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TECHNOLOGY DATA CHARACTERIZING WATER HEATING IN COMMERCIAL BUILDINGS: APPLICATION TO END-USE FORECASTING

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ABSTRACT

Commercial-sector conservation analyses have traditionally focused on lighting and space conditioning because of their relatively large shares of electricity and fuel consumption in commercial buildings. In this report we focus on water heating, which is one of the neglected end uses in the commercial sector. The share of the water-heating end use in commercial-sector electricity consumption is 3%, which corresponds to 0.3 quadrillion Btu (quads) of primary energy consumption. Water heating accounts for 15% of commercial-sector fuel use, which corresponds to 1.6 quads of primary energy consumption.

Although smaller in absolute size than the savings associated with lighting and space conditioning, the potential cost-effective energy savings from water heaters are large enough in percentage terms to warrant closer attention. In addition, water heating is much more important in particular building types than in the commercial sector as a whole. Fuel consumption for water heating is highest in lodging establishments, hospitals, and restaurants (0.27, 0.22, and 0.19 quads, respectively); water heating's share of fuel consumption for these building types is 35%, 18% and 32%, respectively.

At the Lawrence Berkeley National Laboratory, we have developed and refined a base-year data set characterizing water heating technologies in commercial buildings as well as a modeling framework. We present the data and modeling framework in this report. The present commercial floorstock is characterized in terms of water heating requirements and technology saturations. Cost-efficiency data for water heating technologies are also developed. These data are intended to support models used for forecasting energy use of water heating in the commercial sector.

The representation of the water-heating end use is complicated because the number of configurations of plant types and systems is quite large. Also, energy use is a complex function of the plant and the system properties. In this report, we present a method for segmenting the water heating equipment market. We then develop relevant data in terms of this segmentation to create a consistent forecasting framework.

ACKNOWLEDGMENTS

This report on commercial-sector water heating is one of five in a series summarizing technology data for various commercial end uses in the United States. Companion reports describe technology data for space conditioning, lighting, refrigeration, and office equipment in commercial buildings.

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1. INTRODUCTION

Commercial-sector conservation analyses have traditionally focused on lighting and space conditioning because of their relatively large shares of electricity consumption (33% and 40%, respectively), and the large share of space conditioning in fuel consumption (63%), in commercial buildings. In this report we focus on water heating, which is one of the neglected end uses in the commercial sector. The share of the water-heating end use in commercial-sector electricity consumption is 3%, which corresponds to 0.3 quadrillion Btu (quads) of primary energy consumption. Water heating accounts for 15% of commercial-sector fuel use, which corresponds to 1.6 quads of primary energy consumption.

Although smaller in absolute size than the savings associated with lighting and space conditioning, the potential cost-effective energy savings from water heaters are large enough in percentage terms to warrant closer attention. In addition, water heating is much more important in particular building types than in the commercial sector as a whole. Fuel consumption for water heating is highest in lodging establishments, hospitals, and restaurants (0.27, 0.22, and 0.19 quads, respectively); water heating's share of fuel consumption for these building types is 35%, 18% and 32%, respectively.

Forecasting commercial-sector energy consumption is an important issue for utility capacity planning since the commercial sector is the fastest growing consumer of energy. Previously, utilities forecasted electricity and gas consumption based on time series analysis. More recently, with the growth of demand-side management (DSM) programs, there is a need to forecast by building type, end use, and technology options within an end use. Forecasting models in which energy consumption is disaggregated by technology option are also useful to state and federal policy makers in their assessment and implementation of technology-specific standards and policies.

The Electric Power Research Institute (EPRI) develops and maintains the commercial-sector end-use forecasting program COMMEND (Commercial End-Use Planning System) as well as end-use programs for the residential and industrial sectors. To address the above-mentioned analysis needs, EPRI has enhanced COMMEND to allow modeling of specific lighting, space conditioning (HVAC), refrigeration, and office-equipment technology options. The EPRI contractor for this effort, Regional Economic Research, Inc. (RER), worked with Lawrence Berkeley National Laboratory (LBNL) in the development and testing of the technology modules contained in COMMEND 4.0. LBNL is also providing assistance in the development and refinement of technology data for the model.

Although EPRI has not developed the option for modeling discrete water heating technologies, we at LBNL have developed and refined a base-year data set characterizing water heating technologies in commercial buildings and a modeling framework that could easily be used to enhance COMMEND or another commercial end-use forecasting model. The data and modeling framework are presented in this report. We characterize the present commercial floorstock in terms of water heating requirements and technology saturations. We also develop cost/efficiency data for water heating technologies. The data provided are intended to support models used for forecasting commercial-sector energy use for water heating. The data presented here can also be converted to their reduced form and utilized in COMMEND.

2. FORECASTING MODEL AND DATA REQUIREMENTS

Recent end-use forecasting models for the commercial sector forecast future energy consumption by fuel, end-use, and building type. The models start with a user-provided characterization of the present status of related parameters for the commercial sector and forecast future consumption levels by simulating user decisions on energy end-use technology options. In the models, the commercial-sector floor stock is segmented into building types and vintages. Energy use is segmented into different end uses. The model user characterizes the base year by providing input on energy use intensities within this framework.

In addition to the base-year characterization, the models require two major groups of data in order to generate future consumption patterns. The first is a set of cost/efficiency data on end-use technology options, and the second is a set of data on the decision behavior of consumers. Technology options are generally represented by technology tradeoff curves that relate operating costs to equipment costs. This form can be viewed as a variation of the cost/efficiency function. For end uses that may consume more than one fuel type, such curves are defined for each fuel type to facilitate the modeling of fuel-switching decisions. Consumer decisions are based on parameters such as discount rate preferences, consumer resistance to change, short-term utilization elasticities, and consumer price expectations based on past fuel prices.

The decision makers are segmented into levels of discount rate preferences. Models allow for several groups with different discount rate preferences. The discount rates for commercial-sector energy decisions are often quite high compared to the typical discount rates used in business.

Fuel prices and growth of commercial floor space are exogenous to these models. Based on these exogenous time series data for each forecast year, the model incorporates choices for new buildings and retrofit situations into the stock, building up the future forecast. Fuel switching and technology efficiency-level choices are generally based on lifecycle cost (LCC) minimization criteria.

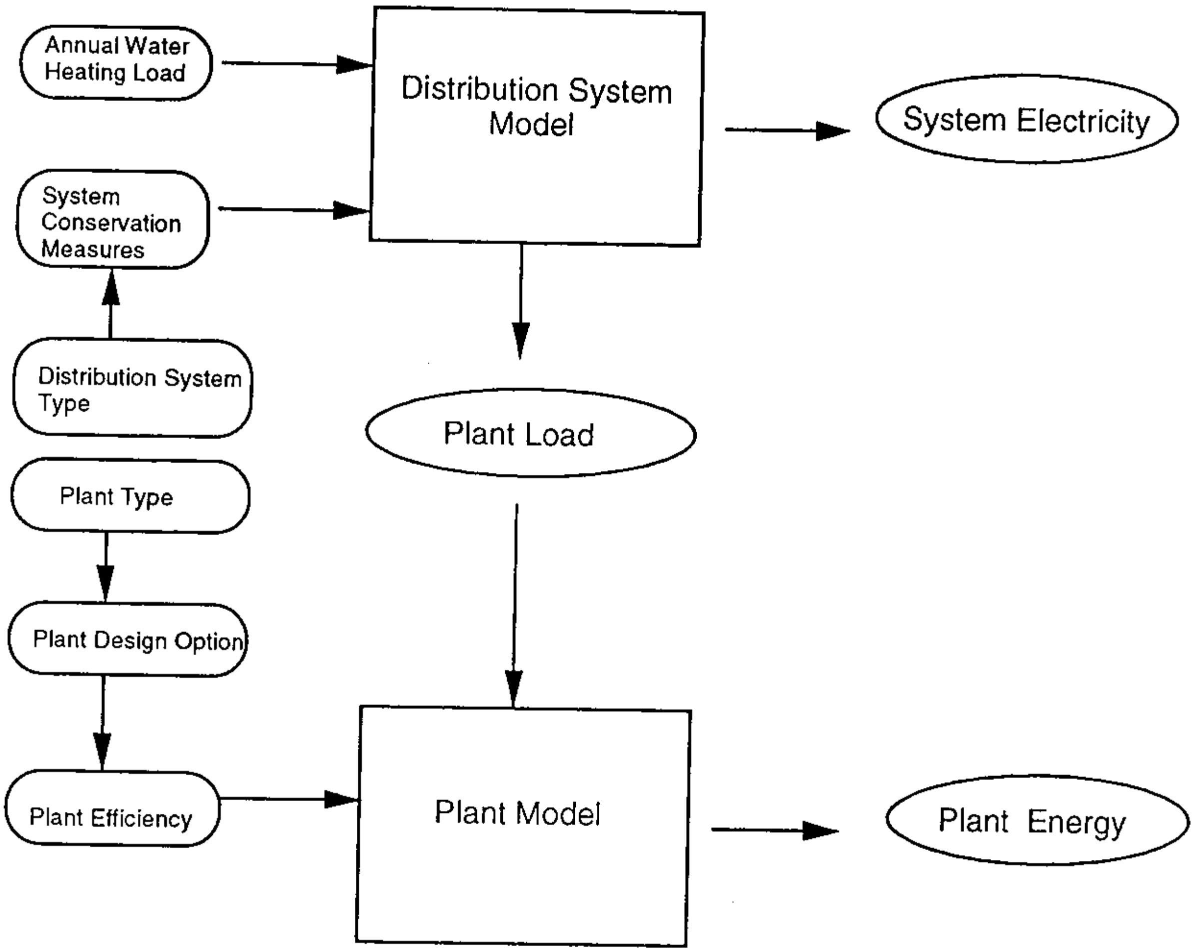
As mentioned above, each end use was represented using a single cost-efficiency function. Although cost-efficiency functions are built using market data, any information regarding which technology option a certain point on the function actually represents disappears once the function is created. Thus, market shares cannot be attributed to specific technologies. Although it is possible to analyze several policy options such as performance standards using cost-efficiency functions, it is nearly impossible to analyze policies addressing individual technology options.

In some of the most recent forecasting models, more detailed options are available and allow the user to model specific end-use technologies. **Figure 1** depicts the proposed water-heating end-use model logic. The general features of the detailed end-use representation are as follows:

- In place of general end-use concepts, an expanded set of technology definitions is used in the models. For example, instead of representing the end use by a curve on which the annual energy use decreases as the initial investment increases, we do it by shares of explicit water-heating technologies, service levels, and operating hours, together with costs and efficiencies for these discrete technology options.

- The level of detail in the models recognizes the complexity of commercial end-use systems and deals explicitly with conservation measures that affect energy use for these systems.

Figure 1. Water Heating End Use Model Logic



When designing a water-heating module, the model features specific to the water-heating end use would include the following:

- The water-heating plant and distribution system would be modeled separately.
- Starting with hot-water demand for different building types, the model would determine the heat loads (for hot water) at the point of use.
- The system model would account for the heat losses in the distribution system and also estimate the electricity use of pumps utilized by the system.
- The plant model would determine the energy used for generating heat to satisfy the water-heating load and account for standby losses.
- The model would deal directly with enumerated lists of plant types (e.g., electric self-heating storage tank, water-heating heat pump, tank heated by space-heating equipment, residential storage system); plant design options (e.g., models with one or more of: tank insulation, intermittent ignition – spark or hot surface, active flue damper, condensing combustion system); system types (centralized systems and distributed systems); and system conservation measures (insulation and pump controls).
- Changes in equipment efficiency levels can be modeled either directly through efficiency equations or in detail through the specification of detailed design options.

End-use forecasting models expanded to address individual technology options will require characterization of the present floorstock in terms of service demand, energy technologies used, and the cost-efficiency attributes of energy technologies available to consumers for new buildings and retrofits. This report provides these types of data for water-heating end uses. Another major type of data required is related to consumer choice modeling. This report does not consider how future choices of users may change or what the choice parameters of decision makers are. **Table 1** shows how the technology data required for forecasting is represented and where these data can be found in this report.

Table 1. Representation of Efficiency, Cost, and Saturation

Energy Technology	Efficiency	Cost	Saturation
Plant Types include product classes such as self-heating storage water heaters. Plant types are further disaggregated by fuel type and fuel-specific design options.	Efficiencies presented in the tables for the plant include recovery efficiency and the annual efficiency. See Tables 7-11.	Cost is a function of both the storage capacity and heat input rate. See Tables 7-11.	Saturations of product classes by building type are presented in Table 4. Saturations of equipment within a product class are presented in Tables 7-11.
System Types consist of centralized systems and distributed systems. System features include insulation and pump controls.	The heat loss and electricity use of pumps are indicators of system efficiency. Thus, conservation measures affect either the heat loss or pump electricity use. See Table 6.	Pump and pipe costs as a function of size are presented. Incremental costs are presented for conservation measures over the base case. See Table 6.	Saturations of system types by building type are presented in Table 4. Percentage of floor area served by a particular system type equipped with a conservation measure is presented in Table 6.

3. SERVICE DEMAND

We characterize two aspects of water heating service demand in this report: (1) annual hot water requirements, which are used to determine the energy used to generate the necessary heat for the hot water service, and (2) peak demand for hot water service, which is the main factor in sizing the water-heating equipment and therefore in the equipment cost. Characterization data are provided for small and large offices, fast-food and sit-down restaurants, retail stores, grocery stores, warehouses, elementary schools, junior high and high schools, health facilities, hotels, and motels.

Annual hot-water requirements for the different building types are presented in **Table 2**. Annual hot-water load is a function of the hot-water temperature differential, therefore Table 2 presents the temperature requirements for different building types. Annual load is also a function of the operating schedule, therefore we present the number of operating days. Hot-water demand is characterized by the number of gallons per unit per day (the definition of a unit varies by building type). In offices and educational facilities, units represent the number of people using the facility. In restaurants, units represent the number of meals served. In hotels and motels, units represent the number of rooms. In stores and warehouses, units represent the number of employees. In healthcare facilities, units represent the number of patients. The number of units is mapped onto the floor area using the prototypical data from Sezgen et al. [3] which are based on EIA data [4]. Using Table 2, one can start with the floor area of a certain building type and determine the hot-water demand in terms of annual gallons at a given temperature differential and the annual hot-water heat load. As discussed below, the annual heat load is the main factor in determining the energy use for water heating.

Peak hot-water demand is characterized by gallons per hour at the peak time. Given the floor area for a certain building type, peak hourly load can be calculated from the water temperature differential, hourly volume per unit, and units per floor area. These peak hourly requirements are to be satisfied by the combination of the storage tank and the heat generation capacity of the plant. The tank and heat generation capacity are presented in **Table 3**. The tank capacity is 80% of the peak hourly volume. The heat generation capacity is assumed to be equal to the peak load. These assumptions reflect conservative design practices in this field.

Table 2. Annual Hot Water Requirements

Building Type	Daily Demand (1) (Gallons/Unit/Day)	Unit (2)	Units/1000ft2 (3)	ΔT (1) °F	Applicable Days/Year (1)	Annual Hot-Water Load (4) (kBtu/year/1000ft2)
Small Office	1	person	2.3	85	250	402
Large Office	1	person	2.3	85	250	402
Fast Food Rest. (5)	0.7	meal/day	784.6	85	365	141,942
Sit-Down Rest. (6)	2.4	meal/day	340.0	85	365	210,886
Retail	2	employee	1.0	85	365	517
Grocery	2	employee	1.1	85	365	550
Warehouse	2	employee	0.5	85	250	170
Elementary School	0.6	person	9.5	85	200	809
Jr. High/High School	1.8	person	9.5	85	200	2,428
Health	90	patient	3.8	125	365	130,454
Motel	20	unit(room)	5.0	85	365	25,684
Hotel	14	unit(room)	2.2	85	365	7,960
Other	1	employee	0.7	85	250	124

(1) Source: EPRI [1] except (a) "daily demand" for sit-down restaurants, hotels and motels were modified by values from ASHRAE [2], and (b) office "applicable days" were changed to 250 from 365. It should be noted that inlet temperature varies widely based on location and time; these numbers approximate the U.S. averages.
(2) "Person" represents employees or others using the facility. For example, in a school, a person is a teacher, student, or staff member.
(3) Source: Sezgen et al. [3].
(4) Annual Hot-Water Load = Daily Demand * Number of Units * Applicable Days/Year* Heat Capacity of Water (c) *ΔT* Density of Water (d); c = 1 Btu/lb-°F, d = 8.33 lbs/gallon.
(5) Average time for a meal is assumed to be 20 minutes.
(6) Average time for a meal is assumed to be 1 hour.

Table 3. Water-Heating Capacity Requirements

Building Type	Hourly Peak Demand (1) (Gallons per Unit)	Unit (2)	Units/1000 ft2 (3)	ΔT (4) °F	Storage Capacity (5) (Gallons/1000 ft2)	Heating Capacity (6) (kBtu/hour per 1000 ft2)
Small Office	0.4	person	2.3	85	0.7	0.6
Large Office	0.4	person	2.3	85	0.7	0.6
Fast Food Rest. (7)	0.7	max. meals/hour	69.5	85	38.9	34.4
Sit-Down Rest. (7)	1.5	max. meals/hour	30.0	85	36.0	31.9
Retail	0.8	employee	1.0	85	0.6	0.6
Grocery	0.8	employee	1.1	85	0.7	0.6
Warehouse	0.8	employee	0.5	85	0.3	0.3
Elementary School	0.6	person	9.5	85	4.6	4.0
Jr. High/High School	1	person	9.5	85	7.6	6.7
Health	7	patient	3.8	125	21.4	27.8
Motel	6	unit(room)	5.0	85	23.9	21.1
Hotel	5	unit(room)	2.2	85	8.8	7.8
Other	0.4	employee	0.7	85	0.2	0.2

(1) Source: ASHRAE [2] except for retail, grocery, and warehouse buildings – for these buiding types, higher hourly peak water use compared to that in offices is assumed.
(2) "Person" represents employees or others using the facility. For example, in a school, a person is a teacher, student, or staff member.
(3) Source: Sezgen et al. [3].
(4) Source: EPRI [1]. Based on ASHRAE [5], the 7 gallons/patient hourly demand for health-care facilities is 3 gallons with ΔT of 110 °F, 2 gallons with ΔT of 120 °F, and 2 gallons with ΔT of 160 °F for clinical, dietary, and laundry purposes, respectively.
(5) Storage Capacity = 0.8 * Hourly Peak Demand * Number of Units
(6) Heat Capacity = Hourly Peak Demand * Number of Units* Heat Capacity of Water (c) * ΔT* Density of Water (d); c = 1 Btu/lb-°F, d = 8.33 lbs/gallon.
(7) Maximum meals per hour is assumed to be 1.5 times the average meals per hour.

4. *WATER-HEATING DISTRIBUTION-SYSTEM TECHNOLOGIES*

Centralized systems and distributed systems are the two competing technology categories for delivering the hot water generated at the plant. Each system type has advantages and disadvantages, and choice of one over the other depends on issues such as space requirements, initial cost versus operating cost, and peak water-heating load. In this section, we present the cost and efficiency attributes for a base case for each type of distribution system and for conservation measures over the base case. For centralized systems, effective conservation measures are pipe insulation and pump controls that turn the pumps off when there is no demand for hot water. For distributed systems, pipe insulation is the conservation measure considered.

Demand-limiting technologies such as efficient showerheads can also be considered part of the distribution system. At this time, hot water demand is characterized in terms of the volume of hot water and there is little information on what proportion of hot water is supplied through efficient showerheads and faucets. As information on the penetration of efficient showerheads and faucets becomes more available, analysts will be able to estimate the proportion of hot water demand that is attributable to them and incorporate this information into their forecasts.

Saturations

The saturations of the plant classes served by the two competing distribution technology categories are presented in **Table 4**. The saturation data are based on EIA data [6] and are disaggregated by building type. In the table, market share represents the percentage of floor area served by the distribution system type. It is clear from this table that residential-type water heaters have a large market share in commercial buildings and are predominantly utilized as part of distributed systems.

The efficiency and cost of a centralized system is a function of the pipe length. Systems with a distance from the plant to the point of use of more than 100 ft. typically utilize circulation systems. This is to prevent water waste (the water in the pipe cools down during the unused period and during the subsequent use, some amount of water is discarded). In our presentation, we assume that all centralized systems use circulation systems, and that none of the distributed systems use circulation pumps. In **Table 5**, we estimate the pipe length for centralized systems and point-of-use systems by building type. The building prototypes are taken from Sezgen et al. [3] and were developed based on EIA data [4].

Saturations of systems equipped with the different conservation measures are given in **Table 6**.

Efficiencies

The efficiency of a distribution system is determined by the heat loss from the pipes to the surroundings and the electricity used by the circulation-system pumps. Table 6 presents such properties. Typical electricity consumption for a pump is assumed to be 1.5 - 2 kW/HP. Pump controls reduce the electricity use in proportion to the ratio of unused hours to total hours. Heat loss is proportional to pipe diameter and length.

Costs

Distribution system costs include pipe and pump costs. Pipe costs are a function of pipe length and material. Pump costs are a function of the pump size. Because distributed systems do not require pumps, only pipe costs are applicable.

Table 4. Market Shares for System Types and Product Classes (1, 2)

Building Type	Centralized System			Distributed System		No Hot-Water Service	Total
	Self-Heating Storage Tank (3)	Tank Heated by Space-Heating Equipment	Tankless Coil Water-Heater	Residential Type Storage System	Point-of-Use Heaters		
Small Office	36%	8%	8%	40% (5)	5% (5)	3%	100%
Large Office	36%	8%	8%	40% (5)	5% (5)	3%	100%
Fast Food Rest.	64%	0%	0%	36%	0%	0%	100%
Sit-Down Rest.	64%	0%	0%	36%	0%	0%	100%
Retail	32%	2%	2%	43%	7%	13%	100%
Grocery	55%	0%	0%	43%	0%	2%	100%
Warehouse	24%	0%	0%	45%	0%	31%	100%
Elementary School	44%	10%	9%	32%	0%	5%	100%
Jr. High/High School	44%	10%	9%	32%	0%	5%	100%
Health	35%	14%	18%	32%	0%	0%	100%
Motel	43%	6%	18%	32%	0%	1%	100%
Hotel	43%	6%	18%	32%	0%	1%	100%
Other							
Parking Garage	41% (4)	0% (4)	0% (4)	15% (4)	0% (4)	44%	100%
Public Assembly	45%	4%	4%	42%	0%	5%	100%
Public Order &Safety	74%	0%	0%	24%	0%	2%	100%
Religious Worship	47%	0%	0%	43%	0%	10%	100%
Miscellaneous	44%	0%	0%	45%	0%	11%	100%
Vacant	21%	0%	0%	33%	0%	46%	100%

(1) Shares are percent of floor area served by a product class.

(2) Source: EIA [6]. At the time this table was created, 1992 CBECS data was not available electronically. Therefore, we assumed that the market shares for small and large offices were the same as that of the office category published in the hard copy of 1992 CBECS; the same is true for restaurants, schools, and lodging.

(3) This class includes tanks heated by separate but dedicated heaters.

(4) Data based on floor area were withheld in EIA [6] because Relative Standard Error was greater than 50% or sample size was small. The shares are estimated using estimates of the numbers of buildings in each category as opposed to the floor area in each category.

(5) According to EIA [6], 2% of office floor area is served by unspecified plant types that are compatible with distributed systems. In this report, this 2% is spread over the other plant types compatible with distributed systems in proportion to the size of their shares.

Table 5. Data for Building Prototypes

Building Type	Floor Area (1) (1000 ft2)	Number of Floors (1)	Centralized System Pipe Length (2) (ft)	Centralized System Pipe Length (2) (ft/1000 ft2)	Point-of-use System Pipe Length (3) (ft/1000 ft2)
Small Office	6	1	155	26	2
Large Office	95	6	352	4	1
Fast Food Rest.	5.2	1	144	28	2
Sit-Down Rest.	2.5	1	100	40	4
Large Retail	80	6	331	4	1
Small Retail	6.4	2	133	21	3
Grocery	21.3	1	292	14	0
Warehouse	14	1	237	17	1
School	45	2	320	7	0
Health	72	6	319	4	1
Motel	11	2	168	15	2
Hotel	142	6	408	3	0
Other	(4)	(4)	237 (4)	17 (4)	1 (4)

(1) Source: Sezgen et al. [3].

(2) Hot-water pipe length is assumed to be a function of the floor area and number of floors:

Pipe Length = 2 * { Square Root(Floor Area/Floor) + 10 * (Number of Floors-1) }

This is based on the assumption that hot-water pipes (supply and return) would run along the length and the height of the building.

(3) Hot-water pipe length of 10 ft is assumed per floor.

(4) We did not develop prototypes for the building types under the Other category. The most important building types in the Other category are public assembly buildings and garages. We use the values for warehouses for the Other category.

Table 6. Distribution System Data

	Option Number	Heat Loss	Electricity Use	Cost (2) 1992$	Saturation (1) New	Saturation (1) Stock
Centralized Systems						
Baseline	0	300 Btu per inch of pipe diameter per ft per ΔT (°F) per month	1.5 - 2 kW/HP	Pump: 135 (1/40hp,3/4") to 615 (1/6hp, 2") Pipes: Copper: 5.50 (3/4") to 12.50 (2") per lineal ft Steel: 6.25 (3/4") to 12.00 (2") per lineal ft	10%	10%
0 + Insulation	1	100 Btu per inch of pipe diameter per ft per ΔT (°F) per month	1.5 - 2 kW/HP	4.00 - 5.00 per lineal foot for 3/4" - 2" pipe	70%	70%
1 + Timer for Pump Controls	2	100 Btu per inch of pipe diameter per ft per ΔT (°F) per month times the fraction of hours used. Varies by building type.	1.5 - 2 kW/HP times the fraction of hours used. Varies by building type.	200 (new) and 400 (retrofit) per building for controls	20%	20%
Total					100%	100%
Distributed Systems						
Baseline	0	300 Btu per inch of pipe diameter per ft per ΔT (°F) per month times the fraction of hours used	None	Pipes: Copper: 5.50 (3/4") to 12.50 (2") per lineal ft Steel: 6.25 (3/4") to 12.00 (2") per lineal ft	100%	100%
0 + Insulation	1	100 Btu per inch of pipe diameter per ft per ΔT (°F) per month times the fraction of hours used	None	4.00 - 5.00 per lineal ft for 3/4" - 2" pipe	0%	0%
Total					100%	100%

(1) Estimate.

(2) Source: EPRI [7]. 1990 dollars were converted to 1992 dollars using a factor of 1.073.

5. WATER-HEATING PLANT TECHNOLOGIES

At the most basic level, water-heating plant types are categorized as those that are compatible with centralized systems and those that are compatible with distributed systems. Plant types that go with centralized systems are self-heating storage tank systems, tanks heated by space-heating equipment and tankless coil water heaters. Plant types that go with distributed systems are the residential-type storage systems and point-of-use water heaters. There may be cases where residential-type storage systems are used in a centralized system but the market share for such applications is low. **Tables 7 through 11** present the cost, efficiency, saturation, and service life data for the above plant types. These tables include design options with additional measures when applicable and/or important. Each table covers equipment powered by electricity, natural gas, and fuel oil.

Self-Heating Storage Tanks

The options for self-heating storage tanks presented in Table 7 include models that were available before 1994 and the efficient models that meet the 1992 EPACT requirements.

Electric storage-type water heaters are well suited for thermal storage types of applications. The water can be heated during off-peak hours and stored until the time of use. The efficiency of such equipment can be further increased by increasing the insulation. Since the top and bottom of an electrically-heated tank can also be insulated, the standby losses of such tanks are lower than for tanks heated by gas or fuel oil. The cost of a commercial-size electric storage-type water heater is higher than the cost of a residential-type water heater because of code requirements and the limited market for such equipment.

Heat pump water heaters are generally two to three times more efficient than conventional electric water heaters when the heat extraction at the evaporator is not put to use in a cooling application. If the operation of the heat-pump water heater coincides with some cooling load, and if the same equipment is used for space cooling, then the resulting efficiency will be even higher – the coefficient of performance (COP) may reach about five for high-temperature water heating and six for low-temperature water heating. There are even more efficient heat-pump water heating technologies that are not yet widely available. Nevertheless, these are included in Table 7 for reference.

Natural gas and oil-fired storage tanks are generally insulated at the sides and the top (except for the flue exit). The burner is located at the bottom of the tank. Heat is transferred to the water from the bottom of the tank and also from the flues that run up through the middle of the tank. Natural gas self-heating storage tanks are categorized in this report by three efficiency levels. Level 1 is the baseline where the models sold prior to 1994 are covered. Level 2 is for equipment equipped with spark ignition, active flue damper, and more insulation. Spark ignition eliminates an energy-consuming standing pilot. Active flue dampers minimize off-cycle energy losses by reducing the convection losses through the flue during unused periods. Level 3 includes a condensing combustion system where the heat rejection by the flue gases is reduced by recovering latent heat of vaporization. Fuel-oil self-heating storage tanks available on the market since 1994 are standard-efficiency models that include insulation.

Sizes for self-heating storage type water heaters are specified by the tank volume and the fuel input rate. To a certain extent, these attributes can be specified independently from one another depending on the nature of the hot water demand in the building. Vendors provide a wide range of choices for the combinations of volume and fuel input rate.

Table 7. Self-Heating Storage Tank / Centralized System

Water-Heating Equipment	Option Number	Size	Annual Efficiency % (1)	Recovery Efficiency %	Cost 1992 $	Service Life	Saturation in 1992 (2) New	Saturation in 1992 (2) Stock
Electricity								
Baseline	0	6-4500 Gallons up to 750 kW	76	100	not applicable	15	(4)	26%
Efficient Models	1	Same as Baseline	85 - 95	100	5-10 per Gallon Storage plus 50-100 per kW Input	15	43%	17%
Water Heater Heat Pump (WH/HP)	2	10-500 kBtu/h Output 1-50 kW Input	180-320 Water Heating 260-380 Water Preheating (8)	200 - 400 300 - 500	70-140 per kBtu/h	15	0%	0%
Multi-pressure WH/HP	3	(3)	350	420	(3)	(3)	0%	0%
Advanced Multi-pressure WH/HP	4	(3)	580	700	(3)	(3)	0%	0%
Natural Gas								
Baseline	0	40-4500 gallons 40-6400 kBtu/h Input	50-60	75 - 85	not applicable	15	(4)	47%
Spark Ignition plus Active Flue Damper plus Insulation (5)	1	Same as Baseline	65-75	75 - 85	5-10 per Gallon Storage plus 5-9 per kBtu/h Input	14	52%	5%
Condensing Combustion System	2	Same as Baseline	75-85	94	10 per Gallon Storage plus 12 per kBtu/h Input	14	1%	1%
Fuel Oil								
Baseline	0	40-4500 gallons 40-6400 kBtu/h Input	55-65 (6)	75 - 85	not applicable	15	(4)	4%
Standard-Efficient Models (5)	1	Same as Baseline	65-75	75 -85	5-10 per Gallon Storage plus 6-10 per kBtu/h Input (7)	14	4%	0%
Total							100%	100%

Source: EPRI [8] unless specified below.

(1) Annual efficiency includes the effects of recovery efficiency and standby losses. The range is due to the varying standby loss under differing use patterns.

(2) Source: EIA [6] for the market shares of equipment with common fuel type. Saturations within groups of equipment with common fuel are from: the 1995 NEMS Commercial Model Technologies Database for electric models, and ADL [9] for fuel-fired models.

(3) Not yet commercially available. Models expected to come in the market starting 1998-2000.

(4) These models were not available after 1993 due to EPACT 1992 (19).

(5) These models meet the EPACT 92 requirements with a recovery efficiency of 78% and Standby loss of about 1.3%/hour for a 2000 gallon unit (up to 4.2%/hour for a 40-gallon unit).

(6) Oil-burning units are more efficient than gas-burning units because of differences in standby losses. These differences are due to pilot lights in gas units and restricted air flow through oil units.

(7) Oil burning units are about 5-10% more expensive than gas burning units not counting the fuel tank cost (which is probably paid for by the main boiler installation).

(8) The COP is a function of the temperature lift – when the desired water temperatures are low, COPs are higher.

Table 8. Tank Heated by Space-Heating Equipment / Centralized System

Water-Heating Equipment	Option Number	Size	Annual Efficiency % (1)	Recovery Efficiency %	Cost 1992 $	Service Life	Saturation in 1992 (2) New (4)	Saturation in 1992 (2) Stock
Electricity								
Baseline	0	40-475 Gallons 40-5000 kBtu/h Heat Exchange Rating	70-90 Heating Season 40-60 Cooling Season (3)	100	5-10 per Gallon 1-2 per kBtu/h of Heat Exchange	20	16%	16%
Natural Gas								
Baseline	0	40-475 Gallons 40-5000 kBtu/h Heat Exchange Rating	60-80 Heating Season 30-50 Cooling Season (3)	75 - 85	5-10 per Gallon 1-2 per kBtu/h of Heat Exchange	20	53%	53%
Fuel Oil								
Baseline	0	40-475 Gallons 40-5000 kBtu/h Heat Exchange Rating	60-80 Heating Season 30-50 Cooling Season (3)	75 - 85	5-10 per Gallon 1-2 per kBtu/h of Heat Exchange	20	30%	30%
Total							100%	100%

Source: EPRI [8] unless specified below.

(1) Annual efficiency includes the effects of recovery efficiency and standby losses. The range is due to the varying standby loss under differing use patterns.

(2) Source: EIA [6] for the market shares of equipment with common fuel type.

(3) Assuming there is not any space heating during the cooling season.

(4) We assumed saturations in new floor-stock to be same as in existing floor-stock for lack of data.

Table 9. Tankless Coil Water Heater / Centralized System

Water-Heating Equipment	Option Number	Size	Annual Efficiency % (1)	Recovery Efficiency %	Cost 1992 $	Service Life	Saturation in 1992 (2) New (4)	Saturation in 1992 (2) Stock
Electricity								
Baseline	0	40-2500 kBtu/h Heat Exchange Rating	60-80 Heating Season 30-50 Cooling Season (3)	100	1-2 per kBtu/h of Heat Exchange	20	25%	25%
Natural Gas								
Baseline	0	40-2500 kBtu/h Heat Exchange Rating	50-70 Heating Season 20-40 Cooling Season (3)	75 - 85	1-2 per kBtu/h of Heat Exchange	20	67%	67%
Fuel Oil								
Baseline	0	40-2500 kBtu/h Heat Exchange Rating	50-70 Heating Season 20-40 Cooling Season (3)	75 - 85	1-2 per kBtu/h of Heat Exchange	20	8%	8%
Total							100%	100%

Source: EPRI [8] unless specified below.

(1) Annual efficiency includes the effects of recovery efficiency and standby losses. The range is due to the varying standby loss under differing use patterns.

(2) Source: EIA [6] for the market shares of equipment with common fuel type.

(3) Assuming there is not any space heating during the cooling season.

(4) We assumed saturations in new floor-stock to be same as in existing floor-stock for lack of data.

Table 10. Residential Type Storage System / Distributed System

Water-Heating Equipment	Option Number	Size	Annual Efficiency % (1)	Recovery Efficiency % (1)	Cost 1992 $	Service Life (yrs)	Saturation (2) New 1991	Saturation (2) Stock 1990
Electricity								
Stock in 1990	All models	52 Gallons	83.0%		Not applicable	1 to 15	0%	51%
Baseline	0	52 Gallons	86.2%	100.0%	265	5 to 30	16%	
0+Reduce Heat Leaks	1	52 Gallons	87.4%	100.0%	268	5 to 30	17%	
1+Heat Traps	2	52 Gallons	89.6%	100.0%	272	5 to 30	18%	
2+R-25 Insulation	3	52 Gallons	92.7%	100.0%	307	5 to 30	0%	
2 + Add On Heat Pump	4	52 Gallons	177.2%	200%-400%	627	5 to 30	0%	
4 + R-25 Insulation	5	52 Gallons	189.6%	200%-400%	660	5 to 30	0%	
2 + Integral Heat Pump	6	52 Gallons	253.8%	200%-400%	1100	5 to 30	0%	
Natural Gas								
Stock in 1990	All models	40 Gallons	50.0%		Not applicable	1 to 15	0%	48%
Baseline	0	40 Gallons	54.4%	76.0%	282	5 to 30	16%	
0 + Heat Traps	1	40 Gallons	55.1%	76.0%	287	5 to 30	13%	
1 + Reduce Heat Leaks	2	40 Gallons	55.4%	76.0%	289	5 to 30	13%	
2 + R-16 Insulation	3	40 Gallons	57.0%	76.0%	306	5 to 30	6%	
3 + R-25 Insulation	4	40 Gallons	57.6%	76.0%	341	5 to 30	0%	
3 + IID w/Flue Damper	5	40 Gallons	64.1%	76.0%	390	5 to 30	0%	
0 + Condense Flue Gases	6	40 Gallons	88.1%	94.0%	1183	5 to 30	0%	
Fuel Oil								
Stock in 1990	All models	32 Gallons	49.0%		Not applicable	1 to 15	0%	1%
Baseline	0	32 Gallons	52.9%	73.0%	725	5 to 30	1%	
0 + 1 in Foam	1	32 Gallons	58.3%	73.0%	739	5 to 30	0%	
1 + Heat Traps	2	32 Gallons	59.7%	73.0%	745	5 to 30	0%	
2 + Reduce Heat Leaks	3	32 Gallons	60.3%	73.0%	758	5 to 30	0%	
3 + 2 in Foam	4	32 Gallons	63.0%	73.0%	786	5 to 30	0%	
4 + Multiple Flues	5	32 Gallons	70.1%	80.0%	920	5 to 30	0%	
Total							100%	100%

Source: DOE [10] and Hwang et al. [11].

(1) Annual efficiency includes the effects of recovery efficiency and standby losses.

(2) Source: EIA [6] for the market shares of equipment with common fuel type.

Table 11. Point of Use Water Heater / Distributed System

Water-Heating Equipment	Option Number	Size	Annual Efficiency % (1)	Recovery Efficiency %	Cost 1992 $	Service Life	Saturation in 1992 (2)	
							New (4)	Stock
Electricity								
Baseline	0	2-10 gallons storage up to 18 kW	95 - 99	100	50-100 per kW input	15	52%	52%
Natural Gas								
Baseline	0	100-2500 kBtu/h Input	75-85	75-85	7-14 per kBtu/h Input	15	48%	48%
Fuel Oil								
Baseline	0	100-2500 kBtu/h Input	75-85	75-85	7-14 per kBtu/h Input	15	0%	0%
Total							100%	100%

Source: EPRI [8] unless specified below.
(1) Annual efficiency is mainly recovery efficiency.
(2) Source: EIA [6] for the market shares of equipment with common fuel type.
The shares here are unreliable because CBECS 1992 withheld figures for the floor area served by
electricity and oil fired point-of-use water heaters due to a large Relative Standard Error.
We developed the shares here based on the number of buildings served by such equipment rather than using the total areas of these buildings.
(4) We assumed saturations in new floor-stock to be same as in existing floor-stock for lack of data.

Annual efficiencies presented in Table 7 account for both the recovery efficiency, which is the efficiency of conversion from fuel to heat energy and the standby losses from the tank. Therefore, given the annual hot water load, these figures can be used to convert heat load to site (final) energy. **Recovery efficiencies** are also presented. **Costs** are naturally a function of the tank size and the heat input rate. The incremental costs for conservation measures are also presented in Table 7. The **Service life** of a commercial storage-type water heater is about 15 years. In Table 7, **Saturation** indicates the share of the total area served by self-heating storage-type water heaters that is served by the particular option represented in that row.

In this report, the category of "Self-Heating Storage Tanks" includes the tanks that have separate but dedicated heaters.

Tanks Heated by Space-Heating Equipment

Boilers that are mainly for space heating are often used to heat the water heating storage tank through a heat exchanger inserted in the storage tank. The high temperature boiler water (typically 180°F) warms up the water in the storage tank. During the space heating season, this system is quite effective. However, during cooling seasons, the boiler that is designed for the high combined load of space heating and water heating has to be run only for the water heating end use and this can bring the seasonal efficiency of this type of equipment down to about 30%. Table 8 presents the sizes, efficiencies, costs, service lives, and saturations for tanks heated by space-heating boilers. **Size** in this table is the heat exchange rate as opposed to the fuel input rate. **Annual efficiency** includes the conversion efficiency from fuel to heat (the efficiency of the boiler). **Recovery efficiencies** are also presented. **Costs** account for only the heat exchangers and tanks, and do not include the boiler. **Service lives** for such equipment are around 20 years. **Saturations** are percentages of total floor area served by tanks heated by space-heating boilers that are served by the particular option represented in that row.

Tankless Coil Water Heaters

Tankless coil water heaters are quite similar to the previous category (tanks heated by space-heating equipment). In this case, there is no storage and the system resembles an instantaneous water heater requiring the operation of the space heating boiler any time there is a demand for hot water. This type of operation can be quite inefficient, especially during the cooling season. As can be seen from Table 9, this class of equipment is generally less efficient than similar equipment with storage. The efficiency for this tankless class of equipment can be improved by the use of a shell-and-tube-type heat exchanger. The thermal capacity of the high-temperature boiler water in the shell reduces the need to fire the boiler at each hot water draw. **Size** in this table is the heat exchange rate as opposed to the fuel input rate. **Annual efficiency** includes the conversion efficiency from fuel to heat (the efficiency of the boiler). **Recovery efficiency** covers the steady-state efficiency for the boiler. **Costs** account for only the heat exchangers and tanks, and do not include the boiler. **Service lives** for such equipment are around 20 years. **Saturations** are percentages of the total floor area served by tankless coil water heaters heated by space-heating boilers that are served by the particular option represented in that row.

Residential-Type Storage Systems

Residential water heaters are not the main subject of this report. However, due to the wide-spread use of such equipment in the commercial sector, they are included in the data set. This section covers the electric, gas, and oil-fired residential-type storage systems. For each case, several design options are presented. These options include varying combinations of insulation, heat traps, and flue dampers. The attributes of residential water heaters are presented in Table 10. The data in this table is drawn from DOE [10] and Hwang et al. [11].

Conventional electric storage water heaters have resistance heating elements inserted in the tank, which makes the conversion from electricity to heat very efficient. Also, since the entire tank is insulated, standby losses are very low. Electric water heaters are usually larger in size than gas/oil-fired storage water heaters since the rate of recovery is lower. The design options for the electric storage water heaters are: (1) models with reduced heat leaks (jacket to feed-through thermal bridges eliminated, voids and imperfections in the insulation eliminated, pressure valve insulated, plastic drain pipes); (2) models with heat traps (small anti-convection devices put on the inlet and outlet connections to the water heater); and (3) additional insulation.

Two other design options in the electrical storage category are related to heat pumps. These are (1) add-on heat pumps and (2) integrated heat pumps. In the former, a separate heat pump is attached to an existing water heater. The latter is a factory-built heat-pump water heater. As would be expected, heat-pump water heaters are two to three times more efficient than resistance water heaters.

Gas and oil water heaters usually have the burner under the tank. The flue extends up through the middle of the tank. Recovery efficiencies are low and standby losses are high with this equipment. The design options covered for gas/oil storage water heaters are (1) heat traps; (2) reduced heat leaks; (3) insulation; (4) flue dampers; (5) multiple flues; and (6) models that condense flue gases. Oil-fired water heaters differ from gas-fired water heaters in some ways. First, the burner is equipped with an oil pump and a blower that mixes oil with air for combustion. Second, oil-fired burners are of larger capacity; therefore, the storage tank volumes are often smaller.

Annual efficiencies presented in Table 10 cover both the recovery efficiency, which is the efficiency of conversion from fuel to heat energy, and also the standby losses from the tank. Therefore, given the annual hot water load, these figures can be used to convert heat load to site energy. **Recovery efficiencies** are also presented. **Costs** are for the complete design option as opposed to incremental costs over the base case cost. **Service lives** of commercial storage type water heaters may range from five to 30 years. A uniform distribution over this range can be used. **Saturations** presented in Table 10 are percents of the total area served by residential storage water heaters that are served by the particular option represented in that row.

Point-of-Use Water Heaters

Point-of-use water heaters generally do not have any storage capacity. The water is heated when it is being drawn through the heater. Since there are no standby losses, annual efficiencies are quite high. The drawback of these systems is the large input capacity required to meet peak load. Table 11 presents the sizes, efficiencies, costs, service life, and saturations for this class of water heaters.

6. HOW TO UTILIZE AND EXPAND PLANT EFFICIENCY DATA IN THE FUTURE

In this report, annual plant efficiencies bridge the gap between hot water demand and the energy used for generating hot water. Nevertheless, recovery efficiencies are also supplied because efficiency technologies may affect either the standby losses or the recovery efficiency separately. In such cases, one can use the data on recovery efficiency and Equations 1 and 2 below to calculate the impact of an improvement in standby loss or recovery efficiency on annual efficiency (sometimes defined as the energy factor). These relationships are also presented in Koomey et al. [12].

$$\text{Energy Factor} = \frac{\text{Energy content of hot water delivered}}{\text{Total energy used to heat the water}} \qquad (1)$$

The total energy used to heat the water is defined as:

$$\text{Total Energy} = \frac{[\text{Energy content of hot water delivered + Standby losses}]}{\text{Recovery efficiency}} \qquad (2)$$

7. COMPARING TOTAL WATER USE AND HOT WATER USE IN THE COMMERCIAL SECTOR

From the data developed in Table 2, it is possible to estimate the annual hot water consumption in the commercial sector. **Table 12** presents the hot water use in gallons for the major building types. The annual hot water use for the commercial sector is about 0.67 trillion gallons. The total water use for the commercial sector is estimated to be about 3 trillion gallons in U.S. Department of the Interior (1993). Thus, about 22% of the water used in the commercial sector is heated.

8. CONCLUSIONS

Because energy consumption is increasing so rapidly in the commercial sector, it is important for energy analysts to have access to commercial energy end-use forecasting models that disaggregate energy consumption not only by fuel type, end use, and building type, but also by specific technology. In this report, we describe our development and refinement of a base-year data set characterizing water heating technologies in commercial buildings.[1] This data set will be useful to forecasters and policy analysts for evaluating commercial-sector policies and programs that target water-heating technologies.

The data presented in this report will be refined and improved as more commercial-sector data become available. Although there is little data now available regarding the market shares of specific technologies, we expect future commercial-sector surveys to respond to this lack by including questions that will allow the better characterization of the commercial sector.

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[1] In addition to developing a data set for water heating technologies, we have developed data sets characterizing lighting, refrigeration, office equipment, and space conditioning technologies. These characterization studies are published as LBNL reports [15, 16, 17, 18].

Table 12. Annual Water and Hot-Water Use in the Commercial Sector, 1990

Building Type	Annual Gallons of Hot Water per 1000ft2 (1)	Floor Area (million ft2) (2)	Annual Gallons of Hot Water (million gallons)	Annual Gallons of Water (3) (million gallons)
Small Office	568	5,060	2,875	
Large Office	568	6,980	3,966	
Fast Food Rest.	200,469	595	119,279	
Sit-Down Rest.	297,840	595	177,215	
Retail	730	12,650	9,235	
Grocery	777	810	629	
Warehouse	240	9,480	2,273	
Elementary School	1,143	2,696	3,081	
Jr. High/High School/College (4)	3,429	5,473	18,765	
Health	125,286	2,130	266,859	
Motel	36,274	1,219	44,218	
Hotel	11,242	1,717	19,302	
Other	175	14,865	2,596	
TOTAL		64,270	670,293	3,027,923

(1) Calculated from Table 2.

(2) Based on EIA [13]. Divisions within lodging, educational building and restaurant types are based on EIA [4].

(3) Source: U.S. Department of the Interior [14]. Total covers the whole commercial floor area.

(4) Does not include dormitories in colleges.

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