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# ANALYSIS OF SOLAR THERMAL WATER HEATERS ON PEAK DEMAND

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## ABSTRACT

*The University of North Florida (UNF) has a long term working partnership with the local utility company, JEA. As a winter peaking utility JEA and UNF are investigating the effects of solar thermal water heaters on peak demand. This investigation includes household usage studies, a solar water heater performance comparison study and their thermal capacitance, and a software model to predict system performance.*

*In this paper, initial household usage and incentivized popular solar thermal systems are studied and incorporated into a solar thermal direct comparison test rig.*

## INTRODUCTION

JEA and UNF are long term partners in building the UNF Clean and Renewable Energy lab. The focus of the partnership and lab is to educate students and explore alternative approaches to meeting the greater Jacksonville area's utility needs. JEA currently is a winter peaking utility, with a large percentage of Jacksonville's population using the most residential power on weekdays between 6am and 10am in the morning and 6pm to 10pm in the evening [1].

Domestic water heating can account for as much as 21% of residential electrical consumption [2]. Residential solar water heating systems have been in use since the late 1800s and presently have the potential of displacing the electricity used in domestic water heating [3]. In an effort to reduce and offset the winter peaks, JEA and UNF are partnering to study the effects of Solar Thermal Water Heating Systems on Peak Demand.

## HOUSEHOLD USAGE AND SYSTEM SIZING

Studies show that residential hot water usage correlates with electrical peak times. Usage trends, as seen on Figure 1, suggest that 29% of hot water usage is between 6am and 10am and 31% is between 6pm and 10pm [4]. JEA's energy demand peaks could be greatly reduced and/or offset through an effective solar water heating system.

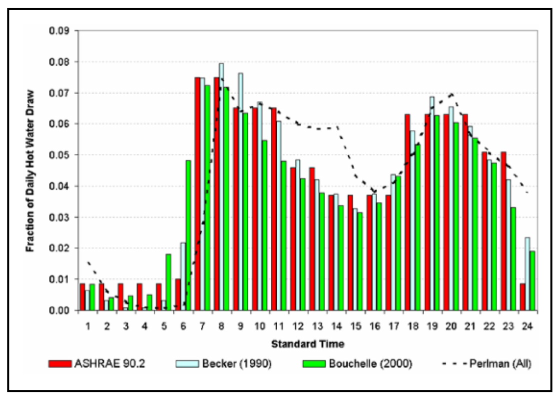


Figure 1. Histogram of identified hourly hot water draw profiles

To best study the effects of solar thermal water heating systems on peak demand, two popular incentivized systems are incorporated into a test rig. The Department of Energy suggests sizing each system's collector area as 20 square feet for each of the first two family members and 1.5 to 2 gallons of storage per square feet of collector [5]. Based on these guidelines the particular systems included in the study are: one Integral Collector Storage (ICS) passive unit with 32 square feet of solar collection area and 40 gallons of storage, and an Active Drain-Back Solar Technology System with an 80 gallon remote storage tank, 10 gallon drain-back heat exchanger tank, and 32 square feet of collector surface area. Based on the average home of 2.8 occupants with the most common being two and the approximate suggested sizing of 20 square feet per occupant, the systems installed each provide a base for a larger than half scale experiment [6].

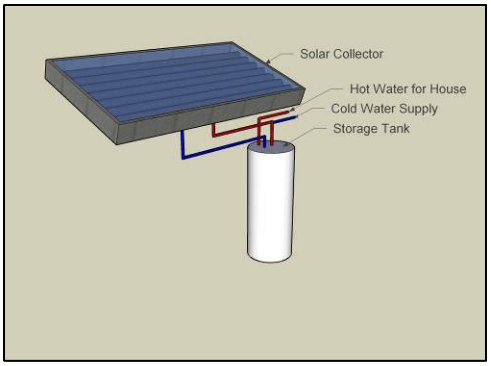


Figure 2. ICS Passive System

The ICS system, shown on Figure 2, is a simple system not requiring any controls or moving parts. The system provides 40 gallons of additional storage and preheats the water entering the conventional electrical resistance domestic water heater. A major concern with this type of system is the potential to freeze in harsh winter environments.

In comparison, the Active Drain-Back Solar Technology System, shown on Figure 3, is more complex. The system incorporates a temperature controlled closed heating loop that circulates water from the heat exchanger through the collector. The system also has an open loop that circulates water from a storage tank through the heat exchanger. The controls strategy compares the temperature of the bottom of the storage tank with the exit temperature of the collector and engages pumps to move water according to the control logic. If the collector cannot provide additional heat to the storage tank it will drain back into the heat exchanger; protecting the active system from freezes.

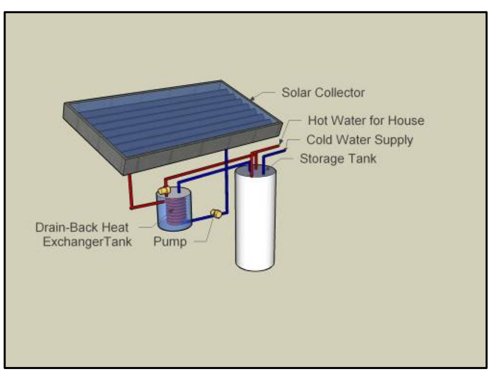


Figure 3. Active Drain-Back System

## TEST RIG SUPPORT STRUCTURE

The test rig is currently installed on the top of the UNF Science and Engineering Building facing south. South facing orientation provides optimal solar collection in any location in the Northern Hemisphere. For year round performance the recommended tilt for the collectors is equal to the latitude. For increased winter performance and to protect from overheating in the summers many installers increase the angle up to 20 degrees greater than the latitude [7]. Conventional roof slopes range from a 4:12 to a 9:12, which corresponds to approximately an 18 to 37 degree range [8]. Due to ease of installation and aesthetics many collectors are installed directly on to the roof of houses and experience minimal loss in performance. The latitude in Jacksonville is 30.3 degrees, which directly corresponds to a 7:12 roof pitch. Initial testing for these systems is with a latitude +10 degree tilt for improved winter performance. The flexibility for varying tilt angles for future testing has been incorporated into the design of construction.

Access to the roof of the UNF Science and Engineering Building is provided by an elevator. Consequently, much of the construction had to take place on the roof, adding a design restraint. An additional design restraint is making the unit hurricane ready without altering the roof or building in any way. The decided best short term approach to this hurdle is to use modular construction allowing for break down in a short time period and relocation of the modules into a near by room through a door with a width of 42 inches. A long term solution is being incorporated into another solar project on the roof and will provide a hurricane approved steel structure.

The support structure, for the time being, includes a multilevel platform constructed of two by six inch pine lumber and half inch plywood. Multilevel construction provides the panels a sturdy mounting structure and prevents one panel from shading the other as seen on Figure 4. The structure also provides a protected location for support systems and components. It is recommended that the Active panel be mounted portrait and the Passive panel be mounted landscape. After study and discussions with suppliers and installers, it was determined that mounting both panels landscape would not affect performance, but was a potential freeze hazard as the active panel could retain a small amount of water even after drain-back. The storage tank for the active system is located in an adjacent storage room and plumbed in through access ports in the wall. This was decided as the storage space best replicates a garage environment similar to that of a typical domestic water heater.

Figure 4. Multilevel Structure

## GROUNDWATER AND USER SUBSYSTEM

A critical component to the experiment is a subsystem for replicating groundwater temperature and pressure for input, and approximate residential hot water consumption. As there is no fresh water supply on the roof; water conservation is important. Groundwater temperature varies from the mid forties to the upper sixties throughout the year. Because the main focus of the study pertains to winter peaks, groundwater temperatures during the months November to March are most critical. Figure 5 shows this to range from approximately 44 degrees to 58 degrees Fahrenheit [9]. Temperatures during this time frame in Jacksonville range from approximately 42 to 51 degrees Fahrenheit for the lows and 64 to 73 degrees for the highs [10]. City water pressure varies from 40 to 60psi.

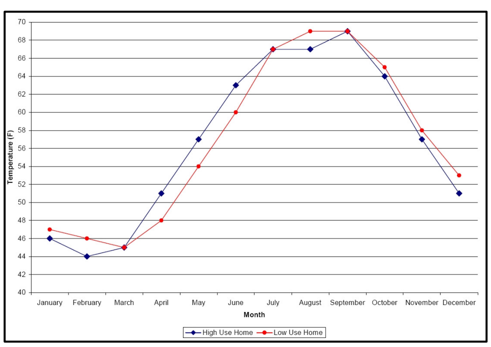


Figure 5. Average Monthly Cold Water Inlet Temperature for Each Home

Household loading includes water temperature, flow rates, time of day, and consumption. Household hot water consumption averages between 45 and 66 gallons a day depending on time of year. Based on the distribution of hot water usage throughout the day, the average hot water consumption, and the reduction as a factor of scale, the load profile can be broken down as 7.5 to 11 gallons of consumed hot water during each morning peak, lull between peaks, and evening peak for each system.

Based on this information the subsystem will need to provide 51 +/- 7 degree Fahrenheit water at a flow rate of approximately 2.3 gallons per hour (gph) during peak periods and 1.15 gph in between the morning and afternoon peaks for each system. To control the variables and minimize water waste a closed loop subsystem was constructed. This subsystem consists of a shallow well pump, a solenoid valve controlled by a timer switch, ball valves for throttling, two 94 gallon tanks, a temperature controlled secondary pump running water through a radiator loop, and a temperature controlled immersion heater. A simple layout is shown on Figure 6.

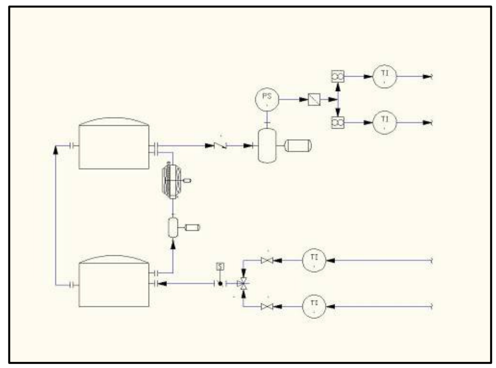


Figure 6. Subsystem Layout

The primary pump for replicating groundwater conditions is a shallow well pump with a pressure switch. Using a pressure switch the pump can be set to shut off when proper designated pressure is reached and the system can be timer controlled with a solenoid valve. This timer and valve can turn on at various times to replicate peaks and will respond very similar to a family opening a valve to turn on the shower. A ball valve is installed on each system to throttle the flow to an established setting. Storage is provided by two 30 by 30 by 26 inch polyethylene tanks. The tanks provide approximately 94 gallons of storage each, presented on Figure 7. The primary pump draws from one tank and the solenoid valve returns to the other. The tanks are connected to provide water level equalization as well as a quiescent reservoir.

Figure 7. Subsystem Water Storage

The temperature control loop is made up of a secondary pump, a radiator with fans, an immersion heater, and a custom made relay network controlled by the data acquisition system.

Sizing the secondary pump and radiator system involved a thorough analysis to effectively rid the water of the heat created by the solar thermal systems. Due to the nature of the closed loop system it is critical that the water temperature return to groundwater temperature before returning to the inlet of the systems. One of the design parameters is the system must run off 115 Volts Alternating Current (VAC). This parameter is important in that many of the portable chiller units require 230VAC and would not be applicable. Using the First Law of Thermodynamics heat removal can be calculated.

$$\Delta Q = \Delta H$$

$$\Delta H = m \times \Delta h$$

Using these equations and some estimated extremes, a radiator with 10,900 British Thermal Units per hour (BTU/hr) heat removal was put into place with two fans moving 550 cubic feet per minute (cfm) each and a pump moving approximately two gallons per minute are incorporated into the cooling loop. The radiator and fans are shown on Figure 8. An immersion heater is also incorporated into the subsystem for the rare days when tank water temperatures drop unreasonably low.

Figure 8. Radiator with Fans

Both the radiator loop and the immersion heater are reasonably oversized in the event that any unexpected extreme temperatures are encountered and controlled using a custom temperature controlled relay network. The Data Acquisition system has programmable control outputs. The outputs are small Direct Current (DC) voltages and are not strong enough to close the power relays. A custom amplifier was built to take the small DC voltage and provide adequate power to close the relays. The amplifier is essentially an additional set of small relays that use the control signals to power a switch completing the circuit between an AC power supply and the power relays. The amplifier is made up of an AC power supply, an AC to DC rectifier, a couple of diodes, transistors and resistors. The components are shown on Figure 9. This system allows temperature set points declared in the data logger to control the secondary pump and fans of the cooling loop and also the immersion heater. These set points can be programmed to replicate ground water conditions.

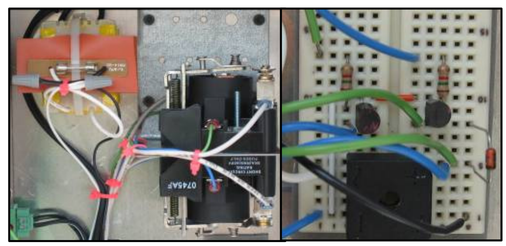

Figure 9. Power Supply, Power Relays, and Custom Amplifier Circuit

The Data Acquisition system, shown on Figure 10, consists of a Data Logger with 20 analog differential channels. The unit collects temperature data from six T-Type Thermocouples. These include: ambient, tank, and each system's inlet and outlet temperatures. A pyranometer collects solar radiation data for referencing. Positive displacement flow meters are installed and provide a pulse for recording flow rates. Data is sampled every second and recorded every fifteen minutes. The Data Logger and custom control network are enclosed in a NEMA cabinet for protection from the elements. A flash memory card is installed in the Data Logger for easy data retrieval and the unit also has a serial cable with USB interface for program updates and data retrieval.

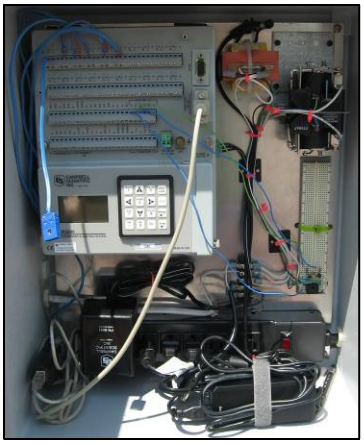

Figure 10. Data Acquisition

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