CHAPTER

FOUR

DOMESTIC HOT WATER SYSTEMS

4.1 Types of DHW Systems

Conventional residential hot water heaters are either gas or electric. Electric water heaters are inherently more efficient than gas units because their elements are directly immersed in the tank yielding a conversion efficiency of nearly one hundred percent (see Figure 1.2.1). Conventional gas water heaters have greater heat loss because of the open flue through the center of the tank and are additionally limited by a combustion and heat transfer efficiency of seventy-seven percent or less (EPRI, 1992). The Gas Appliance Manufacturers' Association (GAMA) summarizes United States industry water heater shipments in their 1992 *Statistical Highlights* publication. The DHW system shipment statistics are shown in Table 4.1.1. In Table 4.1.4 where, for example, in 1991 44.6% of shipped DHW systems were electric, 50.9 % were natural gas and 4.5% were LPG. It is estimated that eighty percent of residential water heater sales are replacement units, while the remaining twenty percent are installed during new construction with nearly one half of shipments electric DHW systems (EPRI, 1992).

Table 4.1.1: GAMA Water Heater Shipment Statistics (Abram, 1992)

Type	Millions of Residential Storage Water Heaters Shipped									
(Year)	91	90	89	88	87	86	85	84	83	82
Electric	3.17	3.23	3.37	3.33	3.96	3.39	3.45	3.48	3.13	2.72
Nat. Gas	3.62	3.63	3.85	3.67	3.67	3.49	3.30	3.28	2.95	2.77
LP	.317	.281	.285	.228	.278	.243	.226	.220	.219	.270
Total Gas	3.94	3.91	4.13	3.96	3.95	3.73	3.53	3.50	3.17	3.04
% Electric	44.6	45.2	44.9	45.7	46.2	47.6	49.5	49.8	49.7	47.2
% Total Gas	55.4	54.8	55.1	50.4	50.0	49.0	47.3	47.0	46.9	48.1
% Nat. Gas	50.9	50.8	51.3	50.4	50.0	49.0	47.3	47.0	46.9	48.1
% LP	4.5	3.9	3.8	3.9	3.8	3.4	3.2	3.2	3.5	3.7

After January 1990, all water heaters manufactured for sale in the United States must meet the federal standards of the National Appliance Energy Conservation Act, summarized in Table 4.1.2. The Appliance Efficiency Group (AEG) is attempting to raise the efficiency levels of electric water heating systems above those required by the federal standards. An Energy Factor (EF) is:" A measure of the overall efficiency of a water heater determined by comparing the energy supplied in heated water to the total daily consumption of the water heater (GAMA, 1992)." Thus, an Energy Factor rating is an estimate of the hot water energy output for each input of energy supplied to the water heater (WSEO, 1991).

Table 4.1.2: Federal Water Heater Standards (WSEO, 1991)

Tank Size	40 Gallons	50 Gallons	60 Gallons	65 Gallons	80 Gallons	120 Gallons
Energy Factor	0.90	0.88	0.86	0.86	0.83	0.79

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) also lists specific standards for water heating equipment. A water heating handbook, developed by the Electric Power Research Institute (EPRI) has a convenient method for determining the standby losses according to tank size and efficiency rating (EPRI, 1992).

$$\text{StandbyLosses} = \frac{\text{Loss Fraction}(\% / \text{hr})}{100\%} * V_{water} * \rho_{water} * Cp_{water} * (T_{set} - T_{env}) \quad \textbf{4.1.1}$$

Their estimates are shown in Table 4.1.3. The type of insulation around the tank can significantly affect tank losses. Some DSM programs simply promote water heater blankets for energy efficiency. Gas-fired tanks typically lose heat at a rate three or more times that of electric units. Even with daytime hot water draws, a large tank can have nighttime losses that account for 50% of the monthly energy costs (Klein, 1994).

Table 4.1.3: Typical Storage Water Heater Performance (EPRI, 1992)

Type	**Gas-Fired**			**Electric**		
Volume (gal)	**40**	**80**	**120**	**40**	**80**	**120**
Typical Energy Factor	0.57	0.47	0.42	0.92	0.88	0.80
Typical Stand-by Loss Fraction (%/hr)	3.75	3.09	2.94	0.80	0.62	0.62

4.2 Solar DHW Systems

The fundamental operations of solar domestic hot water systems are discussed in Chapter 1. The Solar Rating Certification Corporation (SRCC) is the official source for solar hot water system ratings and information. The SRCC is an independent, non-profit organization sponsored in part by the United States Department of Energy. For rating purposes, the SDHW systems are subjected to a defined sequence of operating conditions representative of actual operation. The OG 300 rating and certification program for solar DHW systems integrates the results of collector tests and system tests and standards for system durability, reliability, safety and operation (SRCC, 1993).

The thermal performance ratings are determined using mathematical models and correlations in conjunction with TRNSYS (see Chapter 3.4: TRNSYS Simulation Model). The thermal performance is based on three equal water draws at 8 a.m., noon, and 5 p.m. Three daily average hot water draws of 55, 70, and 85 gallons are used to determine the equal water draws. The four types of SDHW systems that are rated are (SRCC, 1993):

- Forced Circulation (Active) systems that use a pump to circulate the fluid (water or antifreeze) through the collector and storage tank.
- Integral Collector Storage (ICS) or "Batch" water heater systems in which the collector and storage tank are combined into one, directly heating the water without a circulation loop.
- Thermosyphon (passive) systems that locate the storage tank above the collector where natural convection causes the heated fluid (water or antifreeze) to rise into the storage tank above.
- Self-pumping (passive) use a phase change (liquid-vapor) or other passive means to circulate the collector fluid (water or antifreeze) through the collector and storage tank.

The performance rating is the daily energy savings provided by the solar system relative the load (SRCC, 1993):

$$Q_{SAVED}=Q_{CONVENTIONAL} - Q_{AUXILARY} - Q_{PARASITIC} \qquad \textbf{4.2.1}$$

(where $Q_{AUXILARY}$ is the back-up heat requirement and $Q_{PARASITIC}$ is the power required by pumps and controllers)

The annual SDHW system performance ratings shown on rating labels in the following categories:

A: Less than 15 MJ of energy saved per day
B: 15 up to but less than 20 MJ of energy saved per day
C: 20 up to but less than 25 MJ of energy saved per day
D: 25 up to but less than 30 MJ of energy saved per day

E: 30 up to but less than 35 MJ of energy saved per day
F: 35 MJ or more of energy saved per day

While detailed TRNSYS models for the various commercial systems are available, basic configurations of various sizes were chosen for the Wisconsin utility impact analysis to provide a general basis for comparison. Since below zero temperatures are not uncommon during Wisconsin winters, only systems with freeze protection are considered for this thesis. Some representative commercially available SDHW system characteristics are shown in Table 4.2.1 (Poplawski, 1994). Most solar DHW system manufacturers offer utility program discounts and reduced prices for multiple purchases (e.g., see Copper Cricket and AET).

Table 4.2.1 Representative Solar System Characteristics (Poplawski, 1994)

SDHW System	Collector Area (ft^2/m^2)	Tank Volume (gal/L)	Type System	Retail Cost ($)
ASN Solar Skylite	48/4.46	80/303	Active	1,995
ASN Solar Skylite	64/5.95	80/303	PV	2,295
AET C-80	40/3.72	80/303	Active	3653 *
Copper Cricket	42/3.90	53.6/203	Self-Pumping	2180 **
Helio-Pak 2408	64.6/6	80/303	Active	2,697
Helio-Pak 2408	64.6/6	80/303	PV	3,783
Helio-Pak	96/8.92	120/455	Active	4,370
Solahart 300 JK	43/3.96	85.15/327	Thermosypho n	1,600
Sunquest Fresource	64/5.95	x	Active	2,750
Zomeworks SWH	80/7.43	80/303	Active	2,612
*AET DPV system	Quantity	Price		
64ft2/120 gallon/PV	1	3,620.22		
[1993 Catalog]	2 to 5	1810.11		
	6 to 19	1717.27		
	20 +	1625.6		
** Copper Cricket will sell to utilities an installed price of 2,384.00 to 2,560.00				

4.3 Utility Penetration - Replacement Potential

As more stringent environmental regulations continue to do evolve, a switch to natural gas has been apparent. The price for natural gas is now extremely low, yet not all residents have gas available to them, as shown in Table 4.3.1. Over 700, 000 Wisconsin electric customers have electric DHW systems and do not have access to natural gas. In addition, a large portion (75.5%) of Wisconsin households consists of single family residences.

Table 4.3.1: Wisconsin Public Utilities Customer Information

Wisconsin's Statewide Technical & Economic Potential (WCDSR, 1994)			
Utility	**# Residential Electric Customers**	**Single Family Houses**	**Customers without access to Natural Gas**
Dairyland Power Coop.	139,934	75.5 %	90 %
Madison Gas & Electric	95,975	58.8 %	16 %
Northern States Power	176,334	88.5 %	60 %
Wisconsin Power & Light	295,718	84.0 %	59 %
Wisconsin Public Power	85,094	82.9 %	*38.6 %
Wisconsin Public Service	272,776	81.2 %	36 %
Wisconsin Electric Power	846,869	69.1 %	10 %
Statewide:	**1,912,700**	**75.5%**	**38.6 %**

* Wisconsin Public Power does not collect this information. It is assumed that Wisconsin Public Power's values are identical to the weighted statewide averages of the numbers produced by the other utilities.

According the Washington State Energy Office, the most commonly sold tank size in the United States is fifty to fifty-two gallons (WSEO, 1991). The Wisconsin Center for Demand-Side Research also lists a fifty-two gallon, 4.5 kW element DHW as the most popular existing technology in 1991 in Wisconsin (WCDSR, 1994). The typical 1991 fifty-two gallon electric DHW has an EF rating of 0.87.

Given all of these statistics, the target market for this thesis is a single family household with a 52 gallon electric DHW system.

4.4 Water Mains Temperatures

The water heating load is:

$$\text{Water Heating Load} = V_{water}*\rho_{water}*Cp_{water}*(T_{set}-T_{mains}) \qquad \textbf{4.4.1}$$

Where V_{water}, ρ_{water}, Cp_{water} are the draw volume, the density, and the specific heat of water, respectively. While the variations of the water draw volume are the driving force for the heating loads, standby losses and geographical and seasonal mains temperatures cause the considerable variations in hot water loads. In Wisconsin the water mains temperatures range from around 35 to 60 °F annually (depending on the water source). Also, most Wisconsin DHW systems are inside the home (e.g., a basement with relatively constant ambient temperatures), so the losses throughout the year are relatively constant. Therefore, the seasonal load follows the mains temperature variation. Depending on the water mains source (lake, ground well, etc.), the water mains temperatures around the country can range from 40 to 90 °F, so the seasonal hot water load variance in other areas may be less than or greater than in Wisconsin.