Design, Simulation, and Analysis of Domestic Solar Water Heating Systems in Phoenix, Arizona

by

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ABSTRACT

Research was conducted to quantify the energy and cost savings of two different domestic solar water heating systems compared to an all-electric water heater for a four-person household in Phoenix, Arizona. The knowledge gained from this research will enable utilities to better align incentives and consumers to make more informed decisions prior to purchasing a solar water heater.

Daily energy and temperature data were collected in a controlled, closed environment lab. Three mathematical models were designed in TRNSYS 17, a transient system simulation tool. The data from the lab were used to validate the TRNSYS models, and the TRNSYS results were used to project annual cost and energy savings for the solar water heaters.

The projected energy savings for a four-person household in Phoenix, Arizona are 80% when using the SunEarth® system with an insulated and glazed flat-plate collector, and 49% when using the FAFCO® system with unglazed, non-insulated flat-plate collectors. Utilizing all available federal, state, and utility incentives, a consumer could expect to recoup his or her investment after the fifth year if purchasing a SunEarth® system, and after the eighth year if purchasing a FAFCO® system. Over the 20-year analysis period, a consumer could expect to save $2,519 with the SunEarth® system, and $971 with the FAFCO® system.

DEDICATION

This work is dedicated to my family,

Edouard, Nathalie, Sibylle, Benjamin, and Kayci,

who have given me the inspiration that has made this effort possible.

ACKNOWLEDGMENTS

The following people have assisted and influenced my work. I thank each one of them for the role they played in the completion of my thesis.

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CHAPTER 1

INTRODUCTION

Over the past decade, there has been a renewed interest in renewable and sustainable electricity generation. With the world's population and energy demands continuing to grow, citizens and governments have begun adopting long-term energy strategies and environmental restrictions. These policies are enacted due to several factors, including finite fossil fuel availability, increasing energy costs, and a renewed focus on environmental protection. In the United States, and specifically in Arizona, this has led to renewable energy mandates for electrical utilities [1]. In order to facilitate and promote new renewable energy targets, federal governments, state governments, and utilities offer tax rebates, credits, and other incentives to help companies and consumers make investments in renewable energy. One such incentive is for the replacement of electric- and gas-powered water heaters with solar water heating systems [2]. In order to accurately assign incentives and set cost saving expectations for its customers, utilities have begun testing and modeling solar water heating systems to determine their effectiveness.

1.1 Problem Statement

Currently, federal and state governments and local utilities provide financial incentives to install solar water heaters. These incentives, and the cost savings expectations of the consumer, are often based on national averages that may vary greatly in different geographic regions. As a result, utilities and consumers are often uncertain of the cost savings and payback periods of these investments, and may be left to rely on marketing materials or sales pitches. The objective of this research was to quantify the energy and cost savings of two different domestic solar water heating systems compared to an all-electric water heater. This was done for a four-person household in the Phoenix, Arizona metropolitan area. Using location-specific data, local Phoenix-area utilities will be able to better align incentives and consumers will be able to make more informed and accurate decisions.

1.2 Objectives

The following objectives will be the focus of this research:

- Quantify Phoenix-area hot water usage and environmental conditions for a four-person household
- Install three water heaters in a controlled lab environment and develop an automated water draw system
- Collect energy usage data on-site
- Develop a TRNSYS simulation for each water heater
- Validate TRNSYS energy usage outputs with lab results
- Use TRNSYS to quantify annual energy and cost savings of solar water heaters
- Provide recommendations for future research

1.3 Research Summary

The following research was conducted in order to determine the energy and cost savings of the two solar water heating systems compared to the all-electric control unit. First, the three water heating systems were installed in the lab. These were the Bradford White® all-electric heater, used as a control unit, the SunEarth® SolaRay™ solar water heating system, and the FAFCO® 500 Series solar water heating system. The water draw schedule, inlet cold water temperature, outlet hot water temperature, and ambient air temperature were controlled, and energy usage data was collected in the lab. Next, detailed technical specifications of the water heating systems, as well as the controlled water draw schedule and water and ambient air temperatures, were input into a transient system simulation software tool (TRNSYS). Performance ratings from the Solar Rating and Certification Corporation were also utilized for analytical modeling in the TRNSYS simulations. The data collected in the lab were then used to validate the TRNSYS models. Then, a separate set of TRNSYS models were developed using historical average Phoenix, Arizona water main and ambient air temperatures from the National Renewable Energy Laboratory database. The results of these models were used to determine annual energy savings. The forecast annual energy savings were then used to conduct an economic analysis, which determined the payback period as well as the total cost to operate the three water heaters over a twenty-year analysis period. The economic analysis was done with and without available federal, state, and utility incentives.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Solar Water Heating History and Overview

Consumers purchasing residential solar water heaters have several different types of technologies from which to choose. These different options can be segmented into two functional areas: circulation types and collector types. In order to effectively match a system to a residence and obtain the best results, it is imperative to understand the strengths and weaknesses of each system before making a selection.

2.1.1 Circulation Systems

There are two main types of circulation systems: the direct system and the indirect system. In the direct system, potable water flows directly through the collector. In the indirect system, a non-freezing heat transfer fluid (HTF) runs through the collector and then passes on its heat to the water through a heat exchanger.

The simplest form of circulation types is the direct system. In this system, water is circulated through roof-mounted solar collectors and is heated by the sun's energy. This heated water can be used directly or can be sent to a tank to be stored until it is used. Since the water is sent directly to the solar water collector, this type of system is at risk of freezing in cold climates, and can only be used in warm climates where freezing temperatures do not occur. Because direct systems are not protected from freezing, they are not very common.

Water in direct systems can be either actively cycled or passively cycled. In an active system, pumps are used to force water through the collectors. In a passive system, the hot water rising, through natural convection, will move the water from the collector to the storage tank as it heats up. With passive systems, it is recommended that the storage tank be at a greater height than the solar collector, or the system may not function effectively. It is also necessary to protect the hot water from moving from the storage tank back down to the solar collector when the sun is not shining. Because of this added uncertainty, consumers prefer the actively pumped method. In direct systems, a backup electric heating element or a natural gas water heater is generally used to keep the water at a set minimum temperature.

A passive, direct circulated system is depicted in Figure 1 below.

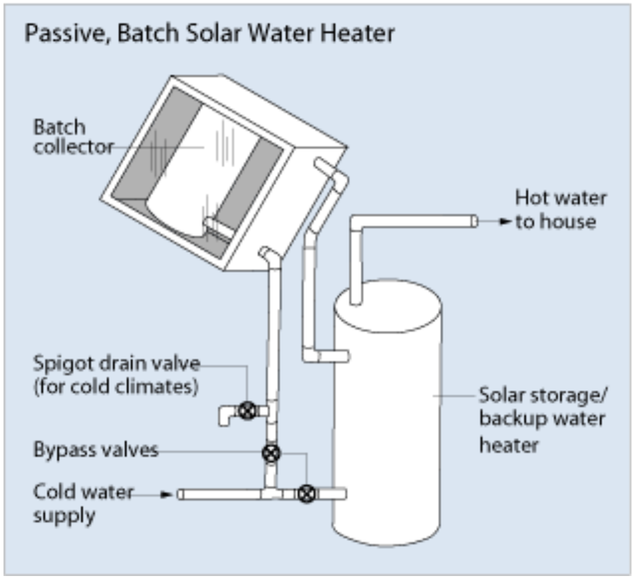

Figure 1. Direct System with Passive Circulation [3].

The second type of circulation system is the indirect, or closed-loop system. In climates where freezing does or may occur, it is necessary to utilize an indirect system. In this system, a non-freezing HTF is cycled through the collector instead of the potable water. The most commonly used fluid is a mixture of water and propylene glycol. It is recommended that the minimum amount of propylene glycol necessary to avoid freezing be used, as water is a better transfer agent of heat than propylene glycol [4]. After the HTF is heated in the collector, it passes through a heat exchanger and transfers its heat to the potable water. Then, the HTF continues its loop and returns to the solar collector to reheat. While the indirect system is necessary for climates where freezing temperatures occur, it also works well in hot climates. As in direct systems, a backup electric heating element or a natural gas water heater is generally used to keep the water at a set minimum temperature.

Indirect systems are configured with either one or two storage tanks. When configured with a single tank, the tank has one or two backup electric heating elements and a heat exchanger. The tank can also be heated with natural gas instead of electric elements. When configured with two tanks, the first tank is used as a preheat tank with a heat exchanger, and the second tank is used as a storage tank prior to use, and includes the heating elements. Water from the preheat tank will be used to fill the final storage tank, reducing the amount of heating required by natural gas or electricity.

The HTF in direct systems is typically actively cycled. A combination of electric pumps, valves, and controllers is necessary to force the HTF up to the solar collector and then back down to the heat exchanger. An active system is depicted in Figure 2 on the following page.

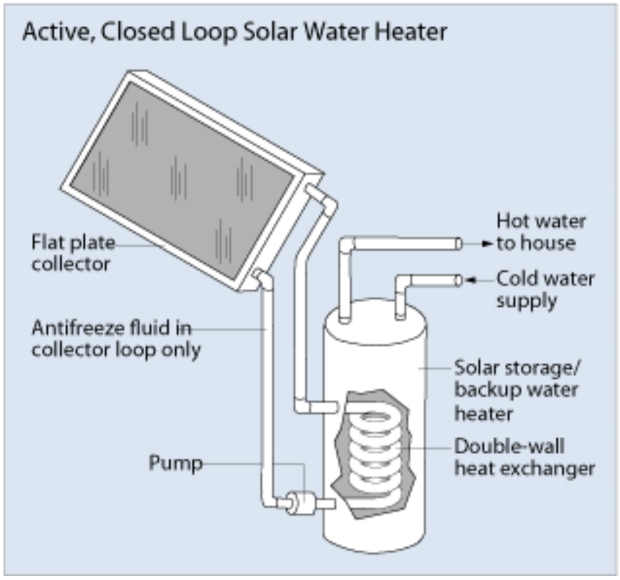

Figure 2. Indirect System with Active Circulation [3].

2.1.2 Collector Types

There are four main types of collectors used in domestic solar water heating systems. These are the batch collectors, glazed and insulated flat-plate collectors, unglazed and non-insulated flat-plate collectors, and evacuated tube collectors [4].

A batch collector, otherwise known as an integrated collector storage system (ICS), is only used in direct systems where the potable water is pumped directly through the collector. These systems do not have freeze protection, and therefore should not be used in cold climates where freezing temperatures occur. Batch collectors heat water in either dark tanks or in tubes placed in an insulated box. The water can remain in the collector until it is hot, or for extended periods of time. As a result, the water temperature can get dangerously hot, and the system should incorporate a tempering valve to mix in cold water which prevents scalding at the tap. The batch collector is depicted in Figure 3 on the next page.

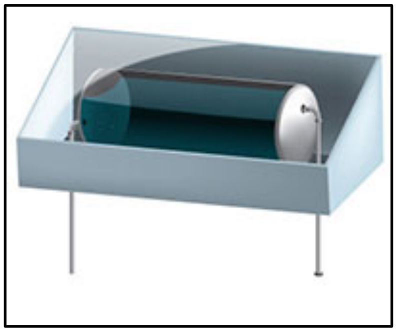

Figure 3. Batch Solar Collector [5].

Flat-plate collectors are the most commonly used collector type for domestic solar water heating [4]. A glazed and insulated flat-plate collector consists of an insulated rectangular box that is typically four feet wide by eight feet long, with a depth of approximately one-half foot. Inside the box is a series of copper tubes surrounded by flat absorber plates. The copper tubes are configured three to six inches apart and are connected at one end to an inlet pipe and at the other end to an outlet pipe. The water runs through the pipes inside the insulated box, which is covered by a glazed and tempered sheet of glass. In a direct circulation system, water runs through the collector, while in an indirect circulation system, the HTF will run through the collector. The insulation helps prevent heat loss due to convection and improves performance in cooler weather. A glazed flat-plate collector is depicted in Figure 4 on the following page.

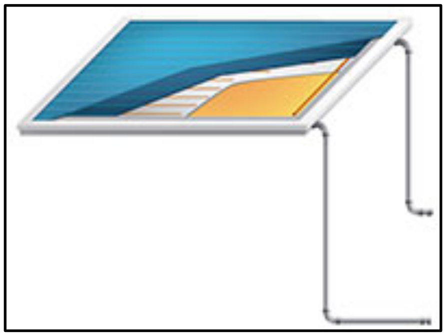

Figure 4. Glazed Flat-Plate Solar Collector [5].

Unglazed copolymer collectors are similar to the glazed flat-plate collectors, except that they are not encased in a box and are not insulated. They are comprised of proprietary plastics with ultra violet coatings which resist degradation caused by extreme temperatures and direct sunlight [6]. While most commonly used in direct circulation pool systems, this collector design is also used in indirect domestic solar water heating systems, which use an HTF. The collectors are black, unglazed, and configured in a web and tube extruded mat. At the top of the collector is a riser header, which is followed by riser tubes separated by a web. The collector ends at the bottom with another header. The fluid will flow from the top header, through the plastic tubes, down to the bottom header. Unglazed copolymer collectors have recently become popular in indirect domestic solar water heating applications due to their low cost of materials and simplicity. Unglazed and non-insulated collectors are less efficient in winter months than the glazed and insulated type, since the fluid loses heat when the outdoor ambient temperature is low or when wind increases convection losses around the collectors. An unglazed flat-plate collector is depicted in Figure 5 on the following page.

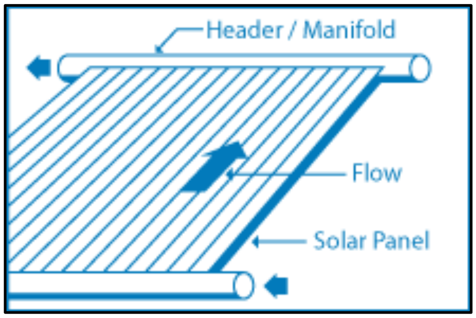

Figure. 5. Unglazed Flat-Plate Copolymer Solar Collector [6].

The fourth common design is an evacuated tube collector. These systems work by heating water or an HTF inside a glass or metal pipe, which is surrounded by a larger glass tube. The space between the inner tube and the outer tube is a vacuum, so very little heat will be lost. This heat retention potential is similar to a vacuum Thermos®. Since the tubes are well insulated, these systems can maintain high efficiency even in very cold conditions down to minus 40° F [4]. The downside of this highly efficient system is that it costs twice as much as a flat-plate collector. The evacuated tubes are also more fragile than a flat-plate collector, and may not be as aesthetically pleasing on a roof as the thinner flat-plate collector. Finally, since these systems are more fragile, they are not recommended in climates where significant snow may accumulate. In climates with minimal snow accumulation, these systems still need to be installed at higher angles than the roof, which reduces the amount of snow accumulation. An evacuated tube collector is depicted in Figure 6 on the following page.

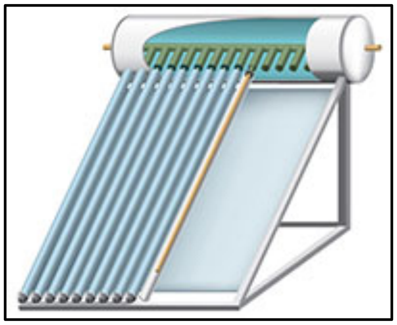

Figure 6. Evacuated Tube Solar Collector [5].

2.2 Solar Rating and Efficiency Corporation Ratings

In this thesis, performance ratings and specifications obtained from the Solar Rating and Efficiency Corporation (SRCC) were necessary for analytical modeling of the solar thermal systems using the TRNSYS software. The SRCC was incorporated in 1980 by the trade association for the solar energy industry and a national consortium of state energy offices with the goal of providing nationalized ratings for the solar thermal industry. Today, through a network of accredited testing facilities, the SRCC works as an independent agency to test and certify solar thermal components [7].

Certifications for the solar collectors are titled OG-100. The SRCC provides specific testing requirements under its Document OG-100, "Operating Guidelines for Certifying Solar Collectors," and its accompanying document, SRCC Standard 100, "Test Methods and Minimum Standards for Certifying Solar Collectors." Testing is done to determine both durability and performance. The test procedures for performance are specified by the American Society of Heating, Refrigerating, and Air Conditioning Engineers using the ASHRAE Standard 93, "Methods of Testing to Determine the Thermal Performance of

Solar Collectors," and ASHRAE Standard 96, "Methods to Testing to Determine the Thermal Performance of Unglazed, Flat Plate, Liquid Solar Collectors [7]."

Performance ratings are reported in either linear equations or quadratic equations. The more precise quadratic equations were used in the TRNSYS models, when available, in order to accurately reflect the changing efficiency slope [8]. The quadratic performance equation is below in Equation 1:

$$Performance = a_0 - \frac{a_1(T - T_{Amb})}{G} - \frac{a_2(T - T_{amb})^2}{G} \tag{1}$$

where:

a_0 is the dimensionless intercept parameter (dimensionless)

a_1 is the 1st order efficiency coefficient ($W/m^2 \cdot K$)

T is the heat transfer fluid temperature (C)

a_2 is the 2nd order efficiency coefficient ($W/m^2 \cdot K^2$)

T_{amb} is the ambient air temperature (C)

G is the total solar radiation incident on the collector (W)

When collector tests are performed on clear days at normal solar incidence levels, the transmittance-absorbance product is essentially the same as the normal incidence value for beam radiation. To account for variations, the intercept efficiency is corrected for non-perpendicular solar incidence by the use of incidence angle modifiers (IAM). The SRCC performs an incident angle modifier test to determine how the collector will perform over a varying range of sun angles, and these modifiers alter the efficiency curve to account for these changes in performance. For flat-plate collectors, two incidence angle modifier

(IAM) coefficients are given, which are represented as b_0 and b_1, and are based on Equation 2 below [8].

$$IAM = 1 - (b_0 * S) - (b_1 * S^2) \qquad (2)$$

where:

S is $1 / [\cos(Incidence\ angle) - 1]$

b_0 is the first order modifying factor (dimensionless)

b_1 is the second order modifying factor (dimensionless)

Using the above equations, combined with geographic parameters such as temperatures, latitude, and solar radiation data, the overall performance of the collectors can be modeled in TRNSYS in any location and in any environment.

CHAPTER 3

METHODOLOGY

3.1 Overview

The TRNSYS simulations and field study were both designed to mimic the average usage of a four-person household in the Phoenix, Arizona metropolitan area. Research was conducted to best estimate hot water temperatures and usage, and the results were used to design distinct water draws. All other parameters were set to simulate weather conditions in Phoenix, Arizona.

3.2 Water Heating Systems

Three different water heating systems were utilized in the study: an all-electric Bradford White® water heater, a SunEarth® SolaRay™ glazed flat-plate collector system with a single tank, and a FAFCO® 500-Series unglazed flat-plate collector system with two storage tanks. First, an overview of each system will be presented, followed by a detailed explanation of the solar collector technology.

3.2.1 All-Electric System Overview

The all-electric control unit was a Bradford White®, 50-gallon, 2-element electric water heater. The unit, model number M-2-50T6DS, includes automated temperature controls for its two immersed, copper screw-in elements. Each element is rated at 4,500 watts, and the two elements do not work simultaneously. The elements work in a master/slave relationship. If the top element is on, the bottom element will remain off. The system operates at 240 volts and a maximum of 4,500 watts. The inside of the tank features Bradford White's Vitraglas® lining to reduce the corrosive effects of hot water, and the outside of the tank is lined with two inches of non-Chlorofluorocarbon foam insulation [9]. In the lab and simulations, the water temperature was set at 125° F.

3.2.2 Glazed Flat-Plate Collector System Overview

The first solar water heating system was a SunEarth® SolaRay™ unit with a glazed flat-plate collector. The unit actively cycles the HTF through the solar collector using a single pump. The HTF consists of 30% DowFrost™ HD propylene glycol and 70% water, which keeps the fluid from freezing to 9° F. The SunEarth® system is a single tank unit with an 80-gallon capacity. The tank serves the dual purpose of preheating the water using solar thermal energy and heating the water using electric heating elements.

The tank includes a single 240-volt, 4,500-watt immersed copper element at the middle of the unit. The wrap-around coil heat exchanger is made of type L copper and is 5/8 inches in diameter and 120 feet in length. The coil is wrapped around the outside of the lower end of the tank and is double-walled and vented to ensure that leakage of the HTF does not contaminate the water inside the tank. The coil spans 24 inches of the tank, between two and 26 inches from the bottom. The capacity of the coil is 2.2 gallons [10].

The electronic unit, or differential temperature controller, utilizes temperature sensors to monitor the temperatures of the potable water in the tank and the HTF in the solar collector. The controller used was a SunEarth® model TR 0301 U. When there is usable heat in the HTF, the system turns on the pump to cycle HTF through the heat exchanger coil, which heats the water at the bottom of the tank. When usable heat is not available, the pump is turned off and the system’s water is heated by electricity through the electric heating element. The system is set to turn on when the temperature of the HTF in the rooftop collector is 16° F greater than the temperature of the water at the bottom of the tank. When the temperature difference falls below 8° F, the pump is turned off. Also, when the temperature of the water at the bottom of the tank reaches the set point (150° F), the pump is turned off. Once the water temperature has fallen 6° F below the maximum set point, the pump will resume, as long as the temperature differential between the collector and the water is still 16° F or greater. Finally, for safety purposes, the system will also shut off the pump when the HTF reaches 266° F. The system can be adjusted to have an on/off differential between 8 and 20° F and a maximum water temperature set point between 32 and 205° F [11]. In the lab and in simulations, the backup electrical heating element was set to keep temperatures in the tank at a minimum of 125° F. A diagram of the single tank system can be seen in Figure 7 on the following page.

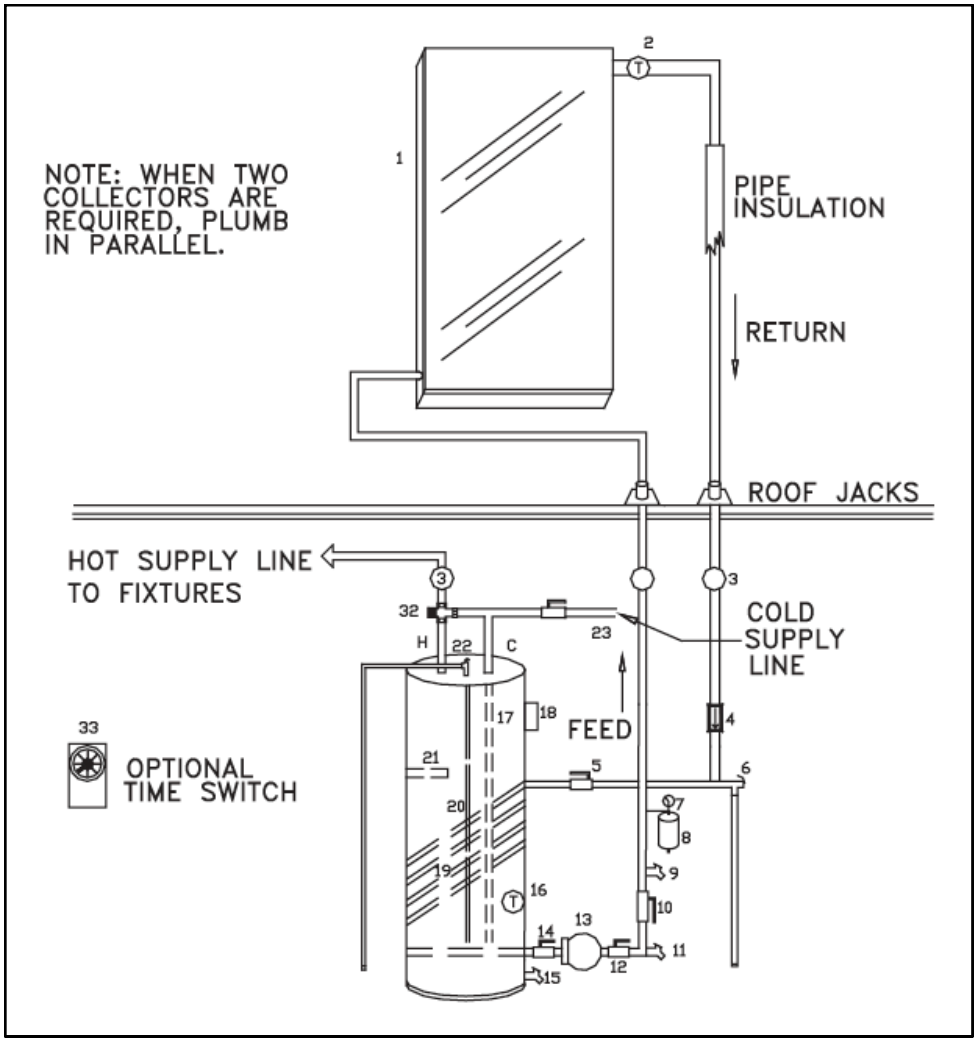

Figure 7. SunEarth® Single Tank Schematic [10]

3.2.3 Unglazed Flat-Plate Collector System Overview

The second solar water heater was a FAFCO® 500 Series dual-tank system. The system is an active-cycled system and uses an HTF consisting of 30% FAFCO®-branded propylene glycol and 70% water, which is sufficient to keep the system from freezing to 9° F. Both the preheat tank and the backup tank are 50-gallon Bradford White® tanks with the same model number as the all-electric experimental control unit. The preheat tank does not contain any electrical elements, but instead has affixed to it a FAFCO® Integrated Circulation Module (ICM) and heat exchanger. The second electric tank has two 4,500-watt heating elements, which are the same as the all-electric unit, which do not run simultaneously and utilize the same master/slave relationship.

Behind the ICM is an external heat exchanger made of 10 copper brazed plates inside a stainless steel enclosure. The HTF is pumped to the roof-mounted solar collectors and back down into the heat exchanger. The ICM will activate the HTF circulation pump and potable water circulation pump when the HTF on the roof is 10° F greater than the water at the bottom of the preheat tank. The system will deactivate the pumps when the HTF temperature on the roof is less than 4° F greater than the temperature of the water at the bottom of the tank. The ICM will also shut off the pumps once the maximum water temperature has been reached, which was set at 150° F, but can also optionally be set to 120° F or 135° F, depending on the requirements of the user [12].

Potable water is filled into the dual-tank FAFCO® system directly into the preheat tank. Water in the preheat tank is cycled through the heat exchanger, which preheats the water before it is pumped into the electric backup tank. When water is drawn from the electric backup tank into the household, hot water from the preheat tank is backfilled into the backup tank, minimizing the use of the electric heating elements in the backup tank. In the lab and simulation, the backup tank’s water temperature was set at 125° F. The dual tank setup can be seen in Figure 8 on the following page. The electric backup tank with heating elements is on the left, while the preheat tank with external heat exchanger and ICM is on the right.

Figure 8. FAFCO® 500 Dual Tank Setup [12].

Summary information for the three water heating systems can be seen in Table 1 below, and were taken from the manufacturer specifications sheets [9] [10] [12].

Table 1. Summary System Specifications

	Bradford White®	**SunEarth®**	**FAFCO®**
Model	Energy Saver Upright	SolaRay™	500 Series
System Type	All-electric	Solar w/ electric backup	Solar w/ electric backup
Solar Type	N/A	Indirect, active loop	Indirect, active loop
Product ID	M2-50T6DS-1NCWW	TE40P-80-1	AC-16UX3-50E-50S
Electric Tank	50 gal	80 gal	50 gal
Preheat Tank	N/A	Same as electric	50 gal
Electric Max Watts	4500 W	4500 W	4500 W
Solar Heat Exchanger	N/A	10 brazed copper plates in stainless steel enclosure, measuring 7.51” X 2.87” X 1.94”	120 ft of 5/8” double-walled copper tubing wrapped around tank

3.2.4 Glazed Flat-Plate Collector

The two solar water heating systems were purposefully chosen to reflect the most commonly used domestic solar water heater types and to demonstrate the differences in the two solar collector technologies. While both solar water systems use indirect, forced-circulation systems, they heat the HTF using very different types of collectors.

The SunEarth® collector is the more complex of the two collector technologies. The single, glazed flat-plate collector is comprised of a box insulated with polyisocyanurate and fiberglass. It is also covered with a glazed and tempered sheet of glass. Inside the box resides a series of copper tubes and plates. The HTF is pumped up to the copper riser tubes and manifolds, and flows through parallel copper pipes inside the insulated box. This type of insulated flat-plate collector allows the HTF fluid to rise to higher temperatures than can be obtained by the unglazed flat-plate FAFCO® collectors. The size of the collector is 48.125 inches wide by 122.25 inches long, with a depth of 3.25 inches. The capacity of the fluid in the collector is 1.3 gallons. SunEarth® claims the collector has a design life of 25 to 30 years [13].

The SunEarth® collector was installed parallel to the roof, with a 4/12 pitch, and faces directly south. A diagram of the collector can be seen in Figure 9 on the following page.

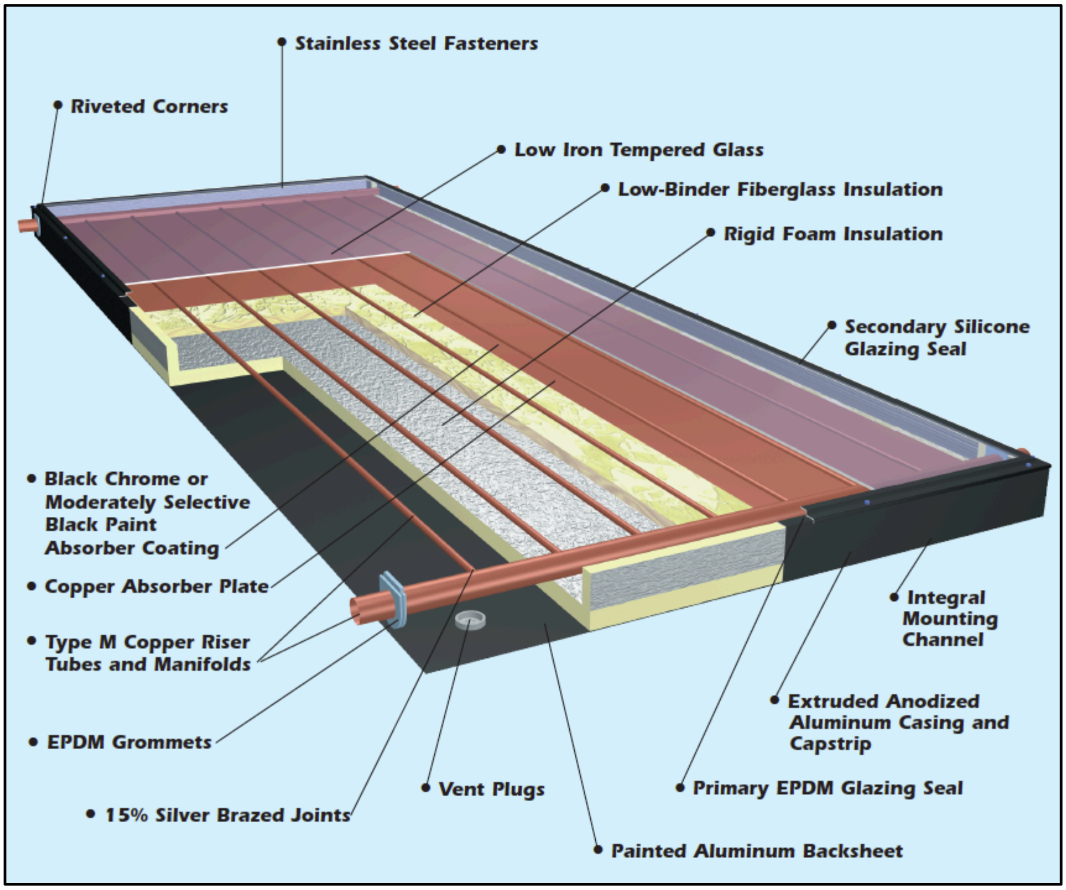

Figure 9: Diagram of the SunEarth® Flat-Plate Collector [13].

The quadratic performance equation from the SRCC for the SunEarth® solar collector is shown on the following page in Equation 3.

$$Performance = a_0 - \frac{a_1(T - T_{Amb})}{G} - \frac{a_2(T - T_{amb})^2}{G} \tag{3}$$

where:

a_0 is the dimensionless intercept parameter (0.718)

a_1 is the 1st order efficiency coefficient (2.29060 W/m^2·K)

T is the heat transfer fluid temperature (C)

a_2 is the 2nd order efficiency coefficient (0.04398 W/m^2·K^2)

T_{amb} is the ambient air temperature (C)

G is the total solar radiation incident on the collector (W)

The incident angle modifiers use the following formula:

$$IAM = 1 - (b_0 * S) - (b_1 * S^2) \tag{4}$$

where:

S is $1 / [cos\ (Incidence\ angle) - 1]$

b_0 is the first order modifying factor (0.322, dimensionless)

b_1 is the second order modifying factor (-0.031, dimensionless)

The flow rate used during the SRCC test was 72 kg/hr·m^2, with the test fluid being water at 1 kilogram per liter. The above parameters were also used in the TRNSYS model. A photo of the SunEarth® flat-plate collector is shown in Figure 10 on the following page.

Figure 10. SunEarth® Flat-Plate Collector

3.2.5 Unglazed Flat-Plate Collector

The FAFCO® system uses an uncovered and unglazed ultraviolet-stabilized copolymer solar collector; a material also commonly used for direct-circulation solar pool heaters. The three solar collectors run in parallel and are each eight feet long and two feet wide, with a thickness of 3/16 of an inch. The gross area of the collectors is 48 square feet, and the total combined capacity is 3.3 gallons. According to FAFCO®, the collectors have a corrosion and chemical resistance that is beyond that of any metal, and the panels are expected to last for over 30 years in situations where the temperature reaches not more than 200° F [14]. A vented bladder expansion reservoir is also installed at the top of the panels and can withstand up to 200° F at 1 psi.

As with the SunEarth® collector, the FAFCO® collectors were installed parallel to the roof, with a 4/12, or 18.43 degree, pitch. The collectors also face directly south.

The quadratic performance equation from the SRCC for the FAFCO® solar collector is:

$$Performance = a_0 - \frac{a_1(T - T_{Amb})}{G} - \frac{a_2(T - T_{amb})^2}{G} \qquad (5)$$

where:

a_0	is the dimensionless intercept parameter (0.887)
a_1	is the 1st order efficiency coefficient (22.61780 $W/m^2 \cdot K$)
T	is the heat transfer fluid temperature (C)
a_2	is the 2nd order efficiency coefficient (-0.17107 $W/m^2 \cdot K^2$)
T_{amb}	is the ambient air temperature (C)
G	is the total solar radiation incident on the collector (W)

The incident angle modifiers were set using the following formula:

$$IAM = 1 - (b_0 * S) - (b_1 * S^2) \qquad (6)$$

where:

S	is $1 / [cos\ (Incidence\ angle) - 1]$
b_0	is the first order modifying factor (0.322, dimensionless)
b_1	is the second order modifying factor (-0.031, dimensionless)

The flow rate used during the SRCC test was 250.9 $kg/hr \cdot m^2$, with the test fluid being water at 1 kilogram per liter. Since the unglazed and non-insulated flat plate collector available in TRNSYS did not utilize the quadratic equation in Equation 6 above, the linear Y intercept and linear slope were instead used. Both incident angle modifiers noted above were also used. The linear Y intercept used in the TRNSYS model was 0.882, while the linear slope was 18.858 W/m^2·K. A photo of the three FAFCO® collectors mounted on the roof can be seen in Figure 11 below.

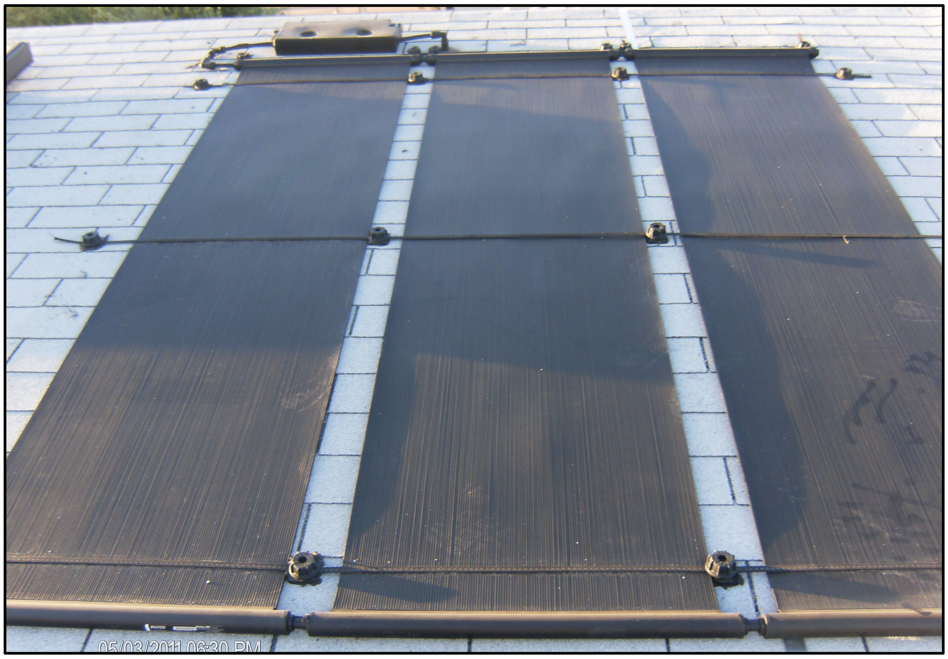

Figure 11. FAFCO® Flat-Plate Collectors

Table 2 below depicts the summary statistics of the FAFCO® and SunEarth® solar collectors, taken from the manufacturer spec sheets [10] [14].

Table 2. Solar Collector Specifications

	SunEarth®	**FAFCO®**
Collector Panel	Empire EP-40	Revolution – 08890
Solar Collector SRCC OG-100 Certification	2007032A	2007030B
Collector Type	Flat-plate with copper tube and plate and glazed glass cover	UV stabilized unglazed plastic polymer tube and web with no cover
Insulation	Polyisocyanurate and fiberglass	None
Gross Area (ft^2)	40.9	48
Net Aperture (ft^2)	37.1	48
Fluid Capacity (gal)	1.3	3.3
Fluid Type	30% DowFrost™ HD Propylene Glycol / 70% Water	30% Propylene Glycol / 70% Water
Installed Angle	18.43 degrees	18.43 degrees

3.3 Water Draws

The water draws were designed to be representative of the hot water usage of an average four-person American household. While many different reasonable scenarios for water draws can be created, it would not be feasible to model and compare them all. Instead, a distinct schedule of six water draws was created to represent average usage. According to research published by the NREL, day-to-day hot water usage has a standard deviation of around 60%, signifying usage levels are highly volatile and hard to model [15]. Furthermore, because inlet tap water temperatures vary by day and climate, water heaters are set to varying temperatures, and households use hot water at different temperatures, it would be impossible to define what a typical usage is for a four-person household. Because of the large amount of variables possible and their respective ranges, approximations were used in distinct schedules.

Instead of simulating each time a hot water tap was opened, the total water usage was combined into six distinct water draws. Research conducted at the University of Wisconsin determined that hot water usage peaks in the both the early mornings and early evenings. These peaks are caused by people bathing prior to work, and their use of hot water after work for washing dishes, washing clothes, or bathing. Since not all members of a household work a typical 8 am to 5 pm job, hot water is also used sporadically throughout the day. Total daily hot water usage in the University of Wisconsin research ranged between 60 and 70 gallons [16]. Finally, hot water draws will vary between weekdays and weekends, but in order to simplify the LabVIEW program used to collect data and the TRNSYS simulations, weekday and weekend draws were combined into a single daily average water draw schedule. The six water draws used in both the TRNSYS models and in the lab are shown in Table 3 below.

Table 3. Water Draw Timetable

Hot Water Draws at 110° F	
Time	**Gallons Drawn**
7:30 AM	22.5
1:00 PM	16.25
3:00 PM	2.5
6:00 PM	5
8:00 PM	10
10:00 PM	7.5

Hot water temperatures, which vary by usage type, also had to be modeled. In order to simplify the temperature of the hot water for the draws in TRNSYS and in the lab, a constant hot water temperature was used for all draws. Data compiled and published by the NREL shows that temperatures for clothes washers and dishwashers tend to be 120° F, while showers, baths, and sinks use mixed hot and cold water at about 105° F [15]. Therefore, in the TRNSYS models and in the lab, water was regulated in the storage tanks by electric elements to 125° F, and a thermostatic mixing valve was utilized to temper the hot water with cold tap water to 110° F for all hot water draws.

The temperature of the water from the city main lines was set at 70° F in the lab. This was set to a static temperature because the water was being recycled in a closed loop environment instead of being piped in from the city water main. In the TRNSYS simulations, true water main temperatures were imported from the NREL's database, which will be discussed further in section 3.4.2. The true water main temperature fluctuated based on the day and time of the water draw, accurately representing Phoenix-area temperatures.

3.4 TRNSYS Simulations

TRNSYS 17 was utilized to model the energy usage of the three water heating systems. Two separate simulations were run for each water heating system. The first set of simulations was designed to copy the exact environmental parameters used in the lab. Results from this set of simulations were compared to the data collected in the lab and were used to validate the TRNSYS models. The second simulation set was based on true historical temperature averages in Phoenix, Arizona. Results from this simulation set were used to estimate annual energy and cost savings. All simulations used the water draw profiles discussed in section 3.3, approximating the usage of a four-person household. All simulations also used historical averages for sunlight incident on the collectors.

3.4.1 Lab Environmental Specifications

When running the TRNSYS models for the first simulation set, the inlet water and ambient air temperatures were set to duplicate those in the lab. In the lab, the ambient air temperature was fixed at 77° F, so all ambient air parameters that affected heat loss in the tanks and piping were set to 77° F. It should be noted that the air conditioning unit in the lab was only able to cool, and not heat. While winter ambient temperatures will cause the temperatures in the lab to fall below 77° F, this was not the case during the period of data collection, since data was only collected during May and June, when night time temperatures do not drop below this level. Therefore, the ambient temperature stayed close to 77° F twenty-four hours a day. Temperatures were fixed at 77° F not to model real-world parameters, but instead to facilitate the comparison of

TRNSYS results to the data collected. Once the TRNSYS models were validated, separate models were utilized to model real-world temperatures.

Inlet water temperatures in the lab and in the first set of TRNSYS models were fixed to a constant 70° F. In the lab, this was done with a thermostatic mixing valve.

3.4.2 Phoenix Environmental Specifications

Weather data from the National Renewable Energy Laboratory were used to simulate average air and water temperatures and sunlight in the TRNSYS models. Specifically, the NREL's TMY3 weather data were utilized. TMY, or typical meteorological year, comprises data from the National Solar Radiation Data Base archives from 1961-1990, and 1991 to 2005 [17]. TMY3 is the most up-to-date data available, and the Phoenix Sky Harbor Intl AP 722780 file was utilized [18].

TMY3 data were used to set all weather parameters in the second set of models. They were used to set the inlet water temperature from the city water main. They were also used to set the ambient temperature of the air around the storage tanks and all piping and collectors. Finally, they were used to calculate solar radiation data incident on the solar collectors in both the first and second set of simulations. Since most water heaters in Arizona are placed outdoors in a garage, the ambient dry-bulb temperature was used instead of an artificial or static temperature, such as a controlled indoor temperature. This enabled TRNSYS to best estimate the energy used to heat the water and to calculate the heat lost to the environment over time. Figure 12 on the following page shows the TMY3 ambient air and water main temperatures in Phoenix, AZ, over the course of one year.

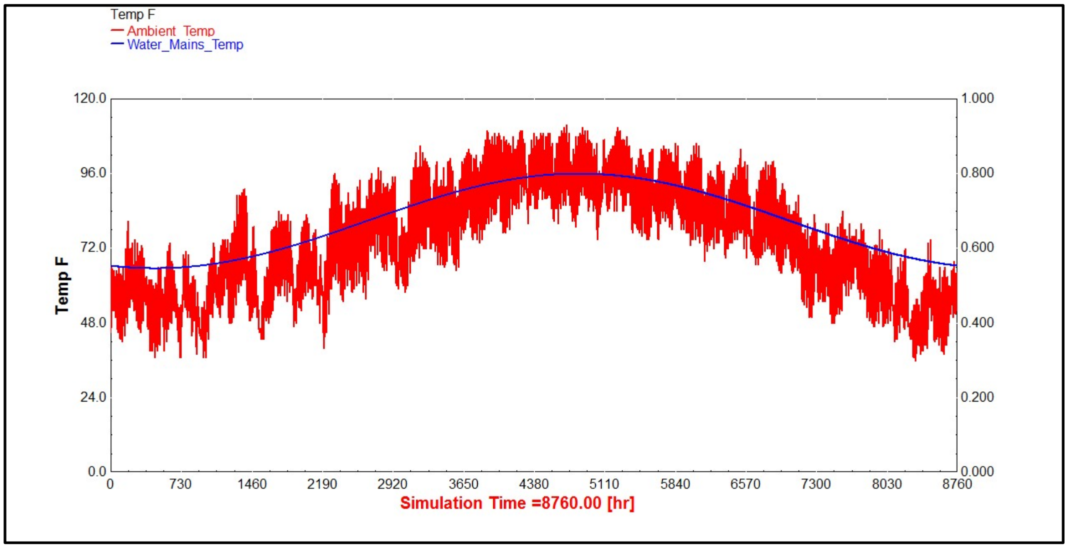

Figure 12. TMY3 Ambient Air and Water Main Temperatures in Phoenix, AZ [18].

3.4.3 Tank Heat-Loss Coefficients

Instead of utilizing the manufacturers' specified insulation values for the water storage tanks, tests were run in the lab to determine the specific heat transfer coefficient of each tank. Two tanks were tested: the all-electric tank, which is also the same tank used for both of the FAFCO® system tanks, and the SunEarth® tank. Water in the tanks was heated and then allowed to cool over time. Temperature measurements were taken every 30 minutes for 117 hours. This process was characterized by a dimensionless temperature, Θ, and was calculated at each temperature reading, using the following equation:

$$\Theta = \frac{T_{\text{water}} - T_{\text{room}}}{T_{w\_initial} - T_{\text{room}}} \tag{7}$$

where:

T_{water} is the temperature of the water at each time instance (°F)

T_{room} is the ambient air temperature in the room (65° F)

$T_{w\_initial}$ is the initial water temperature (°F)

The system was assumed to behave as a first order system with Θ approaching zero, as follows in Equation 8.

$$\Theta = e^{-t/\tau} \tag{8}$$

where:

t is the elapsed time from the initial start time (s)

τ is the average time constant from 6 to 48 hours (s)

Next, the time constant, τ, was calculated at each 30 minute interval, using the following formula:

$$\tau = -\frac{t}{ln(\Theta)} \tag{9}$$

where:

t is the elapsed time from the initial start time (s)

Θ is $\Theta = \frac{T_{\text{water}} - T_{\text{room}}}{T_{w\_initial} - T_{\text{room}}}$, as noted above

Then, the average time constant was taken beginning with hour six and ending with hour 48. Finally, the heat transfer coefficient was calculated, using the following formula:

$$Heat\ Transfer\ Coefficient\ = \frac{V*C}{\tau*\ \mathrm{SA}} \tag{10}$$

where:

V is the volume of the tank (L)

C is the fluid specific heat of water (4.186 kJ/kg·K)

τ is the average time constant from 6 to 48 hours (s)

SA is the surface area of storage tank (m^2)

The resulting heat transfer coefficients were 1.49 $W/m^2 \cdot K$ for the all-electric unit and FAFCO® tanks, and 0.75 $W/m^2 \cdot K$ for the SunEarth® tank, which reflects the observed better insulation of the SunEarth® tank.

3.4.4 System specifications

The specifications of all three water heating systems were carefully documented and entered into TRNSYS. This included the diameter, length, thickness, density, material, specific heat, and conductivity of all tanks, pipes, and insulation. Fluid specifications, such as density, thermal conductivity, viscosity, and expansion coefficients were also documented for each type of fluid and were temperature dependent. The specification of the pumps, heat exchangers, and control units were also used in the TRNSYS programs. These detailed specifications, which were used in the TRNSYS input files, can be seen in their entirety in Appendices 2-4.

3.5 Field Experiment and Data Collection

In order to validate the TRNSYS simulations, a field study was conducted to collect data. A prior Capstone Team at Arizona State University, in partnership with Salt River Project, installed a shed with the three water heaters, created a closed system environment, and coded a computer program in LabVIEW 2011 to run the field experiment. The design of the laboratory experiment is detailed below.

3.5.1 Physical Layout

The field experiment was located in the Phoenix, Arizona suburb of Mesa, on Arizona State University's Polytechnic campus. A 10 foot by 24 foot Tuff Shed® was installed at this location. The roof pitch of the Tuff Shed® is 4/12, or 18.43 degrees, and the sloped roof faces directly south for optimal sun orientation. Insulation was installed inside the Tuff Shed® on the walls and ceiling and a wall-mounted air conditioning unit provided cooling and temperature control.

The three water heating units were installed in the Tuff Shed®, and the solar collectors for the two solar water heaters were installed on the roof of the shed at the same 4/12 pitch.

3.5.2 Water Circulation

In order to recycle the water used at the site, a closed-loop water circulation system was designed and installed. This was done to avoid having to take in city water each time a water draw was initiated. Water was drawn into the system only once to fill the four storage tanks from the three water heating systems and the two water storage drums used to store recycled water. A complete system diagram can be seen in Figure 13 below.

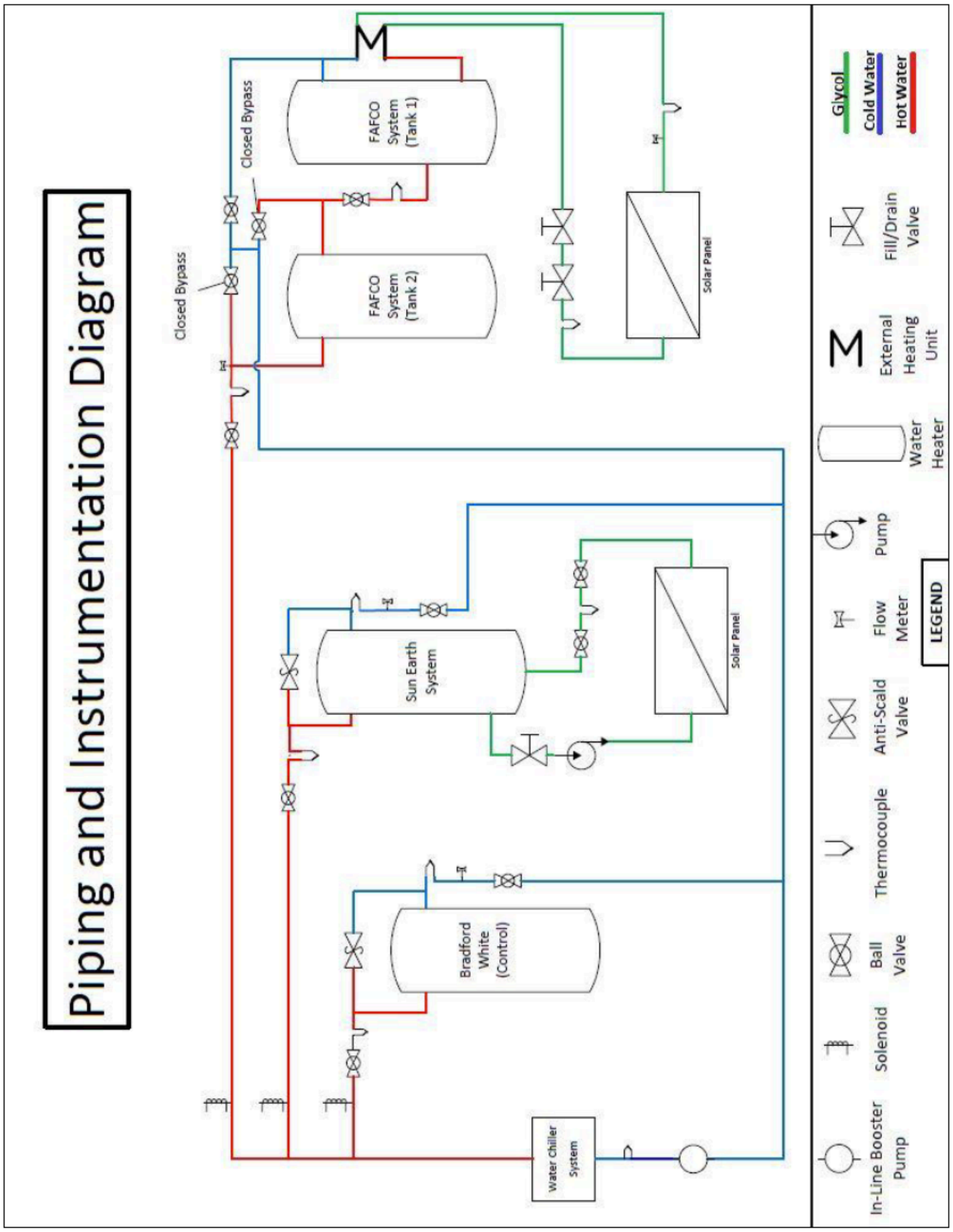

Figure 13. Piping and Instrumentation Diagram of Three Heating Systems.

The water began in a 55-gallon plastic drum located on the ground next to the Tuff Shed®. Hot water that exited the water heaters during scheduled draws was pumped to this outdoor drum for storage until more water was needed inside the system. A photo depicting the hot-water storage and inline pump can be seen in Figure 14 below. All of the pumps used in the system were Intex® Krystal Clear™ model 637R filter pumps, which run continuously. The pumps are rated to move 1,000 gallons per hour. Since the pumps ran continuously, the flow of water was managed by the opening and closing of valves, which was handled by the LabVIEW software.

Figure 14. External Hot-Water Storage Tank and Circulation Pump.

Water from the hot-water storage tank was then pumped to a Y pipe that sent the water either to the chiller system or bypassed the chiller system and headed directly towards the thermostatic mixing valve (see Figure 15 on the following page). Hot water that had entered the chiller was then pumped into the 50-gallon cold-water storage tank. After the water exited the cold-water storage tank, it came to a Y pipe and was either recirculated through the chiller to continue cooling, or was pumped to the thermostatic mixing valve. Water in the cold-water storage tank was continuously recycled through the chiller, and the chiller was set to 56° F. Once the water had reached the set temperature, it continued to cycle through the chiller, but it was not cooled further. At the thermostatic mixing valve, which was the entrance point for the water to reenter the water heating storage tanks, the chilled water from the indoor cold-water storage tank met with hot water from the outdoor hot-water storage tank, which had bypassed the chiller, and passed through the mixing valve set at 70° F.

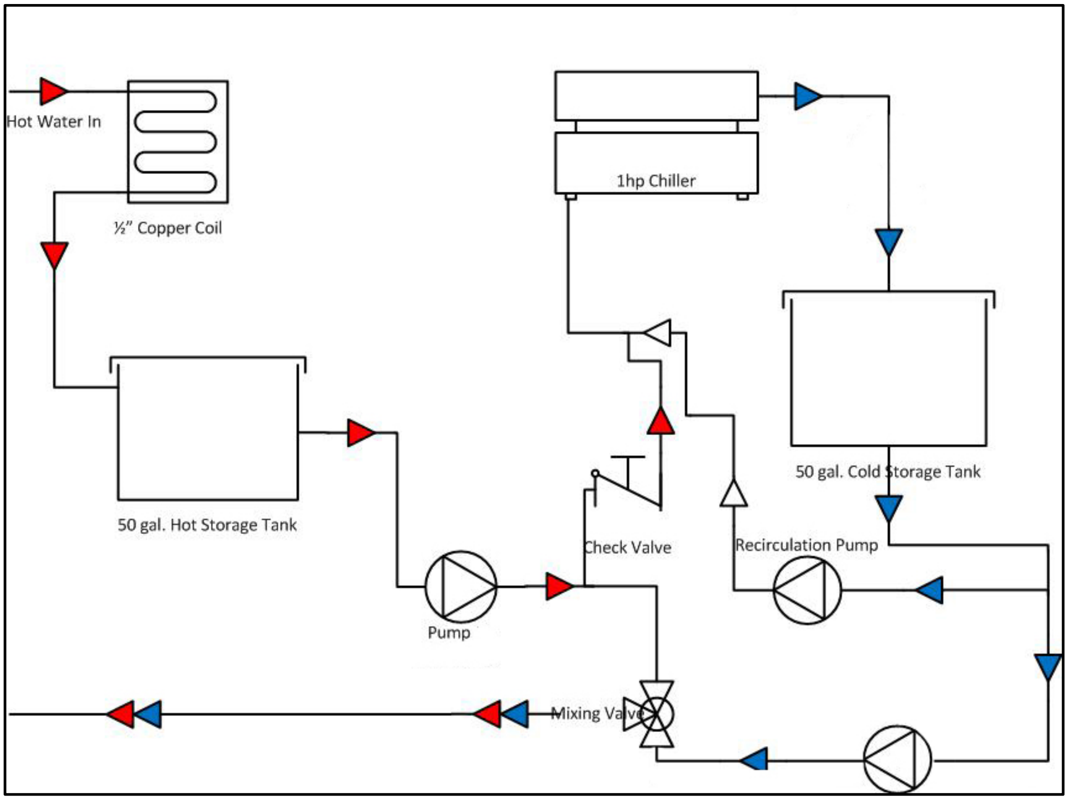

Figure 15. Chiller Diagram.

A photo of the cold-water storage tank and the chiller system can be seen in Figure 16 on the following page. The drum is on top, covered in R-13 insulation, and the black chiller is below, connected via tubing and two continuously running Intex® pumps.

Figure 16. Cold-Water Storage Tank and Chiller.

When the LabVIEW program specified a hot water draw, a valve opened to enable water to be drawn out of the tank, and this water exited through a pipe on the north side of the shed. The water then flowed through 15 feet of copper coils to begin cooling, and came to its final storage location inside the outdoor 55-gallon hot-water storage tank. At this point, the water was allowed to cool to near ambient temperature.

3.5.3 LabVIEW Software and Hardware Components

A LabVIEW program was written to control the water draws, track the inlet and outlet water temperatures of each system, and record the amount of electricity utilized by the three water heating systems. Electricity usage included the electric heating elements, the single SunEarth® pump, and the two FAFCO® pumps. Data was compiled and exported each day.

LabVIEW accomplished this task through the use of data acquisition components (DAQs), temperature sensors, flow meters, and energy meters. The DAQ components utilized were a National Instruments™ (NI) USB-9213 16-Channel USB Thermocouple Measurement Module, an NI 9263-4 4-Channel Analog Output Module, an NI 9201 8-Channel Input Module, an NI 9411 6-Channel Digital Input Module, and an NI 9474 8-Channel Sourcing Digital Output Module. The temperature sensors used to measure the inlet and outlet water temperatures at each unit were Omega Engineering® pipe plug thermocouples, model TC-J-NPT-G-72. The flow meters used to measure water draws were Omega™ turbine style flow meters, model FTB4605. Finally, the energy meters utilized were inductive analogue current sensors by Honeywell®. The model number for the units was CSLT6B100.

Each day, the water and HTF temperatures and energy used by the three water heaters and solar pumps were exported to an Excel file.

3.5.4 Data Collection

Data was collected for one system at a time. Simultaneous data collection for all three systems was not possible due to the power limitations of the pumps and the chiller system. The original goal was to collect data from the winter solstice on December 22, 2011 to the summer solstice on June 20, 2012, but this was not possible due to multiple challenges. The two largest issues with the design of the system included the flow rate limitations of the pumps and the capacity of the chiller system. In addition, there were serious equipment malfunctions with one of the installed systems.

Originally, the LabVIEW program was designed to run all three systems at once. During testing, the team realized that the pumps were not powerful enough to provide a significant flow to all three systems simultaneously. The flow rate was so low at times that not enough water would flow through each system to meet the total draw volume requirement prior to the next water draw beginning. In situations where one water draw began before another was completed, the latter water draw was skipped by the LabVIEW program. At other times, air pockets in the pipes brought the flow rate to zero, and the pumps had to be manually purged.

The second issue was that during the longest water draws, hot water entering the cold-water storage drum overwhelmed the chiller, and the targeted 70° F at the thermostatic mixing valve could not be achieved. Once the water in the cold-water storage tank exceeded 70° F, the mixing valve would not let sufficient water through and the flow rate dropped to nearly zero.

Finally, data collection was halted until all three systems were fully operational. The FAFCO® system did not run properly for the first several months, until warranty repairs were completed. Several components were replaced during warranty visits, including the collectors, pumps, and ICM control unit. In the end, it was determined that the ball bearing in the HTF loop check valve was of improper size, and would stop the flow of HTF. Once this ball bearing was replaced, the system functioned and data collection was resumed.

In order to collect accurate data, the LabVIEW program was modified to only run one water heating system per day. Data for each system were collected between May 23 and June 13, 2012. The data were collected in 24-hour increments in order to determine the energy usage of one full day.

CHAPTER 4

RESULTS

4.1 Lab Results

Data were collected in the lab from late May through early June, and only on days with sunny skies. While long-term data has not yet been collected (and will be the subject of future research), a sample set of data was obtained to validate the TRNSYS models. The average daily energy usage was 10.30 kilowatt-hours for the all-electric system, 0.71 kWh for the SunEarth® system, and 1.56 kWh for the FAFCO® system. The average daily amounts of energy used by the auxiliary pumps and single electric element for the SunEarth® system were 0.23 kWh and 0.48 kWh, respectively. The average daily amounts of energy used by the two auxiliary pumps and the two electric heating elements for the FAFCO® system were 0.21 kWh and 1.35 kWh, respectively.

During hot summer days in Mesa, Arizona, very little energy was used by the solar systems. To reiterate, the ambient temperature in the lab was controlled at a constant 77° F, and the simulated incoming water main temperature was set at a constant 70° F. Using actual data, the warmer water and ambient temperatures would result in even less energy usage, but were the subject of the second set of TRNSYS simulations, which are discussed in section 4.3. A summary of the data collected in the lab is shown in Table 4 on the following page.

Table 4. Lab Results

Energy Usage in kWh							
	All Electric	SunEarth®			FAFCO®		
Date	**Element**	**Pump**	**Element**	**Total**	**Pumps**	**Elements**	**Total**
5/23/12	10.04						
5/25/12	10.57						
5/30/12		0.18	0.25	0.43			
5/31/12		0.17	0.22	0.39			
6/2/12					0.17	0.15	0.32
6/8/12		0.33	0.54	0.87			
6/9/12		0.26	0.89	1.14			
6/10/12					0.23	1.43	1.66
6/11/12					0.25	2.96	3.22
6/13/12					0.20	0.86	1.07
Daily Average	10.30	0.23	0.48	0.71	0.21	1.35	1.56
Monthly Total	**309**	**7**	**14**	**21**	**6**	**41**	**47**

4.2 Data Validation of TRNSYS Models

The average daily energy usage in the first set of TRNSYS models from the months of May and June was compared to the lab data collected on site. In order to match the lab environments, the first set of TRNSYS models fixed the inlet water temperature to 70° F and the ambient temperature to 77° F. The results of the TRNSYS simulations for the months of May and June are shown in Table 5 below.

Table 5. TRNSYS Simulation Set One Results

TRNSYS Results (kWh per month)			
	May	**June**	**May/June Avg**
All-Electric	234	242	238
SunEarth®	12	14	13
FAFCO®	55	53	54

In order smooth out daily temperature and sunlight fluctuations, daily results from the lab were averaged, and then extrapolated to a full month. The extrapolation was necessary because a full month's worth of data was not available. This extrapolated average monthly data from the lab was then compared to an average full month of electricity usage from TRNSYS. The TRNSYS energy-usage average of the full months of May and June was used for comparison. This was done instead of comparing unique days (i.e. June 5 in TRNSYS to June 5 in the lab), because TRNSYS cannot predict the exact temperatures and cloud coverage on a particular day, and instead, uses long-term averages. A comparison of the monthly results from the lab and TRNSYS, as well as the differences, can be seen in Table 6 below.

Table 6. Validation of TRNSYS Results with Lab Data

Electricity Usage per Month (kWh)			
	Lab	**TRNSYS**	**Difference**
All-Electric	309	238	71
SunEarth	21	13	8
FAFCO	47	54	(7)

The results of the TRNSYS models were reasonably close to the collected lab data since some variances were observed. There are several factors that would have caused these variations. First, the temperature of the incoming water in the lab was set by a thermostatic mixing valve, which was not accurate enough to keep the temperature at a constant and exact 70° F, as was done in TRNSYS. The same can be said for the mixing valves regulating the hot water exiting the tanks. While the mixing valves were set as close to 110° F as possible, the actual temperature fluctuated by up to ten degrees Fahrenheit in each direction. The temperature of the ambient air inside the lab also fluctuated by +/- 4° F from the air conditioning unit’s set temperature of 77° F. This was due to the deadband of the thermostat and the difficultly of the air conditioning unit to quickly cool the room after the door had been opened. Finally, the outdoor ambient temperatures and sunlight experienced in Phoenix at the time the data were recorded may not have been equal to the average temperatures and solar radiation data used in the TRNSYS models, which are based on long-term averages. Overall, the results of the lab were very close to that of TRNSYS, and further research with more data will aid in supporting this claim.

4.3 Full-Year TRNSYS Analysis

A second set of TRNSYS 17 simulations were used to estimate the annual energy consumption of the three different water heating systems. In the second set of TRNSYS simulations, the fixed inlet water temperature and ambient air temperatures were replaced with data from the TMY3 weather data files, as seen in Figure 12 on page 30. For the all-electric system, energy usage (in units of kilowatt-hours) was recorded for each of the two elements. For the SunEarth® system, energy usage was recorded for the single electric element and for the single HTF circulation pump. For the FAFCO® system, energy usage was recorded for the two electric elements in the electric backup tank, for the HTF circulation pump, and for the potable water circulation pump. Power was recorded in one minute intervals and energy usage was calculated by integrating these power curves. A summary of total energy usage per month for each unit is displayed in Table 7 on the following page. The '% Saving' row represents energy savings (in kWh) of the solar water heating systems compared to the all-electric system.

Table 7. TRNSYS Energy Usage Results

Energy Usage by Month (kWh)			
Month	**All-Electric**	**SunEarth®**	**FAFCO®**
January	294	119	217
February	249	71	167
March	250	41	152
April	196	16	80
May	159	10	53
June	113	7	11
July	101	6	8
August	111	7	13
September	137	8	28
October	188	16	85
November	231	42	151
December	280	112	217
Annual Total	**2,310**	**453**	**1,182**
% Saving	**0.0%**	**80.4%**	**48.8%**

In Phoenix, the SunEarth® system is projected to use only 19.6% (80.4% savings) of the energy of an all-electric system. The FAFCO® system is projected to use 51.2% (48.8% savings) of the energy of the all-electric system. The abundance of sunlight and cloudless days in Phoenix, combined with the warm temperatures of the inlet tap water and high ambient temperatures, allow the solar systems to work very effectively. The all-electric system in the same environment also reaps the benefits of the high ambient and inlet water temperatures, but cannot take advantage of the sunlight.

As seen in Figure 17 on the following page, the FAFCO® system runs nearly as efficiently as the SunEarth® system during the hottest summer months between June and September. But, during cooler months with less sunlight, its efficiency drops significantly.

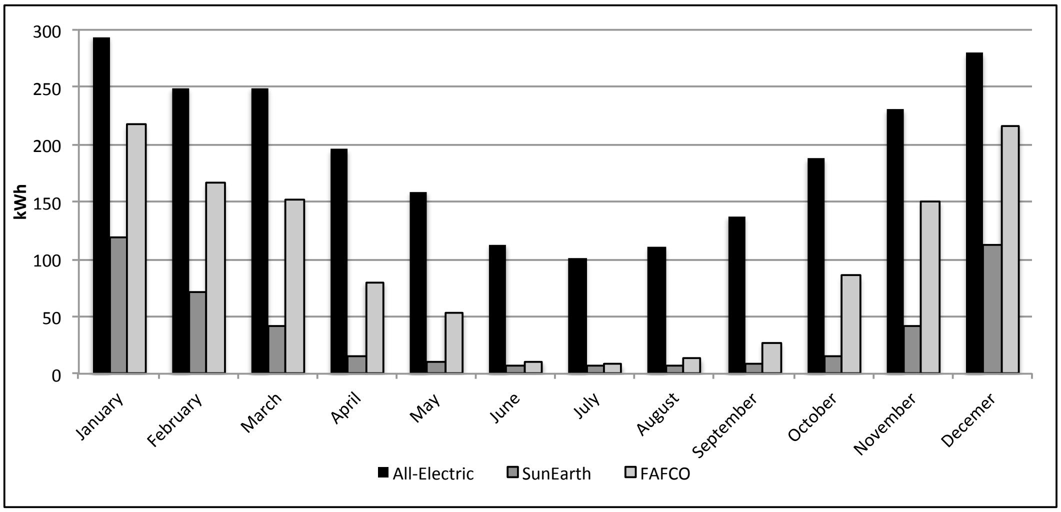

Figure 17. TRNSYS Projected Monthly Energy Usage.

There are four main factors that lower the efficiency of the FAFCO® system as compared to the SunEarth® system. The first and most important factor is that the FAFCO® system uses unglazed collectors that are not insulated. During hot summer months, when ambient temperatures exceed 100° F during solar operation, the lack of insulation is not as important. However, in cooler months, the heat lost due to the lack of insulation decreases the efficiency. Even during the summer months, the insulated collectors of the SunEarth® system allow for the temperatures of the HTF on the roof to remain much hotter in the late afternoon than for the FAFCO® system. This means that at 5 PM, the HTF of the SunEarth® system is still heating the water, while the FAFCO® system has already shut off its pumps. Also, the convective cooling effects of wind chill are stronger on the non-insulated collectors.

The second factor is that the FAFCO® water storage tanks are not as well insulated as the SunEarth® tank. The single SunEarth® tank has a heat transfer coefficient of only 0.75 $W/m^2 \cdot K$, while the two FAFCO® tanks have a heat transfer coefficient of 1.49 W/m^2·K, enabling more heat to be lost to the environment.

The third factor is that the FAFCO® system has a greater exposed surface area over its two tanks. The surface area of the SunEarth® system's single 80-gallon tank is 3.54m^2, while each of the two FAFCO® 50-gallon tanks have a surface area of 2.74m^2, combining for a total of 5.47 m^2. The combined factors of lower insulation and greater surface area result in increased heat lost from the FAFCO® system.

Finally, in the FAFCO® system, having two tanks also means that after water is transferred from the preheat tank to the backup tank, it can no longer be kept warm or reheated using solar energy. If the hot water transferred from the preheat tank to the backup tank is not used quickly, it must be kept warm using the two electric elements. Therefore, the FAFCO® tank is more efficient when water is consistently used, and is less efficient when water is stored for extended periods of time. On the other hand, the SunEarth® system's single tank can continuously heat the water using solar energy, and must only use its electrical element when the solar loop is not running or is insufficient to heat the tank to the specified temperature.

4.4 Economic Analysis

In order to determine the lifecycle cost of each individual system, initial capital, replacement and maintenance costs, and operating (fuel) costs were compiled. Quotes were requested from local dealers to determine the initial installed cost of the systems and recommended service intervals. The initial and replacement costs of the systems include both parts and labor costs. For the cost of electricity consumed, current rates from Salt River Project were utilized, and future rates were forecast using information from the U.S. Energy Information Administration (EIA).

Maintenance and repair work are pertinent in the cost estimates. Regular water flushes are necessary to rid the tank of deposits that can reduce the lifetime of the storage tanks. The all-electric system will have its electric heating element and sacrificial anode rod replaced every four years at a cost of $10 for the 4,500-watt heating element and $25 for the sacrificial anode rod. A surcharge of $75 per visit was added to pay a plumber to come perform the work. Due to the labor charge, some trips were combined if separate maintenance items happened on consecutive years. Only the bottom heating element would be replaced, as it is used the majority of the time, and it was deemed that the top element would survive until the full tank replacement. The entire all-electric water heating tank would need to be replaced after eight years of use.

The SunEarth® system would also have its sacrificial anode rod replaced every four years at a cost of $25, plus $75 for labor. The heating element would only be replaced every eight years, instead of four, because its use would be much less than that of the all-electric tank. The storage tank would need to be replaced on the 15th year, at an installed cost of $1,200. All piping and collectors are projected by the manufacturer to survive the duration of the 20-year analysis period.

For the FAFCO® dual tank system, the sacrificial anode rods would also be replaced every four years, on each tank, at a combined cost of $50 for the two tanks plus $75 for labor. The heating element would be replaced on the electric tank every eight years, similar to the SunEarth® system. Again, the replacement cycle is longer than that of the all-electric tank because the element would not be used as often. Also, only the bottom element would need to be replaced, as it is the element doing the majority of the heating, and the top element only turns on during periods of lengthy hot water draws. The electric tank would be replaced after ten years, and the preheat tank would be replaced on the 15th year. The cost of replacing the tanks is the same as the all-electric tank, and is $785, including the cost of installation. For the preheat tank, the heating elements are removed prior to use. The manufacturer expects the collectors and piping to be maintenance-free for the duration of the 20-year analysis period.

A twenty-year period was utilized for the cost projections, as both the SunEarth® and FAFCO® systems are projected to last at least this long. No discount rate or inflation rate was used because the discount rate is nearly equal to the inflation rate, cancelling each other out. This is a conservative assumption that removes the burden and uncertainty of projecting 20 years of risk-free rates and inflation rates.

Electricity rates were taken from SRP's current rate tables for the Basic Plan as of June 2012. The rates change depending on the month of the year and the amount of kilowatt-hours used in a given month. Tier 1 rates are for the first 700 kilowatt-hours used, and Tier 2 rates are for the 701 to 2,000 kilowatt-hours used. Because the projections are for a four-person household in Arizona, a blended rate was used, which weights Tier 1 prices at 50%, and Tier 2 prices at 50%. The prices used are shown in Table 8 below [19].

Table 8. Electricity Rates by Month and Tier

Electricity Rates per Kilowatt-Hour				
Tier	**kWh Range**	**May – June** **Sept – Oct**	**Jul – Aug**	**Nov - Apr**
Tier 1	First 700 kWh	10.10 ¢	10.64 ¢	7.80 ¢
Tier 2	701-2,000 kWh	10.93 ¢	11.41 ¢	7.80 ¢
Tier 3	> 2,000 kWh	11.62 ¢	12.12 ¢	7.80 ¢
Blended	0 – 2,000 kWh avg.	10.52 ¢	11.02 ¢	7.80 ¢

While local Arizona residential electricity rates rose at an annualized rate of over 3.5% between 2002 and 2008, an annual rate increase of 0% will be utilized for future projections [20]. According to research published by the U.S. Energy Information Administration (EIA) in its 2012 Annual Energy Outlook, electricity rates are not projected to increase between now and 2035. The falling price of natural gas, often used to set wholesale prices, will offset the expected increased prices of coal and renewable energy, and result in a relatively steady price over the next 13 years. The EIA projects electricity prices in 2035 to average 9.5 cents per kilowatt-hour, as compared to 9.8 cents per kilowatt-hour in 2010 [21]. Because these prices are so similar, and are based on many assumptions, for the purpose of this paper, it will be assumed that electricity prices will remain flat for the duration of the analysis period.

Tables 9, 10, and 11 on the following pages show the cost of the all-electric, SunEarth®, and FAFCO® systems, respectively, over twenty years. These costs include materials, labor, and the annual cost of electricity. These tables represent the costs prior to federal, state, and local utility incentives.

Table 9. All-Electric System Costs Prior to Incentives

Year	Capital Cost	Electricity	Annual Cost	Running Cost
1	$785	$203	$988	$988
2		$203	$203	$1,191
3		$203	$203	$1,395
4		$203	$203	$1,598
5	$110	$203	$313	$1,911
6		$203	$203	$2,114
7		$203	$203	$2,318
8		$203	$203	$2,521
9	$785	$203	$988	$3,509
10		$203	$203	$3,712
11		$203	$203	$3,916
12		$203	$203	$4,119
13	$110	$203	$313	$4,432
14		$203	$203	$4,635
15		$203	$203	$4,839
16		$203	$203	$5,042
17	$785	$203	$988	$6,030
18		$203	$203	$6,233
19		$203	$203	$6,436
20		$203	$203	$6,640
Total	**$2,575**	**$4,065**	**$6,640**	**$6,640**

Table 10. SunEarth® Costs Prior to Incentives

Year	Unit Cost	Electricity	Annual Cost	Running Cost
1	$5,500	$37	$5,537	$5,537
2		$37	$37	$5,574
3		$37	$37	$5,611
4		$37	$37	$5,648
5	$100	$37	$137	$5,784
6		$37	$37	$5,821
7		$37	$37	$5,858
8	$85	$37	$122	$5,980
9	$100	$37	$137	$6,117
10		$37	$37	$6,154
11		$37	$37	$6,191
12		$37	$37	$6,228
13	$100	$37	$137	$6,365
14		$37	$37	$6,402
15	$1,200	$37	$1,237	$7,638
16		$37	$37	$7,675
17		$37	$37	$7,712
18		$37	$37	$7,749
19	$100	$37	$137	$7,886
20		$37	$37	$7,923
Total	**$7,185**	**$738**	**$7,923**	**$7,923**

Table 11. FAFCO® Costs Prior to Incentives

Year	Unit Cost	Electricity	Annual Cost	Running Cost
1	$5,000	$98	$5,098	$5,098
2		$98	$98	$5,195
3		$98	$98	$5,293
4		$98	$98	$5,391
5	$125	$98	$223	$5,613
6		$98	$98	$5,711
7		$98	$98	$5,809
8	$135	$98	$233	$6,041
9		$98	$98	$6,139
10		$98	$98	$6,237
11	785	$98	$883	$7,119
12		$98	$98	$7,217
13	$100	$98	$198	$7,415
14		$98	$98	$7,512
15	$885	$98	$983	$8,495
16		$98	$98	$8,593
17		$98	$98	$8,690
18		$98	$98	$8,788
19	$125	$98	$223	$9,011
20		$98	$98	$9,108
Total	**$7,155**	**$1,953**	**$9,108**	**$9,108**

The initial out-of-pocket cost to install each of the three systems without incentives was $785 for the all-electric system, $5,500 for the SunEarth® system, and $5,000 for the FAFCO® system. Without federal, state, and utility incentives, the FAFCO® system was the most expensive to own and operate over the twenty year period, at $9,108. The SunEarth® system was the second most expensive, at $7,923, while the all-electric system was the cheapest, at $6,640. Without incentives or subsidies, neither system would pay for itself in savings when compared to the all-electric unit.

With incentives available as of June 2012, the net result of the initial and 20-year cost analyses change significantly. The available incentives include a federal rebate for 30% of the initial installed cost, a 25% Arizona tax credit based on the initial installed cost, which is capped at $1,000, and a utility incentive from SRP [22] [23]. The utility incentive that SRP had available at the time of experimentation was $0.40 per kilowatt-hour of annual energy savings from the SRCC's OG-300 rating [24]. For the SunEarth® system, this was equal to 40 cents times 2,880 kWh, for a total of $1,152. The FAFCO® system reported average annual savings of 2,350 kWh, for an SRP rebate of $940. After incentives, the initial out-of-pocket cost to install each of the three systems was $785 for the all-electric, $1,698 for the SunEarth® system, and $1,560 for the FAFCO® system. The initial costs, rebates, and net out-of-pocket cost for each system are depicted in Table 12 below.

Table 12. Post-Incentive Costs of Installation

	All-Electric	**SunEarth®**	**FAFCO®**	**Details**
Installed Cost	$785	$5,500	$5,000	
- Federal	$0	($1,650)	($1,500)	30% of total cost
- State	$0	($1,000)	($1,000)	25% of total cost, max $1000
- SRP	$0	($1,152)	($940)	$0.40 / annual kWh saved
Net Cost	**$785**	**$1,698**	**$1,560**	**Out-of-pocket cost**

The annual costs, after accounting for the incentives, can be seen for the all-electric system, SunEarth® system, and FAFCO® system in Tables 13, 14, and 15 on the following pages, respectively. Again, a 0% annual increase in the cost of electricity was factored into the analysis. During the 20-year analysis period, the all-electric system would cost the most, at $6,640. The FAFCO® system would be the second most expensive to own and operate, at $5,668, while the SunEarth® system would cost the least to own and operate, at $4,121.

Table 13. All-Electric Costs Post-Incentives

Year	Capital Cost	Electricity	Annual Cost	Running Cost
1	$785	$203	$988	$988
2		$203	$203	$1,191
3		$203	$203	$1,395
4		$203	$203	$1,598
5	$110	$203	$313	$1,911
6		$203	$203	$2,114
7		$203	$203	$2,318
8		$203	$203	$2,521
9	$785	$203	$988	$3,509
10		$203	$203	$3,712
11		$203	$203	$3,916
12		$203	$203	$4,119
13	$110	$203	$313	$4,432
14		$203	$203	$4,635
15		$203	$203	$4,839
16		$203	$203	$5,042
17	$785	$203	$988	$6,030
18		$203	$203	$6,233
19		$203	$203	$6,436
20		$203	$203	$6,640
Total	**$2,575**	**$4,065**	**$6,640**	**$6,640**

Table 14. SunEarth® Costs Post-Incentives

Year	Unit Cost	Electricity	Annual Cost	Running Cost
1	$1,698	$37	$1,735	$1,735
2		$37	$37	$1,772
3		$37	$37	$1,809
4		$37	$37	$1,846
5	$100	$37	$137	$1,982
6		$37	$37	$2,019
7		$37	$37	$2,056
8	$85	$37	$122	$2,178
9	$100	$37	$137	$2,315
10		$37	$37	$2,352
11		$37	$37	$2,389
12		$37	$37	$2,426
13	$100	$37	$137	$2,563
14		$37	$37	$2,600
15	$1,200	$37	$1,237	$3,836
16		$37	$37	$3,873
17		$37	$37	$3,910
18		$37	$37	$3,947
19	$100	$37	$137	$4,084
20		$37	$37	$4,121
Total	**$3,383**	**$738**	**$4,121**	**$4,121**

Table 15. FAFCO® Costs Post-Incentives

Year	Unit Cost	Electricity	Annual Cost	Running Cost
1	$1,560	$98	$1,658	$1,658
2		$98	$98	$1,755
3		$98	$98	$1,853
4		$98	$98	$1,951
5	$125	$98	$223	$2,173
6		$98	$98	$2,271
7		$98	$98	$2,369
8	$135	$98	$233	$2,601
9		$98	$98	$2,699
10		$98	$98	$2,797
11	$785	$98	$883	$3,679
12		$98	$98	$3,777
13	$100	$98	$198	$3,975
14		$98	$98	$4,072
15	$885	$98	$983	$5,055
16		$98	$98	$5,153
17		$98	$98	$5,250
18		$98	$98	$5,348
19	$125	$98	$223	$5,571
20		$98	$98	$5,668
Total	**$3,715**	**$1,953**	**$5,668**	**$5,668**

As depicted in the above tables, after accounting for incentives, the SunEarth® system will break even with the all-electric system after year 5, and the FAFCO® system will break even after year 8, though it should be noted that the FAFCO® and all-electric systems nearly break even after year 6. A consumer can expect a post-incentive savings of $971 for the FAFCO® as compared to the all-electric, and a savings of $2,519 for the SunEarth® as compared to the all-electric. After accounting for incentives, the solar-powered units will save a homeowner money over time, albeit at the cost of public and utility funding. On the other hand, energy savings are guaranteed, to the benefit of the homeowner and the public, due to a reduction in pollution from electricity generation using the current blend of fuels.

4.5 Reliability

Reliability was observed over the course of the study. Both the all-electric system and the SunEarth® system ran seamlessly, with zero issues. Although the SunEarth® system ran with no issues, it is still recommended that a homeowner check the temperatures on the screen periodically to ensure that the HTF is flowing correctly and heating the water in the tank. This is done by spot checking the display screen and cycling between the temperature of the water at the bottom of the tank and the temperature of the HTF on the roof. A small fan-like symbol on the display will confirm that the pump is running during the day. There is also a small flow meter next to the pump to monitor the flow of the HTF.

The FAFCO® system required warranty repairs after the initial installation to run properly. The system is configured to show a 'FLO' error when the solar preheat system is not functioning properly. In order to remedy the error, FAFCO® replaced both pumps, the three solar collectors, the ball bearing in the HTF loop check valve, and the ICM, under its warranty agreement. Flow meters were added to both the potable water loop and the HTF loop to monitor the flow and aid in troubleshooting. Although multiple components were replaced, it was determined that the ball bearing in the HTF loop's check valve was manufactured in an improper size, which caused the ball bearing to cut the flow of HTF in the loop. Once all the components were replaced, the system ran well, although there were times when the potable water loop stopped flowing, and the FLO error was triggered. The flow error was usually removed upon resetting the system. When a reset was insufficient, water was manually primed into the loop to ensure that there were no air pockets keeping the pumps from flowing.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS FOR FURTHER STUDY

5.1 Conclusion

Both the SunEarth® and the FAFCO® systems had substantial energy savings when compared to the all-electric unit. Over the course of a year, the SunEarth® system is projected to use only 19.6% (80.4% savings) of the energy of the all-electric system, while the FAFCO® system is projected to use 51.2% (48.8% savings) of the energy.

After utilizing all available incentives as of June 2012, both solar water heating systems also produced monetary savings when compared to the all-electric unit. While the SunEarth® system has a higher initial cost than the FAFCO® system, it breaks even with the all-electric unit after five years versus eight years for the FAFCO® system. By the third year, the running cost of the SunEarth® system becomes lower than that of the FAFCO® system due to its greater energy savings that offset its higher initial cost. At the end of the twenty-year period, the SunEarth® system would save $2,519 compared to the all-electric unit, while the FAFCO® system would save $971. The SunEarth® system is recommended due to its greater energy savings, lower ownership cost, and greater reliability.

5.2 Recommendations for Further Study

Recommendations for improvements and further research are detailed in the following sections.

5.2.1 System Improvements

Several changes must be made to the lab environment to enable further research and improve data collection. These changes include increasing the water flow rates of the pumps and the cooling capacity of the chiller system. Currently, only one system may be run at a time. This is due to the pumps not being able to supply enough water to all three systems simultaneously, and also due to the chiller system not being able to cool the water quickly enough during the two largest water draws.

There are two issues with the pumps, which are not powerful enough and therefore have trouble pumping enough water at a high enough flow rate through the systems. The first problem is caused by the outdoor pump that sends water from the outside hot-water storage tank to the chiller system and thermostatic mixing valve. A ‘Y’ pipe splits the piping, but there is no mechanism to control how much volume is routed to each location. When the system is running during a water draw there is insufficient flow from this pump to meet the demands of both the hot water needed at the mixing valve and water going into the chiller to reside in the cold-water storage tank.

The second issue is with the flow of water coming out of the cold-water storage tank. This outlet also goes to a ‘Y’ pipe, which sends water to two different pumps. The first is a pump that sends water to the chiller, then back to the cold-water storage tank, and the second is a pump that sends water into the water heating systems via the thermostatic mixing valve. In such a ‘Y’ configuration, the water tends to flow to the path of least resistance, which is to the chiller pump. With nearly all the water going to the chiller pump, not enough water is delivered to the thermostatic mixing valve, causing insufficient flow rates.

During testing, the most common issue was a lack of flow through the systems. This flow error occurred even when only one system was running at a time. The systems would be running at about 1 GPM and then would suddenly stop. The stoppage would generally happen between water draws, when small air pockets in the pipes or pumps were capable of producing so much resistance that the pumps were only able to recirculate the water through the chiller and not send any water past the thermostatic mixing valve into the systems.

The insufficient water flow also made it impossible to use the inline booster pump, as there was not adequate water coming into the booster pump to boost the water pressure. This would result in the pump reporting a fault error and shutting off. The inline booster pump has been installed but has not yet been used, and will serve the purpose of boosting the pressure and flow rate to the equivalent of city water pressure and domestic flow rates.

The flow rate problems could be remedied by either utilizing more powerful pumps, or by removing all 'Y' pipes and using dedicated pumps for each purpose. This would enable the inline booster pump to increase system pressure, and enable all three systems to run simultaneously. The issue with the chiller not being able to cool the water in time for the remaining portion of the longest hot water draws could be remedied by using a more powerful chiller or by increasing the storage capacity of the chilled water.

5.2.2 Further Research

Further research should include collecting daily data between the winter and summer solstice, and can be conducted using the current water heating systems. Additional research should also include adding new water heating technology to the lab.

The next phase of this project should include collecting data from the winter solstice to the summer solstice, or for a full year, which would aid in further validating the TRNSYS simulations. More daily data over different seasons would smooth out weather patterns and irregularities and allow for the validation of the TRNSYS models during winter months. Also, daily data from one solstice to the next would allow for statistical tests to be conducted to compare the lab data to the TRNSYS results. Currently, statistical analysis using a few days worth of data would not be statistically significant as the sample size is too small. Furthermore, it is recommended that daily data is collected simultaneously for all three systems, as this would enable results to be compared without differing weather and temperatures of consecutive days.

Additionally, different technologies should be added to the lab for further comparison. Three new types of water heaters would be of particular interest. The first is a gas-fired water heater, which is cheaper to operate than the all-electric unit currently being used as a control unit. The second is an on-demand, or tankless, water heater. Tankless water heaters tend to use less energy than traditional tanked electric water heaters, but are also more expensive. The tankless water heater would offer an additional point of comparison for both efficiency and cost comparison, and could be tested using both electricity or gas as a heating source. Finally, an evacuated tube solar water heating system would provide further data on energy and cost savings of different solar water heating technologies.

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APPENDIX A

LABVIEW AND TRNSYS SOFTWARE

LabVIEW 2011 software was utilized to program the automated data collection in the lab. LabVIEW is published by National Instruments, and requires a purchased license. It is a graphical development environment used to create applications through the use of graphical icons connected together as in a flowchart [25]. The software was used to turn the valves in the lab on and off to simulate hot water draws, and to collect energy and temperature data. LabVIEW did this by collecting and recording data from the DAQs, which were connected to the thermocouples and energy sensors.

TRNSYS 17 is a transient systems simulation software package with modular structure. Using TRNSYS, a user specifies the components of a system and connects them using a visual user interface. TRNSYS has the ability to model solar thermal and photovoltaic systems, low energy buildings, HVAC systems, renewable energy systems, cogeneration, and fuel cells [26]. TRNSYS was utilized to model the energy usage of the three water heaters in this thesis. TRNSYS is a joint project between the following entities: Solar Energy Laboratory at the University of Wisconsin-Madison, TRANSSOLAR Energietechnik GmbH, CSTB – Centre Scientifique et Technique du Bâtiment, and TESS – Thermal Energy Systems Specialists. TRNSYS requires a purchased license. A TRNSYS user guide is available in the software suite, and has been published online by the Massachusetts Institute of Technology [27].

APPENDIX B

ALL-ELECTRIC TRNSYS INPUT FILE

```
VERSION 17
*****************************************************************
**************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Thursday, June 28, 2012 at 23:55
*** from TrnsysStudio project: Y:\Documents\Docs\School\Alt
Masters\Thesis\TRNSYS Files\OFFICIAL FILES\Thesis - All
Electric\Bradford_White_true_ambient.tpf
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
*****************************************************************
**************


*****************************************************************
**************
*** Units
*****************************************************************
**************

*****************************************************************
**************
*** Control cards
*****************************************************************
**************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760.000229455
STEP=0.016666666
SIMULATION    START STOP   STEP  ! Start time     End time        Time step
TOLERANCES 0.001 0.001                  ! Integration    Convergence
LIMITS 30 500 50                        ! Max iterations         Max warnings
        Trace limit
DFQ 1                            ! TRNSYS numerical integration solver
method
WIDTH 80                         ! TRNSYS output file width, number of
characters
LIST                             ! NOLIST statement
                                 ! MAP statement
SOLVER 0 1 1                     ! Solver statement     Minimum relaxation
factor  Maximum relaxation factor
```

```
NAN_CHECK 0                        ! Nan DEBUG statement
OVERWRITE_CHECK 0                          ! Overwrite DEBUG statement
TIME_REPORT 0                      ! disable time report
EQSOLVER 0                         ! EQUATION SOLVER statement
* User defined CONSTANTS


* Model "Water Draw Profile" (Type 14)
*

UNIT 2 TYPE 14         Water Draw Profile
*$UNIT_NAME Water Draw Profile
*$MODEL .\Utility\Forcing Functions\Water Draw\Type14b.tmf
*$POSITION 72 457
*$LAYER Main #
PARAMETERS 52
0             ! 1 Initial value of time
0             ! 2 Initial value of function
7.5           ! 3 Time at point-1
0             ! 4 Water draw at point -1
7.5           ! 5 Time at point-2
340.69        ! 6 Water draw at point -2
7.75          ! 7 Time at point-3
340.69        ! 8 Water draw at point -3
7.75          ! 9 Time at point-4
0             ! 10 Water draw at point -4
13            ! 11 Time at point-5
0             ! 12 Water draw at point -5
13            ! 13 Time at point-6
340.69        ! 14 Water draw at point -6
13.181        ! 15 Time at point-7
340.69        ! 16 Water draw at point -7
13.181        ! 17 Time at point-8
0             ! 18 Water draw at point -8
15            ! 19 Time at point-9
0             ! 20 Water draw at point -9
15            ! 21 Time at point-10
340.69        ! 22 Water draw at point -10
15.028        ! 23 Time at point-11
340.69        ! 24 Water draw at point -11
15.028        ! 25 Time at point-12
0             ! 26 Water draw at point -12
18            ! 27 Time at point-13
0             ! 28 Water draw at point -13
18            ! 29 Time at point-14
340.69        ! 30 Water draw at point -14
18.056        ! 31 Time at point-15
```

```
340.69          ! 32 Water draw at point -15
18.056          ! 33 Time at point-16
0               ! 34 Water draw at point -16
20              ! 35 Time at point-17
0               ! 36 Water draw at point -17
20              ! 37 Time at point-18
340.69          ! 38 Water draw at point -18
20.111          ! 39 Time at point-19
340.69          ! 40 Water draw at point -19
20.111          ! 41 Time at point-20
0               ! 42 Water draw at point -20
22              ! 43 Time at point-21
0               ! 44 Water draw at point -21
22              ! 45 Time at point-22
340.69          ! 46 Water draw at point -22
22.083          ! 47 Time at point-23
340.69          ! 48 Water draw at point -23
22.083          ! 49 Time at point-24
0               ! 50 Water draw at point -24
24              ! 51 Time at point-25
0               ! 52 Water draw at point -25
*------------------------------------------------------------------------------

* EQUATIONS "kJ/h to kW"
*
EQUATIONS 3
kW_element1 = [10,1]/3600
kW_element2 = [11,1]/3600
kW_combined = kW_element1+kW_element2
*$UNIT_NAME kJ/h to kW
*$LAYER Main
*$POSITION 917 168

*------------------------------------------------------------------------------


* Model "Energy Usage" (Type 46)
*

UNIT 7 TYPE 46          Energy Usage
*$UNIT_NAME Energy Usage
*$MODEL .\Output\Printegrator\Unformatted\Type46.tmf
*$POSITION 1104 242
*$LAYER Main #
*$# PRINTEGRATOR
PARAMETERS 5
34              ! 1 Logical unit
```

```
-1                ! 2 Logical unit for monthly summaries
0                 ! 3 Relative or absolute start time
24.000001               ! 4 Printing & integrating interval
0                 ! 5 Number of inputs to avoid integration
INPUTS 3
kW_element1             ! kJ/h to kW:kW_element1 ->Input to be integrated &
printed-1
kW_element2             ! kJ/h to kW:kW_element2 ->Input to be integrated &
printed-2
kW_combined             ! kJ/h to kW:kW_combined ->Input to be integrated &
printed-3
*** INITIAL INPUT VALUES
kWh_elem1 kWh_elem2 kWh_comb
LABELS 0

*** External files
ASSIGN "BW_true_ambient_TMY3.txt" 34
*|? Output file for integrated results? |1000
*------------------------------------------------------------------------------

* Model "Temp_kWH_Graph" (Type 65)
*

UNIT 8 TYPE 65          Temp_kWH_Graph
*$UNIT_NAME Temp_kWH_Graph
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 542 49
*$LAYER Main #
PARAMETERS 12
7                 ! 1 Nb. of left-axis variables
6                 ! 2 Nb. of right-axis variables
0.0               ! 3 Left axis minimum
220               ! 4 Left axis maximum
0.0               ! 5 Right axis minimum
5                 ! 6 Right axis maximum
1                 ! 7 Number of plots per simulation
12                ! 8 X-axis gridpoints
0                 ! 9 Shut off Online w/o removing
-1                ! 10 Logical unit for output file
0                 ! 11 Output file units
0                 ! 12 Output file delimiter
INPUTS 13
0,0               ! [unconnected] Left axis variable-1
0,0               ! [unconnected] Left axis variable-2
0,0               ! [unconnected] Left axis variable-3
0,0               ! [unconnected] Left axis variable-4
MixedHotWater_F               ! C to F:MixedHotWater_F ->Left axis variable-5
```

```
ColdWater_in_Main_F          ! C to F:ColdWater_in_Main_F ->Left axis variable-
6
HotWater_outofBW_F           ! C to F:HotWater_outofBW_F ->Left axis variable-
7
GPM_main_in          ! lit/hr to GPM:GPM_main_in ->Right axis variable-1
GPM_hot              ! lit/hr to GPM:GPM_hot ->Right axis variable-2
GPM_main_out                 ! lit/hr to GPM:GPM_main_out ->Right axis
variable-3
kW_element1          ! kJ/h to kW:kW_element1 ->Right axis variable-4
kW_element2          ! kJ/h to kW:kW_element2 ->Right axis variable-5
kW_combined          ! kJ/h to kW:kW_combined ->Right axis variable-6
*** INITIAL INPUT VALUES
Tank_Node1_temp Tank_Node3_temp Tank_Node8_temp Tank_Node9_temp
Mix_hot_out Cold_in_mains TankOut_F GPM_main_in GPM_hot_tank
GPM_main_out
kW_elem1 kW_elem2 kW_comb
LABELS  3
"Temp F"
"GPM and kW"
"Temps kW GPM"
*------------------------------------------------------------------------------

* Model "Bradford White" (Type 534)
*

UNIT 9 TYPE 534        Bradford White
*$UNIT_NAME Bradford White
*$MODEL .\Storage Tank Library (TESS)\Cylindrical Storage Tank\Vertical
Cylinder\Version without Plug-In\No HXs\Type534-NoHX.tmf
*$POSITION 467 350
*$LAYER Main #
*$# CYLINDRICAL STORAGE TANK
PARAMETERS 37
-1               ! 1 LU for data file
9                ! 2 Number of tank nodes
1                ! 3 Number of ports
0                ! 4 Number of immersed heat exchangers
0                ! 5 Number of miscellaneous heat flows
0.189272                 ! 6 Tank volume
1.461            ! 7 Tank height
0                ! 8 Tank fluid
4.032            ! 9 Fluid specific heat
988.5            ! 10 Fluid density
2.3112           ! 11 Fluid thermal conductivity
2.00             ! 12 Fluid viscosity
0.00026                  ! 13 Fluid thermal expansion coefficient
5.364            ! 14 Top loss coefficient
```

```
5.364           ! 15 Edge loss coefficient for node-1
5.364           ! 16 Edge loss coefficient for node-2
5.364           ! 17 Edge loss coefficient for node-3
5.364           ! 18 Edge loss coefficient for node-4
5.364           ! 19 Edge loss coefficient for node-5
5.364           ! 20 Edge loss coefficient for node-6
5.364           ! 21 Edge loss coefficient for node-7
5.364           ! 22 Edge loss coefficient for node-8
5.364           ! 23 Edge loss coefficient for node-9
5.364           ! 24 Bottom loss coefficient
0               ! 25 Additional thermal conductivity
1               ! 26 Inlet flow mode
9               ! 27 Entry node
1               ! 28 Exit node
0               ! 29 Flue loss coefficient for node-1
0               ! 30 Flue loss coefficient for node-2
0               ! 31 Flue loss coefficient for node-3
0               ! 32 Flue loss coefficient for node-4
0               ! 33 Flue loss coefficient for node-5
0               ! 34 Flue loss coefficient for node-6
0               ! 35 Flue loss coefficient for node-7
0               ! 36 Flue loss coefficient for node-8
0               ! 37 Flue loss coefficient for node-9
INPUTS 24
17,3            ! Diverter:Temperature at outlet 2 ->Inlet temperature for port
17,4            ! Diverter:Flow rate at outlet 2 ->Inlet flow rate for port
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Top loss
temperature
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-1
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-2
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-3
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-4
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-5
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-6
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-7
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-8
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-9
```

```
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Bottom loss
temperature
21,1            ! PHX Weather -TMY3:Dry bulb temperature ->Gas flue
temperature
0,0             ! [unconnected] Inversion mixing flow rate
0,0             ! [unconnected] Auxiliary heat input for node-1
0,0             ! [unconnected] Auxiliary heat input for node-2
10,1            ! Upper Element:Fluid energy ->Auxiliary heat input for node-3
0,0             ! [unconnected] Auxiliary heat input for node-4
0,0             ! [unconnected] Auxiliary heat input for node-5
0,0             ! [unconnected] Auxiliary heat input for node-6
0,0             ! [unconnected] Auxiliary heat input for node-7
11,1            ! Lower Element:Fluid energy ->Auxiliary heat input for node-8
0,0             ! [unconnected] Auxiliary heat input for node-9
*** INITIAL INPUT VALUES
37.7778 0.0 ambient_temp_C ambient_temp_C ambient_temp_C
ambient_temp_C
ambient_temp_C ambient_temp_C ambient_temp_C ambient_temp_C
ambient_temp_C
ambient_temp_C ambient_temp_C ambient_temp_C -100 0.0 0.0 0.0 0.0 0 0.0
0.0 0.0 0.0
DERIVATIVES 9
20.0            ! 1 Initial Tank Temperature-1
20.0            ! 2 Initial Tank Temperature-2
20.0            ! 3 Initial Tank Temperature-3
20.0            ! 4 Initial Tank Temperature-4
20.0            ! 5 Initial Tank Temperature-5
20.0            ! 6 Initial Tank Temperature-6
20.0            ! 7 Initial Tank Temperature-7
20.0            ! 8 Initial Tank Temperature-8
20.0            ! 9 Initial Tank Temperature-9
*------------------------------------------------------------------------------

* Model "Upper Element" (Type 1226)
*

UNIT 10 TYPE 1226     Upper Element
*$UNIT_NAME Upper Element
*$MODEL .\Storage Tank Library (TESS)\Tank Heating Device\Electric\Type1226-
Elec.tmf
*$POSITION 652 259
*$LAYER Main #
INPUTS 3
0,0             ! [unconnected] Heating capacity
0,0             ! [unconnected] Thermal efficiency
12,2            ! Top Thermostat:Conditioning signal ->Control signal
*** INITIAL INPUT VALUES
```

```
16199.999571 1. 1.
*------------------------------------------------------------------------------

* Model "Lower Element" (Type 1226)
*

UNIT 11 TYPE 1226     Lower Element
*$UNIT_NAME Lower Element
*$MODEL .\Storage Tank Library (TESS)\Tank Heating Device\Electric\Type1226-
Elec.tmf
*$POSITION 663 428
*$LAYER Main #
INPUTS 3
0,0               ! [unconnected] Heating capacity
0,0               ! [unconnected] Thermal efficiency
13,1              ! Bottom Thermostat:Control signal for stage heating ->Control
signal
*** INITIAL INPUT VALUES
16199.999571 1. 1.
*------------------------------------------------------------------------------

* Model "Top Thermostat" (Type 1502)
*

UNIT 12 TYPE 1502     Top Thermostat
*$UNIT_NAME Top Thermostat
*$MODEL .\Storage Tank Library (TESS)\Aquastats\Heating Mode\Type1502.tmf
*$POSITION 652 142
*$LAYER Main #
PARAMETERS 4
1                 ! 1 Number of heating stages
5                 ! 2 # oscillations permitted
6.111111                  ! 3 Temperature dead band
0                 ! 4 Number of stage exceptions
INPUTS 3
9,17              ! Bradford White:Tank nodal temperature-3 ->Fluid temperature
0,0               ! [unconnected] Lockout signal
0,0               ! [unconnected] Setpoint temperature for stage
*** INITIAL INPUT VALUES
20.0 0 51.666689
*------------------------------------------------------------------------------

* Model "Bottom Thermostat" (Type 1502)
*

UNIT 13 TYPE 1502     Bottom Thermostat
*$UNIT_NAME Bottom Thermostat
```

```
*$MODEL .\Storage Tank Library (TESS)\Aquastats\Heating Mode\Type1502.tmf
*$POSITION 661 553
*$LAYER Main #
PARAMETERS 4
1               ! 1 Number of heating stages
5               ! 2 # oscillations permitted
6.111111                ! 3 Temperature dead band
0               ! 4 Number of stage exceptions
INPUTS 3
9,22            ! Bradford White:Tank nodal temperature-8 ->Fluid temperature
12,1            ! Top Thermostat:Control signal for stage heating ->Lockout
signal
0,0             ! [unconnected] Setpoint temperature for stage
*** INITIAL INPUT VALUES
20.0 0 51.666689
*------------------------------------------------------------------------------

* Model "kWh Graph" (Type 65)
*

UNIT 14 TYPE 65        kWh Graph
*$UNIT_NAME kWh Graph
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 1097 95
*$LAYER Main #
PARAMETERS 12
3               ! 1 Nb. of left-axis variables
0               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
5               ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
1000.0          ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 3
kW_element1             ! kJ/h to kW:kW_element1 ->Left axis variable-1
kW_element2             ! kJ/h to kW:kW_element2 ->Left axis variable-2
kW_combined             ! kJ/h to kW:kW_combined ->Left axis variable-3
*** INITIAL INPUT VALUES
kW_elem1 kW_elem2 kW_comb
LABELS  3
"Kilowatts"
""
```

```
"Energy Usage"
*---------------------------------------------------------------------------

* EQUATIONS "Constants"
*
EQUATIONS 1
ambient_temp_C = 24
*$UNIT_NAME Constants
*$LAYER Main
*$POSITION 763 746

*---------------------------------------------------------------------------


* EQUATIONS "lit/hr to GPM"
*
EQUATIONS 3
GPM_hot = [9,2]*0.004403
GPM_main_in = [2,1]*0.004403
GPM_main_out = [17,2]*0.004403
*$UNIT_NAME lit/hr to GPM
*$LAYER Main
*$POSITION 72 146

*---------------------------------------------------------------------------


* Model "Diverter" (Type 11)
*

UNIT 17 TYPE 11     Diverter
*$UNIT_NAME Diverter
*$MODEL .\Hydronics\Flow Diverter\Other Fluids\Right Facing\Type11f.tmf
*$POSITION 203 455
*$LAYER Main #
PARAMETERS 1
2               ! 1 Controlled flow diverter mode
INPUTS 3
21,5            ! PHX Weather -TMY3:Mains water temperature ->Inlet
temperature
2,1             ! Water Draw Profile:Average water draw ->Inlet flow rate
19,1            ! Tempering Control (<110F):Fraction to heat source ->Control
signal
*** INITIAL INPUT VALUES
20.0 0 0.5
*---------------------------------------------------------------------------
```

```
* Model "Tempering Control (<110F)" (Type 953)
*

UNIT 19 TYPE 953     Tempering Control (<110F)
*$UNIT_NAME Tempering Control (<110F)
*$MODEL .\Controllers Library (TESS)\Tempering Valve Controller\Type953.tmf
*$POSITION 470 509
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive
substitution)
*$#
PARAMETERS 1
5               ! 1 No. of oscillations
INPUTS 4
0,0             ! [unconnected] Setpoint temperature
9,1             ! Bradford White:Temperature at outlet ->Source temperature
21,5            ! PHX Weather -TMY3:Mains water temperature ->Tempering fluid
temperature (return temperature)
0,0             ! [unconnected] Mode
*** INITIAL INPUT VALUES
43.333355 10.0 20.0 1
*------------------------------------------------------------------------------

* Model "Mixer" (Type 11)
*

UNIT 20 TYPE 11      Mixer
*$UNIT_NAME Mixer
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 285 244
*$LAYER Water Loop #
PARAMETERS 1
1               ! 1 Tee piece mode
INPUTS 4
17,1            ! Diverter:Temperature at outlet 1 ->Temperature at inlet 1
17,2            ! Diverter:Flow rate at outlet 1 ->Flow rate at inlet 1
9,1             ! Bradford White:Temperature at outlet ->Temperature at inlet 2
9,2             ! Bradford White:Flow rate at outlet ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* EQUATIONS "C to F"
*
EQUATIONS 12
BW_Node1_F = [9,15]*(9/5) + 32
BW_Node2_F = [9,16]*(9/5) + 32
```

```
BW_Node3_F = [9,17]*(9/5) + 32
BW_Node4_F = [9,18]*(9/5) + 32
BW_Node5_F = [9,19]*(9/5) + 32
BW_Node6_F = [9,20]*(9/5) + 32
BW_Node7_F = [9,21]*(9/5) + 32
BW_Node8_F = [9,22]*(9/5) + 32
BW_Node9_F = [9,23]*(9/5) + 32
ColdWater_in_Main_F = [21,5]*(9/5) + 32
MixedHotWater_F = [20,1]*(9/5) + 32
HotWater_outofBW_F = [9,1]*(9/5) + 32
*$UNIT_NAME C to F
*$LAYER Main
*$POSITION 341 73

*------------------------------------------------------------------------------


* Model "PHX Weather -TMY3" (Type 15)
*

UNIT 21 TYPE 15        PHX Weather -TMY3
*$UNIT_NAME PHX Weather -TMY3
*$MODEL .\Weather Data Reading and Processing\Standard
Format\TMY3\Type15-TMY3.tmf
*$POSITION 203 618
*$LAYER Main #
PARAMETERS 9
7                ! 1 File Type
35               ! 2 Logical unit
3                ! 3 Tilted Surface Radiation Mode
0.2              ! 4 Ground reflectance: no albedo reported
0.7              ! 5 Not used
1                ! 6 Number of surfaces
1                ! 7 Tracking mode
0.0              ! 8 Slope of surface
0                ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Trnsys17\Weather\US-
TMY3\US_AZ_PHOENIX_INTL_AP_722780.csv" 35
*|? Which file contains the TMY-2 weather data? |1000
*------------------------------------------------------------------------------

END
```

APPENDIX C

SUNEARTH® TRNSYS INPUT FILE

```
VERSION 17
******************************************************************
*************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Friday, June 29, 2012 at 00:11
*** from TrnsysStudio project: Y:\Documents\Docs\School\Alt
Masters\Thesis\TRNSYS Files\OFFICIAL FILES\Thesis -
SunEarth\SunEarth_trueambient.tpf
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
******************************************************************
*************


******************************************************************
*************
*** Units
******************************************************************
*************

******************************************************************
*************
*** Control cards
******************************************************************
  *************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760.000229455
STEP=0.016666666
SIMULATION   START STOP   STEP  ! Start time     End time        Time step
TOLERANCES 0.001 0.001                  ! Integration    Convergence
LIMITS 50 50 50                         ! Max iterations         Max warnings
        Trace limit
DFQ 1                           ! TRNSYS numerical integration solver
method
WIDTH 120                       ! TRNSYS output file width, number of
characters
LIST                            ! NOLIST statement
                                ! MAP statement
SOLVER 0 1 1                    ! Solver statement     Minimum relaxation
factor  Maximum relaxation factor
```

```
NAN_CHECK 0                      ! Nan DEBUG statement
OVERWRITE_CHECK 0                      ! Overwrite DEBUG statement
TIME_REPORT 0                    ! disable time report
EQSOLVER 0                       ! EQUATION SOLVER statement
* User defined CONSTANTS


* Model "Water Draw Profile" (Type 14)
*

UNIT 11 TYPE 14        Water Draw Profile
*$UNIT_NAME Water Draw Profile
*$MODEL .\Utility\Forcing Functions\Water Draw\Type14b.tmf
*$POSITION 64 712
*$LAYER Main #
PARAMETERS 52
0             ! 1 Initial value of time
0             ! 2 Initial value of function
7.5           ! 3 Time at point-1
0             ! 4 Water draw at point -1
7.5           ! 5 Time at point-2
340.69        ! 6 Water draw at point -2
7.75          ! 7 Time at point-3
340.69        ! 8 Water draw at point -3
7.75          ! 9 Time at point-4
0             ! 10 Water draw at point -4
13            ! 11 Time at point-5
0             ! 12 Water draw at point -5
13            ! 13 Time at point-6
340.69        ! 14 Water draw at point -6
13.181        ! 15 Time at point-7
340.69        ! 16 Water draw at point -7
13.181        ! 17 Time at point-8
0             ! 18 Water draw at point -8
15            ! 19 Time at point-9
0             ! 20 Water draw at point -9
15            ! 21 Time at point-10
340.69        ! 22 Water draw at point -10
15.028        ! 23 Time at point-11
340.69        ! 24 Water draw at point -11
15.028        ! 25 Time at point-12
0             ! 26 Water draw at point -12
18            ! 27 Time at point-13
0             ! 28 Water draw at point -13
18            ! 29 Time at point-14
340.69        ! 30 Water draw at point -14
18.056        ! 31 Time at point-15
```

```
340.69          ! 32 Water draw at point -15
18.056          ! 33 Time at point-16
0               ! 34 Water draw at point -16
20              ! 35 Time at point-17
0               ! 36 Water draw at point -17
20              ! 37 Time at point-18
340.69          ! 38 Water draw at point -18
20.111          ! 39 Time at point-19
340.69          ! 40 Water draw at point -19
20.111          ! 41 Time at point-20
0               ! 42 Water draw at point -20
22              ! 43 Time at point-21
0               ! 44 Water draw at point -21
22              ! 45 Time at point-22
340.69          ! 46 Water draw at point -22
22.083          ! 47 Time at point-23
340.69          ! 48 Water draw at point -23
22.083          ! 49 Time at point-24
0               ! 50 Water draw at point -24
24              ! 51 Time at point-25
0               ! 52 Water draw at point -25
*------------------------------------------------------------------------------

* Model "Energy Plotter" (Type 65)
*

UNIT 20 TYPE 65      Energy Plotter
*$UNIT_NAME Energy Plotter
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 949 232
*$LAYER Main #
PARAMETERS 12
3               ! 1 Nb. of left-axis variables
2               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
5               ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
2               ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 5
kW_element1          ! kJ/h to kW:kW_element1 ->Left axis variable-1
kW_pump              ! kJ/h to kW:kW_pump ->Left axis variable-2
```

```
kW_TOTAL            ! kJ/h to kW:kW_TOTAL ->Left axis variable-3
29,1            ! Pump Controller:Output control function ->Right axis variable-1
24,1            ! Thermostat:Control signal for stage heating ->Right axis variable-
2
*** INITIAL INPUT VALUES
kW_elem kW_pump kW_TOTAL Pump_Cntrl_Sig Thermostat_Cntrl_Sig
LABELS  3
"Kilowatts"
"Control Signal 1 ON 0 OFF"
"Energy Usage"
*------------------------------------------------------------------------------

* EQUATIONS "kJ/h to kW"
*
EQUATIONS 3
kW_element1 = [25,1]/3600
kW_pump = [23,3]/3600
kW_TOTAL = kW_element1+kW_pump
*$UNIT_NAME kJ/h to kW
*$LAYER Main
*$POSITION 811 178

*------------------------------------------------------------------------------


* Model "Energy Usage Output" (Type 46)
*

UNIT 22 TYPE 46        Energy Usage Output
*$UNIT_NAME Energy Usage Output
*$MODEL .\Output\Printegrator\Unformatted\Type46.tmf
*$POSITION 1067 226
*$LAYER Main #
*$# PRINTEGRATOR
PARAMETERS 5
33              ! 1 Logical unit
-1              ! 2 Logical unit for monthly summaries
0               ! 3 Relative or absolute start time
24.000001           ! 4 Printing & integrating interval
0               ! 5 Number of inputs to avoid integration
INPUTS 3
kW_element1         ! kJ/h to kW:kW_element1 ->Input to be integrated &
printed-1
kW_pump             ! kJ/h to kW:kW_pump ->Input to be integrated & printed-
2
kW_TOTAL            ! kJ/h to kW:kW_TOTAL ->Input to be integrated &
printed-3
```

```
*** INITIAL INPUT VALUES
kWh_element kWh_pump kWh_TOTAL
LABELS 0

*** External files
ASSIGN "SE_trueambient_results_TMY3.txt" 33
*|? Output file for integrated results? |1000
*------------------------------------------------------------------------------

* Model "Thermostat" (Type 1502)
*

UNIT 24 TYPE 1502     Thermostat
*$UNIT_NAME Thermostat
*$MODEL .\Storage Tank Library (TESS)\Aquastats\Heating Mode\Type1502.tmf
*$POSITION 597 788
*$LAYER Main #
PARAMETERS 4
1                  ! 1 Number of heating stages
5                  ! 2 # oscillations permitted
2.777778                  ! 3 Temperature dead band
0                  ! 4 Number of stage exceptions
INPUTS 3
28,29              ! Storage Tank w/ HX:Tank nodal temperature-5 ->Fluid
temperature
0,0                ! [unconnected] Lockout signal
0,0                ! [unconnected] Setpoint temperature for stage
*** INITIAL INPUT VALUES
20.0 0 51.666689
*------------------------------------------------------------------------------

* Model "Electric Element" (Type 1226)
*

UNIT 25 TYPE 1226     Electric Element
*$UNIT_NAME Electric Element
*$MODEL .\Storage Tank Library (TESS)\Tank Heating Device\Electric\Type1226-
Elec.tmf
*$POSITION 596 660
*$LAYER Main #
INPUTS 3
0,0                ! [unconnected] Heating capacity
0,0                ! [unconnected] Thermal efficiency
24,1               ! Thermostat:Control signal for stage heating ->Control signal
*** INITIAL INPUT VALUES
16199.999571 1. 1.
*------------------------------------------------------------------------------
```

```
* Model "Plat-Plate Collector" (Type 539)
*

UNIT 26 TYPE 539     Plat-Plate Collector
*$UNIT_NAME Plat-Plate Collector
*$MODEL .\Solar Library (TESS)\Glazed Flat Plate Collectors\OG100 Quadratic
Efficiency Approach\Type539.tmf
*$POSITION 451 190
*$LAYER Main #
*$# This component sets the flow rate for all connected flow loop components if
the variable speed option is enabled.
PARAMETERS 16
1               ! 1 Number in series
3.799703                ! 2 Collector area
3.91            ! 3 Fluid specific heat
1               ! 4 Collector test mode
.718            ! 5 Intercept efficiency (a0)
8.24616                 ! 6 1st order efficiency coefficient (a1)
0.158328                ! 7 2nd order efficiency coefficient (a2)
72              ! 8 Tested flow rate per unit area
3.91            ! 9 Fluid specific heat at test conditions
0.322           ! 10 1st-order IAM coefficient
-0.031          ! 11 2nd-order IAM coefficient
0.0             ! 12 Minimum flowrate
600             ! 13 Maximum flowrate
100.0           ! 14 Capacitance of Collector
10              ! 15 Number of Nodes
20              ! 16 Initial Temperature
INPUTS 10
23,1            ! Glycol Pump:Outlet fluid temperature ->Inlet temperature
23,2            ! Glycol Pump:Outlet flow rate ->Inlet flowrate
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Ambient
temperature
39,25           ! PHX Weather -TMY3:Beam radiation for surface ->Beam radiation
on the tilted surface
39,26           ! PHX Weather -TMY3:Sky diffuse radiation for surface ->Sky
diffuse radiation on tilted surface
39,27           ! PHX Weather -TMY3:Ground reflected diffuse radiation for surface
->Ground-reflected diffuse radiation on tilted surface
39,29           ! PHX Weather -TMY3:Angle of incidence for surface ->Incidence
angle
39,30           ! PHX Weather -TMY3:Slope of surface ->Collector slope
0,0             ! [unconnected] Pump Control Specification
0,0             ! [unconnected] Outlet Temperature Setpoint
*** INITIAL INPUT VALUES
20.0 398 10.0 0.0 0.0 0.0 45.0 0. 0 60.0
```

```
*---------------------------------------------------------------------------

* Model "Temp Plotter" (Type 65)
*

UNIT 27 TYPE 65      Temp Plotter
*$UNIT_NAME Temp Plotter
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 1109 532
*$LAYER Main #
PARAMETERS 12
9               ! 1 Nb. of left-axis variables
4               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
220             ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
5               ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 13
Tank_Node1_F                ! C to F:Tank_Node1_F ->Left axis variable-1
Tank_Node5_F                ! C to F:Tank_Node5_F ->Left axis variable-2
Tank_Node8_F                ! C to F:Tank_Node8_F ->Left axis variable-3
Tank_Node9_F                ! C to F:Tank_Node9_F ->Left axis variable-4
MixedHotWater_F             ! C to F:MixedHotWater_F ->Left axis variable-5
ColdWater_in_Main_F         ! C to F:ColdWater_in_Main_F ->Left axis variable-6
HotWater_outofBW_F          ! C to F:HotWater_outofBW_F ->Left axis variable-7
HTF_Roof_F          ! C to F:HTF_Roof_F ->Left axis variable-8
HTF_TankHX_F                ! C to F:HTF_TankHX_F ->Left axis variable-9
GPM             ! lit/hr to GPM:GPM ->Right axis variable-1
29,1            ! Pump Controller:Output control function ->Right axis variable-2
24,1            ! Thermostat:Control signal for stage heating ->Right axis variable-
3
kW_TOTAL            ! kJ/h to kW:kW_TOTAL ->Right axis variable-4
*** INITIAL INPUT VALUES
Tank_Node1_temp Tank_Node5_temp Tank_Node8_temp Tank_Node9_temp
Mix_hot_water_out Cold_mains_in HotWater_frTank HTF_Temp_Roof
HTF_Temp_HX
GPM Pump_Signal Thermostat_signal kW_Total
LABELS  3
"Temp F"
"GPM  /  Control Signal  /  kW"
"Temperatures"
```

```
*------------------------------------------------------------------------------

* Model "Storage Tank w/ HX" (Type 1237)
*

UNIT 28 TYPE 1237    Storage Tank w/ HX
*$UNIT_NAME Storage Tank w/ HX
*$MODEL .\Storage Tank Library (TESS)\Cylindrical Storage Tank\Vertical Cylinder With Wrap-Around HX\With Diptube\Type1237-4.tmf
*$POSITION 320 564
*$LAYER Main #
*$# Vertical Cylindrical Storage Tank with Wrap-Around Heat Exchanger
PARAMETERS 96
9            ! 1 Number of tank nodes
1            ! 2 Number of ports
0            ! 3 Number of miscellaneous heat flows
0.302835           ! 4 Tank volume
1.4859       ! 5 Tank height
4.032        ! 6 Fluid specific heat
988.5        ! 7 Fluid density
2.3112       ! 8 Fluid thermal conductivity
2            ! 9 Fluid viscosity
0.00026            ! 10 Fluid thermal expansion coefficient
3.91         ! 11 HX fluid specific heat
1014.9       ! 12 HX fluid density
1.7172       ! 13 HX fluid thermal conductivity
3.29         ! 14 HX fluid viscosity
2.7          ! 15 Top loss coefficient
3.6          ! 16 Edge loss coefficient for node-1
3.6          ! 17 Edge loss coefficient for node-2
3.6          ! 18 Edge loss coefficient for node-3
3.6          ! 19 Edge loss coefficient for node-4
3.6          ! 20 Edge loss coefficient for node-5
3.6          ! 21 Edge loss coefficient for node-6
3.6          ! 22 Edge loss coefficient for node-7
3.6          ! 23 Edge loss coefficient for node-8
3.6          ! 24 Edge loss coefficient for node-9
3.6          ! 25 Bottom loss coefficient
5            ! 26 HX loss coefficient
0            ! 27 Additional thermal conductivity
0.00635            ! 28 Tank wall thickness
150.         ! 29 Tank wall thermal conductivity
0.016916           ! 30 HX pipe inner diameter
0.01905            ! 31 HX pipe outer diameter
36.576       ! 32 HX pipe length
1443.599962        ! 33 HX pipe thermal conductivity
0.6096       ! 34 Height of HX wrap
```

```
0.008128               ! 35 HX tube spacing
0.005           ! 36 HX bond resistance
0.6             ! 37 F' factor
11              ! 38 Number of HX nodes
0               ! 39 Fraction of HX cover for node-1
0               ! 40 Fraction of HX cover for node-2
0               ! 41 Fraction of HX cover for node-3
0               ! 42 Fraction of HX cover for node-4
0               ! 43 Fraction of HX cover for node-5
1               ! 44 Fraction of HX cover for node-6
1               ! 45 Fraction of HX cover for node-7
1               ! 46 Fraction of HX cover for node-8
0.7             ! 47 Fraction of HX cover for node-9
6               ! 48 Tank node adjacent to HX node-1
0.091           ! 49 Fraction of HX length for HX node-1
6               ! 50 Tank node adjacent to HX node-2
0.091           ! 51 Fraction of HX length for HX node-2
6               ! 52 Tank node adjacent to HX node-3
0.091           ! 53 Fraction of HX length for HX node-3
7               ! 54 Tank node adjacent to HX node-4
0.091           ! 55 Fraction of HX length for HX node-4
7               ! 56 Tank node adjacent to HX node-5
0.091           ! 57 Fraction of HX length for HX node-5
7               ! 58 Tank node adjacent to HX node-6
0.091           ! 59 Fraction of HX length for HX node-6
8               ! 60 Tank node adjacent to HX node-7
0.091           ! 61 Fraction of HX length for HX node-7
8               ! 62 Tank node adjacent to HX node-8
0.091           ! 63 Fraction of HX length for HX node-8
8               ! 64 Tank node adjacent to HX node-9
0.091           ! 65 Fraction of HX length for HX node-9
9               ! 66 Tank node adjacent to HX node-10
0.091           ! 67 Fraction of HX length for HX node-10
9               ! 68 Tank node adjacent to HX node-11
0.091           ! 69 Fraction of HX length for HX node-11
4               ! 70 Inlet flow mode: diptube
1               ! 71 Exit node
0               ! 72 Fraction of inlet flow to node-1
0               ! 73 Fraction of inlet flow to node-2
0               ! 74 Fraction of inlet flow to node-3
0               ! 75 Fraction of inlet flow to node-4
0               ! 76 Fraction of inlet flow to node-5
0               ! 77 Fraction of inlet flow to node-6
0               ! 78 Fraction of inlet flow to node-7
0               ! 79 Fraction of inlet flow to node-8
1               ! 80 Fraction of inlet flow to node-9
1.3716          ! 81 Diptube length
```

```
0.016916                ! 82 Inner diptube diameter
0.01905                 ! 83 Outer diptube diameter
1414.8          ! 84 Diptube thermal conductivity
0.6             ! 85 Multiplier for natural convection
0.25            ! 86 Exponent for natural convection
9               ! 87 Number of diptube nodes
1               ! 88 Tank node for diptube node-1
2               ! 89 Tank node for diptube node-2
3               ! 90 Tank node for diptube node-3
4               ! 91 Tank node for diptube node-4
5               ! 92 Tank node for diptube node-5
6               ! 93 Tank node for diptube node-6
7               ! 94 Tank node for diptube node-7
8               ! 95 Tank node for diptube node-8
9               ! 96 Tank node for diptube node-9
INPUTS 25
36,3            ! Diverter:Temperature at outlet 2 ->Inlet diptube temperature
36,4            ! Diverter:Flow rate at outlet 2 ->Inlet diptube flow rate
30,1            ! Pipe - Glycol from Collector to HX:Temperature at Outlet A -
>Inlet temperature for HX
30,2            ! Pipe - Glycol from Collector to HX:Flow Rate at Outlet A ->Inlet
flow rate for HX
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Top loss
temperature
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-1
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-2
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-3
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-4
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-5
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-6
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-7
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-8
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Edge loss
temperature for node-9
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Bottom loss
temperature
0,0             ! [unconnected] Inversion mixing flow rate
0,0             ! [unconnected] Auxiliary heat input for node-1
0,0             ! [unconnected] Auxiliary heat input for node-2
```

```
0,0             ! [unconnected] Auxiliary heat input for node-3
0,0             ! [unconnected] Auxiliary heat input for node-4
25,1            ! Electric Element:Fluid energy ->Auxiliary heat input for node-5
0,0             ! [unconnected] Auxiliary heat input for node-6
0,0             ! [unconnected] Auxiliary heat input for node-7
0,0             ! [unconnected] Auxiliary heat input for node-8
0,0             ! [unconnected] Auxiliary heat input for node-9
*** INITIAL INPUT VALUES
20 0.0 20.0 0.0 AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes
AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes
-100 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
DERIVATIVES 9
20              ! 1 Initial tank temperature for node-1
20.0            ! 2 Initial tank temperature for node-2
20.0            ! 3 Initial tank temperature for node-3
20.0            ! 4 Initial tank temperature for node-4
20.0            ! 5 Initial tank temperature for node-5
20.0            ! 6 Initial tank temperature for node-6
20.0            ! 7 Initial tank temperature for node-7
20.0            ! 8 Initial tank temperature for node-8
20.0            ! 9 Initial tank temperature for node-9
*---------------------------------------------------------------------------

* Model "Glycol Pump" (Type 114)
*

UNIT 23 TYPE 114     Glycol Pump
*$UNIT_NAME Glycol Pump
*$MODEL .\Hydronics\Pumps\Single Speed\Type114.tmf
*$POSITION 620 293
*$LAYER Main #
*$# SINGLE-SPEED PUMP
PARAMETERS 4
398             ! 1 Rated flow rate
3.91            ! 2 Fluid specific heat
287.999992              ! 3 Rated power
0.0             ! 4 Motor heat loss fraction
INPUTS 5
31,1            ! Pipe - Glycol from HX to Collector:Temperature at Outlet A -
>Inlet fluid temperature
31,2            ! Pipe - Glycol from HX to Collector:Flow Rate at Outlet A ->Inlet
fluid flow rate
29,1            ! Pump Controller:Output control function ->Control signal
0,0             ! [unconnected] Overall pump efficiency
```

```
0,0                ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20.0 398 1.0 0.6 0.9
*------------------------------------------------------------------------------

* Model "Pump Controller" (Type 2)
*

UNIT 29 TYPE 2          Pump Controller
*$UNIT_NAME Pump Controller
*$MODEL .\Controllers\Differential Controller w_ Hysteresis\for
Temperatures\Solver 0 (Successive Substitution) Control Strategy\Type2b.tmf
*$POSITION 729 351
*$LAYER Controls #
*$# NOTE: This control strategy can only be used with solver 0 (Successive
substitution)
*$#
PARAMETERS 2
5                  ! 1 No. of oscillations
65.555578                  ! 2 High limit cut-out
INPUTS 6
26,1               ! Plat-Plate Collector:Outlet temperature ->Upper input
temperature Th
28,32              ! Storage Tank w/ HX:Tank nodal temperature-8 ->Lower input
temperature Tl
28,32              ! Storage Tank w/ HX:Tank nodal temperature-8 ->Monitoring
temperature Tin
34,2               ! Glycol Max Cutoff:Conditioning signal ->Input control function
0,0                ! [unconnected] Upper dead band dT
0,0                ! [unconnected] Lower dead band dT
*** INITIAL INPUT VALUES
20.0 10.0 20.0 0 8.89 4.44
*------------------------------------------------------------------------------

* Model "Pipe - Glycol from Collector to HX" (Type 604)
*

UNIT 30 TYPE 604        Pipe - Glycol from Collector to HX
*$UNIT_NAME Pipe - Glycol from Collector to HX
*$MODEL .\NREL Models\Noded Pipe Model\Calculated Convection
Coefficient\Type604a.tmf
*$POSITION 265 222
*$LAYER Main #
PARAMETERS 23
3.048              ! 1 Pipe Length
0.020599                   ! 2 Pipe Inner Diameter
0.022225                   ! 3 Pipe Outer Diameter
```

```
8940            ! 4 Pipe Density
1443.599962             ! 5 Pipe Thermal Conductivity
0.386           ! 6 Pipe Specific Heat
0.019           ! 7 Insulation Thickness
72              ! 8 Insulation Density
0.144           ! 9 InsulationThermal Conductivity
1.045           ! 10 Insulation Specific Heat
1014.9          ! 11 Fluid Density
1.7172          ! 12 Fluid Thermal Conductivity
3.91            ! 13 Fluid Specific Heat
3.29            ! 14 Fluid Viscosity
5               ! 15 Number of Fluid Nodes
5               ! 16 Number of Pipe and Insulation Nodes
32.222244               ! 17 Initial Fluid Temperature
25.555577               ! 18 Initial Pipe Temperature
25.555577               ! 19 Initial Insulation Temperature
0.9             ! 20 Surface Emissivity
0.              ! 21 Contact Resistance
1               ! 22 Convection Mode
1               ! 23 Pipe Orientation
INPUTS 7
26,1            ! Plat-Plate Collector:Outlet temperature ->Temperature at Inlet A
26,2            ! Plat-Plate Collector:Outlet flow rate ->Flow Rate at Inlet A
0,0             ! [unconnected] Temperature at Inlet B
0,0             ! [unconnected] Flow Rate at Inlet B
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Ambient
Temperature
0,0             ! [unconnected] Ambient Pressure
0,0             ! [unconnected] Wind Velocity
*** INITIAL INPUT VALUES
20.0 0. 20.0 0. AmbientTemp_pipes 1. 0.
*------------------------------------------------------------------------------

* Model "Pipe - Glycol from HX to Collector" (Type 604)
*

UNIT 31 TYPE 604     Pipe - Glycol from HX to Collector
*$UNIT_NAME Pipe - Glycol from HX to Collector
*$MODEL .\NREL Models\Noded Pipe Model\Calculated Convection
Coefficient\Type604a.tmf
*$POSITION 507 393
*$LAYER Main #
PARAMETERS 23
4.572           ! 1 Pipe Length
0.020599                ! 2 Pipe Inner Diameter
0.022225                ! 3 Pipe Outer Diameter
8940            ! 4 Pipe Density
```

```
1443.599962            ! 5 Pipe Thermal Conductivity
0.386           ! 6 Pipe Specific Heat
0.019           ! 7 Insulation Thickness
72              ! 8 Insulation Density
0.144           ! 9 InsulationThermal Conductivity
1.045           ! 10 Insulation Specific Heat
1014.9          ! 11 Fluid Density
1.7172          ! 12 Fluid Thermal Conductivity
3.91            ! 13 Fluid Specific Heat
3.29            ! 14 Fluid Viscosity
5               ! 15 Number of Fluid Nodes
5               ! 16 Number of Pipe and Insulation Nodes
32.222244              ! 17 Initial Fluid Temperature
25.555577              ! 18 Initial Pipe Temperature
25.555577              ! 19 Initial Insulation Temperature
0.9             ! 20 Surface Emissivity
0.              ! 21 Contact Resistance
1               ! 22 Convection Mode
1               ! 23 Pipe Orientation
INPUTS 7
28,3            ! Storage Tank w/ HX:Temperature at HX Outlet ->Temperature at
Inlet A
28,4            ! Storage Tank w/ HX:HX flow rate ->Flow Rate at Inlet A
0,0             ! [unconnected] Temperature at Inlet B
0,0             ! [unconnected] Flow Rate at Inlet B
39,1            ! PHX Weather -TMY3:Dry bulb temperature ->Ambient
Temperature
0,0             ! [unconnected] Ambient Pressure
0,0             ! [unconnected] Wind Velocity
*** INITIAL INPUT VALUES
20.0 0. 20.0 0. AmbientTemp_pipes 1. 0.
*------------------------------------------------------------------------------

* EQUATIONS "Constants"
*
EQUATIONS 3
CollectorSlope = 18.43
kJhr_to_watt = 3.6
AmbientTemp_pipes = 23.89 !(degrees C, or 75 F)  ambient temp where pipes
are
*$UNIT_NAME Constants
*$LAYER Main
*$POSITION 230 42

*------------------------------------------------------------------------------
```

```
* EQUATIONS "lit/hr to GPM"
*
EQUATIONS 1
GPM = [11,1]*0.004403
*$UNIT_NAME lit/hr to GPM
*$LAYER Main
*$POSITION 64 925

*------------------------------------------------------------------------------


* Model "Glycol Max Cutoff" (Type 1502)
*

UNIT 34 TYPE 1502    Glycol Max Cutoff
*$UNIT_NAME Glycol Max Cutoff
*$MODEL .\Controllers Library (TESS)\Aquastats\Heating Mode\Type1502.tmf
*$POSITION 620 191
*$LAYER Main #
PARAMETERS 4
1               ! 1 Number of heating stages
5               ! 2 # oscillations permitted
2.777778                ! 3 Temperature dead band
0               ! 4 Number of stage exceptions
INPUTS 3
26,1            ! Plat-Plate Collector:Outlet temperature ->Fluid temperature
0,0             ! [unconnected] Lockout signal
0,0             ! [unconnected] Setpoint temperature for stage
*** INITIAL INPUT VALUES
20.0 0 130.000024
*------------------------------------------------------------------------------

* Model "Mixer - Out to taps" (Type 11)
*

UNIT 35 TYPE 11      Mixer - Out to taps
*$UNIT_NAME Mixer - Out to taps
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 336 847
*$LAYER Main #
PARAMETERS 1
1               ! 1 Tee piece mode
INPUTS 4
36,1            ! Diverter:Temperature at outlet 1 ->Temperature at inlet 1
36,2            ! Diverter:Flow rate at outlet 1 ->Flow rate at inlet 1
28,1            ! Storage Tank w/ HX:Temperature at outlet ->Temperature at
inlet 2
```

```
28,2            ! Storage Tank w/ HX:Flow rate at outlet ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Diverter" (Type 11)
*

UNIT 36 TYPE 11      Diverter
*$UNIT_NAME Diverter
*$MODEL .\Hydronics\Flow Diverter\Other Fluids\Right Facing\Type11f.tmf
*$POSITION 203 712
*$LAYER Main #
PARAMETERS 1
2               ! 1 Controlled flow diverter mode
INPUTS 3
39,5            ! PHX Weather -TMY3:Mains water temperature ->Inlet
temperature
11,1            ! Water Draw Profile:Average water draw ->Inlet flow rate
37,1            ! Tempering Control (<110F):Fraction to heat source ->Control
signal
*** INITIAL INPUT VALUES
20.0 0 0.5
*------------------------------------------------------------------------------

* Model "Tempering Control (<110F)" (Type 953)
*

UNIT 37 TYPE 953     Tempering Control (<110F)
*$UNIT_NAME Tempering Control (<110F)
*$MODEL .\Controllers Library (TESS)\Tempering Valve Controller\Type953.tmf
*$POSITION 145 605
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive
substitution)
*$#
PARAMETERS 1
5               ! 1 No. of oscillations
INPUTS 4
0,0             ! [unconnected] Setpoint temperature
28,1            ! Storage Tank w/ HX:Temperature at outlet ->Source temperature
39,5            ! PHX Weather -TMY3:Mains water temperature ->Tempering fluid
temperature (return temperature)
0,0             ! [unconnected] Mode
*** INITIAL INPUT VALUES
43.333355 10.0 20.0 1
*------------------------------------------------------------------------------
```

```
* EQUATIONS "C to F"
*
EQUATIONS 14
Tank_Node1_F = [28,25]*(9/5) + 32
Tank_Node2_F = [28,26]*(9/5) + 32
Tank_Node3_F = [28,27]*(9/5) + 32
Tank_Node4_F = [28,28]*(9/5) + 32
Tank_Node5_F = [28,29]*(9/5) + 32
Tank_Node6_F = [28,30]*(9/5) + 32
Tank_Node7_F = [28,31]*(9/5) + 32
Tank_Node8_F = [28,32]*(9/5) + 32
Tank_Node9_F = [28,33]*(9/5) + 32
ColdWater_in_Main_F = [39,5]*(9/5) + 32
MixedHotWater_F = [35,1]*(9/5) + 32
HotWater_outofBW_F = [28,1]*(9/5) + 32
HTF_TankHX_F = [28,3]*(9/5) + 32
HTF_Roof_F = [26,1]*(9/5) + 32
*$UNIT_NAME C to F
*$LAYER Main
*$POSITION 995 535

*------------------------------------------------------------------------------


* Model "PHX Weather -TMY3" (Type 15)
*

UNIT 39 TYPE 15        PHX Weather -TMY3
*$UNIT_NAME PHX Weather -TMY3
*$MODEL .\Weather Data Reading and Processing\Standard
Format\TMY3\Type15-TMY3.tmf
*$POSITION 76 138
*$LAYER Main #
PARAMETERS 9
7                 ! 1 File Type
34                ! 2 Logical unit
3                 ! 3 Tilted Surface Radiation Mode
0.2               ! 4 Ground reflectance: no albedo reported
0.7               ! 5 Not used
1                 ! 6 Number of surfaces
1                 ! 7 Tracking mode
CollectorSlope          ! 8 Slope of surface
0                 ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Trnsys17\Weather\US-TMY3\US_AZ_PHOENIX_INTL_AP_722780.csv"
34
```

```
*|? Which file contains the TMY-2 weather data? |1000
*----------------------------------------------------------------------------

END
```

APPENDIX D

FAFCO® TRNSYS INPUT FILE

```
VERSION 17
******************************************************************
*************
*** TRNSYS input file (deck) generated by TrnsysStudio
*** on Friday, June 29, 2012 at 00:13
*** from TrnsysStudio project: Y:\Documents\Docs\School\Alt
Masters\Thesis\TRNSYS Files\OFFICIAL FILES\Thesis -
FAFCO\FAFCO_trueambient.tpf
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** TrnsysStudio to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:software@cstb.fr
***
******************************************************************
*************


******************************************************************
*************
*** Units
******************************************************************
*************

******************************************************************
*************
*** Control cards
******************************************************************
*************
* START, STOP and STEP
CONSTANTS 3
START=0
STOP=8760.000229455
STEP=0.016666666
SIMULATION    START STOP   STEP  ! Start time     End time        Time step
TOLERANCES 0.001 0.001                  ! Integration    Convergence
LIMITS 50 50 50                         ! Max iterations         Max warnings
        Trace limit
DFQ 1                            ! TRNSYS numerical integration solver
method
WIDTH 120                        ! TRNSYS output file width, number of
characters
LIST                             ! NOLIST statement
                                 ! MAP statement
SOLVER 0 1 1                     ! Solver statement     Minimum relaxation
factor  Maximum relaxation factor
```

```
NAN_CHECK 0                              ! Nan DEBUG statement
OVERWRITE_CHECK 0                                ! Overwrite DEBUG statement
TIME_REPORT 0                            ! disable time report
EQSOLVER 0                               ! EQUATION SOLVER statement
* User defined CONSTANTS


* Model "Preheat & Solar Temp Plotter" (Type 65)
*

UNIT 13 TYPE 65       Preheat & Solar Temp Plotter
*$UNIT_NAME Preheat & Solar Temp Plotter
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 1172 398
*$LAYER Outputs #
PARAMETERS 12
6               ! 1 Nb. of left-axis variables
1               ! 2 Nb. of right-axis variables
0               ! 3 Left axis minimum
100             ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
5               ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 7
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Left axis variable-1
25,18           ! Preheat Tank:Tank nodal temperature-1 ->Left axis variable-2
25,25           ! Preheat Tank:Tank nodal temperature-8 ->Left axis variable-3
21,1            ! Solar Collector:Outlet temperature ->Left axis variable-4
28,3            ! Heat Exchanger:Cold-side outlet temperature ->Left axis variable-
5
25,1            ! Preheat Tank:Temperature at outlet-1 ->Left axis variable-6
mains_GPM             ! lit/hr to GPM:mains_GPM ->Right axis variable
*** INITIAL INPUT VALUES
Ambient Preheat_Node1_temp Preheat_Node8_temp Glycol_panel_out
H20_leaving_HX
WaterToBackup GPM
LABELS  3
"Temperatures"
"GPM Water Draw"
"Solar Tank and Collector"
*------------------------------------------------------------------------------
```

```
* EQUATIONS "Equations / Constants"
*
EQUATIONS 3
CollectorSlope = 18.43
kJhr_to_watt = 3.6
AmbientTemp_pipes = 23.89 !(degrees C, or 75 F)  ambient temp where pipes
are
*$UNIT_NAME Equations / Constants
*$LAYER Main
*$POSITION 731 74

*------------------------------------------------------------------------------


* Model "Electric Backup Plot" (Type 65)
*

UNIT 20 TYPE 65        Electric Backup Plot
*$UNIT_NAME Electric Backup Plot
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 1226 1012
*$LAYER Main #
PARAMETERS 12
7                  ! 1 Nb. of left-axis variables
4                  ! 2 Nb. of right-axis variables
0.0                ! 3 Left axis minimum
220                ! 4 Left axis maximum
0.0                ! 5 Right axis minimum
5                  ! 6 Right axis maximum
1                  ! 7 Number of plots per simulation
12                 ! 8 X-axis gridpoints
0                  ! 9 Shut off Online w/o removing
-1                 ! 10 Logical unit for output file
0                  ! 11 Output file units
0                  ! 12 Output file delimiter
INPUTS 11
Tank_Node1_F                ! C to F:Tank_Node1_F ->Left axis variable-1
Tank_Node3_F                ! C to F:Tank_Node3_F ->Left axis variable-2
Tank_Node8_F                ! C to F:Tank_Node8_F ->Left axis variable-3
Tank_Node9_F                ! C to F:Tank_Node9_F ->Left axis variable-4
MixedHotWater_F             ! C to F:MixedHotWater_F ->Left axis variable-5
ColdWater_in_Main_F         ! C to F:ColdWater_in_Main_F ->Left axis variable-6
HotWater_outofBW_F          ! C to F:HotWater_outofBW_F ->Left axis variable-7
kW_element1           ! kJ/h to kW:kW_element1 ->Right axis variable-1
kW_element2           ! kJ/h to kW:kW_element2 ->Right axis variable-2
kW_comb_elements            ! kJ/h to kW:kW_comb_elements ->Right axis
variable-3
```

```
backup_GPM          ! lit/hr to GPM:backup_GPM ->Right axis variable-4
*** INITIAL INPUT VALUES
Node1_temp Node3_temp Node8_temp Node9_temp Mix_Water_out
Cold_mains_in
Hot_fr_tank kW_element1 kW_element2 kW_comb GPM
LABELS  3
"Temp F"
"kW  or  GPM"
"Backup Tank"
*------------------------------------------------------------------------------

* Model "Energy Usage Output" (Type 46)
*

UNIT 22 TYPE 46      Energy Usage Output
*$UNIT_NAME Energy Usage Output
*$MODEL .\Output\Printegrator\Unformatted\Type46.tmf
*$POSITION 1220 823
*$LAYER Main #
*$# PRINTEGRATOR
PARAMETERS 5
33              ! 1 Logical unit
-1              ! 2 Logical unit for monthly summaries
0               ! 3 Relative or absolute start time
24.000001               ! 4 Printing & integrating interval
0               ! 5 Number of inputs to avoid integration
INPUTS 6
kW_element1         ! kJ/h to kW:kW_element1 ->Input to be integrated &
printed-1
kW_element2         ! kJ/h to kW:kW_element2 ->Input to be integrated &
printed-2
kW_comb_elements            ! kJ/h to kW:kW_comb_elements ->Input to be
integrated & printed-3
kW_potable_pump             ! kJ/h to kW:kW_potable_pump ->Input to be
integrated & printed-4
kW_glycol_pump              ! kJ/h to kW:kW_glycol_pump ->Input to be
integrated & printed-5
kW_TOTAL            ! kJ/h to kW:kW_TOTAL ->Input to be integrated &
printed-6
*** INITIAL INPUT VALUES
kWh_elem1 kWh_elem2 kWh_comb kWh_potable_pump kWh_glycol_pump
kWh_TOTAL

LABELS 0

*** External files
ASSIGN "FAFCO_trueambient_Results_TMY3.txt" 33
```

```
*|? Output file for integrated results? |1000
*------------------------------------------------------------------------------

* Model "Water Draw Profile" (Type 14)
*

UNIT 24 TYPE 14        Water Draw Profile
*$UNIT_NAME Water Draw Profile
*$MODEL .\Utility\Forcing Functions\Water Draw\Type14b.tmf
*$POSITION 90 1022
*$LAYER Main #
PARAMETERS 52
0              ! 1 Initial value of time
0              ! 2 Initial value of function
7.5            ! 3 Time at point-1
0              ! 4 Water draw at point -1
7.5            ! 5 Time at point-2
340.69         ! 6 Water draw at point -2
7.75           ! 7 Time at point-3
340.69         ! 8 Water draw at point -3
7.75           ! 9 Time at point-4
0              ! 10 Water draw at point -4
13             ! 11 Time at point-5
0              ! 12 Water draw at point -5
13             ! 13 Time at point-6
340.69         ! 14 Water draw at point -6
13.181         ! 15 Time at point-7
340.69         ! 16 Water draw at point -7
13.181         ! 17 Time at point-8
0              ! 18 Water draw at point -8
15             ! 19 Time at point-9
0              ! 20 Water draw at point -9
15             ! 21 Time at point-10
340.69         ! 22 Water draw at point -10
15.028         ! 23 Time at point-11
340.69         ! 24 Water draw at point -11
15.028         ! 25 Time at point-12
0              ! 26 Water draw at point -12
18             ! 27 Time at point-13
0              ! 28 Water draw at point -13
18             ! 29 Time at point-14
340.69         ! 30 Water draw at point -14
18.056         ! 31 Time at point-15
340.69         ! 32 Water draw at point -15
18.056         ! 33 Time at point-16
0              ! 34 Water draw at point -16
20             ! 35 Time at point-17
```

```
0               ! 36 Water draw at point -17
20              ! 37 Time at point-18
340.69          ! 38 Water draw at point -18
20.111          ! 39 Time at point-19
340.69          ! 40 Water draw at point -19
20.111          ! 41 Time at point-20
0               ! 42 Water draw at point -20
22              ! 43 Time at point-21
0               ! 44 Water draw at point -21
22              ! 45 Time at point-22
340.69          ! 46 Water draw at point -22
22.083          ! 47 Time at point-23
340.69          ! 48 Water draw at point -23
22.083          ! 49 Time at point-24
0               ! 50 Water draw at point -24
24              ! 51 Time at point-25
0               ! 52 Water draw at point -25
*------------------------------------------------------------------------------

* Model "Preheat Tank" (Type 534)
*

UNIT 25 TYPE 534     Preheat Tank
*$UNIT_NAME Preheat Tank
*$MODEL .\Storage Tank Library (TESS)\Cylindrical Storage Tank\Vertical
Cylinder\Version without Plug-In\No HXs\Type534-NoHX.tmf
*$POSITION 426 574
*$LAYER Main #
*$# CYLINDRICAL STORAGE TANK
PARAMETERS 41
-1              ! 1 LU for data file
9               ! 2 Number of tank nodes
2               ! 3 Number of ports
0               ! 4 Number of immersed heat exchangers
1               ! 5 Number of miscellaneous heat flows
0.189272                ! 6 Tank volume
1.461           ! 7 Tank height
0               ! 8 Tank fluid
4.032           ! 9 Fluid specific heat
988.5           ! 10 Fluid density
2.3112          ! 11 Fluid thermal conductivity
2               ! 12 Fluid viscosity
0.00026                 ! 13 Fluid thermal expansion coefficient
5.364           ! 14 Top loss coefficient
5.364           ! 15 Edge loss coefficient for node-1
5.364           ! 16 Edge loss coefficient for node-2
5.364           ! 17 Edge loss coefficient for node-3
```

```
5.364          ! 18 Edge loss coefficient for node-4
5.364          ! 19 Edge loss coefficient for node-5
5.364          ! 20 Edge loss coefficient for node-6
5.364          ! 21 Edge loss coefficient for node-7
5.364          ! 22 Edge loss coefficient for node-8
5.364          ! 23 Edge loss coefficient for node-9
5.364          ! 24 Bottom loss coefficient
0              ! 25 Additional thermal conductivity
1              ! 26 Inlet flow mode-1
9              ! 27 Entry node-1
1              ! 28 Exit node-1
1              ! 29 Inlet flow mode-2
9              ! 30 Entry node-2
1              ! 31 Exit node-2
0              ! 32 Flue loss coefficient for node-1
0              ! 33 Flue loss coefficient for node-2
0              ! 34 Flue loss coefficient for node-3
0              ! 35 Flue loss coefficient for node-4
0              ! 36 Flue loss coefficient for node-5
0              ! 37 Flue loss coefficient for node-6
0              ! 38 Flue loss coefficient for node-7
0              ! 39 Flue loss coefficient for node-8
0              ! 40 Flue loss coefficient for node-9
9              ! 41 Node for miscelaneous heat gain
INPUTS 27
43,3           ! Diverter:Temperature at outlet 2 ->Inlet temperature for port-1
43,4           ! Diverter:Flow rate at outlet 2 ->Inlet flow rate for port-1
31,1           ! Pipe - Water to Preheat Tank:Temperature at Outlet A ->Inlet
temperature for port-2
31,2           ! Pipe - Water to Preheat Tank:Flow Rate at Outlet A ->Inlet flow
rate for port-2
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Top loss
temperature
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-1
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-2
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-3
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-4
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-5
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-6
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-7
```

```
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-8
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-9
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Bottom loss
temperature
0,0             ! [unconnected] Gas flue temperature
0,0             ! [unconnected] Inversion mixing flow rate
0,0             ! [unconnected] Auxiliary heat input for node-1
0,0             ! [unconnected] Auxiliary heat input for node-2
0,0             ! [unconnected] Auxiliary heat input for node-3
0,0             ! [unconnected] Auxiliary heat input for node-4
0,0             ! [unconnected] Auxiliary heat input for node-5
0,0             ! [unconnected] Auxiliary heat input for node-6
0,0             ! [unconnected] Auxiliary heat input for node-7
0,0             ! [unconnected] Auxiliary heat input for node-8
0,0             ! [unconnected] Auxiliary heat input for node-9
0,0             ! [unconnected] Miscellaneous heat input
*** INITIAL INPUT VALUES
20.0 0.0 20.0 0.0 AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes
AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes
20.0 -100 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0
DERIVATIVES 9
AmbientTemp_pipes          ! 1 Initial Tank Temperature-1
AmbientTemp_pipes          ! 2 Initial Tank Temperature-2
AmbientTemp_pipes          ! 3 Initial Tank Temperature-3
AmbientTemp_pipes          ! 4 Initial Tank Temperature-4
AmbientTemp_pipes          ! 5 Initial Tank Temperature-5
AmbientTemp_pipes          ! 6 Initial Tank Temperature-6
AmbientTemp_pipes          ! 7 Initial Tank Temperature-7
AmbientTemp_pipes          ! 8 Initial Tank Temperature-8
AmbientTemp_pipes          ! 9 Initial Tank Temperature-9
*------------------------------------------------------------------------------

* Model "Potable Water Pump" (Type 110)
*

UNIT 27 TYPE 110      Potable Water Pump
*$UNIT_NAME Potable Water Pump
*$MODEL .\Hydronics\Pumps\Variable Speed\Type110.tmf
*$POSITION 668 486
*$LAYER Main #
*$# VARIABLE-SPEED PUMP
PARAMETERS 6
```

```
341             ! 1 Rated flow rate
4.032           ! 2 Fluid specific heat
57.599998               ! 3 Rated power
0               ! 4 Motor heat loss fraction
1               ! 5 Number of power coefficients
1.0             ! 6 Power coefficient
INPUTS 5
32,1            ! Pipe - Water to HX:Temperature at Outlet A ->Inlet fluid
temperature
32,2            ! Pipe - Water to HX:Flow Rate at Outlet A ->Inlet fluid flow rate
30,1            ! Differential Controller:Output control function ->Control signal
0,0             ! [unconnected] Total pump efficiency
0,0             ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20 0 1 0.6 0.9
*------------------------------------------------------------------------------

* Model "Heat Exchanger" (Type 91)
*

UNIT 28 TYPE 91      Heat Exchanger
*$UNIT_NAME Heat Exchanger
*$MODEL .\Heat Exchangers\Constant Effectiveness\Type91a.tmf
*$POSITION 451 398
*$LAYER Main #
PARAMETERS 3
.584            ! 1 Heat exchanger effectiveness
3.91            ! 2 Specific heat of hot side fluid
4.032           ! 3 Specific heat of cold side fluid
INPUTS 4
34,1            ! Pipe - Glycol to Collector:Temperature at Outlet A ->Hot side inlet
temperature
34,2            ! Pipe - Glycol to Collector:Flow Rate at Outlet A ->Hot side flow
rate
27,1            ! Potable Water Pump:Outlet fluid temperature ->Cold side inlet
temperature
27,2            ! Potable Water Pump:Outlet flow rate ->Cold side flow rate
*** INITIAL INPUT VALUES
20.0 0. 20.0 0.
*------------------------------------------------------------------------------

* Model "Glycol Pump" (Type 110)
*

UNIT 29 TYPE 110     Glycol Pump
*$UNIT_NAME Glycol Pump
*$MODEL .\Hydronics\Pumps\Variable Speed\Type110.tmf
```

```
*$POSITION 665 282
*$LAYER Main #
*$# VARIABLE-SPEED PUMP
PARAMETERS 6
227             ! 1 Rated flow rate
3.91            ! 2 Fluid specific heat
43.199999               ! 3 Rated power
0               ! 4 Motor heat loss fraction
1               ! 5 Number of power coefficients
1               ! 6 Power coefficient
INPUTS 5
21,1            ! Solar Collector:Outlet temperature ->Inlet fluid temperature
21,2            ! Solar Collector:Outlet flow rate ->Inlet fluid flow rate
30,1            ! Differential Controller:Output control function ->Control signal
0,0             ! [unconnected] Total pump efficiency
0,0             ! [unconnected] Motor efficiency
*** INITIAL INPUT VALUES
20 0 1 0.6 0.9
*------------------------------------------------------------------------------

* Model "Differential Controller" (Type 911)
*

UNIT 30 TYPE 911     Differential Controller
*$UNIT_NAME Differential Controller
*$MODEL .\Controllers Library (TESS)\Differental Controller with Lock-
Outs\Type911.tmf
*$POSITION 875 344
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive
substitution)
*$#
PARAMETERS 3
5               ! 1 No. of oscillations
0.083333                ! 2 Minimum run-time
0.083333                ! 3 Minimum reset time
INPUTS 7
21,1            ! Solar Collector:Outlet temperature ->Upper input temperature Th
25,25           ! Preheat Tank:Tank nodal temperature-8 ->Lower input
temperature Tl
25,25           ! Preheat Tank:Tank nodal temperature-8 ->Monitoring
temperature Tin
0,0             ! [unconnected] High limit cut-out
0,0             ! [unconnected] Upper dead band dT
0,0             ! [unconnected] Lower dead band dT
0,0             ! [unconnected] Lock-out control signal
*** INITIAL INPUT VALUES
```

```
20 40 20 65.555578 5.555556 2.222222 0
*------------------------------------------------------------------------------

* Model "Solar Collector" (Type 553)
*

UNIT 21 TYPE 553     Solar Collector
*$UNIT_NAME Solar Collector
*$MODEL .\Solar Library (TESS)\Unglazed Collector (No Covers)\OG100 Quadratic
Efficiency Approach\Type553.tmf
*$POSITION 489 225
*$LAYER Main #
*$# This component sets the flow rate for all connected flow loop components if
the variable speed option is enabled.
PARAMETERS 15
1               ! 1 Number in series
4.459309                ! 2 Collector array area
3.91            ! 3 Fluid specific heat
1               ! 4 Collector test mode
250.9           ! 5 Tested flow rate per unit area
4.190           ! 6 Fluid specific heat at test conditions
0.0             ! 7 Minimum flowrate
250.9           ! 8 Maximum flowrate
20.000001               ! 9 Capacitance of Collector
0.9             ! 10 Emissivity of collector surface
0.96            ! 11 Absorptivity of collector surface
15              ! 12 Number of Nodes
20              ! 13 Initial Temperature
-0.159          ! 14 Linear IAM term (b0)
0.107           ! 15 Quadratic IAM term (b1)
INPUTS 14
33,1            ! Pipe - Glycol Return:Temperature at Outlet A ->Inlet temperature
33,2            ! Pipe - Glycol Return:Flow Rate at Outlet A ->Inlet flowrate
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Ambient
temperature
47,4            ! PHX Weather-TMY3:Effective sky temperature ->Sky temperature
47,25           ! PHX Weather-TMY3:Beam radiation for surface ->Beam radiation
on the tilted surface
47,26           ! PHX Weather-TMY3:Sky diffuse radiation for surface ->Sky
diffuse radiation on tilted surface
47,27           ! PHX Weather-TMY3:Ground reflected diffuse radiation for surface
->Ground-reflected diffuse radiation on tilted surface
47,29           ! PHX Weather-TMY3:Angle of incidence for surface ->Incidence
angle
CollectorSlope          ! [equation] Collector slope
0,0             ! [unconnected] Pump Control Specification
0,0             ! [unconnected] Outlet Temperature Setpoint
```

```
0,0             ! [unconnected] Collector intercept efficiency
0,0             ! [unconnected] Collector efficiency slope
0,0             ! [unconnected] Collector efficiency curvature
*** INITIAL INPUT VALUES
20.0 100.0 10.0 10.0 0.0 0.0 0.0 0 CollectorSlope 0 93.333357 .882 67.888797
0
*------------------------------------------------------------------------------

* EQUATIONS "kJ/h to kW"
*
EQUATIONS 6
kW_element1 = [39,1]/3600
kW_element2 = [35,1]/3600
kW_comb_elements = kW_element1+kW_element2
kW_potable_pump = [27,3]/3600
kW_glycol_pump = [29,3]/3600
kW_TOTAL = kW_comb_elements+kW_potable_pump+kW_glycol_pump
*$UNIT_NAME kJ/h to kW
*$LAYER Main
*$POSITION 1011 928

*------------------------------------------------------------------------------


* Model "Pipe - Water to HX" (Type 604)
*

UNIT 32 TYPE 604     Pipe - Water to HX
*$UNIT_NAME Pipe - Water to HX
*$MODEL .\NREL Models\Noded Pipe Model\Calculated Convection
Coefficient\Type604a.tmf
*$POSITION 570 551
*$LAYER Main #
PARAMETERS 23
1.524           ! 1 Pipe Length
0.013843                ! 2 Pipe Inner Diameter
0.015875                ! 3 Pipe Outer Diameter
935             ! 4 Pipe Density
93.599998               ! 5 Pipe Thermal Conductivity
.0021           ! 6 Pipe Specific Heat
0.019           ! 7 Insulation Thickness
72.             ! 8 Insulation Density
0.144           ! 9 InsulationThermal Conductivity
1.045           ! 10 Insulation Specific Heat
988.5           ! 11 Fluid Density
2.3112          ! 12 Fluid Thermal Conductivity
4.032           ! 13 Fluid Specific Heat
```

```
2.00            ! 14 Fluid Viscosity
3               ! 15 Number of Fluid Nodes
3               ! 16 Number of Pipe and Insulation Nodes
25.555577               ! 17 Initial Fluid Temperature
25.555577               ! 18 Initial Pipe Temperature
25.555577               ! 19 Initial Insulation Temperature
0.9             ! 20 Surface Emissivity
0.              ! 21 Contact Resistance
1               ! 22 Convection Mode
1               ! 23 Pipe Orientation
INPUTS 7
25,3            ! Preheat Tank:Temperature at outlet-2 ->Temperature at Inlet A
25,4            ! Preheat Tank:Flow rate at outlet-2 ->Flow Rate at Inlet A
0,0             ! [unconnected] Temperature at Inlet B
0,0             ! [unconnected] Flow Rate at Inlet B
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Ambient
Temperature
0,0             ! [unconnected] Ambient Pressure
0,0             ! [unconnected] Wind Velocity
*** INITIAL INPUT VALUES
20.0 0. 20.0 0. AmbientTemp_pipes 1. 0.
*------------------------------------------------------------------------------

* Model "Pipe - Water to Preheat Tank" (Type 604)
*

UNIT 31 TYPE 604      Pipe - Water to Preheat Tank
*$UNIT_NAME Pipe - Water to Preheat Tank
*$MODEL .\NREL Models\Noded Pipe Model\Calculated Convection
Coefficient\Type604a.tmf
*$POSITION 286 418
*$LAYER Main #
PARAMETERS 23
1.524           ! 1 Pipe Length
0.013843                ! 2 Pipe Inner Diameter
0.015875                ! 3 Pipe Outer Diameter
935             ! 4 Pipe Density
93.599998               ! 5 Pipe Thermal Conductivity
.0021           ! 6 Pipe Specific Heat
0.019           ! 7 Insulation Thickness
72              ! 8 Insulation Density
0.144           ! 9 InsulationThermal Conductivity
1.045           ! 10 Insulation Specific Heat
988.5           ! 11 Fluid Density
2.3112          ! 12 Fluid Thermal Conductivity
4.032           ! 13 Fluid Specific Heat
2.00            ! 14 Fluid Viscosity
```

```
3               ! 15 Number of Fluid Nodes
3               ! 16 Number of Pipe and Insulation Nodes
25.555577               ! 17 Initial Fluid Temperature
25.555577               ! 18 Initial Pipe Temperature
25.555577               ! 19 Initial Insulation Temperature
0.9             ! 20 Surface Emissivity
0.              ! 21 Contact Resistance
1               ! 22 Convection Mode
1               ! 23 Pipe Orientation
INPUTS 7
28,3            ! Heat Exchanger:Cold-side outlet temperature ->Temperature at
Inlet A
28,4            ! Heat Exchanger:Cold-side flow rate ->Flow Rate at Inlet A
0,0             ! [unconnected] Temperature at Inlet B
0,0             ! [unconnected] Flow Rate at Inlet B
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Ambient
Temperature
0,0             ! [unconnected] Ambient Pressure
0,0             ! [unconnected] Wind Velocity
*** INITIAL INPUT VALUES
20.0 0. 20.0 0. AmbientTemp_pipes 1. 0.
*---------------------------------------------------------------------------

* Model "Pipe - Glycol Return" (Type 604)
*

UNIT 33 TYPE 604     Pipe - Glycol Return
*$UNIT_NAME Pipe - Glycol Return
*$MODEL .\NREL Models\Noded Pipe Model\Calculated Convection
Coefficient\Type604a.tmf
*$POSITION 341 228
*$LAYER Main #
PARAMETERS 23
4.572           ! 1 Pipe Length
0.013843                ! 2 Pipe Inner Diameter
0.015875                ! 3 Pipe Outer Diameter
935             ! 4 Pipe Density
93.599998               ! 5 Pipe Thermal Conductivity
.0021           ! 6 Pipe Specific Heat
0.019           ! 7 Insulation Thickness
72              ! 8 Insulation Density
0.144           ! 9 InsulationThermal Conductivity
1.045           ! 10 Insulation Specific Heat
1014.9          ! 11 Fluid Density
1.7172          ! 12 Fluid Thermal Conductivity
3.91            ! 13 Fluid Specific Heat
3.29            ! 14 Fluid Viscosity
```

```
5               ! 15 Number of Fluid Nodes
5               ! 16 Number of Pipe and Insulation Nodes
32.222244               ! 17 Initial Fluid Temperature
25.555577               ! 18 Initial Pipe Temperature
25.555577               ! 19 Initial Insulation Temperature
0.9             ! 20 Surface Emissivity
0.              ! 21 Contact Resistance
1               ! 22 Convection Mode
1               ! 23 Pipe Orientation
INPUTS 7
28,1            ! Heat Exchanger:Hot-side outlet temperature ->Temperature at
Inlet A
28,2            ! Heat Exchanger:Hot-side flow rate ->Flow Rate at Inlet A
0,0             ! [unconnected] Temperature at Inlet B
0,0             ! [unconnected] Flow Rate at Inlet B
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Ambient
Temperature
0,0             ! [unconnected] Ambient Pressure
0,0             ! [unconnected] Wind Velocity
*** INITIAL INPUT VALUES
20.0 0. 20.0 0. AmbientTemp_pipes 1. 0.
*------------------------------------------------------------------------------

* Model "Pipe - Glycol to Collector" (Type 604)
*

UNIT 34 TYPE 604     Pipe - Glycol to Collector
*$UNIT_NAME Pipe - Glycol to Collector
*$MODEL .\NREL Models\Noded Pipe Model\Calculated Convection
Coefficient\Type604a.tmf
*$POSITION 598 347
*$LAYER Main #
PARAMETERS 23
3.048           ! 1 Pipe Length
0.013843                ! 2 Pipe Inner Diameter
0.015875                ! 3 Pipe Outer Diameter
935             ! 4 Pipe Density
93.599998               ! 5 Pipe Thermal Conductivity
.0021           ! 6 Pipe Specific Heat
0.019           ! 7 Insulation Thickness
72              ! 8 Insulation Density
0.144           ! 9 InsulationThermal Conductivity
1.045           ! 10 Insulation Specific Heat
1014.9          ! 11 Fluid Density
1.7172          ! 12 Fluid Thermal Conductivity
3.91            ! 13 Fluid Specific Heat
3.29            ! 14 Fluid Viscosity
```

```
5               ! 15 Number of Fluid Nodes
5               ! 16 Number of Pipe and Insulation Nodes
37.7778                 ! 17 Initial Fluid Temperature
25.555577               ! 18 Initial Pipe Temperature
25.555577               ! 19 Initial Insulation Temperature
0.9             ! 20 Surface Emissivity
0.              ! 21 Contact Resistance
1               ! 22 Convection Mode
1               ! 23 Pipe Orientation
INPUTS 7
29,1            ! Glycol Pump:Outlet fluid temperature ->Temperature at Inlet A
29,2            ! Glycol Pump:Outlet flow rate ->Flow Rate at Inlet A
0,0             ! [unconnected] Temperature at Inlet B
0,0             ! [unconnected] Flow Rate at Inlet B
47,1            ! PHX Weather-TMY3:Dry bulb temperature ->Ambient
Temperature
0,0             ! [unconnected] Ambient Pressure
0,0             ! [unconnected] Wind Velocity
*** INITIAL INPUT VALUES
20.0 0. 20.0 0. AmbientTemp_pipes 1. 0.
*------------------------------------------------------------------------------

* Model "Lower Element" (Type 1226)
*

UNIT 35 TYPE 1226    Lower Element
*$UNIT_NAME Lower Element
*$MODEL .\Storage Tank Library (TESS)\Tank Heating Device\Electric\Type1226-
Elec.tmf
*$POSITION 831 980
*$LAYER Main #
INPUTS 3
0,0             ! [unconnected] Heating capacity
0,0             ! [unconnected] Thermal efficiency
36,1            ! Bottom Thermostat:Control signal for stage heating ->Control
signal
*** INITIAL INPUT VALUES
16199.999571 1. 1.
*------------------------------------------------------------------------------

* Model "Bottom Thermostat" (Type 1502)
*

UNIT 36 TYPE 1502    Bottom Thermostat
*$UNIT_NAME Bottom Thermostat
*$MODEL .\Storage Tank Library (TESS)\Aquastats\Heating Mode\Type1502.tmf
*$POSITION 836 1091
```

```
*$LAYER Main #
PARAMETERS 4
1               ! 1 Number of heating stages
5               ! 2 # oscillations permitted
6.111111                ! 3 Temperature dead band
0               ! 4 Number of stage exceptions
INPUTS 3
37,22           ! Bradford White:Tank nodal temperature-8 ->Fluid temperature
38,1            ! Top Thermostat:Control signal for stage heating ->Lockout signal
0,0             ! [unconnected] Setpoint temperature for stage
*** INITIAL INPUT VALUES
20.0 0 51.666689
*------------------------------------------------------------------------------

* Model "Bradford White" (Type 534)
*

UNIT 37 TYPE 534     Bradford White
*$UNIT_NAME Bradford White
*$MODEL .\Storage Tank Library (TESS)\Cylindrical Storage Tank\Vertical
Cylinder\Version without Plug-In\No HXs\Type534-NoHX.tmf
*$POSITION 584 902
*$LAYER Main #
*$# CYLINDRICAL STORAGE TANK
PARAMETERS 37
-1              ! 1 LU for data file
9               ! 2 Number of tank nodes
1               ! 3 Number of ports
0               ! 4 Number of immersed heat exchangers
0               ! 5 Number of miscellaneous heat flows
0.189272                ! 6 Tank volume
1.461           ! 7 Tank height
0               ! 8 Tank fluid
4.032           ! 9 Fluid specific heat
988.5           ! 10 Fluid density
2.3112          ! 11 Fluid thermal conductivity
2               ! 12 Fluid viscosity
0.00026                 ! 13 Fluid thermal expansion coefficient
5.364           ! 14 Top loss coefficient
5.364           ! 15 Edge loss coefficient for node-1
5.364           ! 16 Edge loss coefficient for node-2
5.364           ! 17 Edge loss coefficient for node-3
5.364           ! 18 Edge loss coefficient for node-4
5.364           ! 19 Edge loss coefficient for node-5
5.364           ! 20 Edge loss coefficient for node-6
5.364           ! 21 Edge loss coefficient for node-7
5.364           ! 22 Edge loss coefficient for node-8
```

```
5.364          ! 23 Edge loss coefficient for node-9
5.364          ! 24 Bottom loss coefficient
0              ! 25 Additional thermal conductivity
1              ! 26 Inlet flow mode
9              ! 27 Entry node
1              ! 28 Exit node
0              ! 29 Flue loss coefficient for node-1
0              ! 30 Flue loss coefficient for node-2
0              ! 31 Flue loss coefficient for node-3
0              ! 32 Flue loss coefficient for node-4
0              ! 33 Flue loss coefficient for node-5
0              ! 34 Flue loss coefficient for node-6
0              ! 35 Flue loss coefficient for node-7
0              ! 36 Flue loss coefficient for node-8
0              ! 37 Flue loss coefficient for node-9
INPUTS 24
40,1           ! Pipe - Water from Preheat to Backup:Temperature at Outlet A -
>Inlet temperature for port
40,2           ! Pipe - Water from Preheat to Backup:Flow Rate at Outlet A -
>Inlet flow rate for port
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Top loss
temperature
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-1
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-2
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-3
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-4
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-5
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-6
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-7
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-8
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Edge loss
temperature for node-9
47,1           ! PHX Weather-TMY3:Dry bulb temperature ->Bottom loss
temperature
0,0            ! [unconnected] Gas flue temperature
0,0            ! [unconnected] Inversion mixing flow rate
0,0            ! [unconnected] Auxiliary heat input for node-1
0,0            ! [unconnected] Auxiliary heat input for node-2
39,1           ! Upper Element:Fluid energy ->Auxiliary heat input for node-3
```

```
0,0             ! [unconnected] Auxiliary heat input for node-4
0,0             ! [unconnected] Auxiliary heat input for node-5
0,0             ! [unconnected] Auxiliary heat input for node-6
0,0             ! [unconnected] Auxiliary heat input for node-7
35,1            ! Lower Element:Fluid energy ->Auxiliary heat input for node-8
0,0             ! [unconnected] Auxiliary heat input for node-9
*** INITIAL INPUT VALUES
48.888911 0.0 AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes
AmbientTemp_pipes AmbientTemp_pipes AmbientTemp_pipes
AmbientTemp_pipes
20.0 -100 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
DERIVATIVES 9
48.888911               ! 1 Initial Tank Temperature-1
48.888911               ! 2 Initial Tank Temperature-2
48.888911               ! 3 Initial Tank Temperature-3
48.888911               ! 4 Initial Tank Temperature-4
48.888911               ! 5 Initial Tank Temperature-5
48.888911               ! 6 Initial Tank Temperature-6
48.888911               ! 7 Initial Tank Temperature-7
48.888911               ! 8 Initial Tank Temperature-8
48.888911               ! 9 Initial Tank Temperature-9
*------------------------------------------------------------------------------

* Model "Top Thermostat" (Type 1502)
*

UNIT 38 TYPE 1502     Top Thermostat
*$UNIT_NAME Top Thermostat
*$MODEL .\Storage Tank Library (TESS)\Aquastats\Heating Mode\Type1502.tmf
*$POSITION 842 720
*$LAYER Main #
PARAMETERS 4
1               ! 1 Number of heating stages
5               ! 2 # oscillations permitted
6.111111                ! 3 Temperature dead band
0               ! 4 Number of stage exceptions
INPUTS 3
37,17           ! Bradford White:Tank nodal temperature-3 ->Fluid temperature
0,0             ! [unconnected] Lockout signal
0,0             ! [unconnected] Setpoint temperature for stage
*** INITIAL INPUT VALUES
20.0 0 51.666689
*------------------------------------------------------------------------------

* Model "Upper Element" (Type 1226)
```

```
*

UNIT 39 TYPE 1226     Upper Element
*$UNIT_NAME Upper Element
*$MODEL .\Storage Tank Library (TESS)\Tank Heating Device\Electric\Type1226-Elec.tmf
*$POSITION 833 829
*$LAYER Main #
INPUTS 3
0,0             ! [unconnected] Heating capacity
0,0             ! [unconnected] Thermal efficiency
38,1            ! Top Thermostat:Control signal for stage heating ->Control signal
*** INITIAL INPUT VALUES
16199.999571 1. 1.
*------------------------------------------------------------------------------

* Model "Pipe - Water from Preheat to Backup" (Type 604)
*

UNIT 40 TYPE 604      Pipe - Water from Preheat to Backup
*$UNIT_NAME Pipe - Water from Preheat to Backup
*$MODEL .\NREL Models\Noded Pipe Model\Calculated Convection Coefficient\Type604a.tmf
*$POSITION 587 660
*$LAYER Main #
PARAMETERS 23
1.6764          ! 1 Pipe Length
0.020599                ! 2 Pipe Inner Diameter
0.022225                ! 3 Pipe Outer Diameter
8940            ! 4 Pipe Density
1443.599962             ! 5 Pipe Thermal Conductivity
0.386           ! 6 Pipe Specific Heat
0.019           ! 7 Insulation Thickness
72              ! 8 Insulation Density
0.144           ! 9 InsulationThermal Conductivity
1.045           ! 10 Insulation Specific Heat
988.5           ! 11 Fluid Density
2.3112          ! 12 Fluid Thermal Conductivity
4.032           ! 13 Fluid Specific Heat
2.00            ! 14 Fluid Viscosity
3               ! 15 Number of Fluid Nodes
3               ! 16 Number of Pipe and Insulation Nodes
48.888911               ! 17 Initial Fluid Temperature
25.555577               ! 18 Initial Pipe Temperature
25.555577               ! 19 Initial Insulation Temperature
0.9             ! 20 Surface Emissivity
0.              ! 21 Contact Resistance
```

```
1               ! 22 Convection Mode
1               ! 23 Pipe Orientation
INPUTS 7
25,1            ! Preheat Tank:Temperature at outlet-1 ->Temperature at Inlet A
25,2            ! Preheat Tank:Flow rate at outlet-1 ->Flow Rate at Inlet A
0,0             ! [unconnected] Temperature at Inlet B
0,0             ! [unconnected] Flow Rate at Inlet B
AmbientTemp_pipes               ! [equation] Ambient Temperature
0,0             ! [unconnected] Ambient Pressure
0,0             ! [unconnected] Wind Velocity
*** INITIAL INPUT VALUES
20.0 0. 20.0 0. AmbientTemp_pipes 1. 0.
*------------------------------------------------------------------------------

* Model "Electricity Usage Plot" (Type 65)
*

UNIT 41 TYPE 65         Electricity Usage Plot
*$UNIT_NAME Electricity Usage Plot
*$MODEL .\Output\Online Plotter\Online Plotter Without File\Type65d.tmf
*$POSITION 1219 925
*$LAYER Main #
PARAMETERS 12
6               ! 1 Nb. of left-axis variables
0               ! 2 Nb. of right-axis variables
0.0             ! 3 Left axis minimum
5               ! 4 Left axis maximum
0.0             ! 5 Right axis minimum
5               ! 6 Right axis maximum
1               ! 7 Number of plots per simulation
12              ! 8 X-axis gridpoints
0               ! 9 Shut off Online w/o removing
-1              ! 10 Logical unit for output file
0               ! 11 Output file units
0               ! 12 Output file delimiter
INPUTS 6
kW_element1             ! kJ/h to kW:kW_element1 ->Left axis variable-1
kW_element2             ! kJ/h to kW:kW_element2 ->Left axis variable-2
kW_comb_elements                ! kJ/h to kW:kW_comb_elements ->Left axis
variable-3
kW_potable_pump                 ! kJ/h to kW:kW_potable_pump ->Left axis variable-
4
kW_glycol_pump                  ! kJ/h to kW:kW_glycol_pump ->Left axis variable-5
kW_TOTAL                ! kJ/h to kW:kW_TOTAL ->Left axis variable-6
*** INITIAL INPUT VALUES
kW_element1 kW_element2 kW_CombElements kW_potable_pump
kW_glycol_pump
```

```
kW_TOTAL
LABELS  3
"kW"
""
"Electricity Usage"
*------------------------------------------------------------------------------

* EQUATIONS "lit/hr to GPM"
*
EQUATIONS 2
mains_GPM = [24,1]*0.004403
backup_GPM = [37,2]**0.004403
*$UNIT_NAME lit/hr to GPM
*$LAYER Main
*$POSITION 149 786

*------------------------------------------------------------------------------


* Model "Diverter" (Type 11)
*

UNIT 43 TYPE 11        Diverter
*$UNIT_NAME Diverter
*$MODEL .\Hydronics\Flow Diverter\Other Fluids\Right Facing\Type11f.tmf
*$POSITION 235 1022
*$LAYER Main #
PARAMETERS 1
2               ! 1 Controlled flow diverter mode
INPUTS 3
47,5            ! PHX Weather-TMY3:Mains water temperature ->Inlet temperature
24,1            ! Water Draw Profile:Average water draw ->Inlet flow rate
45,1            ! Tempering Control (<110F):Fraction to heat source ->Control signal
*** INITIAL INPUT VALUES
20.0 0 0.5
*------------------------------------------------------------------------------

* Model "Mixer - Out to taps" (Type 11)
*

UNIT 44 TYPE 11        Mixer - Out to taps
*$UNIT_NAME Mixer - Out to taps
*$MODEL .\Hydronics\Tee-Piece\Other Fluids\Type11h.tmf
*$POSITION 427 1059
*$LAYER Main #
```

```
PARAMETERS 1
1               ! 1 Tee piece mode
INPUTS 4
43,1            ! Diverter:Temperature at outlet 1 ->Temperature at inlet 1
43,2            ! Diverter:Flow rate at outlet 1 ->Flow rate at inlet 1
37,1            ! Bradford White:Temperature at outlet ->Temperature at inlet 2
37,2            ! Bradford White:Flow rate at outlet ->Flow rate at inlet 2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*------------------------------------------------------------------------------

* Model "Tempering Control (<110F)" (Type 953)
*

UNIT 45 TYPE 953     Tempering Control (<110F)
*$UNIT_NAME Tempering Control (<110F)
*$MODEL .\Controllers Library (TESS)\Tempering Valve Controller\Type953.tmf
*$POSITION 364 905
*$LAYER Main #
*$# NOTE: This control strategy can only be used with solver 0 (Successive
substitution)
*$#
PARAMETERS 1
5               ! 1 No. of oscillations
INPUTS 4
0,0             ! [unconnected] Setpoint temperature
37,1            ! Bradford White:Temperature at outlet ->Source temperature
47,5            ! PHX Weather-TMY3:Mains water temperature ->Tempering fluid
temperature (return temperature)
0,0             ! [unconnected] Mode
*** INITIAL INPUT VALUES
43.333355 10.0 20.0 1
*------------------------------------------------------------------------------

* EQUATIONS "C to F"
*
EQUATIONS 12
Tank_Node1_F = [37,15]*(9/5) + 32
Tank_Node2_F = [37,16]*(9/5) + 32
Tank_Node3_F = [37,17]*(9/5) + 32
Tank_Node4_F = [37,18]*(9/5) + 32
Tank_Node5_F = [37,19]*(9/5) + 32
Tank_Node6_F = [37,20]*(9/5) + 32
Tank_Node7_F = [37,21]*(9/5) + 32
Tank_Node8_F = [37,22]*(9/5) + 32
Tank_Node9_F = [37,23]*(9/5) + 32
ColdWater_in_Main_F = [47,5]*(9/5) + 32
```

```
MixedHotWater_F = [44,1]*(9/5) + 32
HotWater_outofBW_F = [37,1]*(9/5) + 32
*$UNIT_NAME C to F
*$LAYER Main
*$POSITION 1226 1128

*------------------------------------------------------------------------------


* Model "PHX Weather-TMY3" (Type 15)
*

UNIT 47 TYPE 15        PHX Weather-TMY3
*$UNIT_NAME PHX Weather-TMY3
*$MODEL .\Weather Data Reading and Processing\Standard
Format\TMY3\Type15-TMY3.tmf
*$POSITION 96 92
*$LAYER Main #
PARAMETERS 9
7               ! 1 File Type
34              ! 2 Logical unit
3               ! 3 Tilted Surface Radiation Mode
0.2             ! 4 Ground reflectance: no albedo reported
0.7             ! 5 Not used
1               ! 6 Number of surfaces
1               ! 7 Tracking mode
CollectorSlope          ! 8 Slope of surface
0               ! 9 Azimuth of surface
*** External files
ASSIGN "C:\Trnsys17\Weather\US-TMY3\US_AZ_PHOENIX_INTL_AP_722780.csv"
34
*|? Which file contains the TMY-2 weather data? |1000
*------------------------------------------------------------------------------

END
```