CHAPTER

ONE

INTRODUCTION

Domestic Hot Water (DHW) systems account for almost 6% of the energy consumption in the United States and are the second largest consumer of energy in the residential sector. The benefit of solar domestic hot water (SDHW) systems as energy saving devices (typically 60-70% reduction) is well known, yet SDHW systems comprise significantly less than 1% of the domestic water heating market. Previous economic analysis has focused solely on the energy impact of a DHW system. Due to high initial equipment costs and low conventional energy prices, solar systems cannot compete in such analyses. Less well known is that SDHW systems can also reduce peak demand for utilities. Many utilities' peak demand is coincident with solar system peak performance. Recent research at the University of Wisconsin Solar Energy Laboratory showed that for a California utility, the Sacramento Municipal Utility District (SMUD), the average demand reduction for a large number of SDHW systems is on the order of 0.5 kW per system (Beckman et al., 1993). SMUD's current goal of 12,500 SDHW systems installed by the year 2000 is the equivalent of a 6 MW renewable energy power plant in terms of peak reduction (Murley, 1994) . (A cumulative energy savings of 36M kWh is also predicted by 2000.)

The peak load that a utility experiences usually occurs in the afternoon on the third or fourth consecutive day of hot sunny weather, due to large electric air conditioning loads. The key to solar domestic water heating for summer peak clipping is the coincidence of the utility's peak load days and the sunniest, hottest days, when solar systems perform best. The other reason that utilities focus on water draws, specifically electrically heated water, for summer peak clipping is that a large sampling of users have a very diverse effect. Water is considered a non-conditioned end use that is insensitive to climatic changes (Starkweather, 1992). SDHW systems are typically retrofitted onto existing electric DHW systems (see Section 1.2: SDHW System Fundamentals), because natural gas prices make natural gas SDHW retrofits economically unappealing. However, a large segment (over one third) of Wisconsin does not have natural gas (WCDSR, 1994). In these areas, most systems are electric, thereby having good SDHW potential. Another fuel option, liquid propane gas (LPG) is available almost everywhere, but many people are reluctant to use it because of unstable fuel prices and the aesthetics of the large outdoor tank needed for storage.

Other advantages of SDHW systems being explored in this thesis are utility emissions reduction and contribution to utility generating capacity. Considering today's high cost of solar systems, utility subsidies (with demand and energy savings rebates) are necessary for implementing an aggressive large scale SDHW program. Thus, all analyses in this thesis will consider the viewpoint of the utility. The understanding of utility cost analysis and integrated resource planning is paramount. Analyzing the money saved from avoided demand during the utility's peak load period (as in the SMUD study) is valuable for saving money because peaking power has to be purchased, or produced expensively by combustion turbines. But annual solar system performance and the interaction of many solar DHW systems with a utility's traditional resource mix must be analyzed to realize other benefits of a diversified solar energy plant (many SDHW systems).

The key to this study is the fact that hourly data analyses are utilized. Previous studies have looked at SDHW systems as only energy saving devices, and used only average daily water usage statistics (see Chapter 2.4: Literature Review). To accurately evaluate demand reduction, hourly water draw values must be obtained. If an electric water heater has a 4.5 kW element that is either on or off, then the peak demand of one system is 4.5 kW. But, when many systems are averaged, the resultant peak demand is significantly lowered because each heating element demand is not concurrent. The first step in this analysis is to see what the actual contribution a large number of electric water heaters have on the utility's load. The next step is to see what type of reduction a large number of SDHW systems would have on the utility's peak and annual load profiles.

Programs that analyze solar system performance, such as F-chart (Klein and Beckman, 1981) are valuable and accurate at predicting energy savings, but demand and emission reductions are impossible to evaluate with this type of analysis. Detailed information about the characteristics of the utility's power generation capabilities must also be available. Emission reduction cannot be accurately calculated by avoided energy analyses. The type of plant at the margin (the last unit dispatched according to utility power demands) at the time of energy savings is the realistic approximation of avoided pollution from SDHW replacement. (See Chapter 5.2: Load Duration Curves with Power Generation Schemes).

1.1 Motivation for Research

Fueled by federal and state tax incentives between 1978 and 1986, approximately thirteen thousand solar systems were installed in Wisconsin (WEB, 1993). Since then SDHW system installments have stagnated. Although much attention has been focused on renewable sources of energy in the last few years, putting those words into action has not been accomplished. Integrated resource plans are called Advance Plans in Wisconsin (See Chapter 2.1.3: Utility Integrated Resource Planning). While the State of Wisconsin is considered at the forefront of integrated resource planning with inclusion of environmental considerations (NARUC, 1993), until 1994 Wisconsin utilities have continually decreased their projected levels of new renewable energy resources, as evident in Table 1.1.1. Finally, in Advance Plan 7 -1994, utilities have projected adding 423 MW of renewable sources during the twenty year planning period. Of this projection, only 6 MW are directly from solar sources, of which only 1 MW is to be installed by 2005!

Table 1.1.1: Advance Plan Renewable Energy Promises

Renewables in Wisconsin: Historical Promises		
Advance Plan 4	1988	188 MW
Advance Plan 5	1990	148 MW
Advance Plan 6	1992	52 MW
Advance Plan 7	1994	432 MW

Why has solar energy been so neglected when sources such as the Union of Concerned Scientists Report states; "In 15 hours the sun delivers as much energy to the Midwest as its inhabitants consume in a year. (Brower, et al., 1993)" ? Even in the wake of SMUD's successful SDHW program, initiated in 1992, that projects an equivalent renewable energy power plant from solar domestic water heaters of 10 MW, utility skepticism prevails. Most analyses fall short, because they either consider only the energy saving potential for customers with SDHW, or they only look at peak day demand reduction. The benefits of solar water heating extend beyond a peak day analysis. Solar domestic water heaters work when there is significant incident radiation, regardless of ambient temperatures. It is only through annual analysis that solar energy system impact through demand, energy and emission reduction is truly realized.

Electric utility systems gain strength through diversity of generating sources. Solar domestic hot water systems can add to the future vitality of a utility network by contributing to reliability and diversity of generating capacity. Since SDHW systems are customer owned and dispersed throughout the community, a complete failure of one system has little effect on the grid. For an equivalent size fossil fuel generating facility, a failure can result in a tremendous impact on the rest of the system for weeks at a time. From an environmental standpoint, renewable power generating technology is ideal, but from a strict reliability viewpoint, it makes sense to have a diverse balance of fuel types and generating plants (PSCW, 1992).

1.2 Fundamentals of SDHW Systems

Solar domestic hot water (SDHW) systems are used preheat water for household use. Most systems have a conventional heating system included to provide water at the desired set temperature at all times. Although many different sizes and configurations exist, the main components include a solar collector, a storage tank and an auxiliary heat input. SDHW systems are designed with one or two tanks, but in all systems cold water is removed from the bottom of the storage tank, circulated through the collector and replaced at the top of the tank. The circulation can be performed through active pumping (with an electric or photovoltaic pump) or passive natural convection (which takes advantages of the density difference between hot and cold water). For freeze protection, SDHW systems have an additional antifreeze loop with a heat exchanger or a drain-back system.

A two-tank, active solar DHW system with an electric back-up tank and an antifreeze loop is shown in Figure 1.2.2. A controller is usually installed in active SDHW systems to ensure that the fluid passing through the collector is heated (when sufficient solar radiation falls upon the collector) instead of cooled (during nighttime hours or periods of low incident radiation). For a single-tank configuration, the auxiliary heater is located in the upper third of the solar storage tank. A more detailed discussion of electric, gas and solar domestic hot water systems is located in Chapter 4.

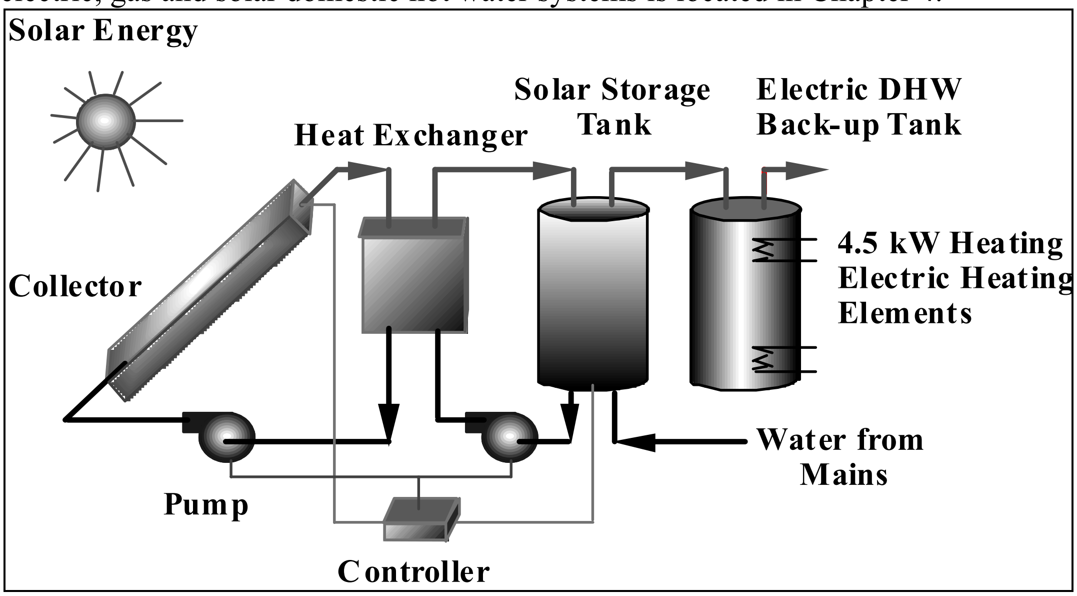

Figure 1.2.1: Schematic of an Active Solar DHW System

1.3 Residential Water Draws

The first issue of SDHW system replacement is evaluation of diversified electrical demand through diversified water draws. Why are water draws so important? Water draws are considered to be a non-conditioned end-use from a demand side management perspective, meaning they do not change dramatically throughout the year as hot water is a daily necessity. Yet, residential water draws are the subject of much study and debate. Being the second largest consumer of energy in the residential sector, water heating is dependent on the size and time of day of water draws. Another attractive feature of water heating load reduction is that unlike heating and cooling loads, water heating loads are somewhat season independent. Many studies and demographics analyses have been performed to estimate the average household water draw (Pontikakis, 1994) . While an individual profile for a family of four with two working parents may look like Figure 1.3.1, not everyone washes their hands, showers, does laundry, or prepares meals at the same time. Therefore, the average of many households is shaped differently than that for any individual profile.

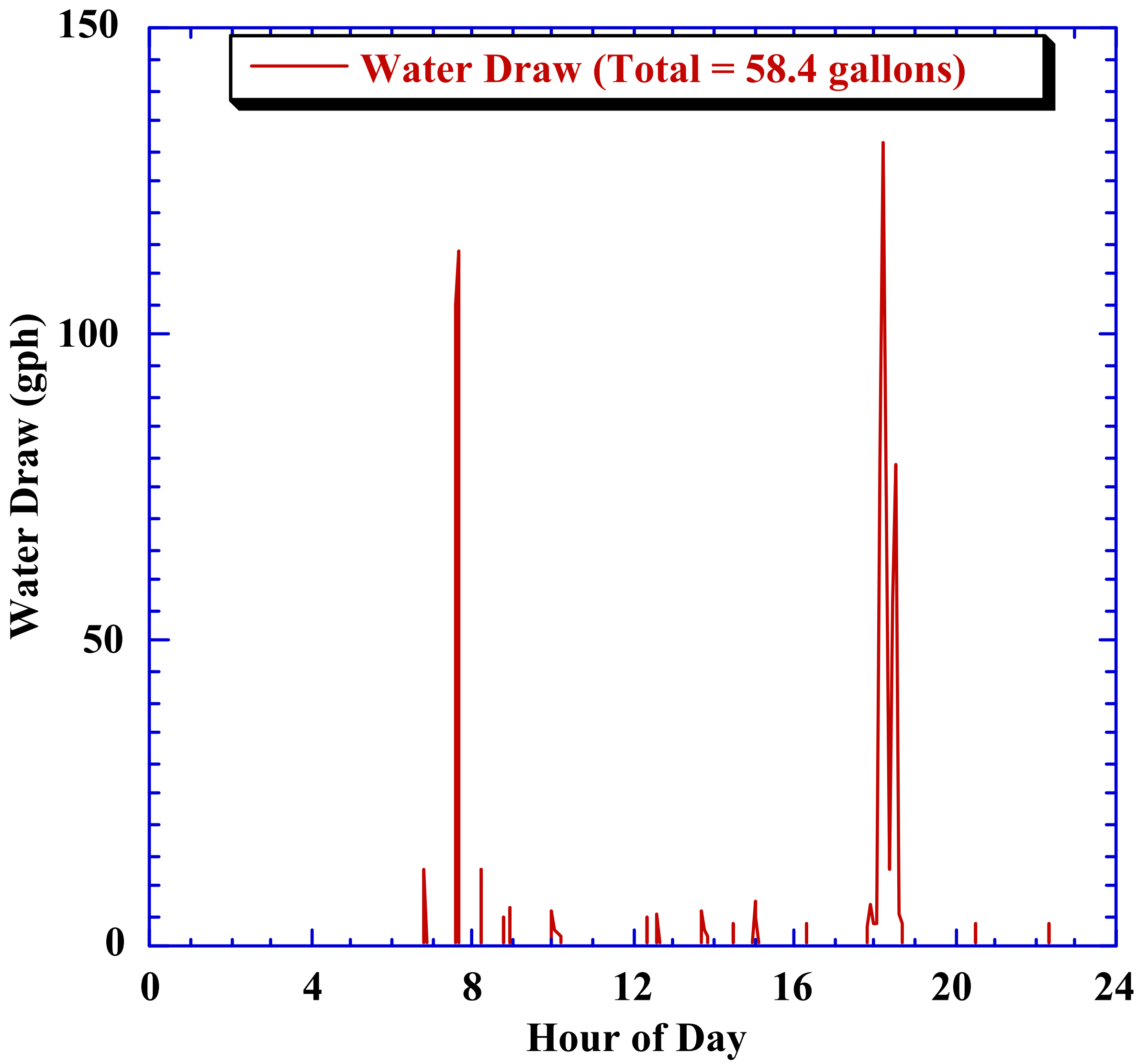

Figure 1.3.1: WATSIM Family of Four - Typical Wednesday

While the number of individual households, or profiles, needed to achieve a truly diversified demand is still under debate, most studies agree on a general shape for the average draw. The magnitude of the average daily draw may vary regionally from 50 gallons per day to 120 gallons per day (EPRI, 1992), with some seasonal variance, but the general *average* shape is known. The RAND (Mutch, 1974) profile is an average hot water use profile that is widely referenced and is shown in Figure 1.3.2. Unfortunately, studies have shown that an average water draw profile cannot be used to predict demand reduction with On/Off heater analyses (See Chapter 3.2.2: Diversified Demand Sample Size).

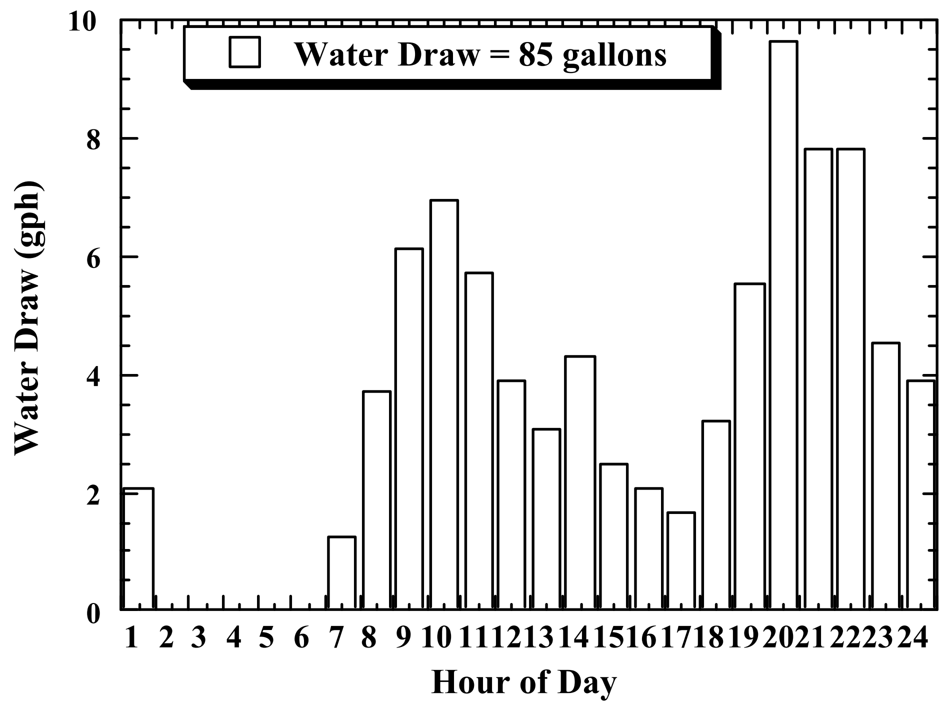

Figure 1.3.2: RAND Average Hot Water Load Profile (TRNSYS, 1994)

Thus, utilities are faced with a rather odd predicament. They want to find the average effect that many solar DHW systems will have on their load profile. They have a reasonable estimate of the average water draw per household, yet they need many individual profiles to effectively evaluate the diversified electrical demand. In addition, utilities do not have the technical resources to monitor thousands of individual water draws (Christensen, 1994). This researcher's approach to demand reduction evaluation is unique and beneficial to utilities for that very reason. Investigations continue on determining realistic individual profiles, the uncertainty of metered data, and time of use predictions, but the estimated average water draw is reasonably well-known. Even when uncertain individual profiles are used, the computation time required to evaluate the demand of thousands of draw profiles and then average all of them to determine the average result limits the analysis to only peak day performance. What about annual performance? Are there not advantages to solar water heating that extend beyond peak demand reduction? Until now, those benefits have gone unrecognized due to the before mentioned constraints.

1.4 Research Objective

The objective of this project is to identify and quantify the advantages and disadvantages to utilities and homeowners of an aggressive large scale solar DHW program. The ultimate goal of this research is the development of an exogenous (utility independent) approach to accurately evaluate SDHW system impact on a utility. The analysis includes not only the determination of energy and demand reduction, but the evaluation of emission reductions and contribution to capacity.

The environmental benefits of solar energy programs can include avoided pollution of the air, the land, and the water. Utilities use various forms of power generation according to different energy needs. Each of these operations incurs a certain cost to the consumer and to the environment. Fossil fuel combustion results in the production of carbon dioxide, sulfur dioxide, various nitrous oxides, and particulates whose cost to the environment can be converted into $/ton produced. With this information, a utility's amount of avoided emissions saved through SDHW programs can be evaluated and the impact of the solar systems on a utility can be quantified. In addition, the merits of sponsoring the installation of these systems can be justified through avoided cost of building and operating new generating facilities.

Evaluation of energy, demand, capacity and emission reduction is being performed through the integration of various computer software programs. The impacts of the SDHW systems are calculated on an hourly basis. Water draws are not constant for each type of DHW system, but are diversified with customer demographics. The program WATSIM, developed by the Electric Power Research Institute (EPRI), has the capability to create residential water draw profiles given customer demographic information. A statistical approach is developed for assessing the effect of thousands of solar water heating systems of different designs on a utility load. A combined approach for integrating the expected behavior of solar water heating into a utility's integrated resource planning is presented.

TRNSYS, a transient system analysis software package, is used to study the interaction of the hourly water draw profiles, and the hourly weather data for various DHW and SDHW systems. To accurately evaluate the avoided emissions, capacity contribution, energy and demand savings, a power generation schedule and a year of actual hourly data from a local utility, Wisconsin Electric Power Company (WEPCO of Milwaukee) were obtained. Evaluation of the utility's integrated resource planning process has resulted in a realistic and legitimate method for incorporating solar energy into utility planning.