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RESIDENTIAL ELECTRIC AND GAS WATER HEATERS

by

Ebrahim Farahan

CES
INTEGRATED COMMUNITY ENERGY SYSTEMS

TECHNOLOGY EVALUATIONS

Prepared by:

Oak Ridge National Laboratory
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August 1977

Prepared for

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Oak Ridge, Tennessee 37830
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The four E's of the cover logo embody the goals of the Community Systems Program of the Energy Research and Development Administration, ERDA, namely:

- to conserve *Energy*;
- to preserve the *Environment*; and
- to achieve *Economy*
- in the design and operation of human settlements (*Ekistics*).

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FOREWORD

The Community Systems Program of the Division of Buildings and Community Systems, Office of Energy Conservation, of the United States Energy Research and Development Administration (ERDA),* is concerned with conserving energy and scarce fuels through new methods of satisfying the energy needs of American Communities. These programs are designed to develop innovative ways of combining current, emerging, and advanced technologies into Integrated Community Energy Systems (ICES) that could furnish any, or all, of the energy using services of a community. The key goals of the Community System Program then, are to identify, evaluate, develop, demonstrate, and deploy energy systems and community designs that will optimally meet the needs of various communities.

The overall Community Systems effort is divided into three main areas. They are: (a) Integrated Systems, (b) Community Design, and (c) Commercialization. The *Integrated Systems* work is intended to develop the technology component and subsystem data base, system analysis methodology, and evaluations of various system conceptual designs which will help those interested in applying integrated systems to communities. Also included in this program is an active participation in demonstrations of ICES. The *Community Design* effort is designed to develop concepts, tools, and methodologies that relate urban form and energy utilization. This may then be used to optimize the design and operation of community energy systems. *Commercialization* activities will provide data and develop strategies to accelerate the acceptance and implementation of community energy systems and energy-conserving community designs.

This report, prepared by Oak Ridge National Laboratory, is part of a series of Technology Evaluations of the performance and costs of components and subsystems which may be included in community energy systems and is part of the Integrated Systems effort. The reports are intended to provide sufficient data on current, emerging and advanced technologies so that they may be used by consulting engineers, architect/engineers, planners, developers, and others in the development of conceptual designs for community energy systems. Further, sufficient detail is provided so that calculational models of each component may be devised for use in computer codes for the design of Integrated Systems. Another task of the Technology Evaluation activity is

*Effective October 1, 1977, U.S. ERDA became U.S. Department of Energy (DOE).

to devise calculational models which will provide part load performance and costs of components suitable for use as subroutines in the computer codes being developed to analyze community energy systems. These will be published as supplements to the main Technology Evaluation reports.

It should be noted that an extensive data base already exists in technology evaluation studies completed by Oak Ridge National Laboratory (ORNL) for the Modular Integrated Utility System (MIUS) Program sponsored by the Department of Housing and Urban Development (HUD). These studies, however, were limited in that they were: (a) designed to characterize mainly off-the-shelf technologies up to 1973, (b) size limited to meet community limitations, (c) not designed to augment the development of computer subroutines, (d) intended for use as general information for city officials and keyed to residential communities, and (e) designed specifically for HUD-MIUS needs. The present documents are founded on the ORNL data base but are more technically oriented and are designed to be upgraded periodically to reflect changes in current, emerging, and advanced technologies. Further, they will address the complete range of component sizes and their application to residential, commercial, light industrial, and institutional communities. The overall intent of these documents, however, is not to be a complete documentation of a given technology but will provide sufficient data for conceptual design application by a technically knowledgeable individual.

Data presentation is essentially in two forms. The main report includes a detailed description of the part load performance, capital, operating and maintenance costs, availability, sizes, environmental effects, material and energy balances, and reliability of each component along with appropriate reference material for further study. Also included are concise data sheets which may be removed for filing in a notebook which will be supplied to interested individuals and organizations. The data sheets are colored and are perforated for ease of removal. Thus, the data sheets can be upgraded periodically while the report itself will be updated much less frequently.

Each document was reviewed by several individuals from industry, research and development, utility, and consulting engineering organizations and the resulting reports will, hopefully, be of use to those individuals involved in community energy systems.

ABSTRACT

This report provides performance data for electric and gas-fired residential water heaters. Performance characteristics investigated include: unit full-load, part-load, and overall efficiencies and detailed examination of standby losses. Also included are brief discussions of energy-conserving options, such as lowering thermostat settings, increasing insulation thickness, and reducing pilot rate.

The information supplied here is intended to provide necessary data for the ICES Systems Engineering Program.

TECHNOLOGY EVALUATION SUMMARY SHEET OF

RESIDENTIAL ELECTRIC AND GAS WATER HEATERS

By: Ebrahim Farahan, ORNL August, 1977

INTEGRATED COMMUNITY ENERGY SYSTEMS

1 INTRODUCTION

This report provides data for the evaluation of lifecycle cost, efficiency, and energy consumption of currently available, storage-type, electric and gas water heaters. Electric heaters have either one or two heating elements; gas-fired heaters are equipped with a main burner and a pilot light. The water temperature is controlled by thermostat settings in either the electric or gas water heater.

2 STANDARD CAPACITIES AND RATINGS

Electric:

Storage tank capacity (gal)	30--100
Dual heating element wattage (minimum) in W/gal	
Upper heating element	30
Lower heating element	20

Gas-fired:

Storage tank capacity (gal)	30 to 100
Main burner input (Btu/h/gal)	1,000

3 PERFORMANCE

Full-load efficiency:

Electric: Efficiency (%) = 104.4 - (0.06) T_0, $120 \leq T_0 \leq 160$ where T_0 = outlet water temperature (°F)

Gas-fired: Essentially constant at 72% for $110 \leq T_0 \leq 180$.

Appliance efficiency over daily operation:

Electric: 80% (see Table 3.4)

Gas-fired: 50% (see Table 3.6)

4 SAFETY REQUIREMENTS

Water heater manufacturers comply with a number of safety codes, including:

1. *Underwriters' Laboratories Code,*
2. *National Electrical Code, and*
3. *National Safety Standards.*

5 ENVIRONMENTAL CONCERNS

Electric: No emissions or noise

Gas : Flue gas emissions as tabulated in Table DS-1.

Table DS-1 Emissions Factors for Natural-Gas Combustion

Pollutants	Domestic and Commercial Heating ($lb/10^6\ ft^3$)
Particulates	5 - 15
Sulfur oxides (SO_x)	0.6
Carbon monoxide (CO)	20
Hydrocarbons (as CH_4)	8
Nitrogen oxides (NO_x)	80 - 120[a]

[a] Use 80 for domestic heating units and 120 for commercial units.

6 COST

The capital cost of water heaters varies significantly among manufacturers. The following analytical expressions for equipment cost vs storage capacity (Q, gal) are recommended for initial estimates or evaluation studies:

$$\text{Water heater cost (electric), } \$ = 153\ (Q/50)^{1.02}\ ,\ 30 \leq Q \leq 100 \qquad \text{(Eq. DS-1)}$$

$$\text{Water heater cost (gas), } \$ = 155\ (Q/40)^{1.1}\ ,\ 30 \leq Q \leq 100 \qquad \text{(Eq. DS-2)}$$

Tables DS-2 and DS-3 show the man hour requirements for installation of electric and gas hot water heaters.

Table DS-2 Manhour Requirements to Install Automatic Electric Water Heaters

Capacity (gal.)	30	40	50	65	80
Erection* Manhours	3.0	3.0	4.0	4.25	

Table DS-3 Manhour Requirements to Install Automatic Gas-Fired Water Heaters

Capacity (gal.)	20	30	40	50	60
Erection* Manhours	4.0	4.0	4.0	5.0	6.0

*Labor includes moving material and equipment 40 ft, uncrating, and finishing.

TECHNOLOGY EVALUATION OF

RESIDENTIAL ELECTRIC AND GAS WATER HEATERS

Prepared by Ebrahim Farahan, ORNL

Date August, 1977

1 INTRODUCTION

1.1 SCOPE

This report is concerned primarily with commercially available, storage-type water heaters for domestic use. The storage capacity of water heaters under consideration ranges from 30 to 100 gal. Included are performance characteristics of both electric and gas-fired heaters and comparisons of energy consumption at different operating conditions as calculated or measured by various investigators. Finally, various options to improve the efficiency of water heaters to reduce energy consumption are discussed.

1.2 PROCESS DESCRIPTION

The basic block diagrams for electric and gas water heaters are illustrated in Figs. 1.1 and 1.2 respectively.

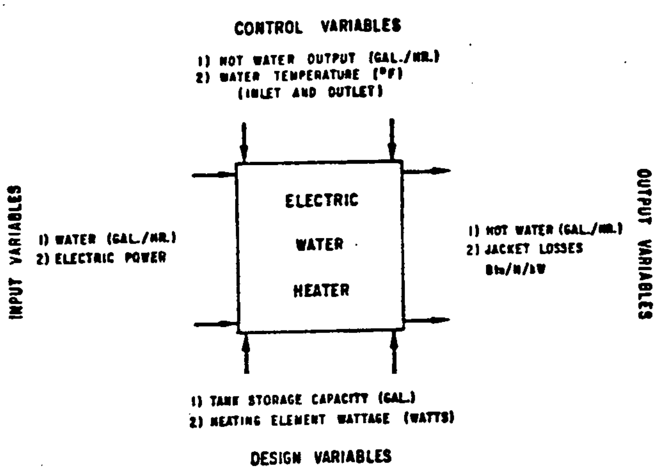

Fig. 1.1 Schematic of Electric Water Heater

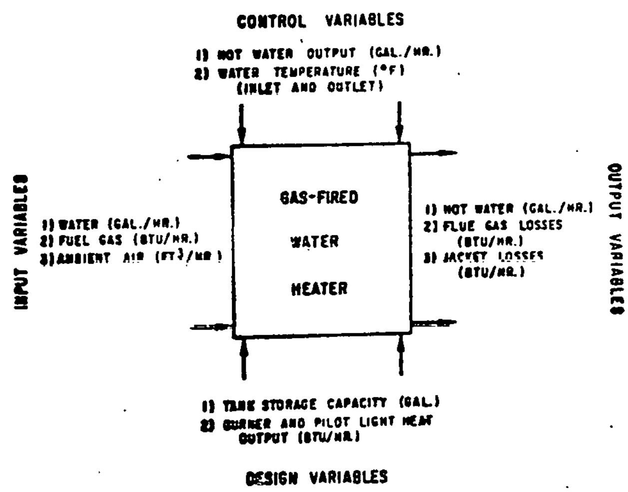

Fig. 1.2 Schematic of Gas Water Heater

In electric water heaters, hot water is generated by submerged heating elements. Generation of hot water in gas water heaters is the result of the combustion process, in which heat is transferred to water through heat-transfer surfaces.

1.3 DESCRIPTION

Standard packaged water heaters consist of a thermally insulated storage tank with cold and hot water connections. A cold water inlet and a hot water outlet are located at the top of the storage tank. The cold water inlet tube extends to the bottom of the reservoir to prevent the incoming cold water from being immediately drawn into the hot water outlet.

The storage tank interior usually is lined with copper or glass to inhibit corrosion. Electric heaters are equipped with a magnesium anode to prevent corrosion of the tank by electrolysis.

1.3.1 Electric

Standard electric water heaters have an immersion heating element at the top of the tank and one at the bottom (Fig. 1.3).

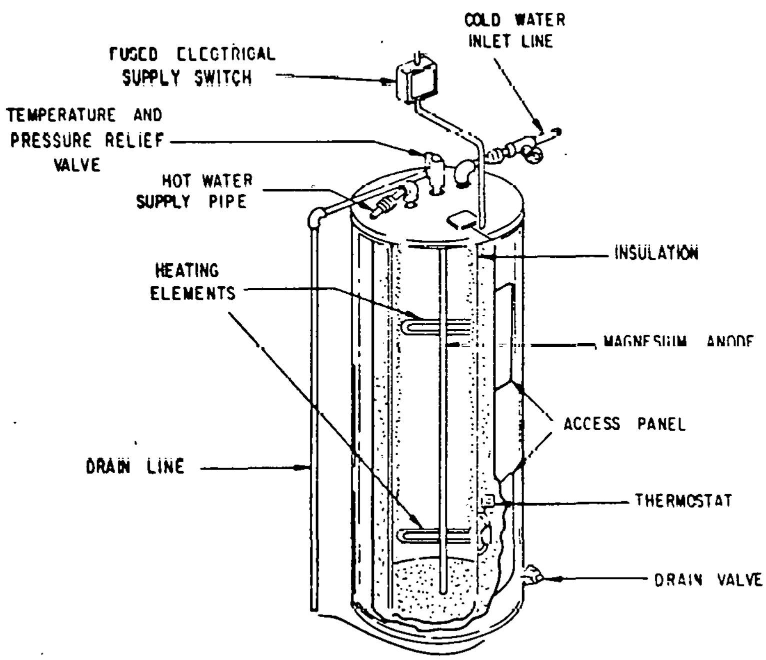

Fig. 1.3 Typical Electric Water Heater

The top element operates after a large water draw and the bottom heating element comes on when the top element thermostat is satisfied during low water usage. The heating elements are customarily interlocked so they would not operate simultaneously.

1.3.2 Gas-Fired

A typical gas-fired water heater (Fig. 1.4) is equipped with a multi-port gas burner similar to a gas range and a pilot which burns continuously. The unit has a safety switch to shut off the gas in the event the pilot fails to burn.

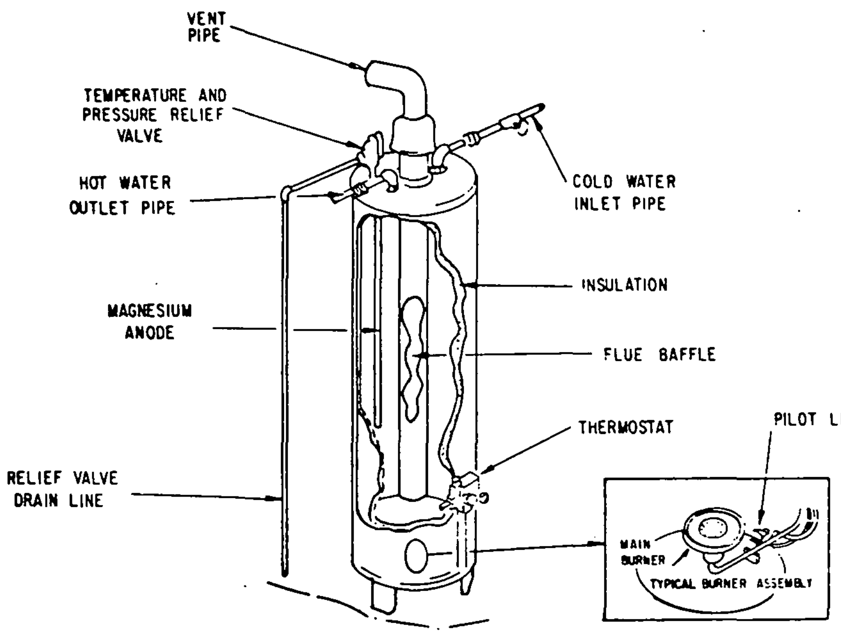

Fig. 1.4 Typical Gas-Fired Water Heater

The heat is transferred to stored water via heat exchange surfaces; i.e., the cone-shaped bottom plate and the flue which is located at the center of the storage tank. The flue is baffled to promote turbulance which in turn increases heat transfer from the flue surface to stored water. Figure 1.4 shows a schematic diagram of a typical gas-fired water heater.

2 STANDARD PRACTICE

2.1 APPLICABLE CODES AND STANDARDS

The applicable codes and standards for electric and gas water heaters are produced and published by American National Standards Institute. Those standards covering household-size electric and gas water heaters are *ANSI - C72 - 1972* and *ANSI - Z21 - 10.1 - 1975*, respectively. The purposes of these standards are twofold: (1) to establish a uniform procedure for determining the performance of water heaters under specified conditions; and (2) to establish minimum requirements. Although compliance with these standards is not mandatory, virtually all manufacturers of these items do comply with the procedures.

2.2 AVAILABLE SIZE RANGES

Automatic storage-type water heaters for residential use range from 30- to 100-gal capacity. Electric water heaters with twin heating elements normally are rated between 4000 and 5500 W, with a minimum power rating of 30 W/gal for the upper unit, and 20 W/gal for lower units.[1]

Residential gas water heaters, as defined by *ANSI - 10.1 - 1975*, have heat inputs of about 75,000 Btu/h, or less.[2] The main burner generally is manufactured with ratings of 1,000 Btu/h (or more) per gallon of tank capacity, and the pilot is designed to burn natural gas at a rate of 700 to 1000 Btu/h.

Tables 2.1 and 2.2, respectively, show typical dimensions of electric and gas water heaters.

Table 2.1 Dimensions and Shipping Weight of Electric Water Heaters[(a)]

Tank capacity (gal)	Diameter (in.)	Height (in.)	Approx. Shipping Weight (lb)
52	20	60	144
80	24	63	188

[(a)] Clearance for piping connections is not included.

Table 2.2 Dimensions and Shipping Weight of Gas Water Heaters[a]

Tank capacity (gal)	Diameter (in.)	Height (in.)	Approx. Shipping Weight (lb)
30	22	60	120
40	24	58	137
50	24	62	166
65	29	57	271
75	29	63	296
100	30	71	365

[a] Clearance for piping connections is not included.

2.2.1 Electrical Requirements

The customary voltage for most electric water heaters is 240 volts with a range from 220 to 248V.

3 MATERIAL AND ENERGY BALANCE

3.1 GENERAL

Three major inputs in a gas-fired water heater are water and a mixture of gas and air for combustion. The outputs are hot water and flue gases. Practically all fossil-fired residential water heaters use gas as fuel. Oil-fired water heaters have not been widely accepted because of difficulties in designing burners at low firing rates and the need for electric ignitors.

The inputs in an electric water heater are electricity and water, and the output is hot water. The design temperature for water heaters ranges from 110° to 170°F; however, there is a trend toward lower temperature settings. The inlet water temperature varies from 40° to 60°F at different locations because of varying geographical and climatical conditions. A list of seasonal water temperatures for major cities in the United States is available in Ref. 3. Figure 3.1 shows the approximate temperature of groundwater from nonthermal wells. This water temperature remains almost constant unless altered by flow through the distribution piping.[4]

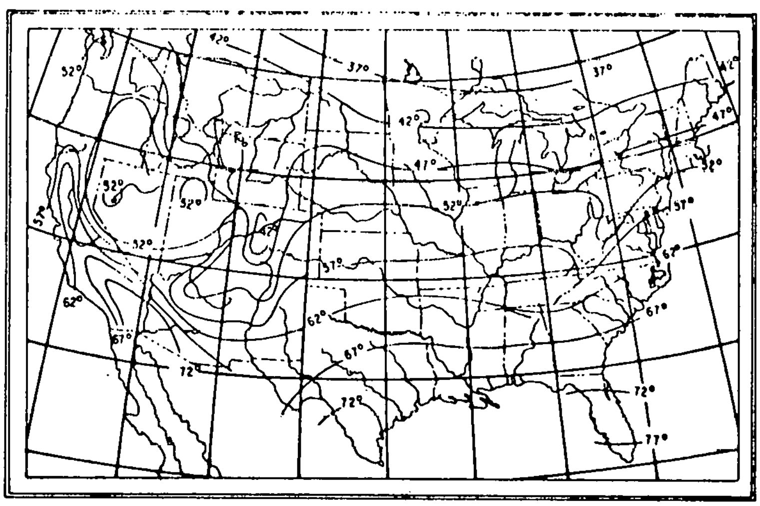

Fig. 3.1 Approximate Temperature of Water from Nonthermal Wells at Depths of 30 -- 60 ft

The amount of energy consumed by a water heater is directly related to the amount of hot water drawn, the ambient temperature, and the temperature difference between inlet water to the tank and outlet hot water.

Figures 3.2 and 3.3 show schematically the energy balance for gas and electric water heaters, respectively,[5] for a daily consumption of 71.4 gal of hot water with an 85°F temperature rise. The pattern at which this

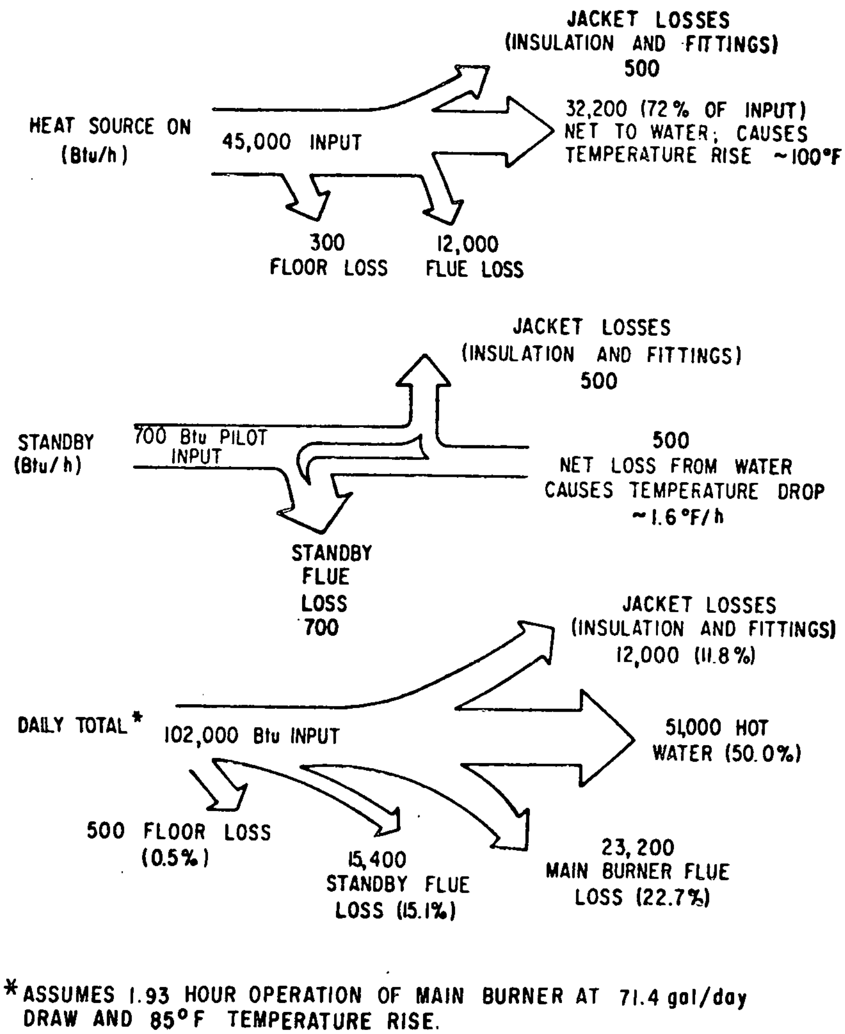

Fig. 3.2 Energy Balance of Gas Water Heater

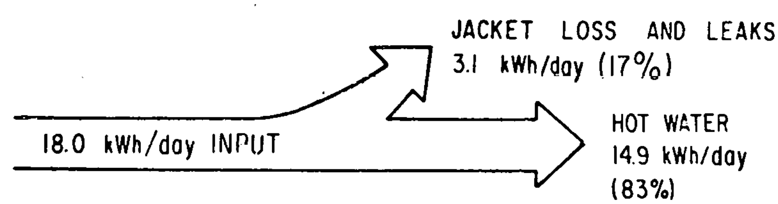

Fig. 3.3 Energy Balance of Electric Water Heater

hot water is utilized is shown in Table 3.1.[5]

Table 3.1 Typical Hot Water Use by Function

Function:	Shower or Bath	Sink[(a)]	Automatic Dishwasher	Clothes Washer Hot Cycle	Clothes Washer Warm Cycle
Volume water per event (gal)	30	1.5	15	50	50
Temperature (°F)	105	105	145	130 wash 100 rinse	100 wash 80 rinse
Volume hot water (145°F) per event (gal)	15	0.8	15[(b)]	24[(b)]	11[(b)]
Rate of draw of hot water (gal/min)	3	2	1.5	8	4
Duration of draw (min)	5	0.4	10[(b)]	3[(b)]	3[(b)]

(a) Sink for hands, face shaving, food preparation, hand dishwashing

(b) Total overall draws in the cycle

3.2 ELECTRIC WATER HEATER

3.2.1 Full-Load Efficiency of Electric Water Heater

At low thermostat settings and during the removal of hot water, the full-load efficiency of an electric water heater approaches 100%. Heat loss through the jacket at lower water temperature is small compared to the power input. However, as the temperature of the water increases, this heat loss also will increase and result in lower efficiencies. Table 3.2 shows the full-load efficiency of a 65-gal and a 33-gal electric water heater at various thermostat settings.[6]

Table 3.2 Full-Load Efficiency of 66-Gal Electric Water Heater[(a)]

Water Temperature (T_0, °F)	Maximum Load (gal/h)	Efficiency[(b)] (%)
110	30.5	97.8
130	22.1	96.6
150	17.2	95.4
170	14.1	94.2

(a) Incoming water temperature = 55°F.

(b) Efficiency (%) = 104.4 - (0.06) T_0, $110 \leq T_0 \leq 170$

3.2.2 Appliance Efficiency

The appliance efficiency is defined as the ratio of useful heat delivered to total energy consumed directly by the appliance.[1]

$$N = \frac{Q_{use}}{Q_{di}} \quad \text{(Eq. 3.1)}$$

where:

$$Q_{use} = \dot{M} C_{pw} (T_w - T_{wi}) \quad \text{(Eq. 3.2)}$$

$\dot{M}$ = water flowrate, lbm/h

C_{pw} = Specific heat of water, Btu/lbm°F

T_w = Temperature of delivered water, °F

T_{wi} = Temperature of inlet water, °F

$Q_{di} = Q_{loss} + Q_{useful}$

Q_{loss} = Standby loss, Btu/h

Equation 3.2 indicates that at a daily demand of zero ($\dot{M}$=0) the appliance efficiency is zero, regardless of the temperature differential ($T_w - T_{wi}$) between inlet and outlet. However, this efficiency increases as the water demand increases, and at high draw rates the appliance efficiency approaches full-load efficiency. The increase of appliance efficiency with hot water withdrawal is illustrated in Fig. 3.4 for two electric water heaters at water delivery temperature of 110 and 150°F. The curves represent calculated data using Eq. 3.1 and standby losses from Sec. 3.2.4.

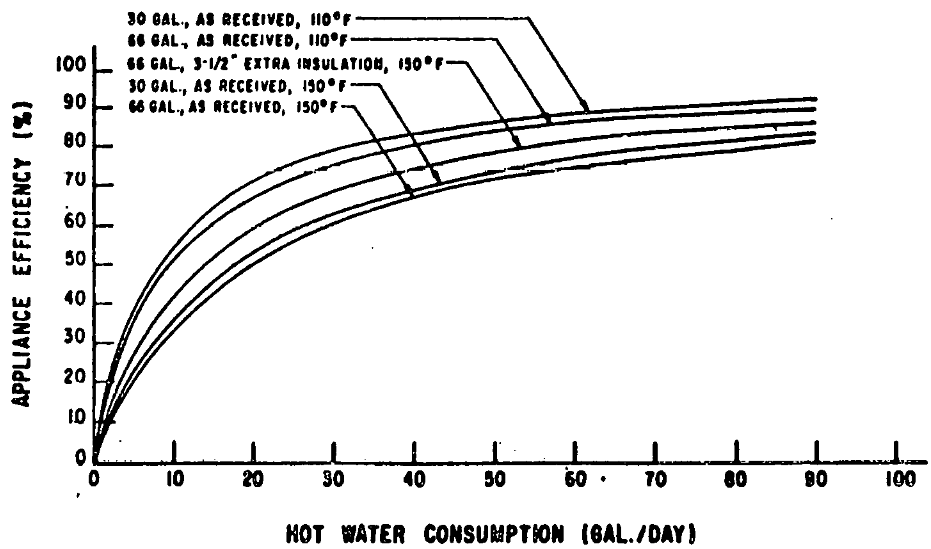

Fig. 3.4 Appliance Efficiency of Residential Electric Water Heater Vs K

3.2.3 Overall Efficiency

The heat lost through the jacket of a water heater is not considered waste heat if the system boundary includes the house, during the heating season. However, the same heat loss during the cooling season would increase the load on the air-conditioning system. To take these effects into consideration, the overall efficiency is defined as the ratio of useful heat delivered to total energy consumed directly and indirectly.[6] The energy consumed directly can be electricity or gas used by the water heater itself, and the indirect consumption is the energy used by the appliances as a consequence of operation of the water heater.

$$\text{overall efficiency} = \frac{Q_{use}}{Q_{total}} \qquad \text{(Eq. 3.5)}$$

In winter Q_{total} is equal to Q_{use} since the heat lost by the water heater is utilized to heat the house, hence resulting in a 100% overall efficiency.

During the summer Q_{total} includes both the energy consumed by the water heater and the energy consumed by the air conditioning system to remove the lost heat through the jacket from the house.

3.2.4 Standby (Jacket) Losses

The major standby loss of an electric water heater is through the jacket. The only other heat loss is through the piping system, which is maximum when hot water flow is terminated and the distribution pipes are filled with hot water. During the standby period, this hot water cools to ambient temperature. The rate of this heat loss is related directly to a number of draws, water temperature, ambient temperature, and the length of distribution pipes. If the distribution pipes are imbedded in a poured-concrete floor, the heat loss through the distribution pipes will increase considerably. Table 3.3 shows standby heat losses for electric water heaters as calculated by various investigators.[5-8] This loss, which varies with ambient temperatures and hot water temperatures, can be reduced by increasing the insulation thickness.

Table 3.3 Daily Energy Consumption of Electric Water Heater and Jacket Loss

	Unit 1[(a)] Mutch	Unit 2[(b)] Spann & Slaughter	Unit 3[(c)] Hoskins	Unit 4[(d)] Lee
Energy Flow		(10^4 Btu/day)		
Useful energy	3.2	5.9	5.0	5.1
Jacket loss	0.88	1.6	1.2	1.1
Total input	4.1	7.5	6.2	6.2
Efficiency	78.8%	79.1%	81%	83.0%

(a) Hot water consumption 50 gal/day; temperature rise 85°F; ambient temperature 70°F; insulation thickness 2 in.; tank size 66 gal.

(b) Hot water consumption 75 gal/day; temperature rise 85°F; ambient temperature 70°F; insulation thickness 2 in.; tank size 66 gal.

(c) Hot water consumption 72 gal/day; temperature rise 85°F; ambient temperature 70°F; insulation thickness 2 in.; tank size 50 gal.; (jacket loss includes the heat loss through distribution pipes)

(d) Hot water consumption 71.4 gal/day; temperature rise 85°F; ambient temperature 70°F; insulation thickness 1 3/4 in.; tank size 50 gal.

Present electric water heaters have jacket insulation varying in thickness from one to two inches. Table 3.4 shows the measured heat losses through the jacket of a 66-gal electric water heater at various tank water temperatures.[6] When the same water heater is retrofitted with 1 1/2-in.-thick insulation, an approximate 27% reduction in standby loss (synonymous with "jacket loss") was obtained.

Table 3.4 Standby Jacket Heat Losses of Electric Water Heater[(a)] (Btu/h)

Water Temperature (°F)	As Received (2 in. Insulation)	1 1/2-in. Kit Retrofitted	Heat Loss Reduction (%)
110	315	227	27.9
130	487	351	27.9
150	660	482	27
170	832	610	26.9

(a) 70°F ambient temperature, 66-gal residential electric water heater.

3.3 GAS-FIRED WATER HEATER

3.3.1 Full-Load Efficiency

The full-load efficiency of a gas water heater is approximately 71 to 73% over the hot water temperature range of 170°--130°F.[6] This lower full-load efficiency, as compared with 100% full-load efficiency of electric water heaters, is caused by flue and higher jacket losses of gas water heaters.

3.3.2 Appliance Efficiency

The appliance efficiency of a gas water heater, as defined by Eq. 3.1 is illustrated by Fig. 3.5 for various daily hot water demands.[6] The direct energy delivered to a gas water heater is the gas consumed by the pilot and by the main burner.

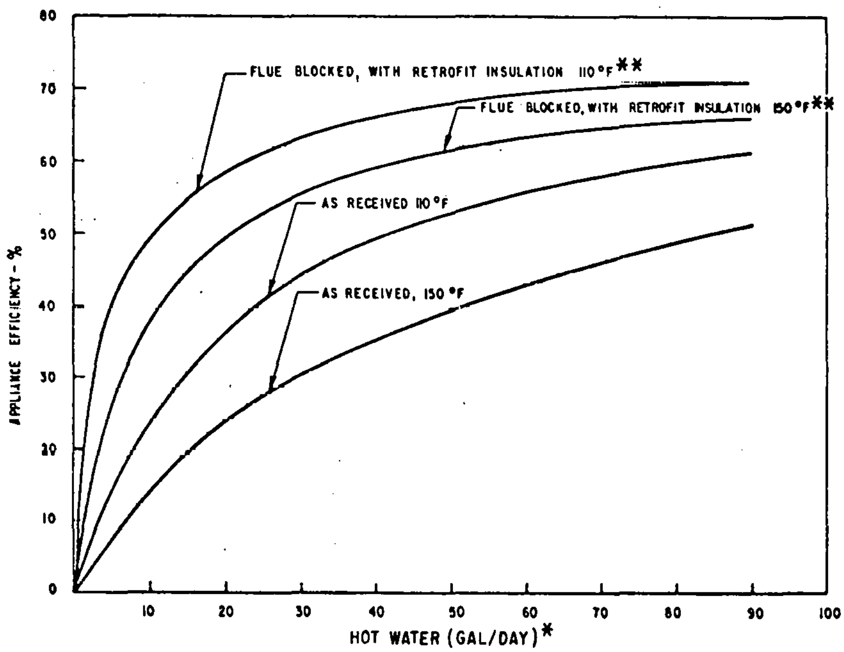

Fig. 3.5 Appliance Efficiency of a Gas Water Heater Vs Hot Water Consumption

*Through 95°F temperature

**Insulation thickness 3 1/2 in

3.3.3 Overall Efficiency

In applying Eq. 3.3 for gas water heaters, Q_{use} is useful heat delivered to the residence. Hence, during the winter for indoor operation, Q_{use} is the sum of hot water delivered and jacket losses.

3.3.4 Flue Losses

Figure 3.6 is a nomograph, developed by the American Gas Association (AGA) showing the effect of excess air, inlet air, and exit gas temperature on flue losses.[2]

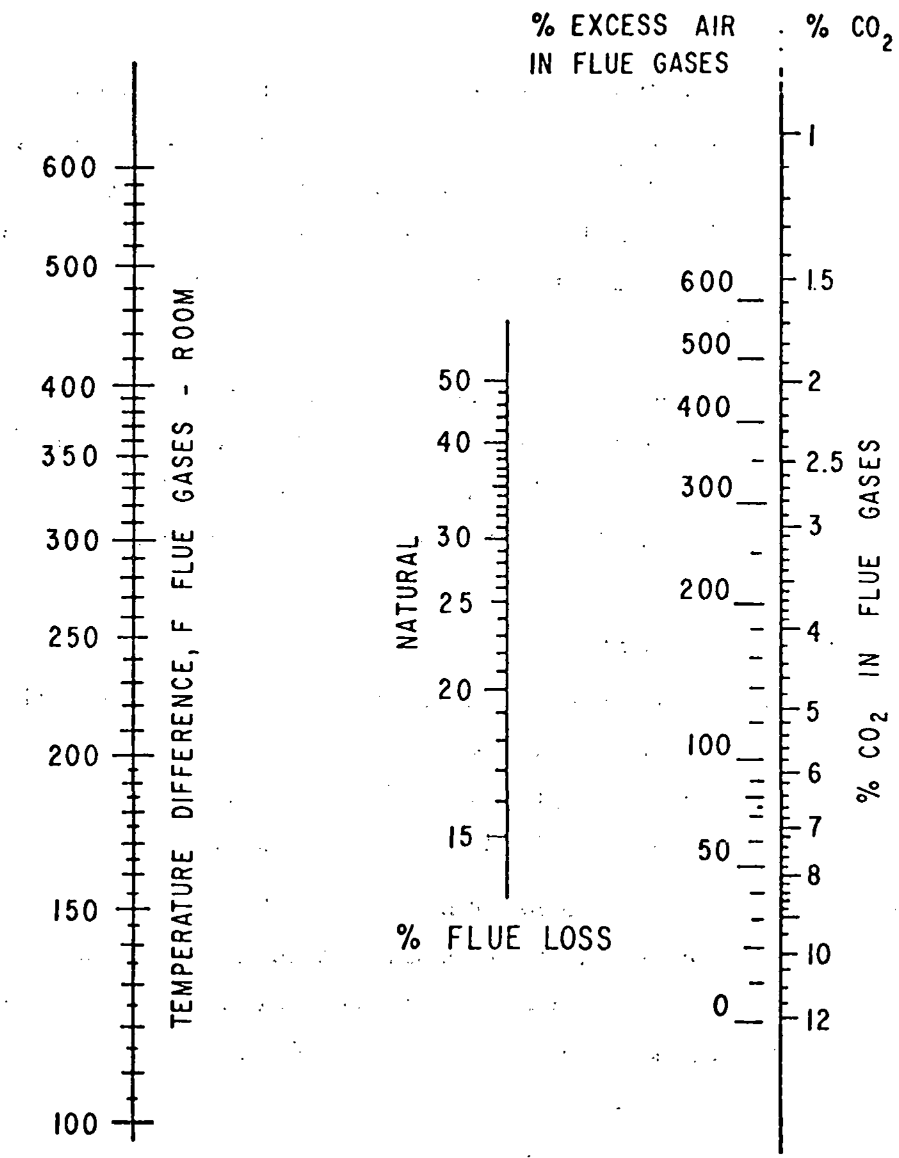

Fig. 3.6 Allignment Chart for Determination of Flue Losses

The AGA nomograph also is represented by an empirical relation as,[8]

$$FL = 1.29\ EA^{0.147}\ (5/9\ T)^{0.419} \qquad \text{(Eq. 3.4)}$$

where:

FL = flue losses, %;

EA = excess air in flue gases, %; and

T = temperature difference between flue gases and ambient air, °F.

From the above expression, it appears that flue losses can be reduced either by reducing the amount of excess air or by decreasing the temperature of exiting flue gases.[5] The latter can be accomplished by redesigning the flue baffles to increase the residence time of combustion gases or by increasing the length of the flue which acts as a heat exchanger.

Both options (excess air or baffles) have certain limitations. Excessive reduction of excess air will increase CO and CO_2 content of flue gases; excessive baffling will eliminate the pressure difference necessary for natural draft between entering air and exiting flue gases.

3.3.5 Standby and Jacket Losses

Standby losses from gas water heaters are considerably higher than those from electric water heaters. Some factors causing this increase in standby losses are constant operation of the pilot light and the thinner jacket insulation used in manufacturing gas water heaters.

The pilot light, which burns constantly to keep the tank water hot and to ignite the main burner when necessary, also acts as a safety precaution against accumulation of gas in the event of a leak. It burns natural gas at an approximate rate of 700 to 1000 Btu/h and has a measured heat-exchange efficiency of 23%.[6]

Pilot flue losses account for 13 to 15% of total energy input and are only a function of pilot gas flowrate. They are nearly constant at different water temperatures.

Most of the presently manufactured gas water heaters have 1 in. insulation between the tank and the jacket. As in the case of electric water heaters, insulation thickness indeed affects the rate of heat loss through the jacket. Figure 3.7 shows a gas water heater operating in three different modes corresponding to the three different curves.[6] When the flue is blocked and the pilot light is off, the total heat loss is equal to jacket loss. This situation simulates a water heater having a mechanical or electrical means of opening the flue and an electrical means of igniting the main burner. The curve with the flue open and the pilot on shows the operation of a factory-built water heater.

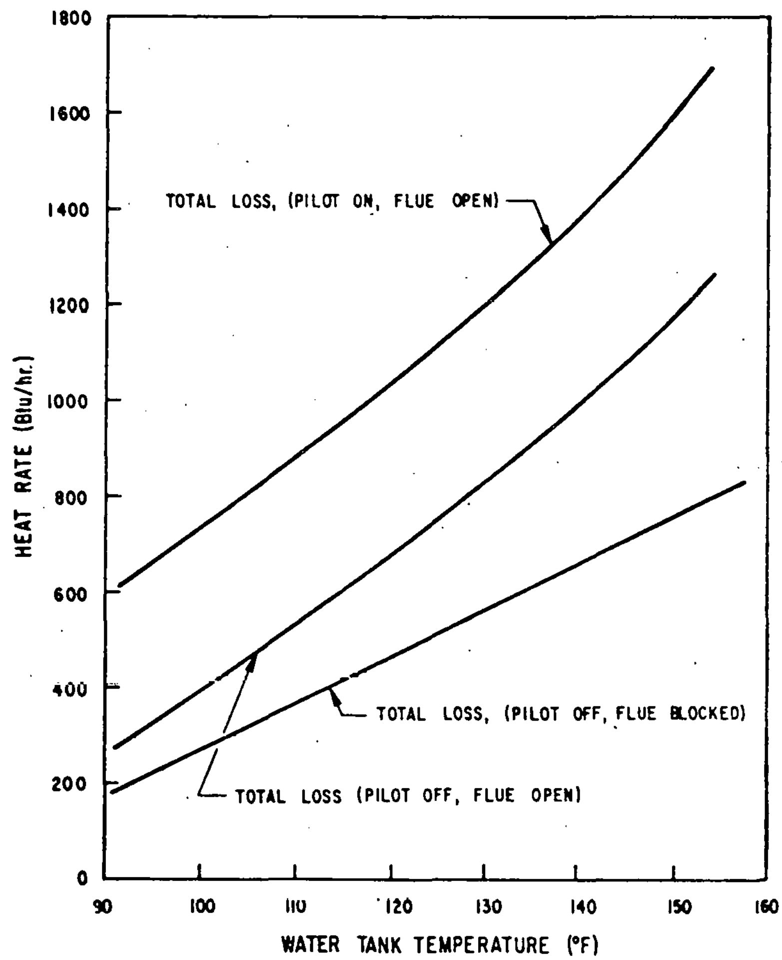

Fig. 3.7 Total Loss Heat Rates Vs Water Tank Temperature for Three Operational Configurations (Gas Water Heater)

Table 3.5 provides jacket and flue losses (main burner and pilot) as measured or calculated by different investigators.[5-8]

Table 3.5 Daily Energy Consumption of Gas Water Heater and Jacket Loss

Energy Flow	Unit 1[(a)] Mutch	Unit 2[(b)] Spann & Slaughter	Unit 3[(c)] Hoskins	Unit 4[(d)] Lee
	(10^4 Btu/day)			
Useful energy	3.2	5.9	5.4	5.1
Jacket loss	2.5	1.8	1.1	1.2
Flue loss				
a) main burner	0.86	2.2	2	2.3
b) pilot	0.55	1.6	1.3	1.5
Total input	7.1	11.6	9.8	10.2
Efficiency	45.5%	51.4%	52%	50.0%

(a) Hot water consumption 50 gal/day, temperature rise 85°F; ambient temperature 70°F; insulation thickness 1 in.; tank size 40 gal; main burner rate 7490 Btu/h-ft^3; and pilot rate 750 Btu/h.

(b) Hot water consumption 75 gal/day; temperature rise 85°F; ambient temperature 70°F; insulation thickness 1 in.; tank size 40 gal.; main burner rate 7520 Btu/h-ft^3; and pilot rate 750 Btu/h.

(c) Hot water consumption 72 gal/day; temperature rise 85°F; ambient temperature 70°F; insulation thickness 1 in.; main burner rate 7490 Btu/h-ft^3; (jacket loss includes distribution piping loss).

(d) Hot water consumption 71.4 gal/day; temperature rise 85°F; ambient temperature 70°F; insulation thickness 3/4 in.; main burner rate 8430 Btu/h-ft^3; and pilot rate 700 Btu/h; (jacket loss includes floor loss).

4 ENVIRONMENTAL EFFECTS

There are no emissions, vibrations, or excessive noise levels involved with electric water heaters.

Gas water heaters discharge hot products of combustion into the atmosphere.

According to the ANSI standard, the average temperature flue gases should not exceed 480°F above room temperature.[2]

Table 4.1 shows emission factors for combustion of natural gas by commercial and domestic appliances.[9]

Table 4.1 Emissions Factors for Natural-Gas Combustion

Pollutants	Domestic and Commercial Heating ($lb/10^6\ ft^3$)
Particulates	5--15
Sulfur oxides (SO_x)	0.6
Carbon monoxide (CO)	20
Hydrocarbons (as CH_4)	8
Nitrogen oxides (NO_x)	(80--120)[a]

[a] Use 80 for domestic heating units and 120 for commercial units.

5 OPERATING REQUIREMENTS

5.1 Electrical Capacity Control

Electric water heaters have either one heating element near the bottom of the tank or two heating elements, one near the bottom and the other near the top of the tank (see Fig. 1.3).

The single heating element type has one thermostat that turns on the heating element when the tank water temperature falls below a preset thermostat setting. This heating element usually is rated at about 8,500 Btu/h (2,500 W).[7]

The double heating element type has one thermostat for each coil, and each thermostat is set independently. The thermostats usually are interlocked so that the upper and the lower heating element cannot operate simultaneously. The heating elements are rated between 13,500 and 19,000 Btu/h (4,000 to 5,500W). The upper heating element is energized during high water withdrawal rates, and the lower element is energized when the upper thermostat is satisfied and the lower is not, which normally occurs during the standby operation. The water heaters with manual adjustable thermostat normally are designed for the following temperature settings.[7]

warm or low : 110-120°F
medium or normal: ∿140°F
hot or high : ∿160°F

5.2 GAS-FIRED CAPACITY CONTROL

A thermostat controls the timing and duration of main burner operation. When the tank water temperature falls below a preset thermostat setting, the main burner is ignited by a continuously burning pilot light.

The main burner firing rate usually is designed for 1,000 Btu/h/gal of storage.[5]

5.3 SAFETY REQUIREMENTS

Gas and electric water heaters usually are equipped with temperature and pressure protective devices. When installing the relief valve, care must be taken to orient the discharge tubing away from electrical wiring — usually directed at the floor.

6 MAINTENANCE REQUIREMENTS

To dispose of sediment that accumulates in the bottom of the tank, periodic opening of the drain valve is suggested for both electric and gas water heaters.

At a location having hard water, it is desirable to remove the scale from the electric heating element.

6.1 EXPECTED LIFE OF EQUIPMENT

Expected life of gas and electric water heaters is about seven years.[8] Some manufacturers have a 10-yr warranties for their products at an extra charge.

7 COST CONSIDERATION

7.1 EQUIPMENT COST

Figures 7.1 and 7.2 show the estimated cost for electric and gas water heaters ranging from 30 to 100 gal of hot water storage capacity. Data are collected from Ref. 10, and from plumbing companies in the Knoxville area. The data shown in Figs. 7.1 and 7.2 are represented by the following expressions of cost vs capacity (Q, gal):

water heater cost, \$ (electric) $= 153\ (Q/50)^{1.02}$ $\quad 30 \le Q \le 100$ (Eq. 7.1)

water heater cost, \$ (gas) $= 155\ (Q/40)^{1.1}$ $\quad 30 \le Q \le 100$ (Eq. 7.2)

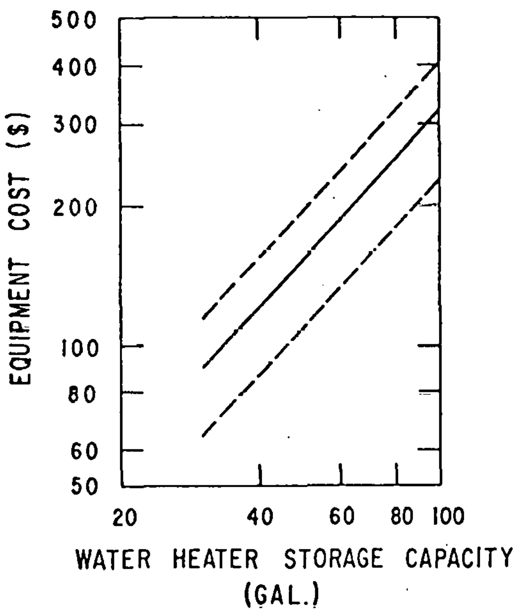

Fig 7.1 Equipment Cost of Electric Water Heater Vs Capacity[a]

[a] Installation cost not included.

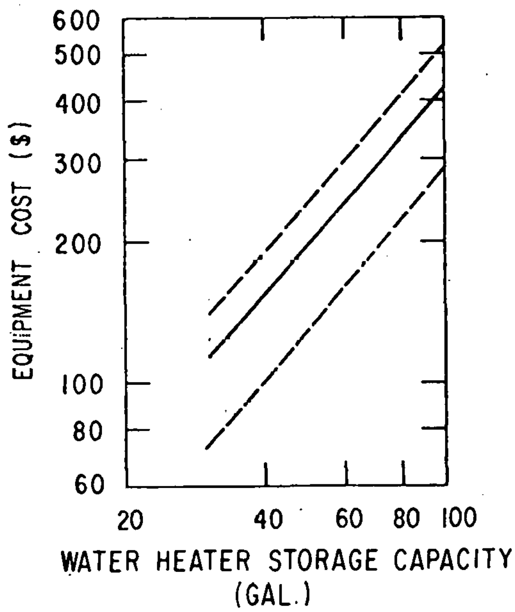

Fig. 7.2 Equipment Cost of Gas Water Heater Vs Capacity[a]

[a] Installation cost not included.

The dashed lines in Figs. 7.1 and 7.2 show the cost range for units with different capacities. The installation cost is mostly dependent on labor cost which varies throughout the country. Tables 7.1 and 7.2 show the manhours for electric and gas water heaters.[11] These data can be used to calculate erection costs at various locations.

Table 7.1. Erection Manhour Requirements for Automatic Electric Water Heaters of Various Capacities

Capacity(gal.)	30	40	50	65	80
Erection* man-hours	3.0	3.0	4.0	4.25	

Table 7.2. Erection Manhour Requirements for Automatic Gas-Fired Water Heaters of Various Capacities

Capacity(gal.)	20	30	40	50	60
Erection* man-hours	4.0	4.0	4.0	5.0	6.0

*Labor includes moving material and equipment 40 ft., uncrating, and finishing.

7.2 OPERATION COST

Water heater operation costs are heavily related to fuel type and operating conditions such as hot water consumption and tank water temperature.

Table 7.3 shows daily energy consumption of gas and electric water heaters as calculated or measured by different investigators.[5,8-10] Knowing the energy cost, the operation cost can be calculated by choosing one of the models listed in Table 7.1.

Table 7.3 Estimates of Daily Water Heater Energy Consumption

	Temperature Rise (°F)	Hot Water Rate (gal/day)	Energy Consumption (10^4 Btu/day)	
			Gas	Electric
Lee	85	71.4	10.2	6.2
Mutch	85	50	7.1	4.1
Spann	95	75	11.6	7.5
Hoskins	85	72	9.8	6.2
Consumer reports	--	100	13.8	9.8

8 STATUS OF DEVELOPMENT AND RECOMMENDATIONS

Hot water heaters account for 15% of residential and 3% of the total national energy consumption.[7] In 1968, the total energy consumed for producing domestic hot water was 1,738 trillion Btu.[6] This information suggests that any effort to increase the efficiency and performance of present installed and future manufactured units is a positive step toward reducing total national energy consumption.

Several energy-conserving designs and options, with respect to both consumer and manufacturer, are discussed below.

8.1 CONSUMER-ORIENTED OPTION

Reduce thermostat setting: present water heaters have normal thermostat setting of 140°F. A thermostat set back 10°F will result in an estimated energy reduction of 9% for electric and 17% for gas water heaters.[8] This is due to reduction of energy used to heat water and reduction of jacket losses.

8.2 MANUFACTURER-ORIENTED OPTIONS

8.2.1 Increased Insulation Thickness

Jacket losses account for nearly all energy losses of electric water heaters (15 to 17% of the energy input to the electric heater)[5,8] and for a large portion of energy losses of gas water heaters (11 to 15% of total heat input).[5,8]

Table 8.1 compares the energy savings from various insulation thicknesses and the increased costs of insulation[8] of both electric and gas-fired hot water heaters.

Table 8.1 Energy and Economic Effects of Jacket Insulation Thickness

	Electric			Gas		
Insulation Thickness (in.)	Energy Savings (%)	Added Cost (1975-$)	Payback Period (yr)	Energy Savings (%)	Added Cost (1975-$)	Payback Period (yr)
2	---	---	---	7	4.9	0.8
3	4	6.1	0.7	10	10.9	1.3
4	7	12.1	1.0	10	17.0	1.9
5	7	19.4	1.4	11	24.2	2.5

Figure 8.1 shows the energy consumption as a function of insulation thickness.[5] As shown, the thickness beyond four inches does not decrease energy consumption appreciably. Too much insulation will result in an over-sized water heater that cannot fit through standard doorways.

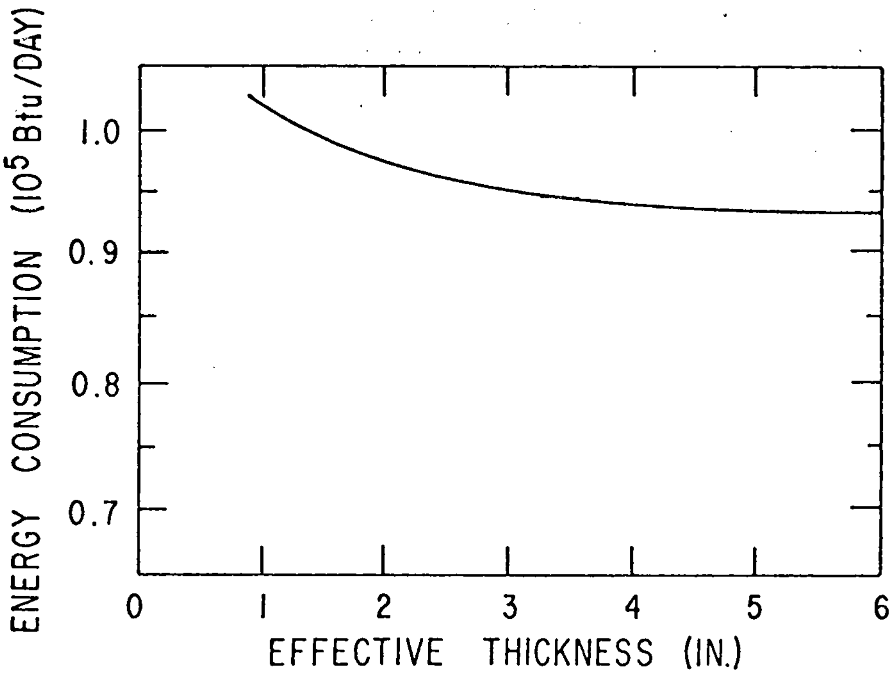

Fig 8.1 Effect of Gas Water Heater Insulation Thickness[a] on Energy Consumption

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[a] *Basis:* Normal density fiberglass (K=0.024 Btu/h/ft^2/°F)

8.2.2 Reduced Pilot Rate

Energy losses from constant operation of a pilot light account for approximately 14% of the energy input. Currently available gas water heaters have pilot rates of about 1000 Btu/h. Any reduction of the pilot rate is limited by the instability of pilot flame. A minimum rate of 400 Btu/h is considered safe and will result in energy savings of approximately 6%.[8]

Among other available options is the introduction of automatic ignitors combined with flue closure. In this design, an electric ignitor ignites the main burner when water temperature drops below a preset thermostat setting. The damper closes during off-burner operation to stop a reverse transfer of heat from hot water to cooler flue gases. This design change would result in a considerable energy savings. However, there are safety problems and the additional equipment and installation cost ($141) surpasses the energy savings during the lifetime of the water heater,[5] this is not considered an economically desirable option.

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