CHAPTER
# ONE

# Introduction

## 1.1 Motivation: Demand Side Management and Solar Domestic Hot Water

Utilities adopt demand side management (DSM) measures for two reasons: either public service commissions (PSCs) require it, or economic considerations make it practical. Examples of demand side measures include shifting of peak demand to off-peak times and providing rebates on consumer purchases of low-flow shower heads, compact fluorescents and solar domestic hot water (SDHW) systems. The Sacramento Municipal Utility District (SMUD) is pursuing DSM for mostly economic reasons. It is cheaper for SMUD to cut energy demand than it is to buy power or build new power plants. As a result, SMUD is paying energy users to install solar domestic hot water (SDHW) systems. As hot water heating is one of the major residential energy uses, the operation of thousands of SDHW systems could substantially decrease energy demand. Other utilities around the country are considering a rebate program similar to SMUD's.

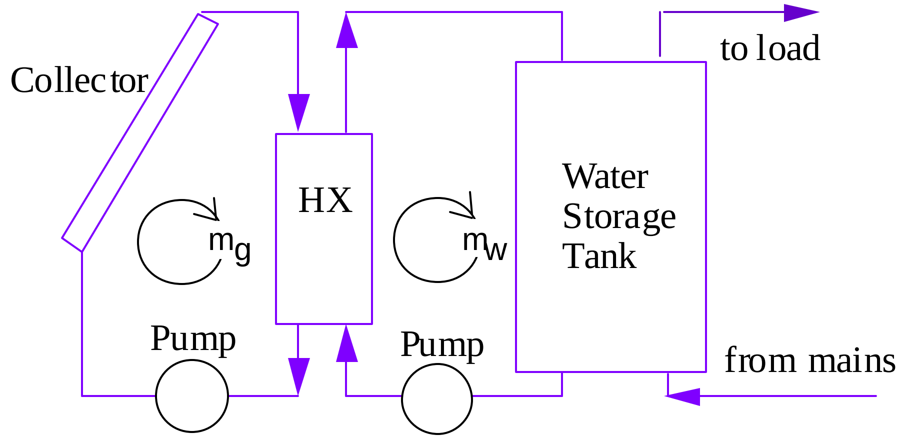


**Figure 1.2.1** Schematic of typical solar domestic hot water system.

In climates where freezing is a concern, a double loop SDHW system is generally used, as is shown in Figure 1.2.1. A 30 to 60 percent solution of propylene glycol in water is often used to take in thermal energy from the collector and transfer it to the water loop in a heat exchanger. The energy is then stored in a water storage tank, which is accessed by the hot water user. In double loop SDHW systems, pumps typically power both loops. The pumps are automatically turned on and off by a control strategy based upon temperature readings at the collector and the tank. Even though electricity is needed to power the two pumps and a controller, this SDHW system can still save energy. The energy consumed by the pumps and controllers can be small in a well designed system. An alternative is to use a small photovoltaic system to provide the necessary power. The introduction of photovoltaic panels to power the pumps removes the need for a controller and also removes parasitic pump and controller power costs, thus saving even more energy.

In order to reduce the system cost, the pump on the water loop could be eliminated, along with the photovoltaic panel that powers it. Instead the use of water's natural buoyant forces could be harnessed to transport the fluid in the water loop. Side-arm natural convection heat exchangers (NCHEs) were designed to allow this natural buoyancy to propel the water in place of a pump. It appears that NCHE systems could be the best for DSM policy in most of the country. Some NCHE systems have been shown to perform better than pumped systems (Bergelt et al. 1993). These systems provide freeze protection, lower start up costs, and less maintenance than the alternatives. Still, optimal design rules for NCHE systems have yet to be found.

## 1.2 Literature Review

Different methods of transferring heat from the glycol-filled collector to the water exist. Mantle heat exchangers, in which coils of hot glycol are wrapped around the water tank, promote better system performance than glycol-filled coils placed within the tank, as the mantle heat exchanger promotes better tank stratification (Furbo 1989). The disadvantages of such a system are that special water storage tanks must be used, adding extra cost to the consumer.

Sidearm heat exchangers are another method for transferring energy to the water. A sidearm heat exchanger is a separate unit that is placed beside the water storage tank, as shown in Figure 1.2.1. As sidearms deliver hot water to the top of the water storage tank, sidearm heat exchangers promote good tank stratification. Sidearms are also more useful for retrofits, as they can be used with any hot water tank. However a sidearm requires a pump to propel the fluid through the water loop, thereby increasing first costs, maintenance and cutting down on energy savings (Fraser 1992).

A NCHE is a sidearm heat exchanger in which the water is propelled not by a pump but through the process of natural convection. As the warmer fluid in the NCHE is less dense, and consequently lighter, than the cooler fluid in the tank, the water will move on its own. A properly-designed SDHW system employing a NCHE may be able to reap the benefit of the sidearm heat exchanger, i.e. good tank stratification, and ease in retrofitting, without penalty of the added pumping cost. Frequently NCHEs operate employing low glycol flow rates. Low flow systems allow for good tank stratification and reduced friction in the plumbing. Reduced flow rates in standard collectors can result in poor flow distribution and hot areas, which penalize collector performance, therefore low flow systems require specialized collectors.

NCHE systems are difficult to design. To promote water flow, large diameter pipes and few fittings should be used to cut down on shear pressure losses. Otherwise no means exist for helping in the design of an efficient NCHE system. Recently Bergelt et al. (1993), have found that cutting down on shear losses may, in some cases, actually decrease, rather than increase, system performance. Given a load, mains water temperature, and radiation data for a particular site, there is an optimum combination of glycol flow rate and shear pressure loss that will maximize system performance. As the collector flow rate increases, the optimum hydraulic resistance shifts to lower values. Too much shear pressure loss slows down the water flow rate, thereby inhibiting the heat transfer in the NCHE. As a result the collector temperature rises, causing the collector efficiency to drop. Too little shear pressure loss promotes higher water flow rates and therefore negatively affects tank stratification. Bergelt et al. show that an optimum combination of collector flow rate and hydraulic resistance exists. For a given load, location, array size and collector type, the optimal NCHE system is a function of piping (hydraulic resistance) and glycol flow rate.

In order to assist in designing an optimum NCHE system, simulation models have been written. In her work at Waterloo University, Fraser (1992) developed a model for a Canadian-manufactured NCHE for use in the WATSUN simulation program (year).

Fraser presents two sets of experimental data to check her model; data for a steady state case, and for a transient case. For both tests an electric heater controls the glycol temperature. Consider the steady state system of Figure 1.3.1. Fraser kept the tank water temperature constant at 19°C by replacing hot water in the tank with cold water. Each inlet glycol temperature resulted in a corresponding NCHE water flow rate and outlet temperatures.

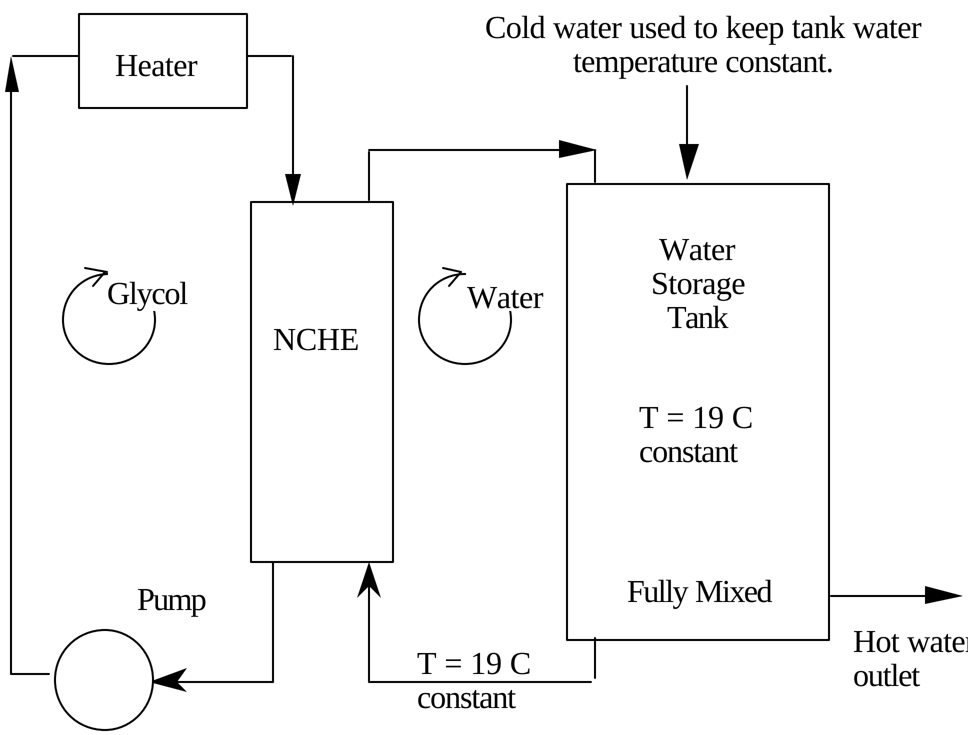


**Figure 1.3.1** Fraser's steady state experimental setup.

Consider the transient test in Figure 1.3.2. In contrast to the steady state test, Fraser's transient test allowed the tank temperature to vary. The heater was set for 70°C, and the system was allowed to run for six hours.

For the NCHE model Fraser requires as inputs experimentally derived curves of shear pressure loss of the heat exchanger (Figure 3.2.2) and the modified effectiveness of the heat exchanger (Figure

3.3.3), both as functions of water flow rate. These curves are discussed in detail in Sections 3.2.3 and 3.3.3 respectively.

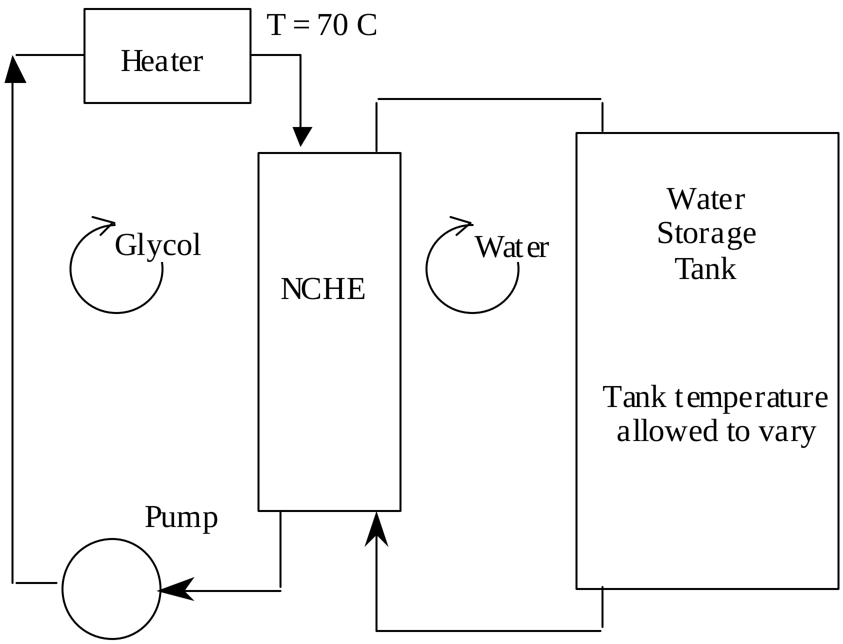


**Figure 1.3.2** Fraser's transient experimental setup.

A good NCHE design would include large heat transfer area and minimal obstructions to flow in order to reduce water-side shear pressure drop. Allen and Ajele (1994) have run steady state experiments on 11 different geometric variations of a shell and coil NCHE. The thermal performance of different sized coils and combinations of coils were each determined experimentally. Allen and Ajele found that the most significant geometric parameter that distinguished the different heat exchanger configurations was the dimensionless flow space, which is described in Section 4.3.3. Configurations with a large dimensionless flow space (especially small single coils) had low UA values and low modified effectivenesses, while configurations with small dimensionless flow spaces (combinations of coils) had large UA values and large modified effectivenesses. Results suggest that an optimal dimensionless flow space may exist for maximum heat exchanger performance. Allen and Ajele also present a heat transfer correlation for flow over vertically oriented helices in a vertical shell.

## 1.3 Objective

As Fraser has provided experimental data on a particular NCHE, and has developed a model, a TRNSYS model was written for the same NCHE and compared with Fraser's results. This model, termed the simple model, utilizes the same experimental curves reported by Fraser. However the simple model can work for any NCHE, as long as there are shear pressure loss and modified effectiveness curves available. The simple model is useful in testing SDHW system parameters, excluding the heat exchanger's design, in order to learn their effect on system performance. The simple model is also useful for comparing different NCHEs for which curves are available. The simple model is presented in detail in Chapter 3.

A second model was written to do away with the necessity of taking experimental measurements for NCHE shear pressure drop and effectiveness. This model, termed the detailed model, uses heat transfer correlations found in the literature to replace the experimental curves presented by Fraser. Consequently the detailed model is applicable to any shell and coil and concentric tube counterflow geometric configuration. This model is useful for learning the effect of heat exchanger geometric parameters on system performance. The detailed model can also be used to design an optimal NCHE. The detailed model is presented in detail in Chapter 4.

The objective of this work is to provide two computationally efficient TRNSYS models for a variety of NCHEs. The detailed model will then be used to understand the effects of various parameters upon the SDHW system performance. Based upon simulation results, an optimal NCHE design will be presented in Chapter 6.