the building interior air. Unit coolers are also used in supermarkets (in addition to the large, remote condensing unit based refrigerated and frozen food display cases), in pizza shops, and restaurant, commercial and institutional kitchens.

Unit coolers for frozen food typically maintain a cabinet interior temperature of 0°F (-18°C), with an evaporator temperature of approximately -20°F (-29°C). Unit coolers for fresh food and cold beverages are operated with an interior temperature between 35°F and 40°F (2° to 5°C) and an evaporating temperature of approximately 20°F (-7°C). For both categories of unit coolers, the condensing temperature is 20° to 25°F (11° to 14°C) above the ambient interior temperature. The COP of the refrigeration system is typically on the order of 1.0 for frozen food coolers and 1.75 for fresh food temperature coolers, accounting for both compressor and fan power consumption. Figure 5-1 shows the configuration of a typical large unit cooler. The entire refrigeration system is located at the top of the unit, with the condensing unit (compressor, condenser, and fan) occupying roughly one half of the refrigeration system volume, and the evaporator and fan occupying the other half. Although ample space is available within the overall footprint of a unit cooler, condenser and evaporator face areas and overall heat transfer capacities are small, accounting for the large air to refrigerant temperature differences noted above.

Source: Beverage Air

Figure 5-1: Configuration of a Typical Large Unit Cooler

5.2.1.2 First Principles Analyses In Figure 5-2, the unit cooler refrigeration system is illustrated schematically, reduced to its thermodynamic fundamentals. From the viewpoint of the lowest achievable level of energy consumption, the system can be viewed with respect to two fundamental considerations:

- The sources of the heat gained by the refrigerated interior, which must be removed as the refrigeration load by the refrigeration system.
- The efficiency, or COP, of the refrigeration system. Given the necessity of maintaining a refrigerated interior temperature level that is dictated by food preservation requirements and the requirement to reject heat to the indoor ambient, the efficiency needs to be evaluated relative to design condition and design load operation and over the range of loads associated with high and low usage periods.

Display Case Heat Gains

The heat gains to the display case can be classified as:

- Internal heat gains
 - pulldown of product temperature
 - lighting
 - fan motor
- Heat gains from the surroundings
 - wall conduction (through the cabinet insulation)
 - door conduction (typically through door glazings)
 - conduction at the door perimeter - through the gaskets and thermal break
 - infiltration (gasket leaks, door openings, open deck, and open tub type coolers)

- in addition, electric resistance antisweat heaters (around the door perimeter and on door glazings) consume electric power and increase conduction heat gains

Figure 5-2: Thermodynamic Schematic of a Commercial Unit Cooler Refrigeration System

The first of these, pulldown of the product temperature, represents the one useful component of the refrigeration load, in that the product needs to be maintained at a particular temperature to provide adequate shelf life. However, this represents a negligible fraction of the cooling load. The majority of both fresh and frozen products are transported to the food store at their refrigerated temperature; while some heat is gained in the process of transferring the product from the loading dock to the display case, it is typically small.

The remainder of the heat gains listed above represent losses that are theoretically reducible, by increasing insulation thickness, improving door gasket and thermal break design, using fewer open type displays, etc. The design of display cases is driven by merchandising considerations, the major one being to maximize the visibility and accessibility of the product, hence glass doors and open deck and tub type displays.

Detailed examination of alternatives to reduce thermal loads is beyond the scope of the present study. It is evident, however, that significant reductions in load could be achieved through the use of more efficient fans and lighting and that all of the above "heat gains from the surroundings" could be reduced significantly. Again, retail food

industry acceptance would be contingent on new designs providing adequate visibility of and accessibility to the food product.

Refrigeration Cycle Efficiency

The vapor compression cycle is inherently a shaft power driven cycle, whose 2nd law limited maximum COP, generally referred to as the Carnot cycle COP, is

$$\text{COP}_{\text{carnot}} = T_c / (T_h - T_c),$$

where T_c and T_h are the absolute temperatures of cold and hot, respectively, ideal thermal reservoirs.

Figure 5-3 is a bar chart comparing Carnot and actual COP levels at standard rating conditions of a 90°F indoor ambient dry bulb temperature for a low temperature case whose product is maintained at -5°F. The first bar is the Carnot COP with T_h of 90°F and T_c of -5°F, representing the theoretical maximum COP if both the indoor ambient dry bulb and frozen product temperatures could be accessed as ideal, or infinite, thermal reservoirs.

Figure 5-3: Effect of Equipment Inefficiencies on Low Temperature Commercial Unit Cooler Refrigeration Cycle Efficiency

The second bar in this figure gives the Carnot COP for T_h and T_c of 110°F/-30°F, the typical condensing and evaporating temperatures of an air cooled (not evaporatively) refrigeration system associated with a 90°F indoor ambient dry bulb temperature and

a -5°F case interior temperature. The difference between bars 1 and 2 is the efficiency loss due to the heat transfer temperature differential between the closed refrigeration cycle working fluid and the ambient air and cabinet interior temperatures. The heat transfer temperature difference has two components: the temperature difference between the air and the refrigerant, and the temperature increase or decrease of the air passing through the condenser or evaporator, respectively, associated with transporting the heat load with a finite air mass flow rate. Figure 5-4 illustrates this latter effect for the evaporator. The temperature differential can be reduced, by increasing the heat exchanger size and air flow rate; any increase in air moving power will partially negate the COP improvement due to reduced temperature lift. (A similar rationale and tradeoff is applicable to the condenser as well.)

Figure 5-4: Typical Temperature Distribution in the Evaporator of a Low Temperature Commercial Unit Cooler

The third bar in Figure 5-3 gives the COP of a simple vapor compression cycle with a liquid line to suction vapor line interchanger with T_h/T_c of 110°F/-30°F (and 10°F subcooling, 95°F superheat) (suction vapor is superheated in the interchanger) and 100% efficient compressor. The difference between bars 2 and 3 is the inherent inefficiency of the vapor compression cycle compared to the thermodynamically ideal Carnot cycle. The vapor cycle bars are based on a 50/50 near azeotropic mixture of HFCs 32 and 125.

A large part of the difference between bars 2 and 3 is attributable to the expansion

losses over the relatively large -30°F/110°F temperature lift. The cycle efficiency can be improved considerably by using a mechanical subcooler (bar 4), an auxiliary refrigeration cycle that subcools the liquid to the average of the high and low side temperatures. The subcooler reduces the enthalpy of the liquid refrigerant, reducing the flash loss; the evaporator of the subcooler operates at a temperature of 30°F so the subcooling refrigeration loop operates at a considerably higher COP than the main low temperature refrigeration loop. This technology is widely used in state-of-the-art supermarket central refrigeration systems, but is not used in unit coolers.

Bars 5 and 6 account for the effect of real motor/compressor efficiency compared to bars 3 and 4 and the difference between bars 5 and 6 accounts for the parasitic power. The 50% motor/compressor efficiency is typical of the compressors used in these coolers, but well below the efficiency of the state-of-the-art compressors that are used in other applications; the assumed level of parasitics is typical.

Overall, then, a typical ambient air cooled low temperature unit cooler system will operate with a COP of somewhat less than 1.0 at design conditions, versus theoretical Carnot COP levels of 4.5, based on the indoor ambient dry bulb temperature. The difference is accounted for by heat transfer temperature differentials, inherent inefficiencies in the vapor compressor cycle, (expansion losses), compressor inefficiencies and parasitics. The magnitude of heat transfer temperature differentials, and parasitics is controlled by factors that are a matter of engineering tradeoffs between interior and outdoor space requirements, heat exchanger costs, other costs (e.g., piping, insulation), and resulting system efficiencies and operating costs. The losses associated with vapor versus ideal Carnot cycle could be reduced by further reduction of expansion losses. Efficiencies of the welded hermetic compressors that are currently used in commercial unit coolers are well below the practical limits (90+% motor efficiency, 75% to 80% isentropic compression efficiency) of compressor efficiency.

The preceding discussion addresses full capacity, design conditions operation. In much of the installed base of refrigeration equipment at part load, significant losses can be incurred due to cyclic operation of compressors.

The first principles analyses establishes the theoretical maximum efficiency and shows where the losses occur. By identifying and applying technologies that reduce these losses or bring us closer to the Carnot cycle COP, we can potentially save substantial amounts of energy. These technologies are discussed below.

5.2.1.3 Current Technologies Currently available technologies for unit coolers have achieved close to 100% market penetration. None of these provide a significant amount of remaining energy savings and are therefore not discussed here.

5.2.1.4 New Technologies The key design measures that could be implemented to improve the COP of the refrigeration systems of unit coolers are:

- Increase (approximately double) the face area of both the condenser and

evaporator. The overall evaporator to condenser temperature lift can be reduced by 15°F to 20°F (8° to 11°C), with a resulting 20 to 25% increase in COP. These changes would result in an increased retail cost of a typical 25 cubic foot unit cooler by approximately \$50 to \$75 (versus a typical price of \$2,000 to \$2,500). Implementation would be straightforward, and equipment could be available by 1995.

- Apply standards similar to 1993 Residential Standards for refrigerators, to unit coolers resulting in increased insulation (5% savings), improved gaskets and seals (3% savings) and replace the low efficiency compressors typically used in this equipment with the best compressors currently available for domestic refrigerators (25% savings). Overall, a 25 to 30% increase in efficiency can be realized. An increase in retail price of approximately \$75 to \$100 would result. Implementation would be straightforward and equipment could be commercially available by 1995.
- Replace air cooled condensers in current equipment by water cooled condensers. City water could be preheated for domestic hot water use or a cooling tower arrangement or outdoor radiator could be used to reject heat. This would result in a COP improvement from 1.0 to 1.5 for frozen foods refrigeration and from 1.75 to 2.6 for fresh foods. Energy use would be reduced by one-third. No credit is taken for the preheat to the domestic hot water.

Since none of the above technologies have been applied to the unit coolers in the marketplace today, these technologies are considered "new" technologies as they relate to commercial unit coolers. The technologies per se are straightforward, well-understood, mature technologies that have been proven in other applications.

It should be noted that the CFC issue impacts this class of equipment very directly, with the two most commonly used refrigerants, CFC-12 and CFC-502 in the process of being phased out. In at least the near-term, HCFC-22 will be used in both frozen food and refrigerated food and beverage unit coolers. To minimize the high discharge temperatures associated with R22, semi-hermetic compressors with forced air cooling will be used in freezers. The design measures noted above serve to reduce R22 discharge temperatures as well. The change from CFC-12 to R22 has negligible impact on the COP.

The COP improvements in unit coolers described above are converted to energy savings potential at the national level. First, we calculated the percent energy savings and applied this to the baseline energy use to obtain total U.S. annual energy savings. Electricity is converted from kWh delivered at the building to primary energy Btu input at power plant using the conversion factor of 1 kWh = 11,200 Btu. Table 5-1 shows the COP improvement, energy use reduction and the annual energy savings for the U.S. Since increased face area of condensers and water cooled condensers are mutually exclusive, the totals do not include the increased face area option, to avoid double counting. A technically feasible potential savings of 53% of

the baseline energy use for unit coolers is estimated amounting to roughly 79×10^{12} Btu/year in primary energy savings.

Table 5-1: Results - Refrigeration - Unit Coolers - New Technologies

Baseline Energy Use = 149×10^{12} Btu
Baseline COP = 1.0 (Frozen) 1.75 (Fresh Foods)

Technology	% COP Improvement	% Energy Reduction	Energy Savings (x 10^{12} Btu)
<ul style="list-style-type: none"> 1993 Residential Standards Applied to Unit Coolers <ul style="list-style-type: none"> – Increase insulation (5% savings) – High efficiency compressors (25% savings) – Improved gaskets and seals (3% savings) Increased Face Area of Condenser and Evaporator* Water-Cooled Condensers 	 4.8 33 2.9 22* 47	 5 25 3 18* 32	 7.5 37.3 4.5 27.4* 48.0
Total	88	53*	79**

* Water Cooled Condensers and increased face area of condensers are mutually exclusive. this item is, therefore, excluded from totals.

** Savings are calculated as % of remaining energy use. Total savings is, therefore, less than the sum of all measures. Savings = $-(1 - 0.05)(1 - 0.25)(1 - 0.03)(1 - 0.32) = 0.53$.

5.2.1.5 Advanced Technologies To move beyond the 53% energy savings available through application of technologies to unit coolers from other areas, we need advanced technologies. These include:

- Advanced vapor compression cycle technologies; and
- Advanced alternative cycles including reverse stirling cycle and advanced absorption cycle.

Advanced Vapor Compression Cycle Techniques

Advanced vapor compression cycle techniques include:

- Two or multiple stage expansion/vapor extraction or multiple stage mechanical subcooling, to reduce expansion losses (10-15% increase in COP)
- Matched glide non-azeotropic refrigerant mixtures, to reduce the effective heat transfer/heat transport temperature differential (5-10% increase in COP)
- Use of inherently higher efficiency refrigerant, e.g., ammonia, propane (15% increase in COP)

Multistage expansion and vapor extraction (or multistage mechanical subcooling)

would reduce the expansion loss to a lower level than is attained by mechanical subcooling alone. For example, with three stages of mechanical subcooling, the difference between the condensing and evaporating temperature would be divided into four equal temperature steps. In the first three, small refrigeration loops operating at progressively lower evaporating temperatures would subcool the liquid; the final stage would be the normal throttling type expansion. Compared to conventional single stage mechanical subcooling, three stage subcooling would increase the COP of a low temperature system by about 10%.

A non-azeotropic refrigerant mixture whose glide approximates the condenser and evaporator air side glides (10°F to 15°F) could improve the COP by up to about 10%, by reducing the effective lift by about 10°F. HFC32/HFC134a is an example of a NARM having a temperature glide in this range.

Some refrigerants that are generally ruled out of commercial refrigeration applications because they are flammable and/or toxic, e.g., ammonia and propane, have thermodynamic property based COPs that are more than 10% higher than any of the low boiling HFCs, and transport properties that result in increased refrigerant side heat transfer coefficients. These fluids could be used if a central refrigeration system was used that was located remotely from the publicly occupied part of the supermarket and connected with a low temperature secondary loop. (However, the resulting system really wouldn't be a unit cooler). Analyses of the safety implications of using a flammable refrigerant in a domestic refrigerator, with its welded/brazed hermetic refrigeration system and limited refrigerant charge have shown that the risks are minimal; unit coolers have generically the same type of refrigeration system, and similarly low hazard levels could be expected.

Reverse Stirling Cycle. The COP of an ideal reverse Stirling cycle is comparable to the Carnot cycle. A Stirling cycle refrigeration system would need secondary liquid heat transport loops to connect it with both the cold interior air and, for heat rejection, the indoor ambient air. For a given investment in heat exchangers, the same level of heat transport temperature differentials as would occur in a vapor cycle can be expected. Parasitics would be somewhat higher for the reverse Stirling. The basic losses within a Stirling cycle--regenerator ineffectiveness and pressure loss, non-isothermal compression and expansion, and dead volume effects, plus drive motor inefficiency--could be less than the combined motor, compressor, and expansion losses in a vapor cycle. Not including parasitics, current vapor cycle unit coolers operate at approximately 33% of Carnot, based on the evaporating and condensing temperatures. When fully developed, reverse Stirling could achieve COP levels as high as 50% of Carnot, 30% higher than current vapor compression, on the same temperature basis. This is somewhat reduced when parasitics are considered. Estimated overall COP improvement of 15 to 25% is expected.

Advanced Absorption Cycle. All of the preceding addresses electrically powered systems; in the United States, the average efficiency with which a primary fuel source is converted to electric power and delivered to a point of use is approximately 30%. In view of the losses involved in generating and transmitting electric power,

thermally actuated cycles may have the potential for higher primary fuel basis COPs. Compared to an electrically powered COP of 1.0, with electricity delivered at a primary fuel efficiency of 30%, a thermally activated cycle would need to operate with a COP of 0.30 to provide comparable primary fuel COP. Over this large lift, and with an appropriate refrigerant -- absorbent/adsorbent pair, 0.6 might be a reasonable target COP value for a double effect cycle, so that an improvement in primary fuel COP over current vapor cycle on the order of 100% might be obtainable. The inherent disadvantages (e.g., the need for gas lines and flue vents) of a direct fired appliance in most of the establishments where unit coolers are used is a significant obstacle to commercial acceptance of this approach. If we consider 45% power plant efficiency the improvement in COP of absorption cycle over current vapor compression would be around 40%.

Other New Cycles. Other "new" cycles that have attracted significant development support include thermoacoustic and orifice pulse tube, Malone cycle, and magnetic refrigeration. None of these cycles is likely to prove to have inherent internal loss levels, in practically sized equipment, that are lower than can be attained with current, well designed vapor cycle equipment. Table 5-2 shows the energy savings for each of the above advanced technologies.

Table 5-2: Results - Refrigeration - Unit Coolers - Advanced Technologies

Baseline Energy Use = 149×10^{12} Btu
Baseline COP = 1.0 (Frozen) 1.75 (Fresh Foods)

Technology	% COP. Improvement	% Energy Reduction	Energy Savings (x 10^{12} Btu)	
			Each Measure	Subtotal
1. Advanced Vapor Cycle Techniques				35
- Multistage mech. subcooling	10-15	11	16	
- Use of NARMS or	5-10	7	10+	
- Inherently higher efficient refrigerants - propane, ammonia	15	13	19	
2. Reverse Stirling Cycle	15-25	17		25
3. Advanced Absorption CYcle (Double-effect, direct-fired)	100* 40**	60 29		75* 43**
Aggregate Savings				75

+ Exclude from total--overlap with higher efficiency refrigerant.

* Based on current average primary fuel to delivered electricity conversion efficiency of 30% for the U.S.

** Based on incremental power conversion efficiency of 45%.

Since advanced technologies, advanced vapor compression, reverse stirling and advanced absorption cycles are mutually exclusive only the one with the highest potential savings is included in the aggregate.

5.2.2 Ice Makers

5.2.2.1 System Description Commercial ice makers fall into three primary categories:

- Cubers--Produce ice at about 95% quality. A key functional requirement of cubers is that they produce ice with very high clarity.
- Flakers--Produce ice flakes which are in the 60-70% quality range. Common applications for flaked ice include holding fish for display cases and hospitals where choking on ice cubes could be a problem.
- Nugget machines--Produce an intermediate quality ice, 80-90%, and are largely based on the flaker principal.

Commercial ice makers generally fall within a size range from 200 lb/day under-counter cubers up to 2,000 lb/day modular flakers. Manufacturers measure the energy performance of an ice maker in terms of kilowatt hours (kWhs) of electricity consumed per 100 lbs of ice made. To provide a common base for COP measurement, the energy performance information in kWh/100 lb units has been converted to COP units. These units are defined as the theoretical amount of energy to make a given quantity of ice divided by the total energy consumed by the machine to make the given quantity of ice. There is a broad range of COP's for current ice makers. Commercially available units range from 0.4 to 0.8 COP efficient depending on their design and method for cooling the condenser.

Figure 5-5 shows a typical ice cuber in conjunction with the ice storage bin. The ice cuber is mounted on top of a storage bin. Due to the large storage volume, ice makers typically run almost continuously since the storage volume is sized to meet peak demand and the ice maker constantly replenishes ice removed from the bin. The COP of an ice maker depends critically on the thermal design of the evaporator. A common approach is to use a vertical ice cube tray as shown in Figure 5-6 and trickle water over its surface. The back of the ice cube tray contains a serpentine copper tube through which the refrigerant flows which causes the water to freeze. This design is reasonably efficient since the evaporator serpentine coil is in good contact with the ice cube tray. However, there is an efficiency penalty related to the requirement to partially melt ice for harvesting. Typically, 10-15% of the ice produced needs to be melted to free it from this type of evaporator tray.

There are many other geometries employed for orienting the refrigeration tubing around a physical structure to provide a form for the water to freeze in. The greater the extent to which the water to be frozen surrounds the evaporator coil, the greater the efficiency of the system. The evaporator tray shown in Figure 5-6 above only transfers useful cooling on one side where the ice cube tray is located and energy losses occur on the other. One of the most efficient machines uses tubes, surrounded by evaporator tubing, through which water flows during freezing and makes cylindrical ice which is cut as it flows out of the tube during the harvest. This design

Figure 5-5: Ice Cuber

Figure 5-6: Vertical Ice Cube Tray

is one of the most efficient since the refrigerant completely surrounds the surfaces upon which water is freezing.

Ice flakers are very different in mechanical design than cubers as shown in Figure 5-7. Typically, water is introduced into an auger which continuously scrapes the inside wall of the evaporator thereby forcing ice flakes forward. These systems also have a broad COP range of approximately 0.5 to 0.8 and depend significantly on the geometry between the evaporator coils and cylinder walls and whether the system is air-cooled or water-cooled.

5.2.2.2 First Principles Analyses First principles analyses for unit coolers, described earlier in Section 5.2.1.2, applies to ice-makers as well and is, therefore, not repeated here.

5.2.2.3 Current Technologies Energy efficiency is becoming a more important basis of competition among manufacturers. The technology improvements which are allowing ice makers to operate in the range of 0.8 COP are listed below:

Figure 5-7: Ice Flaker

- Water-cooled condensers provide higher overall efficiencies than air-cooled systems. Water-cooled condensers are commercially available; however, they have disadvantage of requiring a larger water line connection along with greater water consumption for the cooling water.
- Harvest assist mechanism--one manufacturer uses a small mechanically driven plunger to force the ice off of the ice cube tray during the harvest cycle in which ice is melting to free it from the evaporator. This device increases the overall performance of the machine since less melting occurs prior to ice release.
- Several manufacturers are working on improved evaporator designs whereby the wetted surfaces of the evaporator, upon which the water freezes, completely surround the refrigerant flow, while maintaining an acceptable ice shape. One manufacturer offers such a unit; however, the ice cubes are cylindrical rather than cubic which is less desirable by customers in this industry. The leading manufacturers are working toward this end while maintaining cubic ice shapes in both half- and full-cube sizes.

By our definition, all of the above are considered "current" technologies, since they are incorporated in some of the high-end models sold today. Given the technology developments cited above, future COP could be in the 0.8 range. Energy efficiency is not the top priority in purchasing ice makers. Reliability is a major problem with most commercial ice makers and is one of the leading factors upon which manufacturers compete. First cost is also an important factor. There are no energy efficiency standards for ice makers, and it is likely that energy efficiency will continue to be a secondary factor. Currently, the average COP of ice makers is about

0.6 which will slowly increase to 0.7-0.8 by the year 2000. This projection is based on the observation that the technology is commercially available, but the driving forces for customers to purchase the most efficient machines are not strong. Table 5-3 shows the COP improvement, current market penetration, and energy savings for current technologies. A total of 15×10^{12} Btu/yr energy savings can be achieved. Of the 105×10^{12} Btu of energy consumed by ice makers, 15×10^{12} Btus could be saved using these current technologies.

Table 5-3: Results - Refrigeration - Ice Makers - Current Technologies

Baseline Energy Use = 105×10^{12} Btu/yr
Baseline COP. = 0.60

Technology	% COP. Improvement	% Energy Reduction	Current Market Penetration	Energy Savings (x 10^{12} Btu/yr)
Current Technologies				
• Water-Cooled Condensers, Harvest Assist Mechanism and Improved Evaporator Designs - Such as Cylindrical Ice Making	20	17	15	15

5.2.2.4 New Technologies High efficiency compressors are not currently employed in ice makers. By our definition this would be a "new" technology. Replacing the current compressors with high efficiency compressors and increasing the insulation levels could result in COP improvement from 0.6 to 0.82.

The above technologies or energy conservation opportunities are divided into current and new technologies as discussed above. These improvements in COP are converted to potential energy savings both as percentage of the baseline energy use and total U.S. energy savings per year for ice makers. Conversion factor for electricity is 1 kWh delivered on site equals 11,200 Btus of primary energy inputs at the power plant. Table 5-4 shows the COP improvements, percent energy reduction, and energy savings from application of new technologies to all ice makers. By the application of new technologies (new to ice makers) such as high efficiency compressors and added insulation, an additional 27% reduction in energy use or 28×10^{12} Btu/yr can be achieved as shown in Table 5-4. Since the current and new technologies are not mutually exclusive, they can be combined to provide savings of 39×10^{12} Btu/yr. (Total energy savings = $15 \times 10^{12} + 0.27 \times (105.2 - 15) \times 10^{12} = 39.3 \times 10^{12}$ Btu/yr.) The total U.S. annual energy savings potential is estimated at 39×10^{12} Btu's per year out of 105×10^{12} Btu's per year of baseline annual primary energy consumption.

Table 5-4: Results - Refrigeration - Ice Makers - New Technologies

Baseline Energy Use = 105×10^{12} Btu/yr
Baseline COP. = 0.60

Technology	% COP. Improvement	% Energy Reduction	Current Market Penetration	Energy Savings (x 10 ¹² Btu/yr)
New Technologies				
• High Efficiency Compressors increased Insulation	37	27	0	28

5.2.2.5 Advanced Technologies The advanced technologies applicable to ice-makers are similar to those for unit coolers. These include:

- Multistage expansion/vapor extraction or multiple stage mechanical subcooling to reduce expansion losses (10% improvement in COP).
- Use of inherently higher efficiency refrigerant such as propane or ammonia (10% to 15% improvement in COP).
- Reverse Stirling cycle for ice makers could potentially improve COP's by 15% to 25% over current average values.
- Advanced absorption cycle ice maker (double effect, direct fired) could achieve 100% improvement in COP assuming a 30% efficiency of conversion of primary energy to electricity. This improvement in COP would reduce to 40% if we assumed power conversion efficiency of 45%.

Table 5-5 shows the COP improvement and energy savings from advanced technologies applied to ice-makers.

Table 5-5: Results - Refrigeration - Ice Makers - Advanced Technologies

Baseline Energy Use = 105×10^{12} Btu/yr
Baseline COP. = 0.60

Technology	% COP. Improvement	% Energy Reduction	Energy Savings (x 10 ¹² Btu/yr)
1. Multi-stage mech. subcooling	10-15	11	12
2. Inherently higher efficiency refrigerants	15	13	28
3. Reverse Stirling Cycle	15-25	17	
4. Advanced Absorption Cycle (Double-effect, direct-fired)	100* 40**	50 29	52 31
Maximum Aggregated			52

* Based on 30% primary energy to electricity conversion.

** Based on 45% primary energy to electricity conversion.

5.2.3 Commercial or Supermarket Refrigeration Systems

5.2.3.1 System Description For the purpose of this analysis, supermarket refrigeration system means the typical low or medium temperature refrigeration system used in larger supermarkets to hold and display frozen foods, cold beverages, and fresh foods. Large walk-in freezers used in restaurants are also included in this category. The vapor compression cycle is used in all supermarket refrigeration systems. As indicated in Figure 5-8, the major elements of this type of system are the refrigerated display cases (with evaporator and fan), the central compressor unit (which is located in an equipment room, remote from the display cases), and the condenser which can be cooled by ambient air (dry), evaporatively cooled, or water cooled. The refrigeration systems are located remotely from the display cases, interconnected by long runs of liquid and suction tubing. The compressor units can consist of a single compressor or multiple, rack mounted, parallel compressors. For frozen food, a display case interior temperature of -5°F to 0°F (-21° to -18°C) is typically maintained, with an evaporator temperature of approximately -30°F to -20°F (-35° to -29°C). Fresh food and cold beverages are operated with an interior temperature between 32°F and 45°F (0° to 8°C) and an evaporating temperature of approximately 10° to 20°F (-12° to -7°C). The simplest systems consist of a single compressor, a condenser with "head pressure" control to maintain a minimum condensing temperature/pressure regardless of the ambient temperature, and expansion valves at the display cases.

5.2.3.2 First Principles Analysis The first principles analyses are similar to the analyses for unit coolers except that COP levels are somewhat different. Because of these differences the analyses are presented here though somewhat repetitive. In Figure 5-9, this system is illustrated schematically, reduced to its thermodynamic fundamentals. From the viewpoint of the lowest achievable level of energy consumption, the system can be viewed with respect to two fundamental considerations.

- The sources of the heat gained by the display case, which must be removed as the refrigeration load by the refrigeration system.
- The efficiency, or COP of the refrigeration system. Given the necessity of maintaining a refrigerated display case interior temperature level that is dictated by food preservation requirements and the requirement to reject heat to the outdoor ambient, the efficiency needs to be evaluated relative to design condition and design load operation, and over the seasonal range of loads and ambient temperatures.

(May Be as Small as 3/4 HP, as Large as 40 HP)

Unit May Be Low or Medium Temperature, 2 or More, Equal or Unequal Compressor in Parallel

Figure 5-8: Conventional Refrigeration System Used for Supermarkets

Figure 5-9: Thermodynamic Schematic of a Supermarket Refrigeration System

Heat Gains to the Display Case Interior

The heat gains to the display case can be classified as:

- Internal heat gains
 - pulldown of product temperature
 - lighting
 - fan motor
- Heat gains from the surroundings
 - wall conduction (through the cabinet insulation)
 - door conduction (typically through door glazings)
 - conduction at the door perimeter - through the gaskets and thermal break
 - infiltration (gasket leaks, door openings, open deck, and open tub type cases)
 - in addition, electric resistance antisweat heaters (around the door perimeter and on door glazings) consume electric power and increase conduction heat gains.

The first of these pulldown of the product temperature, represents the one useful component of the refrigeration load, in that the product needs to be maintained at a particular temperature to provide adequate shelf life. However, this represents a

negligible fraction of the cooling load. The majority of both fresh and frozen products are transported to the supermarket at their refrigerated temperature; while some heat is gained in the process of transferring the product from the loading dock to the display case, it is typically small.

The remainder of the heat gains listed above represent losses that are theoretically reducible. To put this in perspective, a typical 12 1/2 foot glass door, frozen food display case has an interior volume of 150 cubic feet and requires approximately 6000 Btu/hr of refrigeration capacity or 40 Btu/hr per cubic foot. The heat gain of open type displays is larger. In comparison, the thermal load on a 5 cubic foot freezer in the domestic refrigerator designed to meet the 1993 appliance energy efficiency standards, at the DOE closed door test condition, is 150 Btu/hr or about 30 Btu/hr per cubic foot of internal volume, despite a much higher surface area to volume ratio. The design of display cases is driven by merchandising considerations, the major one being to maximize the visibility and accessibility of the product, hence glass doors and open deck and tub type displays. Detailed examination of alternatives to reduce thermal loads is beyond the scope of the present study. It is evident, however, that significant reductions in load could be achieved through the use of more efficient fans and lighting and that all of the above "heat gains from the surroundings" could be reduced significantly. Again, retail food industry acceptance would be contingent on new designs providing adequate visibility of and accessibility to the food product.

Refrigeration Cycle Efficiency

The vapor compression cycle is inherently a shaft power driven cycle, whose 2nd law limited maximum COP, generally referred to as the Carnot cycle COP, is

$$\text{COP}_{\text{Carnot}} = T_c / (T_h - T_c),$$

where T_c and T_h are the absolute temperatures of cold and hot, respectively, ideal thermal reservoirs.

Figure 5-10 is a bar chart comparing Carnot and actual COP levels at standard rating conditions of a 95°F ambient dry bulb temperature and 75°F ambient wet bulb temperature, for a low temperature case whose product is maintained at -5°F. (Note: With an evaporatively cooled condenser, the effective heat sink temperature is the ambient wet bulb temperature). The first bar is the Carnot COP for T_h/T_c of 75°F/-5°F, representing the theoretical maximum COP if both the ambient wet bulb and frozen product temperatures could be accessed as ideal, or infinite, thermal reservoirs.

The second bar represents the Carnot COP, but with the ambient dry bulb temperature as the heat rejection reservoir. The difference represents the general magnitude of the efficiency penalty associated with not using an evaporatively cooled condenser; the actual difference between ambient wet and dry bulb temperatures varies by region, time of year, and time of day, but the 20°F difference used here is close to the average.

Figure 5-10: Effect of Equipment Inefficiencies on Low Temperature Supermarket Refrigeration Cycle Efficiency

The third bar gives the Carnot COP for T_h/T_c of 110°F/-30°F, the typical condensing and evaporating temperatures of an air cooled (not evaporatively) refrigeration system associated with a 95°F ambient dry bulb temperature and -5°F case interior temperature. The difference between bar 2 and 3 is the efficiency loss due to the heat transfer temperature differential between the closed refrigeration cycle working fluid, and the ambient air and cabinet interior temperatures. As illustrated in Figure 5-11, the heat transfer temperature difference has two components: the temperature difference between the air and the refrigerant, and the temperature decrease of the air passing through the evaporator, associated with transporting the heat load with a finite air mass flow rate. Similar logic applies to the condenser side heat transfer. The temperature differential can be reduced, by increasing the heat exchanger size and air flow rate; any increase in air moving power will partially negate the COP improvement due to reduced temperature lift. (This rationale applies to the condenser as well.)

The fourth bar gives the COP of a simple vapor compression cycle with T_h/T_c of 110°F/-30°F (and 0° subcooling/0° superheat) and a 100% efficient compressor. The difference between bars 3 and 4 is the inherent inefficiency of the simple vapor compression cycle compared to the thermodynamically ideal Carnot cycle. Two sets of values are included in the vapor cycle bars: one for HP-62, a near azeotropic blend of HFC's 125, 143a, and 134a (40%/45%/15% by weight, respectively) which has been developed for low temperature refrigeration application, and one for the

HFC-125 as the working fluid. For the simple cycle (bar 4) the difference in working fluid thermodynamic properties can have a pronounced effect on the

Figure 5-11: Typical Temperature Distribution in the Evaporator of a Low Temperature Display Case

theoretical COP.

A large part of the difference between bars 3 and 4 is attributable to the expansion losses over the relatively large -30°F/110°F temperature lift. The cycle efficiency can be improved considerably by using a mechanical subcooler, an auxiliary refrigeration cycle that subcools the liquid to the average of the high and low side temperatures. The subcooler reduces the enthalpy of the liquid refrigerant, reducing the flash loss; the evaporator of the subcooler operates at a considerably higher COP than the main low temperature refrigeration loop, increasing the overall COP as shown in Bar 5.

Bars 6 and 7 account for the effect of real motor/compressor efficiency and parasitic power. The 70% motor/compressor efficiency is at the state of the art; the assumed level of parasitics is typical. The difference between bars 6 and 7 is due to parasitic losses.

Overall, then, a well designed ambient air cooled low temperature commercial refrigeration system will operate with a COP on the order of 1.4 at design conditions, versus theoretical Carnot COP levels of 4.5 (based on the ambient dry bulb temperature) or 5.7 based, on the ambient wet bulb temperature. The difference is accounted for by heat transfer temperature differentials, inherent inefficiencies in the vapor compressor cycle, compressor inefficiencies and parasitics. The magnitude of

heat transfer temperature differentials and parasitics is controlled by factors that are a matter of engineering tradeoffs between interior and outdoor space requirements, heat exchanger costs, other costs (e.g., piping, insulation), and resulting system efficiencies and operating costs. The losses associated with vapor versus ideal Carnot cycle could be reduced by further reduction of expansion losses. Efficiencies of the best compressors are beginning to approach practical limits (90+% motor efficiency, 75% to 80% isentropic compression efficiency).

The preceding discussion addresses full capacity, design conditions operation. In much of the installed base of refrigeration equipment at part load and/or low ambient temperature conditions, significant losses are incurred due to cyclic operation of compressors, head pressure controls that maintain a minimum condensing temperature level regardless of the ambient temperature level (to provide enough pressure to force the design flow rate of refrigerant through expansion valves that have been sized on the basis of this pressure level). State of the art systems are in widespread (although not universal) use that use capacity control techniques such as uneven parallel compressors or variable speed drives and floating head pressure controls to minimize these losses.

5.2.3.3 Current Technologies Table 5-6 summarizes a variety of efficiency improvements on the typical supermarket refrigeration system. These are currently available technologies. The measures were identified and savings estimated by ADL specialists who are at the forefront of refrigeration technologies. Their knowledge and experience constitutes the basis for these estimates. Additionally, literature and interviews with outside experts are used wherever necessary.

Table 5-6: Options for Improved Efficiency of Commercial Refrigeration Systems - Current and New Technologies

Conservation Measure	Improvement In Seasonal COP*	Commercially Available?	Approximate % of Installed Base
Variable capacity (variable speed, uneven parallels, cylinder unloading)	10-15%	Yes	67%
Partial floating head pressure control	10 - 15%	Yes	50%
Fully floating head pressure control	Additional 5 - 10%	No	0
2 stage R22 with intercooling and subcooling for low temp vs. 1 stage R502 or 1 stage R12	10 to 15%	Yes	<10%
Evaporatively Cooled Condensers	5 - 10%	Yes	25%
Mechanical Subcooling	5%	Yes	25%

As indicated in Table 5-6 above, several of these improvements--uneven parallel compressors for capacity control, partial floating head pressure controls, and evaporatively cooled condensers are already in widespread use. The supermarket

industry runs on very small profit margins (net margin of 1 to 2% sales), with the cost of the electric power consumed by the refrigeration systems being roughly comparable to profit margins. This has provided ample incentive for the widespread adoption of efficiency improving technologies in this industry. The average COPs of the installed base of commercial refrigeration systems are typically on the order of 1.2 for frozen food coolers and 2.0 for fresh food temperature coolers, accounting for both compressor and fan power consumption.

The cabinet thermal designs are reasonably efficient, typically with 2 inches of foam insulation on all walls and double glazing on glass doors. While additional wall thickness would reduce thermal loads, there are complex tradeoffs between the resulting increased cabinet footprint and the value of floor space in supermarkets. Air changes associated with frequent door openings and infiltration into open cases accounts for a significant portion of the total load.

It should also be noted that the CFC issue impacts this class of equipment very directly, with two of the three most commonly used refrigerants, CFC-12 and CFC-502, being phased out. In at least the near term, HCFC-22 will be used in both frozen food and refrigerated unit coolers. To minimize the high discharge temperatures associated with R22, liquid injection or multistage compression with intercooling are used with low temperature systems. The design measures noted above serve to reduce R22 discharge temperatures as well. The impact of switching from CFC-12 to R22 on the refrigeration COP is negligible (slightly positive). In the medium term, the use of HP-62, or similar blends, can be expected in low temperature refrigeration applications.

The "new" technologies that could be applied to the commercial systems (central) such as air shields, easy access doors, pass-throughs and other case modifications relate more to the design of the display cases rather than the refrigeration system. Display case designs should be analyzed. However, this is outside the scope of the present project. Similarly, the use of ultra-high temperature sterilization and aseptic packaging of milk are related more to food processing technologies and not refrigeration per se. This technology is widely used in Europe at the present time and has the potential of completely eliminating refrigeration required for milk. The technologies and associated COP improvements in central commercial refrigeration systems are converted to energy savings potential at the national level. Both the percent reduction in energy use and the total U.S. annual energy savings potential are calculated. Table 5-7 shows the energy savings potential for this class of equipment. Since all of the technologies with the exception of "fully floating head pressure control" are currently available in the marketplace today, these are aggregated using the same methodology as before where new percent savings are applied to remainder of the energy use. The savings for the fully floating head pressure control are estimated as additional to the currently available "floating head pressure control" technology, and can, therefore, be added together. Total energy savings of 148×10^{12} Btu/yr could be achieved out of a baseline energy use of 490×10^{12} Btu/yr.

Table 5-7: Results - Refrigeration - Central Systems - Current and New Technologies

Baseline Energy Use = 490×10^{12} Btu/yr
 Baseline COP. = 1.2 (Frozen Foods), 2.0 (Fresh Foods)

Technology	% COP. Improvement	% Energy Reduction	Current Market Penetration	Energy Savings (x 10^{12} Btu/yr)
• Variable capacity	10 to 15	11.1	67	16
• Floating heat pressure control	10 to 15	11.1	50	27
• Fully floating head pressure (new technology)	Add 5 to 10	7	0	31
• Two stage R22 with intercooling and subcooling (new technology)	10 to 15	11.1	10	41
• Evaporatively cooled condensers	5 to 10	7	25	21
• Mechanical subcooling	5	4.8	25	12
Total Evaporator Designs				148

* Energy savings are calculated as % of remaining energy use for each subsequent measure. [Savings for 2nd measure = $0.5 \times 0.111 \times (490-16) \times 10^{12}$]

5.2.3.4 Advanced Technologies Advanced technologies need to be developed to go beyond the savings possible with current and new technologies. Further increases would require advanced vapor compression cycle technologies or advanced alternative cycle technologies to make a closer approach to Carnot limits than current systems. These advanced vapor cycle technologies, and other advanced cycle technologies, are considered below.

Advanced cycles that could be considered include:

- Advanced vapor cycle modifications
- Reverse Stirling cycle
- Advanced absorption cycle

Advanced Vapor Cycle. Advanced vapor cycle techniques (with the potential efficiency increase indicated in parenthesis) include:

- Multiple stage expansion/vapor extraction or multiple stage mechanical subcooling, to reduce expansion losses (10%)
- Matched glide non-azeotropic refrigerant mixtures, to reduce the effective heat transfer/heat transport temperature differential (5 - 10%)
- Use of inherently higher efficiency refrigerant, e.g., ammonia, propane (10 - 15%)

Multistage expansion and vapor extraction (or multistage mechanical subcooling) would reduce the expansion loss to a lower level than is attained by mechanical

subcooling alone. For example, with three stages of mechanical subcooling, the difference between the condensing and evaporating temperature would be divided into four equal temperature steps. In the first three, small refrigeration loops operating at progressively lower evaporating temperatures would subcool the liquid; the final stage would be the normal throttling type expansion at the display case. Compared to conventional stage mechanical subcooling, three stage subcooling would increase the COP of a low temperature system by about 10%.

A non-azeotropic refrigerant mixture whose glide approximates the condenser and evaporator air side glides (10°F to 15°F) could improve the COP by up to about 10%, by reducing the effective lift by about 10°F. HFC32/HFC134a is an example of a NARM having a temperature glide in this range.

Some refrigerants that are generally ruled out of supermarket refrigeration applications because they are flammable and/or toxic, e.g., ammonia and propane, have thermodynamic property based COPs that are more than 10% higher than any of the low boiling HFCs, and transport properties that result in increased refrigerant side heat transfer coefficients. These fluids could be used if the central refrigeration system was located remotely from the publicly occupied part of the supermarket and connected with a low temperature secondary loop. An efficient low temperature secondary loop would also be needed for absorption or Stirling technology to be usable.

Reverse Stirling Cycle. The COP of an ideal reverse Stirling cycle is comparable to the Carnot cycle. A central Stirling cycle refrigeration system would need a secondary heat transport loop to connect it with the cold cases. For a given investment in heat exchangers, the same level of heat transport temperature differentials and parasitics as would occur in a vapor cycle can be expected. The basic losses within a Stirling cycle--regenerator ineffectiveness and pressure loss, non-isothermal compression and expansion, and dead volume effects, plus drive motor inefficiency--could be less than the combined motor, compressor, and expansion losses in a vapor cycle. Not including parasitics, a well designed, state of the art vapor cycle will operate at close to 50% of Carnot, based on the evaporating and condensing temperatures. When fully developed, reverse Stirling could achieve COP levels as high as 50% of Carnot, comparable to current state of the art vaporcompression, on the same temperature basis.

Advanced Absorption Cycle. All of the preceding addresses electrically powered systems; in the United States, the average efficiency with which a primary fuel source is converted to electric power and delivered to a point of use is approximately 30%. In view of the losses involved in generating and transmitting electric power, thermally actuated cycles may have the potential for higher primary fuel basis COPs. Compared to an electrically powered COP of 1.4, with electricity delivered at a primary fuel efficiency of 30%, a thermally activated cycle would need to operate with a COP of 0.42 to provide comparable primary fuel COP. Over this large lift, and with an appropriate refrigerant -- absorbent/adsorbent pair, 0.6 might be a reasonable target COP value for a double effect cycle, so that an improvement in primary fuel COP on the order of 50% might be obtainable.

Other New Cycles. Other "new" cycles that have attracted significant development support include thermoacoustic and orifice pulse tube, Malone cycle, and magnetic refrigeration. None of these cycles is likely to prove to have inherent internal loss levels, in practically sized equipment, that are lower than can be attained with current, well designed vapor cycle equipment.

Table 5-8 shows the calculations for energy savings for each of the measures and the maximum attainable through a single technology or appropriate combination of technologies. Since the technologies 4,5 and combination of 1 and 3 are mutually exclusive, only the highest potential savings of 246×10^{12} Btu/yr. is used as the aggregate. (i.e., we can apply technology 4 or technology 5 or technology 1 and 3 combined. Technology 2 and 3 are again mutually exclusive.

Table 5-8: Results - Refrigeration - Central Systems - Advanced Technologies

Baseline Energy Use = 490×10^{12} Btu/yr
Baseline COP. = 1.2 (Frozen Food), 2.0 (Fresh Food)

Technology	% COP. Improvement	% Energy Reduction	Energy Savings (x 10^{12} Btu/yr)
1. Multi-stage mech. subcooling	10-15	11	53
2. Matched glide NARMS	5-10	7	35
3. Inherently higher efficiency refrigerants	15	13	64
4. Reverse Stirling Cycle	30-50	29	141
5. Advanced Absorption Cycle (Double-effect, direct-fired)	100*	50	246
	40**	29	141
Maximum Aggregated			246

* Based on 30% primary energy to electricity conversion.

** Based on 45% primary energy to electricity conversion.

5.3 Cooking

5.3.1 Status of Cooking Technologies

All commercial food service equipment is represented in both gas-fired and electric models. The efficiency of commercially available gas-fired cooking equipment varies significantly depending on the specific manufacturer and model. There are no mandated minimum efficiency standards in this industry, and uniform test procedures for measuring actual cooking efficiency are in the process of being developed.¹ The largest impact on the future efficiency of the installed base of cooking equipment will depend more on factors that influence the purchase decision criteria for this equipment than on technology developments. Quite simply, the installed base of commercial gas-fired cooking equipment efficiencies could be significantly increased if customers purchased more efficient models. However, the cost premium associated with the high efficiency cooking equipment does not always justify the resultant savings.

As a result, in projecting future efficiency, we need to consider customer trends and driving forces behind the more energy efficient system. Often times, the higher efficiency systems also provide better cooking performance which is extremely important to the fast food chains. Electric powered cooking equipment has not changed in efficiency as dramatically as gas-fired models. Modest improvement in electric models continues to be made through better control systems which minimize temperature overshoot, added levels of insulation, and improved method of contacting heating elements to the cooking surface.

Table 5-9 summarizes the present and future rated capacity, and estimates for percent utilization and efficiency for the following classes of cooking equipment:

- Broilers
- Fryers
- Griddles
- Ovens
- Ranges
- Steamers

This information was developed based on our familiarity with these products through our product development activity in this business. We have been involved in the development of fryers, ovens, ranges, and steamers which provides us with much of this information. In addition, we relied heavily on manufacturers' catalogs provided by Garland Commercial Industries, Vulcan Corporation, Cleveland Range, Frymaster, Beverage Air, and Middleby Marshall. There is a wide variety of rated capacities for these classes of equipment depending on the specific model. For this reason, we expressed ranges of rated capacity as shown in Table 5-9. In addition, the average percent utilization varies tremendously depending on the actual application which prompted us to use ranges for these estimates as well.

¹PG&E Test Kitchen.

The efficiency figures presented summarize our estimates for the actual cooking efficiency of the device which is defined as the theoretical amount of energy required to cook the food divided by the total energy input to the system. These cooking efficiencies may not relate to manufacturers' published efficiencies since each equipment class has a different protocol to determine its efficiency figure of merit. For example, fryers are compared on "water boil efficiency", whereas steamers are compared on boiler horsepower. Actual cooking efficiency is a generic parameter which allows comparison among equipment classes. Due to the large number of variables which affect these estimates, we prefer to present them as ranges. To accurately determine the actual U.S. average for these parameters would require developing additional data for installed base and efficiency of the many different classes within each category of food equipment. This data is not available and would require significant effort to develop. In using the overall improvement potential model, we have selected the mid-point of these ranges for data entry. The 1990 stock efficiency represents the average efficiency levels for the 1990 inventory, the future stock efficiency is the average efficiency level for the year 2000 inventory assuming gradual replacement of low efficiency equipment. The last column "best available efficiency in year 2000" represents the efficiency of new equipment being built in the year 2000. The product of efficiency times rated capacity is not always consistent between gas and electric equipment because choosing the mid-point does not always result in a consistent comparison of the same class of cooking equipment.

Table 5-9: Commercial Sector Cooking Improvement Potential

Cooking Equipment	Fuel	1990 Utilization Factor %	Future Utilization Factor %	1990 Rated Cap 1000 (Btu/hr)	Future Rated Cap 1000 (Btu/hr)	1990 Stock Eff. %	Future Stock Eff. %	Best Avail Eff. by 2000 %
Broilers	Gas	60	60	60-110	60-100	20-30	30	30
	Electric	60	60	40-60	40-50	40-60	60	60
Fryers	Gas	15	15	80-120	80	25-45	45	50
	Electric	15	15	48-75	48	55-65	65	75
Griddles	Gas	15-20	30	90-120	80-100	35-45	50	55
	Electric	15-20	25	60-70	25-60	50-65	60	65
Ovens	Gas	30-60	40-60	50-120	80-110	35-45	40	45
	Electric	30-36	40-60	50-60	50-60	65-70	70	70
Ranges	Gas	25-50	15-40	48-120	40-100	40-50	50	60
	Electric	25-50	15-40	48-68	40-70	65-75	73	80
Steamers	Gas	15-20	5-20	60-300	40-250	40-60	65	70
	Electric	20-50	20-25	25-120	25-120	60-70	80	90

5.3.2 First Principles Analyses for Cooking Equipment

The cooking efficiency is defined as the theoretical amount of energy required to cook the food consisting of sensible, latent, and endothermic heats of reaction divided by the total energy input to the system as shown below:

$$\eta_{\text{Cooking}} = \frac{Q_{\text{food}}}{Q_{\text{in}}}$$

η_{Cooking} = Cooking efficiency

Q_{Food} = Heat required by the food

Q_{in} = Total input energy

The total input energy is the sum of the theoretical amount required given the steady state cooking efficiency of the device and the amount of energy consumed during standby periods.

$$Q_{\text{in}} = \frac{(M_{\text{food}})(\Delta H_{\text{cooking}})}{\eta_{\text{ss}}} + Q_{\text{SB}} t_{\text{SB}}$$

When:

M_{Food} = Mass of Food (lb)

$\Delta H_{\text{Cooling}}$ = Theoretical amount of energy required to cook the food (200 - 700 Btu/lb depending on application)

R_{SS} = Steady state cooking efficiency

Q_{in} = Standby energy loss rate

t_{SB} = Standby time

The amount of heat required to cook food is most importantly effected by whether the food is frozen or unfrozen for a starting condition. Energy intensive applications are cooking frozen french fries in a deep fat fryer, frozen hamburger patties on a griddle, and frozen pies in a convection oven. The amount of heat required to cook the food for these applications is 600 - 700 Btu/lb. Less energy intensive applications such as reheating, toasting, and baking have theoretical energy requirements in the 200 - 400 Btu/lb range.

Cooking efficiency can theoretically be increased in two ways:

- Increasing the steady state cooking efficiency; and
- Reducing the standby energy losses.

On average, the steady state cooking efficiency for cooking equipment is between 50-60% but the actual operating efficiency is in the 20-30% range due to the fact that they are sized for the peak period and idle with significant standby energy losses. Figure 5-12 shows a typical part load performance curve for a deep fat fryer. Note that although the cooking efficiency approaches 50% for steady state operation, the actual cooking efficiency is only 30% at 10 lb/hr production rate which is typical for most applications.

Theoretical steady state cooking efficiencies are limited by the number of air changes required to cook the food, jacket energy losses during cooking, and flue losses in gas fired equipment. If each one of these losses were controlled to the minimum, theoretical cooking efficiencies could be increased from the current levels shown in Table 5-9 to 75% for gas and 85% for electric. The greatest advances could be made in the area of the gas fired fryer, broiler, griddle, and oven.

Figure 5-12: Typical Part Load Performance Curve for a Deep Fat Fryer

In the following sections, each type of cooking equipment is discussed along with the technologies that may be applied to this equipment. All quantification of energy savings is provided in Section 5.3.9.

5.3.3 Broilers

Commercial broilers typically use infrared burners, both atmospheric and powered, for high production of broiled foods. Broilers have a higher average percent run time than other types of commercial equipment since the burners are left on during busy operating periods. Broilers fall into four primary categories:

Figure 5-13: Commercial Broilers - Self-Standing Model (left) and Salamander Above Range Type (right).

- Free-standing, draw type infrared broilers as shown in Figure 5-13 (left).
- Salamander broilers designed to fit above a range as shown in Figure 5-13 (right). Versions of these models are also used as cheese melters.
- Charbroiler equipment with solid radiant tiles and heavy grate with cast in grease troughs.
- Conveyorized broilers used by the fast food chains since they have very high production capability.

Total rated capacity of gas-fired units range from 60,000 to 110,000 Btu/hr and electric units range from 40,000 to 60,000 Btu/hr. The average percent utilization of broilers is approximately 60% since they are left on during the periods of the day that broiled food is being served, even though they may not be in use. By their nature, broilers are inefficient because they often have an opening at the front to provide proper air circulation for the broiling process and have high stack gas losses associated with the high operating temperatures. Current efficiencies of gas-fired broilers are estimated to be in the 20-30% range. Electric powered broilers use metal clad heating elements to provide the radiant heat and do not suffer from flue gas

losses which allow them to operate in the 40-60% efficiency range. Current technologies which are increasing the efficiency of broilers are:

- Powered infrared burners (gas-fired only);
- Improved controls (both);
- Improved configurations of resistive elements (electric only);
- Conveyorized broilers (both);
- Air impingement technology (both); and
- Increased insulation levels.

These technologies are currently available in broilers. Some apply to electric only, some to gas only, and some apply to both.

Conveyorized broilers are being used by the fast food chains due to their high production capacity. For example, a standard unit is capable of broiling 900 burgers per hour. These systems are more efficient than the average draw-type broiler with cooking efficiencies of 30%. Another development which will boost the efficiency of broilers in the future is the addition of a blower to the radiant burner on draw-type broilers. This forced draft operation will allow better control of excess air and faster preheat times. Both of these developments should increase the future efficiency for gas broilers by the year 2000 to approximately 30%. It is important to note that there is not a standard efficiency measurement protocol for broilers, and these estimates are based on our judgment of how the equipment would perform given a test protocol analogous to that for griddles and fryers.

Electric powered broilers are continuing to be improved upon by more precise controls and enhanced radiant view factors from the heating elements to the food surface. These improvements should boost the average efficiency of electric broilers to approximately 60% by the year 2000. Some of the new technologies applicable to broilers are:

- Reduced diameter heating elements (electric only);
- Energy management systems (both electric and gas); and
- Microwave combined with other cooking methods (electric).

These technologies are currently being developed.

Some of the more advanced technologies for longer term R&D are:

- Inductively heated equipment - up to 70% actual cooking efficiency can be achieved but R&D needed to reduce high cost of inductive power supply.
- Microwave assisted cooking.

5.3.4 Fryers

Commercial deep fat fryers can be floor standing in the 35-60 lb range or countertop units in the 10-20 lb range. The most popular commercial deep fat fryer is a floor standing 50 lb fryer. A schematic of a single pot unit is shown in Figure 5-14. These fryers can be arranged in a single cabinet consisting of 1-6 frypots. The

market segments for 50 lb deep fat fryers are shown in Table 5-10. The largest segment is hamburg-based fast food chains which typically use high efficiency infrared gas fryers with a small cold zone. The next segment of general restaurant uses a mix of fryers ranging from low efficiency gas-fired tube fryers to the high efficiency infrared. Lastly, the chicken/fish fast food chain currently uses low to medium efficiency tube fryers with large cold zones since the particulate generation associated with batter falling off of the food product during frying is substantial.

Electric fryers are a much smaller segment of the market. Primary types of electric fryers differ by the type of heating element:

- Conventional standard circular calrod elements.
- Flattened ribbon elements arranged on a serpentine pattern.

Figure 5-14: Single Pot Fryer Unit

The ribbon elements provide more surface area for heat transfer and cause less shortening scorching.

Table 5-11 summarizes the efficiency ranges as currently defined by manufacturers. These figures can be converted to an absolute cooking efficiency defined as the theoretical energy required to cook 1 lb of frozen french fries divided by the total

Table 5-10: Deep Fat Fryer Market Segments

Market Niche	Cook Mode	Fried Food (Prioritized)	% Value Through Fryer	Oil Type	Example	Share
Hamburg-French Fry Fast Food	Batch	Fries Chicken Fish Onion Ring	35%	Animal-vegetable Vegetable	McDonalds Burger King Hardees	40-50%
General Restaurant	To order	No Major Emphasis on Fried Products	0-15%	Commercial Low Stability	Wendy Lum etc.	30-35%
Chicken/Fish Fast Food	Batch	Chicken Fish	90-95%	10-20 hrs AOM	Catfish King Long John Silver	10-15%

energy consumed by the system. Based on this conversion, gas fryers have a cooking efficiency in the range of 25-45%, and electric fryers have an efficiency in the range of 55-65%. Technology improvements which account for the higher efficiencies are as follows:

- Powered infrared burners--these burners increase the overall heat transferred to the frypot by imposing a high radiant heat flux directly to the wall of the fry kettle. These burners are used in conjunction with a forced draft blower which also helps to control excess air and reduce standby energy losses.
- Infrared burners used inside of immersed tubes--one manufacturer has developed a method to install a ceramic fiber matrix infrared burner into the tube which typically uses atmospheric in-shot burners. This significantly improves efficiency by increasing radiant loading and decreasing excess air.
- Improved electric heating elements along with modulating temperature control for electric fryers.
- Inductively heated electric fryers.
- Insulation installed on electric fryers.

Table 5-11: Summary of Performance for Different Fryer Classes

Type Efficiency	Gas			Electric
	Low	Medium	High	High
Water boil efficiency	45	63	70	93
Standby loss kBtu/hr	10.2	10.0	9.9	3.5
Barrelling performance lb/kBtu	0.58	0.77	0.90	1.35

The nature of the frying process will limit the efficiency of gas fryers incorporating the most advanced technology developments to the 40-45% range. The cooking

efficiency will be limited to 65-75% for electric fryers. Large energy losses will always be associated with the standby energy loss necessary to maintain the shortening at cooking temperature (335-360°F) throughout the day. Infrared gas fryers are currently available and are the fryer of choice among the top fast food chains. However, a significant number of low-medium efficiency gas fryers are sold because they have a lower first cost and are considered more reliable by many customers. The operating cost difference between a high-efficiency and low-efficiency gas fryer often does not justify the price premium of the more efficient equipment.

An exciting opportunity for large energy savings and fast cook time potentially exists with oil-less fryer technology coupled with reformulating the pre-fried product. Oil-less fryers are basically convection ovens which can cook the fried product quickly if the product is prepared to a higher solids content than typically used for deep fat fryers. Since the latent heat load associated with frying is the dominant thermal requirement reducing the water vapor liberation from 30% by weight to 5-10% significantly reduces the amount of heat required to cook the food. This reduction enables convection cooking to meet the fast cook times required for fast food restaurants even though the external heat transfer coefficients are not nearly as high as that for a deep fat fryer where the food is immersed in the oil. This technology is in its embryonic form, and it's currently being implemented for vending machine applications only. Significant research and development would be necessary to further both the food processing methods and convection oven technology to enable this system to be acceptable for general use in restaurants. The overall energy savings however could be significant, in the 40% range based on thermal analyses for gas, and 30% range for the electric.

One manufacturer has introduced a new electric fryer with advanced ribbon style elements and triacs instead of mercury contactors to control the power to these elements. This electric fryer is also the first electric fryer to be sold with insulation. This unit is capable of operating in the 65-68% cooking efficiency range.

The market share of the various classes of fryers is quite stable, and we do not see a significant change by the year 1995. By the year 2000, the average efficiency of gas and electric fryers based on current trends could be 45% and 65% respectively. We do not envision microwave or inductive heating technology to be applied significantly to this class of fryer in this decade.

Best available technology in the year 2000, which will provide 50% efficiency, will be an infrared fryer with enhanced corrective section. For the electric which will achieve 75% cooking efficiency, the fryer will contain extended ribbon style elements with a well insulated frypot and demand control.

Tecogen has developed a microwave assisted gas fryer capable of achieving 70% cooking efficiency. Barriers to its acceptance are the requirement for a cover to contain the microwave energy which is not acceptable to fast-food chains and the higher cost of the magnetrons. Inductive heated fryers have been developed by Metcal. The inductively heated fryer could achieve 70% cooking efficiency but its

commercialization is burdened by the high cost of the inductive power supply.

5.3.3 Griddles

Commercial griddles (Figure 5-15) range from 36"-72" wide in which every foot in width of the griddle usually has a separate thermostat with heating element or gas burner. Firing rates for 3 ft. and 4 ft. wide griddles range from 90-120,000 Btu/hr for gas-fired units and 60-70,000 for electric powered griddles. Current cooking efficiency determination of griddles has been measured through a uniform test procedure developed by Pacific Gas and Electric. Based on these tests, gas-fired griddles range from 35-45% in cooking efficiency depending on the specific model. Electric griddles have cooking efficiencies in the 50-65% range. Like commercial deep fat fryers, griddles have a significant standby energy loss since the griddles are left hot between use periods. Utilization factor on griddles is low ranging from 15-20% of peak capacity for both gas and electric powered units. Aside from the technologies that apply to most types of cooking equipment such as improved controls, there are three other technologies which are increasing the performance of gas-fired griddles:

- Infrared burners,
- Griddles heated with a circulating loop, and
- Double-sided griddles.

Figure 5-15: Illustration of a Commercial Griddle

The lowest efficiency griddles are gas-fired with conventional atmospheric bar type burners under the griddle surface. These griddles typically have poor control over excess air and operate with a cooking efficiency around 35%. The next most efficient unit is the gas-fired griddle employing infrared burners under the griddle surface for heating. These systems are capable of reaching cooking efficiencies of approximately 45%. Fast food chains are continually searching for ways to cook faster on griddles and as a result manufacturers have developed double-sided griddles. These griddles have an upper heated lid (usually electric) so that the food product is contacted by the griddle surface above and below. This drastically reduces the cook time and increases the operating efficiency of the griddle by getting more heat into the food product and reducing radiant and convective losses from the griddle surface during standby. Double-sided griddle cooking efficiencies can approach 50% for gas-

fired versions.

A development under contract to the Gas Research Institute is a griddle which utilizes circulating hot oil and a remote burner system for heating. This griddle has a very good temperature uniformity and zoning characteristics. We estimate that cooking efficiency of this system to be over 55%. Electric griddles are also being improved by providing better contact between the electric heating elements and the underside of the griddle surface and reducing conductive heat losses throughout the system. Based on these developments, we estimate the best available efficiency of griddles to be approximately 55% for gas-fired units and 65% for electric by the year 2000.

5.3.6 Ovens

Commercial ovens fall into three primary categories as shown in Figure 5-16:

- Convection ovens;
- Deck ovens; and
- Range ovens.

All of these categories are represented in both gas-fired and electric models. The gas-fired models are divided into two primary classes consisting of direct and indirect fired. In the direct fired ovens, the gas flame is in direct contact with the oven cavity and food products being cooked. Indirect fired ovens heat the oven through a heat exchanger so that the flue gas does not come into contact with the food. This is particularly important for chicken since the CO and NO_x associated with the gas flame can cause chicken to appear pink (even though it is thoroughly cooked) which is undesirable to the customer.

The efficiency improvements of the gas-fired ovens has consisted primarily of controlling burner excess air through the use of power burners. Convection oven technology can also be viewed as an energy conserving measure since the cook time associated with convection cooking is reduced thereby reducing the total energy requirement needed to perform a specific cooking function. There is a wide range of rated capacity for these ovens from 50-120 Btu/hr for gas-fired models and 50-60 Btu/hr for electric models. The average percent utilization is approximately 30-60% for gas units and 30-36% for electric units. No standard efficiency tests exist for ovens. If one were developed and applied in a manner similar to that for deep fat fryers, current gas-fired ovens would probably be in the 35-45% range with the direct fired ovens representing the higher figures. Electric ovens are considerably more efficient since they do not have the flue losses and are estimated to be in the range of 65-70%.

As with the other classes of cooking equipment, the primary factor determining future average efficiency will be the market factors that lead to the purchase of more efficient commercially available equipment and to a lesser extent on future technology developments. Air impingement technology has been successfully applied to convection ovens which will drive the efficiency of the gas-fired models into the 40% range. Since more gas-fired convection ovens are being used, the best available

Convection Oven

Deck Oven

Range Oven

Figure 5-16: Illustration of Various Oven Types

efficiency for commercial gas ovens is estimated to be approximately 45%. Electric ovens would be approximately 70% by the year 2000. A variety of advanced burners is being developed which will improve the heat uniformity in the burner section through the use of ported infrared burners and inconel wire mesh burners. Although these developments will improve bake performance, they will not have a significant impact on overall energy efficiency.

5.3.7 Ranges

Ranges are sold either in combination with an oven or as a separate range top as shown in Figure 5-17. Range tops can vary from two to six burners with a four-burner range being the most common. The rated capacity of a four-burner range can vary from 48-120 Btu/hr for a gas-fired model, and 48-68 Btu/hr for an electric version. Current efficiencies of gas-fired ranges are 40-50% based on an efficiency standard based on boiling water in a stock pot. The efficiency is expressed as the theoretical energy required to boil a known amount of water divided by the actual energy consumption of the range. Due to the fact that most conventional ranges have atmospheric burners with poor control of excess air, their efficiency is typically about 40-50%. Electric range tops are considerably more efficient since the pan bottom is in direct contact with the surface of the electric heating element. Water boil efficiencies for electric ranges are approximately 65-75%. In addition to the technologies that apply to most cooking equipment, there are three important technology developments that will boost the efficiency of range tops for commercial applications in the future:

- Premixed power burner (gas);
- Radial fin top burners (gas);
- I-R jet burners (gas);
- Inductive range top (electric).

The efficiency of range top has received more attention by food equipment customers than other classes of food equipment. One manufacturer has developed an advanced premixed power burner system illustrated in Figure 5-18 which is capable of boosting the efficiency of the gas-fired range top to 60%. Another manufacturer has introduced a radial fin top which provides more effective heat absorbing surface than conventional systems with three concentric ring burners rated at different firing rates for each ring. There is also a new development of an infrared jet burner which increases the efficiency of gas range top up to 65%. We estimate that these newly available products will increase the efficiency of gas ranges to 60% by the year 2000.

Electric range tops are already quite efficient at roughly 65-75%. New developments are directed at losing less heat from the bottom of the range top and directing it to useful heating in the pot above. This work should lead to incremental improvement in electric range top efficiency resulting in best available efficiency of 80% by the year 2000.

Figure 5-17: Illustration of Range-Top on Oven (left) Compared to Separate Range-Top

Figure 5-18: Illustration of Advanced Power Burner

5.3.8 Steamers

Commercial food service steamers consist of steamer cabinets and kettles which are injected with steam from steam boilers dedicated for this function. Some restaurants do use steam provided from the main space heating boiler, but this is becoming less common since the steam piping often causes rust to be introduced to the steam used in the cooking operation. Figure 5-19 shows an example of a free standing twin steamer and steam kettle which are fed by a steam boiler below them. Figure 5-20

Figure 5-19: Example of Free Standing Twin Steamer (left) and Steam Kettle (right)

Figure 5-20: View of Steam Boiler which Feeds Steam Cabinets and Kettles

shows a view of the steam boiler which is the heart of any steam cabinet/kettle system. The vast majority of these steam boilers are gas-fired with atmospheric draft port burners. The efficiency of these steam boilers is only 40-60% due to the very high excess air level associated with their operation. Electric steam boilers operate in the 60-70% efficiency range. Again, no standard test procedure exists for measuring the cooking efficiency of a steamer. Instead, manufacturers use the steam generation efficiency (the ratio of the amount of steam generated to fuel consumed) and rate their boilers in terms of horsepower where one horsepower is equal to 33.5 lbs/hr steam. Electric powered steamers are less common and operate in a higher efficiency

range of 60-70% because they do not have the flue gas losses associated with the gas-fired units. Key developments which are underway to increase the efficiency of gas-fired steamers relate to the use of preheat coils and power burners. One manufacturer is currently using a preheat coil in which the flue gas preheats the fill water thereby increasing the overall efficiency of this system and allowing faster recovery. This same advanced steam generator is designed to incorporate a power burner package which transfer heat around a center cylindrical core featuring a unique air mixer which provides premix fuel air to the burner. This system is capable of operating in the 65+% efficiency range. Commercial food service steamers will probably undergo the largest efficiency gain of all classes of cooking equipment during the next decade. One of the primary reasons is that the technology to generate steam efficiently is being borrowed from residential steam boiler designs which were developed in response to the DOE minimum efficiency standards program. The best available efficiency of commercial food service steam boilers is expected to be 70% for gas-fired units and 90% for electric by the year 2000. Fundamentally, the efficiency of the steam boiler can be increased beyond 70% but the manufacturing cost associated with this level of heat recovery is prohibitive. The electric steam boiler efficiencies will be increased by designing elements which are more resistant to fouling and using increased levels of insulation in the steam boiler cabinet.

5.3.9 Estimates of Total U.S. Energy Savings in Cooking Equipment

Based on the above discussions of technologies and their application to various cooking equipment types, we estimated the percent reduction in energy use and the total annual energy savings in the U.S. Gas energy use is on-site and in Btu's of input, requiring no conversion. Electricity energy use is converted back to the power plant inputs using 11,200 Btu's of primary energy per kWh delivered at the building. Current and new technologies are separated according to their current or future availability in the marketplace. Current technologies are those that have been applied to and are available in the marketplace for the specific equipment type. New technologies are those that may be applied to and be available in the future for the specific class of products.

Since there is a significant diversity of equipment types in the cooking end-use, we have grouped the types of equipment where a technology has been applied or could be applied in the future. Tables 5-12 and 5-13 show the energy savings potential of current technologies for electric and gas respectively. The technologies listed here have been discussed earlier in the text in the previous sections on cooking equipment. These tables aggregate the equipment types to which each technology applies, the corresponding baseline energy use is aggregated, the energy savings are estimated as a percent of the baseline energy use and the total annual U.S. Energy savings are estimated. For the electric cooking equipment, current technologies show a savings potential of 70×10^{12} Btu's out of a baseline energy consumption of 251×10^{12} Btu's or roughly 28% of the current energy use.

Table 5-12: Results - Cooking - Electric - Current Technologies
(Baseline Energy Use = 251×10^{12} Btu/yr)

Technology	Applies to Equipment Type	Baseline Energy Use for Applicable Equipment ($\times 10^{12}$ Btu)	% Energy Reduction	Market Penetration	Energy Savings ($\times 10^{12}$ Btu)
• Zone control through modularity	All except ranges	242	10	5	23
• Reduced thermal mass	Griddles only	25	5	10	1
• Resistive type elements in different configurations to improve heat transfer	All electric except steamers	212	10	5	18
• Conveyorized broilers	Broilers only	5	3-	25	1
• Air impingement technology	Broilers, ovens, and steamers	184	15	30	17
• Insulation, gaskets and seals, insulated lids, covers and doors	All except griddles and ranges	216	10	50	9
Double-sided griddle	Griddle only	25	5	30	1
Total					70

* Each subsequent technology energy savings are applied to a reduced baseline obtained by subtracting previous applicable savings from baseline shown in column 3 of this table.

Table 5-13: Results - Cooking - Gas - Current Technologies
(Baseline Energy Use = 289×10^{12} Btu/yr)

Technology	Applies to Equipment Type	Baseline Energy Use for Applicable Equipment ($\times 10^{12}$ Btu)	% Energy Reduction	Market Penetration	Energy Savings ($\times 10^{12}$ Btu)
• Zone control through modularity	All except ranges	210	10	5	20
• Reduced thermal mass	All gas	290	3	55	4
• Reduced thermal mass	Griddles only	14	5	5	1
• Power and infrared burners	All gas	290	15	40	24
• Conveyorized broilers	Broilers only	28	30	30	6
• Air impingement technology	Broilers and ovens	151	15	30	15
• Insulation, gaskets and seals, insulated lids, covers and doors	All except griddles and ranges	196	10	85	2
• Double-sided griddle	Griddle only	14	5	20	1
Total					73

* Each subsequent technology energy savings are applied to a reduced baseline obtained by subtracting previous applicable savings from baseline shown in column 3 of this table.

The major current technologies for electric cooking equipment that can provide these savings are:

- Zone control through modularity including the concept of several cooking stations with smaller equipment;
- Resistive type elements in configurations that improve heat transfer;
- Air impingement technology; and
- Improved insulation, gaskets and seals.

For the gas cooking equipment, current technologies show a savings potential of 73×10^{12} Btu's out of a baseline energy consumption of 289×10^{12} Btu's or roughly 25% of the current annual U.S. energy use for gas cooking. The major current technologies for gas cooking equipment that can provide these savings are:

- Zone control through modularity including several smaller cooking stations;
- Electronic ignition;
- Powerful and infrared burners;
- Conveyorized broilers;
- Air impingement technology; and
- Improved insulation, gaskets and seals.

Table 5-14 for electric and Table 5-15 for gas cooking equipment, show the potential for new and advanced technologies. These technologies are either currently available for other equipment or are under development or could be developed within a reasonable period of time.

Table 5-14: Results - Cooking - Electric - New Advanced Technologies
(Baseline Energy Use = 251×10^{12} Btu/yr)

Technology	Applies to Equipment Type	Baseline Energy Use for Applicable Equipment ($\times 10^{12}$ Btu)	% Energy Reduction	Energy Savings ($\times 10^{12}$ Btu)
• Reduced diameter heating elements (Life & Reliability Improvement)	All electric	251	20	50
• Energy Management System	All electric	251	15	30
• Oil-less cooking	Fryers only	33	35	10
• Inductive Cooking**	All electric	251	25	43**
• Microwave Assist**	All electric	251	14	18**
Total	All electric	251		133

* Subsequent technology energy savings based on baseline reduced by preceding technologies energy savings.

** Inductive cooking and microwave assist are mutually exclusive. Only the higher savings included in the total.

Table 5-15: Results - Cooking - Gas - New Advanced Technologies
(Baseline Energy Use = 289×10^{12} Btu/yr)

Technology	Applies to Equipment Type	Baseline Energy Use for Applicable Equipment ($\times 10^{12}$ Btu)	% Energy Reduction	Energy Savings ($\times 10^{12}$ Btu)
• Energy Management System	All	289	15	41
• Steam combined with other heating models	Broilers only	28	10	3
• Oil-less cooking	Fryers only	28	35	11
Total		289		55

* Since only energy management applies to all equipment types, the savings for broilers and fryers is first deducted from the baseline and then the energy management savings were calculated.

The significant new and advanced technologies for electric cooking equipment are:

- Reduced diameter heating elements (life and reliability improvements are needed before technology can be utilized);
- Energy management systems - commonly used for HVAC and lighting controls today but not yet accepted in the cooking end-use due to the so-called "bus-load" factor (a sudden peak demand during any time of the day);
- Microwave combined with other cooking methods; and
- Oil-less fryer technology.

The major new and advanced technologies for gas-fired cooking equipment are generally similar to the electric and include:

- Energy management systems; and
- Oil-less cooking technology.

5.3.10 Systems Approach to Food Service Equipment - Integrated Restaurant
Heat wasted by commercial appliances is usually vented from the building and not used for other purposes. In some cases the heat could be recovered for other uses with heat exchangers. An example is the heat vented from commercial dishwashers and kitchen hoods. This heat could be used to preheat water for dishwashing and general use.

Cooking equipment uses only part of the energy generated for their operation. The rest is discarded either inside or outside the working environment, such as in commercial kitchens. This increases the discomfort for personnel in the facility. To

increase the comfort level, and save energy, the waste heat should be recovered. By re-introducing this amount of heat to meet other energy demands, such as space and water heating and space cooling, the energy usage of the facility as a whole can be optimized. This carries both financial and environmental advantages aside from the energy savings.

A model facility with typical cooking equipment installations and energy use patterns could be simulated on a day-to-day basis to estimate the amount of energy savings through heat recovery that could be achieved via load matching for loads of various types. The savings would be achieved in different end-uses depending on the geographic location of the restaurant. Such a detailed energy use matching is beyond the scope of this study.

A rough estimate of the potential for heat recovery is 27×10^{12} Btu/yr from cooking equipment heat.

The greatest benefit in an "integrated restaurant are achievable due to reduced air conditioning as a result of reduction in radiant losses from cooking equipment and appropriate use of ventilation. Since heating, ventilating, and air conditioning (HVAC) are not a part of this study, we cannot fully consider the integrated restaurant concept here. For the benefit of the reader, a rough order of magnitude estimate of total restaurants' energy savings potential due to the integrated restaurant concept, is in the range of 44 to 77×10^{12} Btu/yr. for the U.S. in addition to the 27×10^{12} from heat recovery. The total potential savings are, therefore, in the 70×10^{12} to 100×10^{12} Btu/yr. This is not included in the aggregate savings in this report.

5.4 Office Equipment

A first principles analyses including component efficiencies for all office equipment is presented. A brief description of the current equipment and key issues related to their energy use are discussed. An assessment of the energy savings potential through the application of current, new and advanced technologies are provided.

5.4.1 First Principles Analyses

Office equipment as discussed in this report includes:

- Computers - Mainframe, mini, workstations, desktop
- Printers - impact and non-impact
- Copiers
- Typewriters - electronic
- Facsimile equipment

Figure 5-21 is a conceptual representation of the office equipment being discussed in this section. Majority of the electronic equipment has certain basic building blocks

that when arranged in different combinations, can be made to represent various types of office equipment. The common functional building blocks that apply to all equipment are power supplies and semiconductor devices (such as CPU and semiconductor memory).

Figure 5-21: Functional Block Diagram for Office Equipment

These two blocks are shown as the foundation slabs in the block diagram. In addition, various functional columns support different types of equipment. All the computer equipment mainframes, minis, desktop PC's, workstations and laptops are supported by additional functional blocks including emission displays and electromechanical components. Emission displays include cathode ray tubes (CRT's) liquid crystal displays (LCD's), and other display panels. Electromechanical components are mainly motors, solenoids, relays etc.

Again, as shown in the block diagram, printers, copiers, and fax equipment require electromechanical, optical and thermal or electrochemical components, in addition to the basic semiconductors and power supplies. The "optical" category includes imaging lamps for copiers and printers, while thermal/electrochemical includes subsystems such as fusers for fusing toner to paper. It should be noted, however, that there are certain equipment types that overlap building blocks and therefore not easy to represent (e.g., fax-boards for PC's, scanners, combined appliances or "hydras" such as fax/copier/printer/scanner).

Each of these functions are discussed here from the point-of-view of their energy use implications, theoretical limits to efficiencies and areas of significant efficiency losses. Specific energy saving technologies are discussed in Section 5.4.2 and the potential for energy savings is estimated in Section 5.4.3.

Semiconductor Devices Computational speeds and devices per chip have dramatically increased over the last three decades, while switch energy has reduced by orders of magnitude due to reduction in line widths. This is illustrated in Figure 5-22. The source of these graphs is the "High Performance ULSI Digital Systems and Their Implications" (Ref. 1). The speed has increased from 10^{-4} MFLOPS (MFLOPS = Millions of floating point operations per second) to hundreds

of MFLOPS. The number of devices per chip, as shown in Figure 5-22 from the same source has increased from one to several million devices per chip. The line widths on a chip have at the same time reduced from 100 μm to less than 1 μm . These changes have resulted in tremendous increases in computing power. Since the electric power requirement is dependent upon the line widths, the electric power required has dropped considerably even with increases in computing power by orders of magnitude. One of the limitations is on line widths achievable by lithography. Currently, x-rays are used to achieve the S-O-T-A line widths in lithography. The semiconductor industry is achieving this high degree of energy efficiency while substantially increasing processing power, more as a by-product of technology development rather than as a goal in itself. There does not appear to be any benefit in DOE-sponsored energy conservation programs in the area of semiconductors. The limits on energy use reduction in semiconductors is likely to reach its theoretical limits in the next decade as line widths cannot be reduced any further. Other means to increase packing densities such as three-dimensional chips may enter the market.

Power Supplies Currently, two types of technologies are in use for power supplies for PC's, laptops and workstations. These are:

- Linear power supplies with efficiencies in the 30% to 60% range; and
- Switching power supplies with efficiencies in the 80% to 95% range.

Linear power supplies are being displaced by switching type power supplies. However, because of the lower cost of linear supplies, they are still being used in new equipment. The trend is towards increasing use of the switching type power supplies. One of the problems created by the increasing use of switching power supplies is the poor power factor and high total harmonic distortions. The major areas of losses in power supplies are:

- Semiconductor conduction losses;
- Magnetic losses such as core losses and I^2R losses in coils;
- Switching losses (VI and I^2R);
- Component inefficiencies in capacitors, inductors and resistors; and
- Control circuit losses.

The first three items in the above list contribute most significantly to the losses.

Theoretically, a power supply could have maximum efficiency close to 100%. The above-mentioned losses reduce this efficiency to 80-95% range in switching power supplies and 30-60% in linear power supplies.

Energy conservation technologies and their potential are discussed in 5.4.2 and 5.4.3 respectively.

Commercial Chip Complexity

24

Commercial Device Complexity

25

Figure 5-22: Semiconductor Complexity Changes Over Time

Emission Displays Emission displays such as CRT's, LCD's, plasma displays and others are significant power consumers. Color displays have significantly higher energy use than monochrome displays of the same type.

The energy consumption in an emission display depends on three factors:

- Energy required to create brightness on the screen;
- Energy required by the driving electronics; and
- Power supply energy consumption.

The losses in a display are:

- Shadow mask in color CRT's;
- Heat losses in heating the filament;
- High voltage (10K to 20K volts) power supply inefficiencies;
- Conduction and switching losses in controls;
- I^2R losses in deflection coils.

The first three losses mentioned above are the most significant contributors to the lowered efficiency of the display. No standard definition of display efficiency was found. One way to define efficiency from an energy standpoint may be:

Energy required to create a standard pattern on panel
Total energy input to the display

Some advanced technologies, discussed later in the text can eliminate the shadow mask completely and thereby improve efficiency while other technologies using "microtips" can eliminate the heating required in a CRT to substantially improve its efficiency. A detailed discussion of the technologies and the potential savings are provided later in the text. Additional factors related to visual performance may be added to the definition shown above. For example, image definition depends in part on the density of pixels, but also on brightness, contrast, refresh-rate, and probably other factors. In particular, flat Liquid Crystal Display (LCD) screens are generally much less bright than Video Display Terminals (VDTs), which accounts for a significant amount of their energy savings. VDTs may be too bright for many indoor applications, but conversely many laptop LCDs are virtually unusable in bright light (e.g., outdoors).

Electro-Mechanical Components Motors and motor controllers are the key components in this category. Other electro-mechanical components include solenoids, relays, etc. Motors are used in office equipment for disk drives, fans, paper handling, vacuum blowers (cleaning), locomotion of subsystems and other purposes. Given the large number of uses, there are a significant number of small motors in office

equipment. The motors are small in size and getting even smaller as equipment is downsized for smaller footprints, and lower power requirements to make batteries last longer. Small motors are rather inefficient. Motors in the smaller sizes such as those used in office equipment have efficiencies in the 60-70% range compared to theoretical maximum efficiencies of 100%.

Losses in these motors are:

- Core losses;
- I^2R losses in windings;
- Bearing (friction) losses; and
- Windage losses.

Advanced technologies are suggested later in the text that can substantially reduce these losses and increase small motor efficiencies.

Mass-Storage Devices Today's mass-storage market is an extremely varied one. The mainstay of mass-storage products is the rotating magnetic disk, led by the fixed hard disk. These devices are generally available in capacities of multiple hundreds of megabytes. Gigabyte drives are common in the 3.5 inches form and multi-gigabyte in the 5.25-in. form. At the smaller end of the spectrum are 40 and 80 megabyte 1.8-in drives. Floptical drivers are recent entrants in the market and they combine optical and magnetic recording technologies. Flopticals use floppy media in the 3.5-in form and can store 21 megabytes on a single disk. Bernoulli Box (by Iomega Corp.) is a combination of floppy and hard disk technology and reaches a storage density of 150 megabytes. Optical drives include CD-ROM (compact disk - read only memory) devices, WORM (write-once, read many) drives. A new type of optical drive, one that is rewritable, is available from Sony Corp. but has not yet become a significant factor in the market.

Optical Components For imaging purposes in copiers, printers, facsimile equipment, high intensity light sources are used. Currently used technologies include halogen, quartz, strobes, and fluorescent lamps.

The major losses in these lamps are:

- Filament heating energy losses;
- Ballast losses;
- Losses in converting UV light into visible light by the phosphor in fluorescent lamps; and
- Lack of concentration of light where needed.

Thermal Processes Crushing toner particles and meshing them into paper fibers is accomplished by combination of heat and pressure in most office equipment. The

subsystem that performs this function in copiers, printers and facsimile equipment is called the fuser assembly.

In a theoretical sense the fuser heating requirements could be completely eliminated since the function could be theoretically performed simply by applying pressure. Issues of image quality prevent us from approaching this theoretical maximum. The major losses are:

- Standby losses from the fuser heater when not in use; and
- Heat losses due to heating the whole sheet of paper in the active mode.

Non-xerographic processes, discussed later in the text can eliminate the need for the fusing process. Savings potential of this and other technologies are provided in the following sections.

5.4.2 Energy Conservation Technologies for Office Equipment

5.4.2.1 General Technologies in the office sector may be classified as shown in Figure 5-23 by type of equipment to which a technology applies and the level of assembly to which the technology belongs. Types of equipment are mainframes, minis, workstations, desktop PC's, laptops, copiers, printers, and facsimile equipment. The levels of assembly are system, subsystem, device/component, processes, and materials. Examples of technologies at different levels of assembly and the equipment they apply to are shown in Figure 5-23.

	Computers					
	Workstations and PC's	Mini- Computers	Mainframe Computers	Copiers	Printers	Fax
System	Power Management					
Subsystem	RAID's*					
Devices/Components	3-Dimensional Semiconductor					
Processes	BiPolar TTLs to CMOS					
Materials	Room Temperature Super Conductors for Semiconductors, Motors, Transformers, etc.					

*RAID = Random Array of Independent Drives

Figure 5-23: Examples of Cross Cutting Technologies for Different Types of Office Equipment

In the following sections, technologies at different levels of assembly are discussed.

As in the rest of the report, the classification by current (available in current equipment), new (transferable from other equipment) and advanced (need R&D to bring to commercialization) technologies is maintained.

5.4.2.2 Computers For all computers, the trend over the past couple of decades has been towards increased speeds of transactions which results in increased overall power consumption but lower total power on a per million transactions basis. Trend towards miniaturization has led to greater power density per square foot of floor area and also greater available computing power on a per square foot basis. These trends have been largely driven by computing technology advancements and not by energy conservation efforts. The growth of this end-use has been sharply upwards, and will continue to be this way as more and more applications are automated and new uses are found for computer technology. Given this staggering growth in computer inventory, the overall energy consumption is likely to keep increasing even though the energy efficiency of the equipment is improving as well. Saturation of computers is decades away. According to the articles in "Technology 2001 - The Future of Computing and Communications", (Ref. 2) the advancement and applications will continue well beyond 2000.

Mainframe and mini-computers are generally used by medium and large data processing centers of financial companies, banks, airlines, utilities, universities, other service industries, large manufacturing firms and transportation companies. These computers reject heat to the rooms where they are located and generally have to be maintained at room temperatures in the 70°F to 75°F for proper operation. Some of the mainframes have to be cooled directly by chilled water in the 40°F to 48°F range due to their high rate of heat generation. Heat generation is an indicator of the power consumption as well, since the energy provided to the computers ultimately ends up as heat in the space.

Mainframes and minis are generally operated continuously from ten hours a day to 24-hours a day. They are often supported by Uninterruptable Power Supply (UPS)/Battery systems that provide clean power and support for about 15 to 20 minutes in case of a power failure. The systems are further backed by emergency power in case utility power outage goes beyond the 15 to 20 minute period. Emergency power is generated by fuel-fired engines or turbines. Operation of the computers are critical to the continuity of business operations and therefore energy conservation is not the primary driving factor in design and development except for the changes in technology that automatically make these machines more energy efficient on the basis of the quantity of output.

Personal computers (PCs), workstations, and laptop computers have provided increasingly greater computing power and capabilities and their inventory has also grown substantially over the last two decades. This trend is likely to continue. The trend towards miniaturization continues as evidenced by the appearance of products

such as notebook computers in the marketplace. Though energy conservation has not been a major criterion in the design of these computers except laptops, technology changes have automatically resulted in energy efficiency improvements. The major energy consuming components of a PC or laptop computer or workstation are monitor (display), power supply and fan, the disk drive and the CPU. Figure 5-24 shows the active power distribution by components by type of computer.

Figure 5-24: Active Power Distribution by Components for Desktop and Laptop Computers

Source: Arthur D. Little estimated based on measurements and judgement.

There are significant energy conservation opportunities in the computer segment of the office equipment end-use. These opportunities range from behavioral modifications to new technology developments. The following summarizes the potential options for each equipment type.

The continuous operation of Mainframe computers limits the conservation options. The market need for faster and more powerful mainframes drives the design of these computers. New models which utilize more energy-efficient technologies are offset to some degree by the added power required for higher speeds and more features. Mainframe sales are projected to decrease in 1990 (Ref. 3) which reflects the trend towards distributed processing. The processing power is being distributed to the user level with networks of computers replacing some of the centralized power of mainframes.

System level energy conservation measures such as power management are entering the marketplace. Using the computer's ability to manage its own power use, power management software is being developed which turns off components not in use at any given time. Information is transferred from disk drives to semiconductor memory such that the drive would be accessed less frequently by transferring related information at one time.

Workstations and personal computers are considered to have essentially the same energy use characteristics and savings opportunities. Market forces are causing trends in the workstations and personal computers which have very positive energy conservation effects. The increasing use of complementary metal-oxide semiconductor (CMOS) technology versus n-channel metal oxide semiconductors (NMOS) technology has a very positive energy usage impact. CMOS technology requires roughly one thousand times less power than NMOS in a standby mode. This is a currently implemented technology and applies to many products in the electronics industry, including printers, copiers and typewriters. A second positive trend is the increasing use of portable computers which consume a fraction of the power of desktop computers. Thirdly, due to the increasing levels of integration in electronic products, lower operating voltages will be more prevalent in the future. This also has a positive effect on energy consumption. A discussion by major components of the PC/workstation system are discussed below:

- *Computers* Encouragement of energy-conscious use of personal computers and workstations has a very significant potential benefit. Raising the awareness level of companies and employees relative to the cost of leaving an idle computer powered could save 25 to 50% of the energy used for these equipment types. This applies to all components of a computer system. Power management software can achieve the same results. The potential savings from manual shut-off of PCs and peripherals is large, but recent field experiments by NRC-Canada and Ontario Hydro suggest that this effect may be short-lived (telecon Jeff Harris of LBL) further strengthening the case for automated power-management.
- *Semiconductors* Energy consumption for semiconductor devices depends on line widths which have shown dramatic reductions over the last three decades. Since energy use is also reduced with line widths, energy savings becomes a by-product of semiconductor technology advancement. This trend will continue for several years into the future further reducing the semiconductor energy use, while the computing power and speed increase.
- *Three-dimensional semiconductor devices* will further increase power densities (computing power) and reduce energy use. This would be classified as an advanced technology.
- *Power Supplies* Power supplies with current technologies providing 80% to 95% efficiencies for switching type and 30% to 60% for linear type and a trend towards the switching type will result in substantial savings. Switching power supplies will, in a few years, displace the linear type at least in newer equipment.
- *Room temperature superconductor transformers* could further improve efficiencies of power supplies. This would be classified as an advanced technology.

- *Motors* and motor controllers are getting smaller with the downsizing of all computers. Though motor horsepower is being reduced, its efficiency remains about the same in the 60% to 70% range.
- Research into rare earth magnets for motors would allow delivery of higher starting torques with lower starting currents. This is an advanced technology that could be accelerated with DOE-support.
- Motor controllers are under development, that maximize starting torque while keeping heat generation to a minimum, by managing startup transients.
- The rare earth magnet motors and improved motor controllers could boost efficiency of small motors from their current level of 60% to 70% to 85%.
- Mass-storage technologies have achieved storage densities of gigabytes compared to hard disk drives with capacities of several hundred megabytes. The increase in densities result in substantial reduction in energy used per unit of storage capacity.
- *Emission Displays* CRT's are the most commonly used displays for desktop computers and provide color capability which LCD's and other monochrome technologies do not. Flat panel display technology is progressing rapidly due to its application in television, computers, and host of other applications.
- "Microtips" technology (advanced category) has the capability to provide flat panel displays with color at 30% to 50% less energy consumption since no heating is necessary. (Source: Dr. Capp Spindt of SRI)
 - A new type of cathode consisting of an array of miniature field-emitter tips called "microtips" are the basis of this technology.
 - A sharp tip of a conductor, such as molybdenum, can produce an intense electric field when voltage is applied. Small voltage is needed to induce field emission.
 - When tip is placed next to a phosphor screen, electrons leaving the tip generate a bright spot on the panel.
 - One-hundredth of a watt per square cm. is needed for the panel itself.
 - Driving electronics are complex and consume significant power.
 - Overall a 30% to 50% reduction in energy use over currently available CRT's is possible.
 - LETI, a French Government Laboratory in Grenoble, France is close to demonstrating a 6" monochrome version CRT using "microtips" technology.

Beam Index Technology (advanced) eliminates the shadow mask, improving efficiency of color CRT's. Generally used with a small screen and then projected to a larger screen. Energy savings of 20% to 25% can be achieved by this technology.

5.4.2.3 Printers and Copiers

System Description In order to understand the subsystems and processes within printers and copiers, brief system descriptions with schematic diagrams are provided. Laser printer operation is shown in Figure 5-25. Raster-scanned light from a laser is deflected by a mirrored cylinder to expose the surface of a photo-receptor drum. The charged areas attract toner to the drum, which is then transferred to paper and then fused on by heat and pressure.

Source: "Electricity-Saving Office Equipment", Rocky Mountain Institute, September, 1990
Figure 5-25: Simplified Schematic Diagram of Laser Printer Operation

Figure 5-26 is a schematic diagram of a xerographic photocopier. The photocopier system consists of the following subsystems.

- Exposure
- Image formation
- Paper handling and image transfer
- Duplexing unit
- Controls

The various components in each of the subsystems are shown in Figure 5-26.

The active power distribution in printers and copiers is shown in Figure 5-27. For printers, 70% of the energy is used by the fuser heater and for copiers, the fuser heater energy amounts to 60% of the total. The laser consumes 15% and CPU and motors the remaining 15% of the power used in printers. The imaging lamp in a copier consumes 25% and CPU and motors the remaining 15% of the energy used in copiers.

It is clear from the above description that the most significant potential for energy

savings is likely to be in the fuser section of printers and copiers.

Energy Conservation Technologies In section 5.4.2.2 on computers, we discussed conservation for semiconductors and motors. The same discussion applies to the CPU's and motors for copiers and printers. This is not repeated here, but the potential for energy savings for motors is estimated in the subsequent sections.

Design enhancements and engineering changes of printers and copiers have the potential to reduce energy use by incorporating the following current technologies:

Source: "Electricity-Saving Office Equipment", Rocky Mountain Institute, September, 1990.

Figure 5-26: System Diagram of the Canon NP-8580 Photocopier (reproduced by kind permission of Canon, U.S.A.)

- Design enhancements to minimize fuser heater stand-by power. Improved electronic controls to automatically place printers and copiers in a lower temperature stand-by mode would reduce energy consumption. Success of this approach is predicated on designing the

electronics so that the machine can heat to the operating temperature rapidly on demand (10 seconds). Improved insulation of the fuser section in combination with such electronic controls would conserve stand-by heat, promoting faster reheat times.

- Reduce necessary heat for fusing by modifying toner polymer chemistry with polymers which can be heat-pressure fused at lower temperatures. Work being done by a U.S. copier manufacturer aimed at fusing temperatures in the 225°F to 260°F range compared to current range of 325°F to 360°F would reduce energy consumption.

Source: Arthur D. Little estimates based on small sample of measurements and judgement based on market knowledge

Figure 5-27: Active Power Distribution for Copiers, Printers and Typewriters

- Lower power laser for writing in printers and lower wattage exposure lamps for copiers (small savings in energy since on-time is limited).

- Power management software applies to printers and copiers just as it applies to computers. Roughly 30% energy savings are possible.
- Copier print-speed increase can reduce the energy required per copy especially for high-volume machines since the power consumption for high volume copiers is not significantly higher than that for low volume copiers as seen in the comparison of various models in reference 41 in Section 4. Duplex copying and printing wherever appropriate could also contribute to energy conservation.
- Electronic information transfer technology is more efficient than making paper copies and will eventually decrease the need for multiple copies of documents. Although printed copy of certain information will always be required, electronic information transfer technology (E-Mail, LAN's) will enable transfer of information without making paper copies. Such a behavior switch will take considerable conditioning and time as all behavior changes do. An example is the arrival of the PC (ca. 1980), which was supposed to result in the paperless office in ten years; the fact is that paper consumption has been increasing during this period at 2% to 5% per year.

In order to go beyond this initial level of energy savings, new and advanced technologies need to be developed. These include:

- Cold pressure fusing (new);
- High resolution inkjet printing technology (new);
- Highly focused light sources for exposure subsystems (new);
- Lower voltage (3V instead of 5V) chips (new);
- High efficiency motors for paper handling, locomotion and vacuum subsystems (advanced); and
- Magnetostatic printing (advanced).

In order to go beyond this, new technologies need to be developed. One of the major areas for development is the cold fusing process. Further development of cold pressure fusing technology could result in energy savings of roughly one-third of the printer/copier energy use. Substantial work has already been done in the development of this technology and the limitations of this approach have been well documented over the years (1950's to 1980's).

Polymer technology is a substantial limitation with toners designed for cold pressure fusing. In order for a toner to properly fuse to a sheet of paper, it must be able to melt flow in a manner that the individual toner particles fuse together as well as into the structure of the paper. Cold pressure fusing requires toner polymers to be soft and friable (easily fractured in processing and fusing), and have good cold flow properties. Polymers of this type tend to be of lower molecular weight, and are often materials such as waxy or rosin like polymers. However, these polymers typically

have properties which make toners incorporating them to be difficult to process and store. These materials tend to have lower melting points, glass transition temperatures, and softening points. They can create temperature control problems in the extrusion process which make dispersing the carbon and other additives in the polymers difficult. They can also cake or fuse in the toner processing equipment, and they can be unstable in storage and transportation. (High temperatures in trucks or warehouses can ruin the toner). Attempts have been made to improve the toner processing by using cryogenic grinding or slower feed rates, but these serve mainly to raise the cost of the toner either by the use of highly specialized equipment, or more pieces of equipment to maintain throughput rates. These latter steps are not likely to result in any net decrease in energy consumption.

Use of increased levels of pressure for fusing is a way to use higher molecular weight polymers with higher melt properties, thus alleviating some of the above-mentioned problems. Poor image quality due to excessive calendaring (smoothing) of the paper sheet, excessive spreading of the toner (blurred image), and insufficient fusing of the toner to the paper leading to image flaking or rub-off, are issues that need to be addressed in the development of the cold-fusing process.

Delphax has developed the ion deposition technology to include a cold pressure fusing system, but there are some inherent features of the technology that make this possible, such as the ability to use the heavy and strong image cylinder (not a photoconductor as in copiers and laser printers) as the backup roll of a pressure fusing system. This approach has worked in its intended applications (continuous forms printing of variable information, i.e., labels or utility and credit card statements), since the image quality (resolution) at 240 dots per inch (dpi), and the glossy appearance of a pressure fused toner, are not as critical in these uses. Delphax' development efforts have continued to be in the area of large printers for variable information output, and not toward office size copiers and printers. However, the process is energy efficient within its intended range of use, consuming 500 watts vs. 1200 watts for conventional systems.

Another technology is to develop improved highly focused light sources for exposure system. A company in Chicago, Myoptics, is developing a more efficient way to focus light energy that would result in efficiency improvements by 300% to 400%. Kodak plans to use this technology in their future products to reduce exposure/imaging light in copiers. (Source: Interview with Kodak staff).

Another significant energy user in high-speed copiers is the air control/vacuum system for paper handling and cleaning. Vacuum blower power on large high-speed copiers is in the 500 watt range. Currently this system is very inefficient and considerable savings could be achieved by improving it using high efficiency motors and reduction in utilization requirements.

Motors and solenoids used for locomotion of sub-assemblies inside the copiers represents a significant energy use. Small size high-speed motors are generally rather inefficient. Increased coils, core metal and improved materials such as rare earth magnets could be used for high efficiency motors and solenoids to reduce this part of the energy consumption.

Inkjet technologies such as the Canon Bubble-jet and some of the solid ink printers built by various companies using the Drop-on-demand inkjet principle, can compete with laser printers on copy quality, but are limited by speed. Inkjet technology is currently employed in small office printers and for home use where speed is less critical and cost of the hardware is lower. Inkjet technologies, if further developed could save 35% of printer/copier energy use.

Magnetographic printing technology is somewhat similar to xerography in that an image is created on a drum and transferred to paper with subsequent fusing of the image. However, this technology requires a monocomponent (sometimes called magnetic toner), as the image on the drum is a magnetic image and toner is attracted to that image by magnetic rather than electrostatic forces.

5.4.2.4 Facsimile Equipment Facsimile equipment utilization will continue to grow at a significant rate for the next decade. The eventual acceptance of electronic information exchange may to some extent decrease the utilization of facsimile equipment resulting in less energy consumption. Energy conservation efforts for facsimile equipment must target the printing process. Present product designs already consume minimal energy in standby mode and little more can be gained in this area. Energy conservation opportunities include:

- Development of inkjet technology for use in facsimile equipment to replace laser printers can result in substantial energy savings. Inkjet technology does not require a thermal transfer thereby consuming significantly less energy by as much as 35% of the total facsimile energy use.
- Electronic information transfer technology. Facsimile transfers data electronically and the use of paper printouts could be avoided if communication were between computers directly. Electronic transfer of information will eventually displace a significant portion of the facsimile market.

5.4.2.5 Typewriters The present market forces for typewriter sales result in positive and negative effects on energy consumption. The steady decline in electric typewriter usage is a positive event as these typewriters are relatively large energy consumers. The increased use of electronic typewriters is positive as the electronic versions require considerably less operating and standby energy, versus the electric typewriter. However, it appears that user operating habits may negate a percentage of the savings in the transition to electronic typewriters. Electric typewriters are typically turned off

when not in use due to their rather noisy standby mode. On the other hand, electronic typewriters are typically quieter in standby mode and would tend to be left on during idle periods. Energy conservation opportunities include:

- Better user operational habits can minimize this effect and result in reasonable energy savings for this category.
- Electronic information transfer technology will also decrease the need for electronic typewriters.

5.4.3 Energy Savings Potential for Office Equipment

Table 5-16 summarizes the baseline annual energy use in the U.S. for different types of office equipment. Table 5-17 illustrates the energy savings potential of current technologies available in the marketplace today. Table 5-18 provides energy savings potential for new technologies and Table 5-19 shows energy savings potential for the advanced technologies. As discussed earlier, mainframes are operated continuously and energy efficiency improvements are generally offset by the market need for added features and higher speeds.

The energy savings potential is estimated based on the baseline energy use, shown in Table 5-16 and knowledge of the impact of technological developments for the different types of equipment. As these tables indicate, an immediate significant option for conservation is to alter user behavior. Although this option has merit, it may prove difficult to achieve these savings since users may not readily respond to conservation initiatives of this type. Effort on the part of corporations to encourage employees to alter their usage patterns may simplify this effort to some degree. The alternative of using technology to achieve conservation goals would avoid the challenge of altering user behavior. The technologies that provide automatic turn-off or increase the probability of users turning-off the equipment (such as rapid turn-on printers and copiers and CRTs) would result in acceptance and/or willingness to turn off the equipment.

Table 5-16: Office Equipment - Baseline Energy Use

Equipment Type	Total U.S. Annual Energy Use (GWH)	Total U.S. Annual Energy Use ($\times 10^{12}$ Btu)
• Mainframe computers	7,450	83
• Workstations	653	7
• Desktop PCs	4,717	53
• Laptop PCs	50	1
• Printers	4,422	50
• Typewriters	1,212	14
• Copiers	11,020	123
• Facsimile	379	4
Total	29,903	335

Many of the technologies shown in Tables 5-17, 5-18 and 5-19 are overlapping or

mutually exclusive technologies. They represent attempts by different manufacturers to save energy for the same functions in the same equipment category. For example, several manufacturers are working on different ways of cold fusing toner to paper for printers and copiers. Each of these technologies are discussed in the previous subsections of the report.

Table 5-17: Office Equipment Energy Savings - Current Technologies
(Baseline Energy Use = 252×10^{12} Btu/yr excluding mainframes)

Technology	Applies to Equipment Type	Baseline Energy Use for Applicable Equipment ($\times 10^{12}$ Btu)	% Energy Reduction	Market Penetration	Energy Savings ($\times 10^{12}$ Btu)
• CMOS replacing NMOS	All computers except mainframes	61	50	60	12
• Switching power supplies replacing linear supplies	All computers except mainframes	61	10	60	2
• Reduced temperature fusing through toner chemistry changes 225°F to 260°F compared to 325°F to 360°F conventional fusing in copiers and printers	Copiers and printers	173	(1/3 of fuser energy)	0	34
• Digital copiers making multiple copies from memory-only first copy from exposure lamp	Copiers	123	5 to 10	0	10
• Lower wattage exposure lamp	Copiers	123	12	0	15
• Lower power laser for writing	Printers	50	8	0	4
• Equipment shutdown at night and on weekends. Power management software, awareness programs, minimize reentry/reboot time, rapid turn-on CRT's	All office equipment except mainframe	252	30	50	38
• Electronic information transfer to reduce printing and copying	Printers, copiers and facsimile	177	35	0	62
Aggregate = $12+2+34+15+4+(252-67) \times 0.3 \times 0.5 = 95$					95

Note:

- Many of the technologies are overlapping especially for copiers and printers - totals include technologies with highest savings potential from among those that overlap. means excluded from column total

Table 5-18: Office Equipment Energy Savings - New Technologies
(Baseline Energy Use = 252×10^{12} Btu/Yr excluding mainframes)

Technology	Applies to Equipment Type	Baseline Energy Use for Application Equipment ($\times 10^{12}$ Btu)	% Energy Reduction	Energy Savings ($\times 10^{12}$ Btu)
Cold pressure fusing technology. Pressure instead of temperature used to fuse toner to paper. (Problem with image quality at present.)	Copiers and printers	173	33	57
High resolution inkjet printing technology to replace laser printing.	Printers, copiers, and facsimile.	177	35	62*
Efficient focusing of light energy - Myoptics of Chicago.	Printers and copiers	173	15	26
Lower voltage (3V instead of 5V) in new chips - results in reduced fan & battery power.	All office equipment	252	8	20
Flat panel displays to replace CRT's.	Computers (PCs workstations)	60	8	5
Aggregate = $57 + (173 - 57) \times .15 + (252 - 74) \times .08 + (60 - 5) \times .08$				93

*Indicates exclusion from the total due to overlap with other technologies.

Table 5-19: Office Equipment Energy Savings - Advanced Technologies
(Baseline Energy Use = 252×10^{12} Btu/Yr excluding mainframes)

Technology	Applies to Equipment Type	Baseline Energy Use for Application equipment ($\times 10^{12}$ Btu)	% Energy Reduction	Energy Savings ($\times 10^{12}$ Btu)
High efficiency motors using rare earth magnets and motor controllers that maximize starting torque.	All office equipment except mainframes	61 (computers)	5**	3
		173 (print/copy)	3**	5
"Microtips" technology for flat panel CRT's.		60 (PC's & workstations)	10***	6
Ion deposition printing with cold pressure fusing.	Printers and copiers	173	50	87
Magnetostatic printing.	Printers	50	50	25*
Aggregate = $3 + 5 + (60 - 3) \times 0.1 + (173 - 5) \times 0.5$				98

*Excluded from aggregate due to overlap with other technologies.

**Motors represent roughly 30% of energy use in computers and approximately 15% for printers and copiers. High efficiency motors provide 20% efficiency improvement or 17% energy reduction in motor energy for these applications. Thus, $(.17 \times .30) = 5\%$ and $(.17 \times .15) = 3\%$.

***Displays represent 25% of desktop computer energy use. "Microtips" technology can reduce display energy use by 40%. Thus, energy savings for PC's and workstations = $(.40 \times .25) = 10\%$.

5.5 Commercial Water Heating

5.5.1 System Description

Commercial water heating equipment is represented in gas-fired, oil-fired, and electric models. These may be automatic storage, circulating tank, instantaneous, hot water supply boilers and immersion storage type heaters.

One way to describe the commercial water heater is to examine high efficiency water heater (Polaris by Mor-Flo) with efficiency in the 90% to 94% range. This is shown in Figure 5-28. The figure also shows some of the features of this water heater that bring about this high efficiency. High efficiency models are currently available, and the installed base of commercial water heater efficiencies could be significantly increased if customers purchased the higher efficiency models. However, the cost premiums associated with the high efficiency water heaters is a major obstacle to their widespread adoption in the commercial sector. Current market penetration is less than five percent.

Unlike the water heating products for the residential market which have an "annual" efficiency (EF) rating, commercial water heaters are not subject to national "annual" efficiency regulations. This is in part due to the difficulty in establishing a standard commercial water heating load profile which is appropriate for the wide variation in water heating loads (building types) that these products are sold into.

5.5.2 First Principles Analyses

Current electric resistance and gas-fired water heater designs are reaching their technical limits as recovery efficiencies approach:

- Maximum gas recovery efficiency ~95% (condensing);
- Maximum electric recovery efficiency ~97% (primary energy COP = .29)

In each case, the high quality energy input to the water heater (electric power or hydrocarbon fuel) is dissipated to heat; in the most efficient water heater of this type, as high a percentage as practical of the dissipated heat is transferred to the water. The limiting efficiency for either type of water heater, set by the 1st law (conservation of energy) of thermodynamics, is 100%. This limiting efficiency can be approached by successively increasing the fraction of the input energy that is recovered (e.g., by recovering an increasing fraction of the energy, including the latent heat of the moisture, in the combustion products) and reducing the standby heat losses, (e.g., by increasing tank insulation thickness, by reducing convective flow of air up the flue).

In a thermodynamic sense, service hot water contains low grade heat relative to the thermodynamic availability of electric energy or the chemical energy in hydrocarbon fuels. If such a high quality energy input is used to drive a heat pump cycle that extracts heat from either ambient air or some other available heat source, the

Thermal Efficiency: +94 percent.

Stainless steel tank assures long life. No anode rod or glass lining necessary.

Foam insulation with R-16 factor minimizes heat loss; meets California Title 24 requirements.

Stainless steel coiled flue transfers heat from flue gases to the water resulting in +94% efficiency.

Bullet-shaped submerged stainless steel combustion chamber eliminates conventional water heater heat loss, lime build-up and noise.

Burner generates intense heat that is forced through the combustion chamber and coiled flue by a powered combustion air blower.

Negative pressure gas valve maintains uniform gas/air mixture for even, efficient combustion for a variety of inlet pipe applications.

Plastic vent pipes, which can be installed through the wall, serve as combustion air inlet and flue gas outlet.

Other features/benefits:

- Solid state electronic thermostat assures precise temperature control; dial is located on front of heater for easy setting.
- LED indicator for Power, Igniter, Burner displays heater operation, simplifies troubleshooting.
- All water and vent connections are at the bottom of the water heater eliminating pipe and flue heat loss.
- Low jacket surface temperatures allow water heater to be installed with zero clearance to combustible materials.
- Silicon carbide hot surface igniter heats to 2600° F to light burner flame. Solid state electronic control eliminates pilot flame and automatically shuts off gas should flame go out.
- Built-in condensate trap.

Figure 5-28: Illustration of a High Efficiency Water Heater

efficiency (heat delivered to water ÷ electric energy or fuel energy input), limits are set by the second law of thermodynamics.

The 2nd law limits for water heating efficiencies can be identified as:

$$\bullet \text{Electric-COP}_{\text{work}} = \frac{Q_{\text{out}}}{W} = Q_{\text{out}} / \int_{T_{\text{in}}}^{T_{\text{out}}} dW \quad (1a)$$

$$= (T_{\text{out}} - T_{\text{in}}) / \int_{T_{\text{in}}}^{T_{\text{out}}} T_{\text{dt}} / (T - T_{\text{amb}}) \quad (1b)$$

$$= (T_{\text{out}} - T_{\text{in}}) / \{T_{\text{out}} - T_{\text{in}} + T_{\text{amb}} [\ln(T_{\text{out}} - T_{\text{amb}}) - \ln(T_{\text{in}} - T_{\text{amb}})]\} \quad (1c)$$

$$\bullet \text{Gas-COP}_{\text{heat}} = \frac{T_{\text{out}}}{T_{\text{out}} - T_{\text{amb}}} \frac{T_{\text{H}} - T_{\text{amb}}}{T_{\text{H}}} \quad (2)$$

$$\text{COP}_{\text{heat}} = \frac{Q_{\text{out}}}{Q_{\text{H}}}$$

Where: T_{in}	=	Water Inlet Temperature
T_{out}	=	Hot Water Delivery Temperature (°K)
T_{amb}	=	"Ambient" (or other heat source) Temperature (°K)
T_{H}	=	High Temperature Heat In (°K)
Q_{out}	=	Heat Delivery to Water (Btu)
Q_{H}	=	Fuel Input (Btu)
W	=	Electric Input (Btu)
T	=	Flow Water Temperature during the heating process

On a primary energy basis the COP for an electric appliance collapses to Equation 2 where the work term has been modified by the thermal efficiency of a Carnot heat engine operating between a high temperature heat source and the water temperature.

Ideal shaft work or "electric" based water heating COP's depend on the inlet water temperature, the desired water delivery temperature, and the ambient temperature as shown in Table 5-20.

Table 5-20: Ideal Heat Pump Water Heating COP (Work Input)

		Ideal COP (Work Input Basis) at 50°F Water Inlet Temperature	
		Water Delivery	
Ambient Temp. (°F)	(°K)	120°F = 322°K	140°F = 333°K
40	277	7.3	6.0
50	283	8.3	6.7
60	289	9.7	7.5
70	294	11.6	8.6

The heating COP of existing electrically-powered, air-source, vapor-compression, heat pump water heaters operating within the temperature range covered by Table 5-20 is typically on the order of 3, considerably less than the levels indicated in Table 5-20. To illustrate the major losses (and opportunities for efficiency improvement) involved in the actual heat pump hardware, Figure 5-29 shows for one specific case (50°F ambient, 50°F water inlet temperature, 140°F water delivery temperature), the COP levels as losses are successively accounted for. Bar 1 is the COP power equation (1c), with the water continually heated at the Carnot COP as the temperature increases from T inlet to T outlet. Most heat pump water heaters heat the water to the delivery temperature in a single pass through a constant temperature condenser, so the succession of heat rejection temperature that is inherent in the "Bar 1" COI level is replaced with a single, maximum, heat rejection temperature, with the resulting COP given in Bar 2. Bar 3 shows the effect of heat transfer temperature differentials. Bar 4 is the COP of an ideal vapor cycle with substantial liquid subcooling, Bar 5 includes the effect of compressor inefficiency, and Bar 6 includes the effect of parasitics (fan and pump power, heat losses).

For direct gas-fired heat pumps, the ideal COP for the gas heat pump will range from three to seven as indicated in Table 5-21 depending on the temperature driving the engine.

Figure 5-29: Effect of Equipment Inefficiencies on Electric/Shaft Power Driven Heat Pump Water Heating

*Heating Cycle Efficiency

Table 5-21: Ideal Gas Heat Pump COP

Engine - High Temperature (°F) (°K)		COP - Ideal (Delivery Temperature = 120°F = 322°K Air Temperature = 50°F = 283°K)
400	477	3.4
800	700	4.9
1200	922	5.8
1600	1144	6.2
2000	1366	6.6

A number of heat pump cycles are potentially appropriate for the commercial water heating application and are listed in Table 5-22.

Table 5-22: Heat Pump Cycles

Direct Energy Input	Cycle
Electric	Vapor Compression Stirling
Gas	Absorption Duplex Stirling VM

Each of these cycles has the potential for high performance levels with:

- Electric COP's >4 (primary COP > 1.2 for 30% power plant efficiency)
- Gas COP's > 1.5 (primary COP)

In general, direct-fired appliances should have the highest primary energy based COP given that the reject heat from the "power plant" portion of the cycle can be heat sunk to the hot water supply.

Current electric heat pump water heater COP's are in the 3.0 to 3.5 range.

Losses and inefficiencies are due to:

- Compressor inefficiencies;
- Motor inefficiencies;
- Working temperature differences at condenser and evaporator;
- Cyclic losses; and
- Vapor compression cycle design using single stage of compression.

5.5.3 Natural Gas Water Heaters - Energy Conservation Technologies

Tank type commercial gas water heater designs could be modified for substantial "annual" efficiency gains by incorporating current technologies as follows:

- Spark ignition to replace standard pilots;
- Active flue damper to eliminate off cycle flue losses;
- Better insulation to reduce stand-by losses;
- Condensing combustion systems for improved steady-state performance; and
- Replace tank type water heaters by instantaneous type to eliminate standby losses.

Further gains in efficiencies can be achieved through advanced technologies including:

- Gas-fired absorption heat pump with waste heat recovery;
- A gas-engine driven heat pump water heater with waste heat recovery;
- Duplex Stirling Cycle water heater; and
- Vuillemier cycle water heater.

The first three improvements are offered by water heater manufacturers as options or product upgrades. In particular, the active flue damper and improved insulation should provide substantial improvements in stand-by losses given the higher water temperatures that these often operate at (e.g. 140°F to 160°F as compared to 120°F for residential). The flue damper, spark ignition and better insulation should improve the "annual" performance of these products by 20% to 25% which is comparable to similar improvements in residential water heating products. Creating a commercial water heater with a condensing combustion/heat exchanger would increase the steady state efficiencies (typically 80 to 84%) to 92+% which would translate to roughly another 10% (function of load profile) incremental improvement in "annual" performance.

Tankless or "boiler" type hot water heaters typically operate between 80 to 85% with a condensing heat exchanger providing the largest opportunity for efficiency improvement. Condensing type designs could increase efficiency to 92+%, but would require extensive product redesign.

Major COP improvements and water heating energy use reductions could be achieved by advancing the state-of-the-art using gas-based heat pump technologies. These include gas-fired double effect absorption heat pump water heater and gas-engine driven vapor compression heat pump water heater.

The gas-fired heat pumps for this application potentially have COP levels of 1.5 to 1.8. Absorption heat pumps (water - ammonia) could be configured as a relatively efficient device. Such a design could be configured to produce 140°F to 160°F water from a 40° or 50°F ambient in three steps as follows:

- Initial cold water heating using the absorber reject heat;
- Intermediate lift using the heat pump effect; and
- Final temperature increase using the flue gas from the generator.

Such a system could easily achieve a 1.5 COP or higher. Design and development issues would include size, proper working pairs, and proper cycle configuration for cost minimization.

Gas-engine driven heat pump water heaters with waste heat recovery from the engine could provide a COP in the range of 1.5 to 1.8 (ambient air source, not accounting for potential to provide air conditioning). This would be a major improvement in efficiency level from the present stock efficiency of roughly 60% for a tank type

water heater.

Gas-fired water heating heat pumps using a Duplex Stirling or Vuilleumier cycles are potential candidates for this application. These two cycles have the potential of delivering COP's in the 1.5 to 1.8 range with the Duplex Stirling unit capable of achieving higher COP. Water heating is an ideal application for these two approaches in that, the heat pump lift is high which favors a Stirling-like design. The waste heat from the "engine" can be recovered in the water stream and permits the use of simpler engine preheater. A Duplex Stirling could achieve 50% of Carnot for the heat pump portion of the cycle with 25% (gas input basis) efficient engine and still achieve a COP of greater than 1.5.

Most of the technologies mentioned above also apply to oil-fired water heaters. The same discussion as above applies to oil-fired equipment, except that the percent energy reduction for some of the technologies may be somewhat lower. For most of the advanced technologies the percent energy reduction is the same for oil as it is for gas.

5.5.4 Electric Water Heaters - Energy Conservation Technologies

Electric resistance water heaters are not subject to a national "annual" efficiency regulation as are the residential products. These commercial products have an efficiency level (EF) similar to the residential product or roughly 98% - based on electric input. Currently available electric heat pump water heaters, with COP of 3.0 to 3.5 are much too expensive and, therefore, have minimal commercial market penetrations. Potential improvements are mainly applications of advanced technologies including:

- Advanced vapor compression heat-pump water heater; and
- Stirling cycle water heater.

Stirling and "Advanced" vapor cycle water heating heat pumps have the potential of providing higher performance than current heat pump technology.

Current heat pump water heating products can be characterized as an expensive niche product with efficiencies roughly 3 to 3 1/2 times that of an electric resistance water heater. A typical residential heat pump water heater uses an external condenser with a small pump to circulate the water through the condenser in a counterflow arrangement. Externalizing the condenser from the tank allows the integration of standard resistance tanks with heat pump equipment. Condenser designs have been incorporated into the tank by inserting the condenser into the water tank or by wrapping the condenser around the exterior of the steel water heater tank. These three configurations have roughly the same performance levels. Pumped loop design can operate at a condenser temperature below the delivery temperature (e.g., delivery 140°F, and condensing temperature of 130°F) by using the superheat off the

compressor to "top-off" the water temperature.

The compressor/evaporator/fan module are usually located in a basement, garage, or utility room to provide a more constant temperature source condition that is somewhat uncoupled from the outdoors.

Examining a typical heat pump water heater, R-22 (or R-12) is commonly used as the working fluid in conjunction with a small reciprocating compressor. These compressors have a typical EER rating 9 to 10 Btu/w-hr (note: The EER rating conditions for an A/C compressor are relatively close to typical heat pump water heating conditions.)

While an efficiency gain to a coefficient of performance of 3 to 3.5 is a large increase over electric resistance tanks, it is still far short of the ideal COP of about 8.

One of the major contributors to degrading the heat pump performance is the motor/compressor. By using the best commercially available technology, the compressor EER can be increased from about 9.5 (typical for water heating products) to 11.6 (the best A/C compressor technology). This would boost the product COP by about 20%. An advanced compressor (not available today) with 90% isentropic efficiency and a 90% motor efficiency would result in an EER of roughly 13.5 which has the potential to increase the heat pump COP by 50%.

Modifications to the basic vapor cycle such as multi-pressure could produce a 10% to 15% gain in performance. Multi-pressure heat pumping could provide this gain with a two pressure design featuring two compressors and condensers. Such a design is relatively easy to implement with a single condenser with the appropriate manifolding for routing refrigerant flow, a single evaporator, and a single two-stage compressor.

In summary, incorporating better compressor technology and a multi-pressure vapor cycle could increase the heat pump water heater COP:

- From 3.5 to a COP of 4.62 (best available compressor technology)
- From 3.5 to a COP of 5.8 (advanced compressor technology)

Stirling cycle heat pump water heater could achieve similar COP improvements with long-term R&D.

5.5.5 Estimates of Energy Savings Potential for Water Heaters

The energy savings options or technologies described above result in energy use reductions which are estimated at the national level using the baseline annual energy use for the U.S. and the percent reduction in energy. Gas energy use is on-site and in Btu's of input energy requiring no conversion. Electricity on the other hand is converted from kWh at the site to Btu input at the power generation plant taking into

account the generation and transmission efficiency of electricity. The conversion factor is 11,200 Btu per kWh. (Assumes 30% primary energy conversion to delivered electricity at building).

Current technologies are those that are incorporated in water heaters available in the marketplace today. Advanced technologies are those not available in water heaters sold today and require long-term R&D to bring them into the marketplace.

Table 5-23 shows the current technologies' potential for energy savings for gas and oil water heating equipment. Table 5-24 is a similar table for advanced gas and oil technologies and Table 5-25 shows potential for advanced electric water heating technologies.

Swimming pool water heaters, which are predominantly gas-fired, provide the same potential for energy savings with the same technologies applied as any gas-fired

Table 5-23: Energy Savings Potential of Current Gas and Oil Technologies for Water Heaters
 Baseline Energy Use = 519×10^{12} Btu's (gas)
 Baseline Energy Use = 147×10^{12} Btu's (oil)
 Baseline COP = 0.60

Technology	% Efficiency Increase	% Energy Reduction	Current Market Penetration %	Remaining Energy Savings* ($\times 10^{12}$ Btu)	
Spark ignition, Active Flue Damper and Insulation	20	17 (gas) 15 (oil)	10	Gas 79	Oil 20
Condensing Combustion System	33	25	2	108	31
Aggregate				187	51

* Condensing combustion energy savings are based on baseline energy use minus energy savings from measure #1.

water heater. Energy savings for swimming pool water heaters are shown below:

- Current Technologies - savings = 135×10^{12} Btu/yr $\times$ $187/519$ = 48.6×10^{12} Btu/yr.
- Advanced Technologies - savings = 135×10^{12} Btu/yr $\times$ 0.64 = 86.4×10^{12} Btu/yr.

Table 5-24: Energy Savings Potential of Advanced Gas and Oil Technologies for Water Heaters
Baseline Energy Use = 519×10^{12} Btu/yr (gas)
Baseline Energy Use = 147×10^{12} Btu/yr (oil)
Baseline COP. = 0.6

Technology	% COP Increase	New COP.	% Energy Reduction	Availability	Energy Savings (x 10^{12} Btu)	
Gas-fired (or oil) absorption heat pump water heat recovery	150	1.5	60	1995	Gas 311	Oil 88
Gas-Engine (or diesel) Driven Heat Pump Water Heater with Heat Recovery	150	1.5	60	1998	311	88
Gas-Based (or diesel) Driven Multi-Pressure Heat Pump Water Heater	180	1.7	64	1998	332	94
Duplex Stirling or Vuilleumier Cycle	150	1.5	60	2005	311	88
Aggregate*					332	94

* Since all of the technologies are mutually exclusive, only the highest energy savings level is included in the aggregate.

Table 5-25: Energy Savings Potential of New and Advanced Electric Technologies for Water Heaters

Baseline Energy Use = 132×10^{12} Btu/Year.

Technology	% COP Improvement	New COP.	% Energy Reduction	Availability Year	Energy Savings* (x 10^{12} Btu)
Heat Pump Water Heater (New)	200	3.0	67	1993	88
Multi-Press Heat Pump Water Heater (Adv.)	250	3.5	71	1998	94
Advanced Multi-Press Heat Pump Water Heater (Adv.)	480	5.8	82	2000	108
Aggregate					108

*Since all technologies are mutually exclusive, only the highest savings are included in the aggregate.

5.6 Vending Machines

Vending machines in public areas usually fall into the following categories:

Beverage

- Hot beverage;
- Cold beverage (postmix cup);
- Cold beverage (can or bottle);

Food

- Hot food merchandisers;
- Cold food merchandisers;
- Candy/pastry;

Other

- Cigarette; and
- Stamp/token.

The cold beverage machines are custom made for the vendors of soft drinks and juices while other vending machines are made as standard items for vending machine operating companies. An example of a vending machine that serves both cold refrigerated foods and non-refrigerated snacks is shown in Figure 5-30. The first principles analyses shown for unit coolers in the refrigeration section applies to refrigerated vending machines as well. The technologies discussed for the unit coolers can also be applied to refrigerated vending machines.

Energy consumption is analyzed for vending machines in the following modes of operation:

- Standby;
- Vending; and
- Pull-down.

Since numbers of vends per hour is highly dependent on location, the manufacturers often have a difficult time predicting the run time of equipment for the vending cycle. Most manufacturers estimate three vends/hour on an average for refrigerated food and five vends/hour for beverage and other vending machines. Standby for most merchandisers uses power to operate the display light and to keep the money mechanisms energized. Refrigerated units must also maintain operating temperatures over a variety of ambient temperatures. Heated units have a high standby to maintain water (coffee, tea, soup) at a high temperature.

Figure 5-30: Illustration of a Vending Machine with Refrigerated and Non-Refrigerated Compartments

Many of the cold beverage dispensers are manufactured under contract to the major soda producers. Each customer has different specifications for amount of display lighting and quantity of product stored within the vending machine. Listed below are some of the design characteristics of importance to the buyers of vending machines.

- Ruggedness;
- Reliability;
- Security;
- Footprint;
- Appearance;
- Vend Time; and
- Ease of service.

As can be seen, energy conservation is not one of the features important to the buyers. Only recently have manufacturers started to receive requests from clients for energy efficient equipment. The majority of placement situations have the host site either retaining a portion of the vendors proceeds or leasing space to a vendor. Profit margins have remained high enough not to lend any focus to energy consumption. Vending contractors are more concerned with upkeep and long-term performance than energy efficiency.

Suggested areas for increasing energy efficiencies of vending machines would include:

- Higher efficiency refrigeration components;
- Lamp ballasts with improved efficiencies;
- Automated control of off-peak temperatures;
- Increased efficiencies of insulation;
- Automatic turndown of water heaters;
- Increased airflows through condensers; and
- Proper balancing of marketing and efficiency.

Table 5-26 summarizes energy savings achievable from these improvements, which represent new technologies by our definition.

Table 5-26: Energy Conservation Improvements for Vending Machines - New Technologies

Baseline Energy Use
Cold Beverage = 72×10^{12} Btu/yr
Food & Confectionery = 14×10^{12} Btu/yr
Other = 22×10^{12} Btu/yr

Category	Technologies	Energy Savings %	Energy** Savings (x 10^{12} Btu)
Cold beverage	Thicker insulation	15%	11
	Improve condenser air flow	5%	3
	Higher efficiency lighting	10%	6
	Improve dispense mechanism	5%	3
	High efficiency refrigeration	10%	5
	Zone* and off-peak controls	20%	9
Subtotal			37
Other	Higher efficiency lighting	10%	2
	Improve dispense mechanism	5%	1
Subtotal		15%	3
Food and Confectionery	Higher efficiency lighting	10%	1
	Improve motor efficiency	5%	1
	High efficiency refrigeration	10%	1
	Improved controls (incl. off-peak temperature)	10%	1
Subtotal		31%	4
Total			44

* Zone control refers to refrigeration of the lowest one-third of the cans or bottles.

** Energy savings of each subsequent measure is based on a baseline reduced by the savings for all previous measures.

Table 5-27 shows advanced technologies that could be applied to refrigeration systems in vending machines.

Table 5-27: Results - Vending Machines - Advanced Technologies

Baseline Energy Use = 86×10^{12} Btu/yr
(includes cold beverage and food and confectionery vending machines)

Technology	% COP Improvement	% Energy Reduction	Energy Savings*** (x 10^{12} Btu/yr.)	
			Each Measure	Subtotal
1. Advanced Vapor Cycle Techniques				20
- Multi-stage mech. subcooling	10-15	11	9	
- Use of NARMS or	5-10	7	6+	
- Inherently higher efficient refrigerants-propane, ammonia	15	13	11	
2. Reverse Stirling Cycle	15-25	17		15
3. Advanced Absorption Cycle (Double-effect, direct-fired)	100*	50		43
	40**	29		25
Aggregate Savings				43

+ Exclude from subtotal--overlap with higher efficiency refrigerant.

* Based on current average primary fuel to delivered electricity conversion efficiency of 30%.

** Based on incremental power conversion efficiency of 45%.

*** Since technologies 1, 2, and 3 are all mutually exclusive, only the highest savings are included in the aggregate.

Figure 5-31 shows a breakdown of energy use in a typical vending machine placed in a conditioned environment. The major energy using subsystems are lighting, refrigeration, motors, and coin mechanism.

Refrigerated vending machines located outdoors in the northern climates are likely to be in the heating mode during the winter to keep the cold beverage from freezing. During summer the refrigeration system has a high duty cycle since summer temperatures even in the northern climates are high.

In the southern climates, the refrigeration system for vending machines placed outdoors, operate almost throughout the year though duty cycle is reduced during winter months and is very high during the summer.

Non-Refrigerated Food

Refrigerated Food

Heated Beverage

Refrigerated Beverage

Figure 5-31: Breakdown of Energy Use for Various Vending Machines

5.7 Water Coolers

Commercial water coolers can be divided into:

- Floor standing;
- Wall hung (barrier free); and
- Wall hung w/remote chiller.

Major water cooler manufacturers include: Halsey Taylor; Elkay; Haws; and Oasis.

Water cooler units are sized for the anticipated number of persons served per hour. This figure is then translated into gallons per hour of demand. Criteria for sizing the water cooler capacity in offices, schools, hospitals, stores, and hotels is 25 people per one gallon/hour of cold water. Temperatures used for design purposes are 90°F room temperature, 80°F water inlet temperature, and 50°F water for drinking.

It is only within the last several years that manufacturers have placed an emphasis on energy efficiency. Much of the effort in years past was focused on reliability and operational ruggedness. Water coolers were sold on the basis of the abuse that they could endure and still operate.

The first principles analyses shown for unit coolers is also applicable to water coolers. Areas of significant efficiency losses are the same as for unit coolers. Component efficiency levels such as for compressor, motor, etc., are also in the same range as for unit coolers. The distribution of energy consumption is compressor and motor - 40%, storage coil - 30%, standby losses - 30%. This is estimated based on ADL judgment.

Halsey Taylor is one of the leaders in increasing the efficiency of their water coolers. All of their branded lines carry the "Energy Efficient" logo on the front of the unit. The areas that have been addressed and improved upon by manufacturers are:

- Bonding of coolant and water coils;
- Extruded Polystyrene (EPS) construction of evaporator housing;
- High value insulation and one piece housing;
- Refrigeration compressor has higher operating efficiency; and
- Maximum wattage is 500, average is 440.

Table 5-28 summarizes the potential energy savings from some of these improvements.

Table 5-28: Energy Conservation Improvements for Water Coolers - New Technologies
Baseline Energy Use = 44×10^{12} Btu/yr

Category	Technologies	Energy Savings	Energy Savings ($\times 10^{12}$ Btu)
Drinking fountains	Higher value insulation	10%	4.
	Energy efficient compressors	10%	4.
	Improve bond between coil and evaporation	5%	2.
	Improve motor efficiencies	5%	2.
	Redesign of storage coil	10%	3
Total			15

Advanced technologies such as reverse stirling cycle, advanced vapor cycle and advanced absorption cycle may be applied to water coolers. However, due to the small size, this application would be further out in time. Table 5-29 summarizes the potential energy savings from applying these advanced technologies to water coolers.

Table 5-29: Energy Conservation Improvements for Water Coolers - Advanced Technologies
Baseline Energy Use = 44×10^{12} Btu/yr

Technologies	% Energy Reduction	Energy Savings ($\times 10^{12}$ Btu/yr.)
1. Advanced Vapor Cycle (Higher efficiency refrigerators)	13	6
2. Reverse Stirling Cycle	17	8
3. Advanced Absorption Cycle	50	22
Aggregate		22

5.8 Laundry

The basic operation and typical cycles for washers and dryers were described earlier in the development of the baseline energy use numbers for washers and dryers. Dry cleaning equipment energy use was too small to be considered for national energy conservation programs, as shown in Section 4.

Energy savings opportunities in washers and dryers may be such that a modification of washer design may save energy in the dryer or hot water heater and similarly modification of a dryer may result in energy savings for the washer. Wherever this is the case, we have indicated this in the text. The energy savings potential estimated here is based on coin and route operations as well as on-premise laundries.

5.8.1 Washers

5.8.1.1 First Principles Analyses for Washers As discussed earlier in Section 4, the typical wash cycle consists of wash fill, agitate, spin, rinse fill, agitate, and spin steps. The hot water is provided from an external source. The first principles analyses of heating water were discussed in Section 5.5.2 earlier. The only other washer related first principles analyses applies to motors. 87% percent of washing energy is consumed by hot water heating and 13% by the agitator and spin motors, and the drain pump. The motor efficiency for currently used split-phase motors is approximately 65%. A capacitor type motor provides efficiencies in the 75% range and theoretically motor efficiencies could approach 100%. The major losses in motors of this size are:

- Core losses
- I^2R losses in windings
- Friction losses in bearings
- Windage losses

Advanced motor technologies reduce some of these losses and improve efficiencies.

5.8.2.2 Energy Conservation Opportunities Washer energy use is distributed as follows for the current system.

Energy savings can be achieved by implementing the technologies discussed below:

(a) Current Technologies

- Higher spin speeds for washers to reduce drying energy;
- Horizontal axis and other low water usage designs to reduce hot water heating energy;

(b) New Technologies

- Wash/Rinse fill level switch; (currently available in new residential washers only)
- High efficiency motors; (Available in residential not in commercial washers only)
- Eliminate warm rinse option;
- All cold wash (improved detergents)

(c) Advanced Technologies

- Ozone washing
- Ultrasonic washing

Each of these are further described below:

(a) Current Technologies: Higher Spin Speed (Reduces Drying Energy)

Increasing the speed of the final spin will slightly increase the energy required for the wash cycle but will have a significant influence on the energy consumption of the drying phase. The current spin speed of about 560 RPM results in an average retained water level (depending on fabric type and other variables) of approximately 100% (1 lb of water per lb of clothes). Several washers currently being introduced to the market (Figure 5-32) offer spin speeds up to 1000 RPM resulting in a force of 300 g's or more. Although there is no available data on the resulting moisture level, one industry observer who tested the machine described above claimed that it halved the amount of drying required. A more conservative assumption of a 40% reduction in moisture level is certainly reasonable leading to a 40% reduction in energy required to perform the useful drying. The increased spin cycle energy is negligible, while the decrease in dryer energy will be 54×10^{12} Btu/yr.

Horizontal Axis or Other Low Water Usage Designs Vertical axis washers of the type in use today utilize nearly three gallons of water per pound of clothes washed. Water usage in a vertical axis machine is primarily driven by the need to "float" the clothes for agitation and deep rinsing. Horizontal axis machines, which are now entering the market work by splashing or tumbling the clothes through a smaller pool of water at the bottom of the tub, reducing water consumption by about 70% compared to the baseline. Other technologies, have been proposed to achieve low water use including the use of bladders to hold the wash/rinse water in more intimate contact with the wash load. If wash/rinse temperatures remain the same and these low water use designs were universally implemented, the resulting decrease in water heating energy would be 70% or 31×10^{12} Btu/yr, taking into account current market penetration of five percent. Note that 70% applies only to water heating energy for washers and does not apply to the motor energy use in washers.

(b) New Technologies: Wash/Rinse Fill Level Most new residential washers allow the user to select a wash size through a front panel switch selection which establishes the amount of wash and rinse water based on the load size. This same switch could be implemented in coin-op equipment, but there is no clear economic incentive for in

Figure 5-32: High Spin Speed Washer

the user to select low water use settings. It is possible that the advent of "smart card" technologies or other techniques will be used to introduce incentives for appropriate behavior through variable pricing schemes which depend on water consumption. We assume for this analysis that the user will select the switch setting corresponding to the appropriate load size. The distribution of load sizes determined the GRI study (Ref. 4) is shown below along with the calculated reduction in water usage in Table 5-30. The net reduction in water usage (and thus heating energy) would be 14% if these features were utilized, corresponding to a 12% reduction in total washer energy (6.5×10^{12} Btu).

Table 5-30: Frequency Distribution and Water Savings by Load Size

Load Size	Frequency	% Reduction in Water Compared with Baseline (large fill)
Small	9%	40%
Medium	51%	20%
Large	38%	0

Higher Efficiency Motors A split-phase motor is typically used in washers today with an approximate efficiency of 65%. Substitution of a capacitor type motor would increase efficiency to 75%. The present estimated primary energy consumption for washer motors is 7×10^{12} Btu/yr. Switching to higher efficiency motors would reduce this to 6.1×10^{12} Btu. Energy savings of 0.9×10^{12} Btu/yr can be achieved by this measure.

Eliminate Warm Rinse Option Detergent and washer manufacturers generally agree that a cold rinse is sufficient for all wash types and is desirable for delicate and permanent press. Elimination of the option of a warm rinse would save 15% of washer energy or 8×10^{12} Btu/yr.

All-Cold Wash By improving the detergent chemistry, hot water could be completely eliminated. Since 87% of energy used in washers is for hot water, energy savings are 87% of washing energy or 47×10^{12} Btu/yr in the U.S. This measure has the added advantage of simplified plumbing. The disadvantages are oxygen bleaches are ineffective, microbial attenuation is a problem and consumer acceptance difficult.

The modifications described above are summarized in Tables 5-31 and 5-32. Table 5-31 shows energy savings potential from current technologies that is technologies that are currently in the marketplace for commercial clothes washers; Table 5-32 shows technologies that may be implemented and are not currently available for commercial washers in the marketplace.

3 of 3

Table 5-31: Washers - Current Technologies - Energy Savings
Baseline Energy Use = 54×10^{12} Btu/year

Technology	% Energy Reduction	% Current Market Penetration	Remaining Energy Savings ($\times 10^{12}$ Btu)
1. Higher spin speeds	Saves drying energy (see Dryers)		
2. Horizontal axis design	61	5	31
Total	61	5	31

Table 5-32: Washers - New Technologies - Energy Savings
Baseline Energy Use = 54×10^{12} Btu/yr

Technology	% Energy Reduction	% Current Market Penetration	Remaining Energy Savings ($\times 10^{12}$ Btu)
1. Fill level switch	12	--	6.5
2. High efficiency motors	1	--	0.9
3. Eliminate warm rinse cycle	15	--	8
4. All cold wash	87	--	47
Total	87	--	47

(c) Advanced Technologies

Ozone Washing Ozone washing process utilizes a 3 Kw ozone generator for a 230 lbs (of clothes) capacity washer (according to John Gallo of Tri-O-Clear). All cold water can be used and the waste water can be reused. Limited detergent chemistry changes may be necessary. The cycle time is reduced so that three loads of wash can be done in an hour as opposed to two loads/hour for conventional washing machines. The disadvantage of ozone is that it tends to bleach and/or degrade delicate fabrics.

Total energy requirements for the ozone washing process for 230 lb capacity are:

$$\bullet \text{Ozone Production Energy} = 3000W \times \frac{\text{load}}{230 \text{ lbs}} \times \frac{\text{hr}}{3 \text{ loads}} \times \frac{11.2 \text{ Btu}}{\text{Whr}} = 49 \text{ Btu/lb}$$

$$\bullet \text{Drive Motors run one-third less time} = 146 \times 0.67 = \frac{98 \text{ Btu}}{\text{lb}}$$

$$\bullet \text{Total energy use} = 147 \text{ Btu/lb of clothes}$$

Savings = 1033 Btu/lb or 88%. Since baseline energy consumption for the U.S. coin and route operations is 35×10^{12} Btu/yr, energy savings = 31×10^{12} Btu/yr for coin

and route operations. For on-premise laundry baseline energy use is 19×10^{12} and energy savings = 17×10^{12} Btu/yr. Total savings for all washers = 48×10^{12} Btu/yr.

Ultrasonic Washing The benefits of ultrasonic washing are that the effectiveness of detergents is increased, the process may be lethal to microbes and the motor demand is reduced. The disadvantage is that clothes have to be flat while washing.

An eleven quart lab washer can hold two pounds of clothes, has a five minute cycle for two pounds and has 700 watts of power.

$$\text{Energy use} = 700 \text{ watts} \times \frac{5 \text{ mins}}{2 \text{ lbs}} \times \frac{\text{hr}}{60 \text{ mins}} = \frac{29.2 \text{ watt/hr}}{\text{lb}} = \frac{327 \text{ Btu}}{\text{lb}}$$

The energy use for an ultrasonic washer is, therefore, 327 Btu/lb of clothes. Energy savings relative to conventional washers = 853 Btu/lb of clothes or 72% of washer energy. Total U.S. energy savings = 39×10^{12} Btu/yr.

Advanced technologies are summarized in Table 5-33.

Table 5-33: Washers - Advanced Technologies - Energy Savings
Baseline Energy Use = 54×10^{12} Btu/yr

Technology	% Energy Reduction	Energy Savings ($\times 10^{12}$ Btu)
1. Ozone washing	89	48
2. Ultrasonic washing	72	39
Total	89	48

5.8.2 Dryers

5.8.2.1 First Principles Analyses

Within the normal range of interior and outdoor ambient relative humidities (30% to 70%), the equilibrium moisture content of common fabrics is on the order of 5% (1 lb. moisture per lb fabric). Consistent with the practice of "hanging clothes out to dry", wet clothes will dry passively, with no external heat input. Even in the absence of radiant heat input such as solar, air at less than saturation humidity passing the clothes due to natural convection currents will transfer sensible heat to the wet fabric, evaporating a portion of the moisture content. The total energy content of the air is unchanged, with the lost sensible heat replaced with the latent heat of the evaporated moisture. While the exchange of sensible for latent heat in an interior ambient the drying process is truly passive, exploiting the modest thermodynamic availability of less than saturated ambient air relative to wet fabric.

In the sense of the preceding paragraph, therefore, no energy input is required to dry clothes (in contrast to refrigeration, space conditioning, and water heating equipment which at design conditions establishes thermal conditions which are not at equilibrium with ambient conditions). A clothes dryer serves the purpose of drying laundry in much less time and volume, with much less manual handling of the laundry, than the passive drying process described in the preceding paragraph. To establish sufficient heat and mass transfer driving potential to dry the laundry rapidly, external heat input and forced air flow is necessary. In this regime, the latent heat of vaporization of the water to be removed from the fabric is the benchmark for minimum heat input to the drying process. Additional heat is required due to a number of heat losses:

- Sensible heat gain to the drying process air, which is exhausted at a higher temperature than the inlet temperature;
- Sensible heat to the fabric load, whose temperature is increased;
- Dryer cabinet losses, both losses to ambient and the heat required to warm the cabinet to the temperatures at the end of a drying cycle;
- For gas fired dryers, the latent heat portion of the HHV is not recovered; and
- Overdrying, i.e. continuing to operate the dryer beyond the point where the fabric moisture content would be in equilibrium with ambient air.

In Section 4.7, the typical breakdown of these losses is discussed, and many of the potential improvements discussed below are aimed at reducing one or more of these losses.

In current commercial dryers, the heat input is supplied directly from either gas combustion or electric resistance heat (a small portion of commercial sector applications, but a significant portion of residential sector dryers). The required heat input is low grade ($<200^{\circ}\text{F}$), and could, in principle, be supplied by a heat pump cycle, where the energy content of the exhaust drying air is recovered and upgraded by the heat pump. The temperature lift is roughly comparable to the temperature lift of a space conditioning heat pump. The range of COP (for supplying heat input to the process) that could be expected is:

- For a thermally actuated (e.g., gas fired) cycle: 1.5 to 2.0
- For a shaft power driven (e.g., electric motor) cycle: 3 to 5 (0.9 to 1.5 based on primary energy)

For an overall energy utilization efficiency, the heat pump COP would be multiplied by the thermal efficiency of the drying process (heat input $\div$ latent heat of moisture removed) and, for electrically powered heat pumps, by the primary energy efficiency at electric power generation, transmission, and distribution.

5.8.2.2 Energy Conservation Opportunities More than 95% of the commercial dryers are gas-fired. Gas-fired heating at 36% efficiency accounts for 91% of the clothes drying energy with the remaining 9% for electric motors. Dryer modifications and design changes that can result in substantial energy savings are:

- High recycle/high air flow through the dryer (current);
- Automatic cycle termination at the end of the useful drying phase (new);
- Heat recovery from dryer exhaust to heat hot water for washers (new);
- Higher efficiency motors (new);
- Heat pump clothes dryers (advanced);
- Desiccant-based closed cycle drying process (advanced); and
- Microwave drying (advanced).

Each of these are described below along with their potential to save energy. These technologies apply to coin and route operations as well as to on-premise laundries.

High Recycle/High Airflow (Current Technology) A high recycle rate for the dryer results in an increase in the moisture load of the exhaust and consequently an increase in overall efficiency. Similarly, high drum airflow results in more effective transfer of moisture to the air. These features have been demonstrated to raise the efficiency of a 30 lb capacity dryer from 36% to 55%. The 53% improvement in efficiency results in a 35% reduction in energy use. Estimated 1990 market penetration is 10%, and most new commercial dryers brought to market are expected to provide this level of efficiency. Full saturation of the market with these more efficient dryers would save 42×10^{12} Btu during the "useful" drying phase. Figure 5-33 shows a high recirculation dryer.

Automatic Termination of Drying (New Technology) As described in section 4.7.2.2, drying beyond approximately 5% remaining moisture level accomplishes no useful purpose since this is the equilibrium moisture content. Most home dryers have automatic cycle termination based on some indirect measurement of clothing moisture such as a rise in exhaust temperature. However, because time interval controls are the least expensive and because automatic termination of the dry cycle could lead to customer dissatisfaction, this feature is not typically used in coin-op and route dryers. Universal inclusion of automatic termination based on moisture level would eliminate the "Continued" Drying Energy for a savings of 12×10^{12} Btu/year.

Efficient axial air flow

The illustration shows how Speed Queen's axial air flow dries clothes faster and far more efficiently than traditional air flow design, allowing 100% of the heated air to pass through the drying cylinder. The illustration also shows how the improved air flow system employs recycled air in both dryer units adding to the drying effectiveness and energy conservation properties of the stacked drying tumbler.

Figure 5-33: High Recirculation Dryer

Heat Recovery Dryers (New Technology) A substantial amount of the latent and sensible heat in the dryer exhaust stream can be recovered by installing a heat exchanger in the exhaust duct. Laboratory tests as part of the GRI study, (Ref. 5) found that 50% of the total inlet fuel value could be recovered in the form of hot water. Figure 5-34 shows the schematic of a system which utilizes a storage system tank to manage hot water obtained from heat recovery dryers. Based on machine utilization profiles obtained from actual store surveys, a computer model of the hourly production of hot water by the dryers and usage by the washers was developed to determine the number of required dryers and associated hot water storage tank sizes. The model found that a single heat recovery dryer using only heat recovered in the "useful" drying period could meet the hot water requirements of up to 5 washers with a modestly sized storage tank (similar in capacity to that required for gas water heating).

The energy savings potential for this concept is essentially equal to the entire hot water demand of the wash cycle 9170 Btu/load out of a total energy use for washing of 12640 Btu/load. This amounts to 72.5% of clothes washing energy or 39.2×10^{12} Btu/yr. Facility modification costs were estimated to be approximately \$2,500 for a medium-sized facility, and heat recovery dryers were estimated to command a \$600 premium. There are essentially no heat recovery dryers installed today, but a commercial dryer introduced to the market by Speed Queen in June, 1991, has the capability for addition of heat recovery at a future time. The total energy savings potential for this technology is 39.2×10^{12} Btu/yr.

Figure 5-34: Laundry Facility Heat Recovery System

Higher Efficiency Blower/Tumble Motors (New Technology) The tumble/blower motor for dryers currently in service is typically a split-phase 1/2 hp motor with approximately 65% efficiency (0.56 kW). A capacitor type motor operating at 75% efficiency would consume 0.48 kW. This would save 1.4×10^{12} Btu/yr.

Heat Pump Clothes Drier Figure 5-35 is an illustration of a prototype residential heat pump clothes dryer by the Nyle Corporation in Bangor, Maine. Similar technology could be employed for commercial clothes dryers. Basically, this type of clothes dryer is a dehumidifier. Using a refrigeration cycle, the air is cooled and water is condensed out. The latent heat removed in condensing the water is immediately put back into the air stream. In addition, heat from the compressor is also added to the air stream. In this particular clothes dryer, none of the air is vented so that the temperature of the air keeps rising. Since this design is based on design of large lumber and leather drying systems and food dehydrators, adoption to commercial clothes drying could be accomplished with reasonable ease. European heat pump clothes dryers tend to operate within a narrow temperature range so as not to freeze the evaporator coil on the low end and not to boil off all refrigerant at the high end. The highest temperature is, therefore, limited to 125°F in European heat pump clothes dryers. The Nyle Corporation prototype sends only part of the air over the evaporator and varies this percent air in response to changing temperature. When the air is at a lower temperature, a greater volume of air is allowed over the evaporator coil and conversely as the air temperature rises, volume of air passing over the evaporator is reduced. Either automatic dampers or variable speed fan can be used to vary the airflow. The temperature range that can be used with this type of a dryer is 60°F to 160°F. (The residential clothes dryer prototype was funded by U.S. DOE under the Inventions Program in the Office of Energy Utilization.)

The heat for drying which is 67,000 Btu/hr in a gas-based dryer is substituted by a compressor consuming 20,000 Btu/hr (primary energy) or 30% of the gas heat. Drying time in both cases (gas and electric) is the same. Since gas heat represents 91% of total dryer energy use the energy savings are 30% of 0.91 or 27% of total dryer energy use, in primary energy terms relative to gas-fired dryer energy consumption. The energy savings at the national level is estimated at 37×10^{12} Btu/yr.

Desiccant-Based Closed Loop Dryer Figure 5-36 shows a schematic diagram of a dryer cycle using a desiccant wheel to extract moisture from the dryer.

The desiccant wheel is regenerated by using a gas-burner. Drying efficiency can be improved by a factor of 2 from about 36% to 72% resulting in energy savings of 45% of the total dryer energy (9% of total dryer energy is for electric motors which remains unchanged). An added advantage of this system is that drying is done at a lower temperature which is beneficial for the fabric. The modifications described above are summarized in Table 5-34 for currently available technologies, in Table 5-35 for new technologies in Table 5-36 for advanced technologies.

Heat-pump clothes dryer

Figure 5-35: Heat Pump Clothes Dryer

Figure 5-36: Desiccant-Based Closed Loop Dryer

Table 5-34: Dryers - Current Technologies - Energy Savings
Baseline Energy Use = 136×10^{12} Btu/year

Technology	% Energy Reduction	% Current Market Penetration	Remaining Energy Savings ($\times 10^{12}$ Btu/yr)
High recycle/high air flow	35	10	42
Total	35	10	42

Table 5-35: Dryers = New Technologies - Energy Savings
Baseline Energy Use = 136×10^{12} Btu/year

Technology	% Energy Reduction	% Current Market Penetration	Remaining Energy Savings ($\times 10^{12}$ Btu/yr)
1. Higher (washer) spin speeds	40	-	54
2. Auto drying termination	9	-	12*
3. Heat recovery dryers	(Water Heating)		39**
4. High efficiency motors	1	-	1
Total		-	(55 +39 in HW)

*Savings are 12×10^{12} Btu/year if measure applied by itself, not included in total.

**39 $\times 10^{12}$ Btu/year savings is for water heaters.

Table 5-36: Dryers - Advanced Technologies - Energy Savings
Baseline Energy Use = 136×10^{12} Btu/year

Technology	% Energy Reduction	% Current Market Penetration	Remaining Energy Savings ($\times 10^{12}$ Btu/yr)
1. Desiccant-based dryer	45	-	61
2. Microwave drying	0	-	0
3. Heat Pump dryer (dehumidifier)	27	-	37
Total	45	-	61

Microwave Drying Electric energy with a primary conversion efficiency of 30% has to pay a substantial penalty in primary energy terms. Even with a 100% efficiency of microwave delivered to the clothes, the energy use for evaporating 1 lb of water per lb of clothes is 3571 Btu/lb of clothes based on 30% primary energy to delivered electricity conversion. The drive motors are an additional 300 Btu/lb so that total energy required is 3871 Btu/lb which is higher than conventional gas dryers.

If we assume a higher primary energy to electricity conversion of say 45%, the energy consumption would be 2222 Btu/lb of clothes for the drying and 300 Btu/lb for motors or a total of 2522 Btu/lb of clothes. This is still higher than the 1180 Btu/lb of clothes for a conventional gas dryer.

5.9 Electronics (Excluding Office Equipment)

This category of equipment includes:

- Electromedical equipment,
- Cash registers, point-of-sale (POS) terminals, and automated teller machines,
- Telephone equipment.

Telephone equipment, due to its rather low energy use brought about by advances in technology from electromechanical to electronic switching systems, is not discussed further in this section. Electromedical equipment and POS equipment are analyzed here. Since all equipment in the electromedical and the cash handling categories uses computer, displays and printers, the conservation measures identified earlier for these apply here. However, these are not repeated.

First principles analyses that applies to office equipment, also applies to the rest of the electronics. The basic components remain the same, the losses and limits of performance also are applicable from the discussion on office equipment.

5.9.1 Electromedical Equipment

This category of equipment includes the medical imaging systems and is divided into:

- Radiographic
- Computed Tomography (CT)
- Magnetic Resonance Imaging (MRI) and
- Ultrasonic scanners.

Brief descriptions of the equipment are taken from the Encyclopedia of Medical Devices and Instrumentation, (Ref. 6). This is provided here to help the reader understand some basics of the equipment and how they work. Potential energy conservation technologies are identified for each type of equipment. Lastly, energy savings are estimated for all electromedical equipment.

5.9.1.1 Radiographic Equipment Radiography is a form of physical diagnosis in which X rays are used to obtain medically useful information about a patient. A beam of X rays is passed through the patient. The differential absorption of radiation by different tissues modulates this beam. The transmitted beam is detected and its information content is recorded. In addition, radiological imaging methods are increasingly used to control both diagnostic and therapeutic manipulations such as needle biopsy and percutaneous transluminal angioplasty. The necessary X-ray equipment is composed of many subsystems. These include means for X-ray production, spatial and spectral shaping of the X-ray beam, patient handling, as well as means for image detection and capture, intermediate image handling, image processing, display, and storage. Auxiliary equipment and logic are customarily included in the design and construction of X-ray apparatus for the control and

automation of the examination process. The functional organization of an X-ray imaging system is shown in Figure 5-37. In one form or another, these elements are present in all X-ray imaging systems.

Figure 5-37: Functional Diagram of an X-Ray System

Radiographic equipment has not changed significantly over the past decade. Some improvements have been made in the imaging film which results in shorter exposure times, and thus lower average power consumption. The dominant energy consumer in this type of equipment is the X-ray generation and its control (45%), patient handling (20%) and the remaining 35% are standby by losses and power supply losses.

Radiological equipment produces X-rays with tube voltages of 25 to 150 kW at power levels extending from less than 100 W to more than 100 kW. Exposure times range from a millisecond to several minutes. A wide voltage range is required to produce the required contrast characteristics in the final image. Wide power and exposure time ranges are needed to deliver the appropriate dose rate and total dose to the image receptor. Control and regulation of such varying power levels led to the early introduction of control and feedback elements into X-ray generators, which dominate the power consumption for this type of equipment.

Although the X-ray generation and control process is very inefficient, no breakthroughs are foreseen by industry participants in this area. Net consumption for radiography has decreased somewhat through the introduction of higher power X-ray tubes and highly responsive films. Kodak and Dupont are known to be continuing research into more rapid exposure time films. Energy conservation opportunities are largely limited to power management techniques, as many machines are left in standby when no usage is planned. This is due to warmup and stabilization concerns.

Other measures include high efficiency motors and replacement of linear power supplies by switching type power supplies. Quantification of the savings is provided later in this section.

5.9.1.2 Computed Tomography CT equipment also utilizes an X-ray beam. Figure 5-38 provides a block diagram of the major elements of a CT, as well as a view of the gantry and patient table. The major advance in CT relative to radiography is the digital acquisition and analysis of the image in slices. CT machines collimate the X-ray beam and image a small sector or slice during each exposure. CT scans numerous small sectors onto a detector which produces an electrical signal. This detector output signal is then analyzed with the aid of a computer. CT was introduced in 1971 with subsequent improvements to the computer and associated equipment. The dominant energy consumer is the X-ray generating tube and the associated cooling elements, which account for 25% of the total energy. X-ray control accounts for 10%, computer and display 30%, patient handling 5%, and power supply, the remaining 30%.

Again no breakthroughs in X-ray generation are foreseen. Energy conservation opportunities are largely limited to behavioral modifications/power management, as many machines are left in standby when no usage is planned. This is due to warmup and stabilization concerns. CT can benefit from semiconductor and display technology energy-saving developments in the computer equipment area. However, similar to Mainframe computers, any savings in power will likely be offset by the desire for faster, higher performance. Potential energy reduction technologies include:

- Power management (or behavior modification); power management software similar to that discussed under office equipment could result in savings of 15% to 25%;
- New low energy displays could reduce energy use by about 5%;
- High efficiency motors with rare earth magnets and better motor controllers to reduce heat generation and manage transients could save 5% to 10% of the energy use; and
- Changeover from linear to switching power supplies could reduce energy consumption by another 10%.

5.9.1.3 Magnetic Resonance Imaging (MRI) Nuclear Magnetic Resonance Imaging is a new diagnostic tool used by radiologists to produce cross-sectional pictures of a patient's anatomy. It is most useful in visualizing changes in soft tissue characteristics by means of video display and hardcopy output. Initially patented in 1972, MRI is now available in many clinics across the country.

MRI image formation is accomplished by placing the patient in a magnetic field and subjecting it to radio frequency (RF) electromagnetic radiation. Atomic nuclei with magnetic moments bring about a resonant absorption of RF energy at a sharply defined frequency proportional to the strength of the magnetic field. The small field

Figure 5-38: CT Scanner System (a) Block diagram; (b) gantry and patient table

gradient may be altered so that the corresponding slight differences in the resonance frequencies can be used to construct a two or three dimensional image of the distribution of resonant nuclei within the patient.

Standard MRI equipment consists of six subsystems as shown in Figure 5-39. The primary magnet is a superconductive magnet which requires cryogenic cooling. The gradient magnet consists of three axis magnet coils driven by audio amplifiers. The RF equipment consists of a pulse transmitter and broad band receiver. The computer controls all these subsystems in addition to performing the signal processing. The generated images are then stored and displayed as needed.

The power distribution among these subsystems is as follows:

- Magnets and cooling - 35%
- RF Subsystem - 10%
- Computer and display - 30%
- Power supply - 15%
- Patient handling - 10%

Figure 5-39: A schematic diagram of an MRI scanner showing six basic subsystems: magnet, computer, gradient, radio, data storage, and display subsystems.

The dominant energy consumers are the magnetic cooling system and the computer. MRI equipment has a high utilization profile due to its high cost and limited availability. Many machines are operated 24 hours a day, 7 days a week. Equipment reliability is the main contributor to any downtime. MRI computer equipment consumption will benefit from semiconductor and display technology advances. The development of high temperature superconductors would significantly decrease the cooling requirements, and could well provide the most significant energy savings opportunity in this category of equipment. Energy savings could amount to 20% relative to current energy use from the application of room temperature superconductors.

Other technologies that can save energy are:

- Power management - 20% savings;
- Low energy displays - 5% savings;
- High efficiency motors - 5% to 10% savings;
- Switch to high efficiency power supplies - 5% savings.

5.9.1.4 Ultrasonic Imaging Medical images are formed by passing various types of radiation (or energy) into the body and measuring the output with a suitable detector. Diagnostic ultrasound images are generated by producing ultrasound waves in an external transducer, directing these waves through the body and measuring several properties of the scattered echoes from reflectors inside the body. Ultrasound images have two unique properties that distinguish them from the more commonly used X-ray plane film images. First, they display soft tissue structures which permits organ identification as well as the diagnosis of various focal and diffuse soft tissue disease states. Second, they have been found to have very low, if any, biological effect (or risk) to the patient.

A typical portable ultrasonic scanner is shown in Figure 5-40. The major elements of this equipment are the transducer, computer, display, and output device. Figure 5-41 is a block diagram of the "front end" of the ultrasonic equipment. The rectangular blocks represent the circuit building blocks. The transducer is shown transmitting into the patient. The circles indicate operating controls that affect the echo amplitude data written into the ultrasonic image. At the top of the figure, the echo waveforms are presented at various stages of signal processing.

Usage profiles vary from heavy in hospitals to moderate in physician offices. The equipment requires minimal warmup time and is typically turned off when not in use. Power distribution in this type of equipment is as follows:

- Displays - 10%;
- Imager/transducer - 40%;
- Power supply - 25%; and
- Output device - 25%.

The portability requirement limits the maximum current drain to less than 15 amperes which is the rating of a standard outlet. Product designers are required to add performance features while remaining below this input power limitation. This tends to move the design in the direction of lower energy use. Further changes such as the increased use of CMOS semiconductor technology, high resolution LCD displays, and switching power supplies could further reduce energy consumption.

5.9.1.5 Estimates of Total U.S. Energy Savings in Electromedical Equipment

Based on the above discussions, we have estimated the energy savings potential of various technologies as they apply to electromedical equipment. It should be noted that office equipment and electromedical equipment have many similarities in the subsystems that constitute the equipment. It is, therefore, logical to expect that many of the technologies that apply to office equipment also applies to electromedical systems.

Table 5-37 provides baseline energy use for each type of equipment for reference and Tables 5-38 summarizes the potential energy savings from the various technologies and shows to which equipment these technologies apply.

Figure 5-40: Portable Ultrasonic Scanner

HP SONOS 1000 Cardiovascular Imaging System

Technical Data

Features

Enhanced (128-channel) or basic (64-channel) system.

Wide range of dual- and single-frequency transducers.

Upgradable to the HP SONOS 1500 with HP Acoustic Quantification technology and Digital Storage and Retrieval.

Vascular imaging options for 64- and 128-channel systems include 7.5 and 4.5 MHz linear array transducers.

TEE imaging options include 5.0 MHz biplane and single plane probes.

Frequency Agility for optimal low-frequency Doppler and color flow without compromising high-resolution 2-D imaging.

High Definition Color Flow for greater blood flow sensitivity without a loss in frame rate.

HP Colorization option assists your ability to perceive a larger number of echo intensities in 2-D images, M-mode traces, and spectral Doppler displays.

Steerable PW/CW Doppler.

Comprehensive analysis package.

Continuous Loop Review mode, High Definition Acoustic Zoom, and other versatile display modes.

Figure 5-41: Block Diagram for Automated Teller Machines

Table 5-37: Baseline Energy Use - Electromedical Equipment

Equipment Type	Total U.S. Energy Use (x 10 ¹² Btu/yr)
Radiography (X-rays)	8
Computer Tomography	2
Magnetic Resonance Imaging (MRI)	1
Ultrasound	2
Total	13

Table 5-38: Energy Savings Potential for Electromedical Equipment - New and Advanced Technologies

Technology	Applies to Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	% Energy Reduction	Energy Savings (x 10 ¹² Btu)
1. Power management (N)	All except ultrasound	10.7	20	2.1
2. Low energy displays (N) (LCD, plasma, microtips)	CT, MRI, Ultrasound	5.6	5	0.3
3. Room temperature superconductors to replace cryogenics. (A)	MRI only	1.0	20	0.2
4. High efficiency motors with rare earth magnets and improved motor controllers. (A)	All	13	7	0.7
5. Power supplies change over from linear to switching type. (N)	All	13	10	1.0
Total		13		4.3

A = Advanced technologies; N = New technologies

*Savings for each subsequent technology is based on an energy use reduced by the savings for all previous technologies, e.g., savings for high efficiency motors = (14.7 - 2.2 - .4 - .6) x .07 = 0.8.

5.9.2 Cash Handling Machines

In this category, we have included:

- Cash Registers and Point of Sale Terminals; and
- Automated Teller Machines (ATM).

5.9.2.1 Point-of-Sale Terminals and Cash Registers POS terminals are used in a broad range of retail establishments. Cash registers are included in this equipment type. This ranges from a sophisticated terminal which communicates to a central computer in a large department store to the "cash register" at the local convenience store or fast food restaurant. Figure 5-42 depicts a typical retail terminal. The power distribution by components is as follows:

- Display - 15%;
- Computer - 45%;
- Printer - 10%; and
- Power supply and fan - 30%.

The microprocessors in the majority of POS terminals are believed to be NMOS semiconductor technology. The general trend towards the use of CMOS technology will result in a decrease in power consumption. Printers are typically small dot-matrix impact type and displays are either LED, LCD, or vacuum-fluorescent. Aside from the technology driven energy conservation, opportunities for POS terminals are largely limited to improvement in standby power management. Since these terminals do not consume significant power, designers and users do not focus on reduction in the standby power. Since the displays used in POS terminals require no warm-up (versus CRTs), it is possible to turn off the display in the standby state. Placing the computer in a low power "sleep" mode is also possible. While high-end POS terminals may employ these types of conservation measures, it is not felt that the majority of these products focus on this design option. Development of more efficient power supply topologies would produce a reasonable benefit. Linear power supplies are 30% to 60% efficient while switching power supplies can be in the 80% to 95% efficiency range. Potential energy savings for the U.S. are presented later in the text.

5.9.2.2 Automated Teller Machines Figure 5-43 provides a block diagram of a typical ATM. The microprocessor controller is typically NMOS technology. The printer is a dot-matrix impact type. The dominant energy consumers are the computer and the CRT display. The power distribution among the components (excluding heater) is as follows:

- Display - 20%;
- Computer - 45%;
- Printer/reader/dispenser - 10%; and
- Power supply - 25%.

Figure 5-42: Typical Retail POS Terminal

An estimated 43% of ATMs are exposed to the elements and require heaters to function properly. One manufacturer requires 800 to 1400 watts of additional power to maintain the minimum 40 degree operating temperature. The remaining components of ATMs, (printer, dispenser, reader) consume a significant proportion of the peak power but are used for a small percentage of the total operating time. Increased use of swipe or dip style card readers is gaining popularity, which will allow the deletion of the card reader motor assembly.

The continuous operation of ATMs is the most significant energy consumption factor. The nature of these machines requires customer access at any time of the day. Again, energy conservation opportunities relate to developments in semiconductor and display technology. These include the further use of CMOS technology, higher levels of integration and lower operating voltages. A transition to more efficient

display technologies such as Liquid Crystal Displays (LCDs) could reduce display power significantly. Energy savings potential for ATM's is presented in the following section along with that for POS terminals.

Figure 5-43: Block Diagram for Automated Teller Machines

5.9.2.3 Estimates of Total U.S. Energy Savings Potential for Cash Handling Machines Energy savings estimates for POS terminals and ATM's are shown in Table 5-39. The most significant savings are achievable by market forces and technology trends as seen from this table.

Table 5-39: Energy Savings Potential for Cash Handling Machines

Technology	Applies to Equipment Type	Baseline Energy Use (x 10 ¹² Btu)	% Energy Reduction	Market Penetration (%)	Energy* Savings (x 10 ¹² Btu)
1. Conversion from NMOS to CMOS technology. (C)	Both	24.6	10	50	1.2
2. Power management. (N)	Both	24.6	15	-	3.5
3. Displace linear power supplies by switching type. (C)	Both	24.6	15	10	2.7
Total					7.4

C = Current; N = New; A = Advanced

*Subsequent measure savings = (Baseline - Savings of previous measures) x (% savings) x (1 - % market penetration).

5.10 References

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