STRENGTHENING THE SELF-SUFFICIENCY OF POOR COMMUNITIES THROUGH ADOPTING THE CONSTRUCTION AND UTILIZATION OF INTEGRATED COLLECTOR STORAGE SOLAR WATER HEATERS

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ABSTRACT

In pursuit of community-wide technological adoption, an Integrated Collector Storage (ICS) Solar Water Heater was built and customized to suit that of poor and off-grid communities. Designed and tested under simulated off-grid circumstances, the prototype device proved suitable in its methods of construction and utilization and most favorable in performance. An effectively customized ICS Solar Water Heater provided the basis for moving forward from system construction and testing to the planning of community-wide technological integration.

1. INTRODUCTION

Technological systems and practices, when resourcefully designed and distributed to suit that of particular destinations or demographics, serve to benefit groups of people that do not typically have such routine access. In lieu of this approach, a domestic solar water heating system was customized, built and tested for application to poor and off-grid communities. Accomplishing this involved constructing an operable device that factored for the many constraints and challenges poor and off-grid communities commonly face. In doing so, a successfully customized solar water heating device resulted, providing the foundation and means for pursuing community-wide technological adoption. The U.S./Mexican border cities of Tijuana and Tecate offered well-suited community destinations for such application, and so, became the focus communities of implementation. System customization, construction and simulated testing, coupled by the planning for community-based technological adoption, mark the scope for which this work presents its findings. The latter portion of this work, carrying out the process of community-wide technological adoption, is underway and to be presented once concluded. With Solar Water Heating serving as the technological system and practice of focus, this paper details the particulars involved with creating the foundation necessary for facilitating the access of such systems to poor and off-grid communities.

2. SIGNIFICANCE

Worldwide efforts to eradicate poverty contend with staggering levels of internal migration and urbanization. This rate of urbanization, greater than that for which government sponsored infrastructure can provide for, leads to overcrowded informal settlements devoid of the most basic of amenities. Settlements in the U.S./Mexican border cities of Tijuana and Tecate, clustering in response to the area's job opportunities in factory and service work, experience long delays before being supported with essential infrastructure by government agencies or utility companies. Lacking access to decent housing, health care and education, or the basic amenities of sanitation, running water and electricity, places heavy strain on residents of informal settlements, further exasperating their vulnerabilities and worsening their capabilities for effectively grappling impoverishment. In some cases, such inaccessibility drives residents of informal settlements to collectively pool their resources to purchase infrastructure and/or rely on private nongovernmental entities to facilitate its attainment. In addition to the efforts existing to service densely populated, overtaxed urban centers, equally as important are efforts directed to that of rural communities experiencing population decimation as a result of the high rates of urbanization. As rural communities lacking in resource and opportunity serve as a root cause of urbanization, efforts to instill measures of self-sufficiency within their processes offers an effective means for keeping communities and cultures intact while slowing rates of urbanization. The embedded challenge associated with instilling measures of self-sufficiency within that of impoverished urban and rural communities is adhering to the many constraints facing such communities in the methods of delivery and installation. Effectively customized delivery that goes beyond the conventional processes of commerce, serves to reach and empower groups of people that otherwise would not be marketed toward or not have access.

3. APPROACH

A device that accounts for the limited amenities and financial constraints poor and off-grid communities face, describe the requirements necessary for choosing a well-suited system. Equally as important in system choice is resident involvement, which provides the framework for successful and sustaining technological integration. Accounting for these criteria led to the selection of a solar water heating device known as an Integrated Collector Storage (ICS) Solar Water Heater. The process of affirming that this device met such criteria, thus representing the body of this work, underwent numerous stages including system selection, customized construction, simulated testing and data collection. This comprehensive approach of customizing a solar water heating system to suit that of poor and off-grid communities concludes with an assessment of system implementation for a particular community of focus based upon full participation in system construction and utilization.

3.1 System Selection

Residents of poor and off-grid communities face hardship affording and gaining access to the basic domestic amenities that serve to support household well-being. Extensive labor is often required of residents for acquiring amenities such as water and fuel sources. The associated expenses that result from such purchases weigh heavily upon household income, further inhibiting their pursuits of alleviating their impoverished circumstances. Household efforts to reduce the restraining effects of costly resource purchasing results in less than favorable usage, causing families to live within spaces not as comfortable, healthy or safe as they could be otherwise. The benefits that result from the integration of renewable systems, whether for electricity, space-heating or hot water, are that when integrated suitably, they serve to relieve many such hardships. Functioning by that of naturally occurring and non-finite processes, renewable systems serve to provide greater resource availability and volume to its residents, in turn strengthening household well-being. In this respect, the renewable system selected to represent this works' efforts toward customizing an effective approach for community integration, is that of the Integrated Collector Storage (ICS) Solar Water Heater. The equipment makeup of the device is described by basic materials acquisition and straightforward construction and the device's operation is described as undemanding and adaptable to one's particular needs. In application, the device provides an efficient and reliable supply of heating water for bathing, cooking, cleaning, laundering, heating and other domestic purposes. Its utilization serves to lessen household dependency for unaffordable, inefficient, laborsome and polluting means of heating water, in turn causing residents to comfortably increase their usage. Avoiding the high ongoing costs associated with conventional fuels purchasing, such as butane, electricity and fuel wood, these systems serve to free up funds for causes better served, such as medical treatment, educational materials and business ventures. In sum, for the objective of customizing a renewable system to effectively suit and benefit that of poor and off-grid communities, the ICS Solar Water Heater proved favorable for proceeding toward community integration.

3.2 Technology Overview

Integrated Collector Storage Solar Water Heaters are passive by nature, meaning that unlike active solar water heaters which require electric pumps, controllers and oftentimes heat-transfer fluids to function, they rely only on natural processes such as sunlight and gravity to operate. As illustrated in Figure 3.1, the fundamental composition of an ICS Solar Water Heater consists of a sizeable metal tank filled with water, encased in a reinforced and well-insulated wooden enclosure, covered with a sheet of glass and titled upward at a slope of geographical latitude. Its name, "Integrated Collector Storage," is derived from the fact it combines the storage of water, that being a 40 gallon water tank, with the collection of heat, the tank's boxed and insulated enclosure.

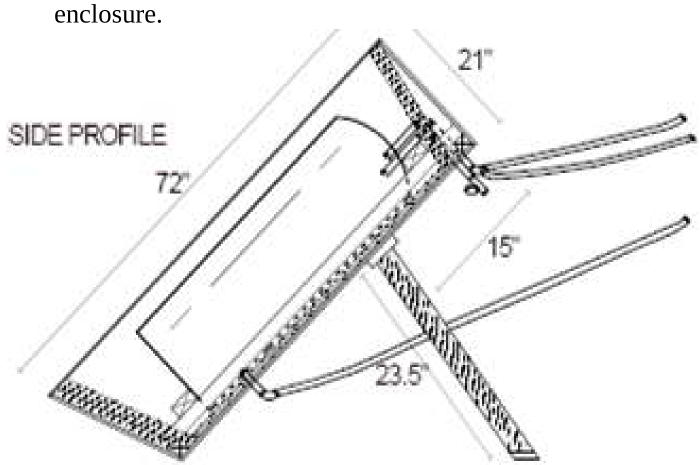

Fig. 3.1 ICS Solar Water Heater Device Makeup

The ICS Solar Water Heater effectively works by facilitating the greenhouse effect. Heat, by way of sunlight, is directed into the enclosure through its top-layered sheet of glass and trapped inside to effectively heat the water. As for the system's water circulating process, as illustrated in Figure 3.2, a cold water run is piped and pressurized into the tank's bottom inlet valve, assuring the tank is always full. Solar water heating is then underway as the tank is sun-baked throughout the sunlit hours of the day. The process of thermal stratification, that which separates bodies of water according to temperature, occurs within the tank, bringing the hottest water with its lighter density to the top and the coldest water with its heavier density to the bottom. A hot water run is piped from the tank's top outlet valve, that which receives the hottest stratified water and sends it to the household's hot water applications. Like that of a conventional water heater, as the tank is always full and pressurized by a cold water supply, hot water is supplied to its respective applications when a hose, faucet or showerhead is opened.

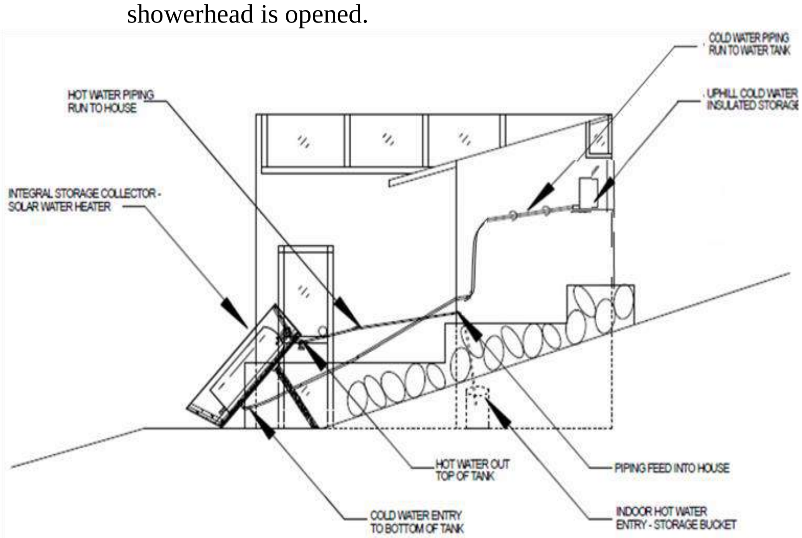

Fig. 3.2: ICS System Circulation with "Tijuana House."

3.3 <u>Device Construction</u>

The construction process and acquisition of materials for the ICS Solar Water Heater began by exhausting all avenues of attaining its parts through recyclable and decommissioned means. This led to attaining a ¼" sheet of tempered glass, a throwaway conventional water heater and used sticks of 2x4's, plywood sheets, hose piping and screws. Other parts such as plumbing fittings, polystyrene insulation, paint, caulking, weather-stripping and heavy-duty hardware were purchased from local hardware stores with an expenses grant provided by the Department of Architecture at the University of Cal Poly Pomona.

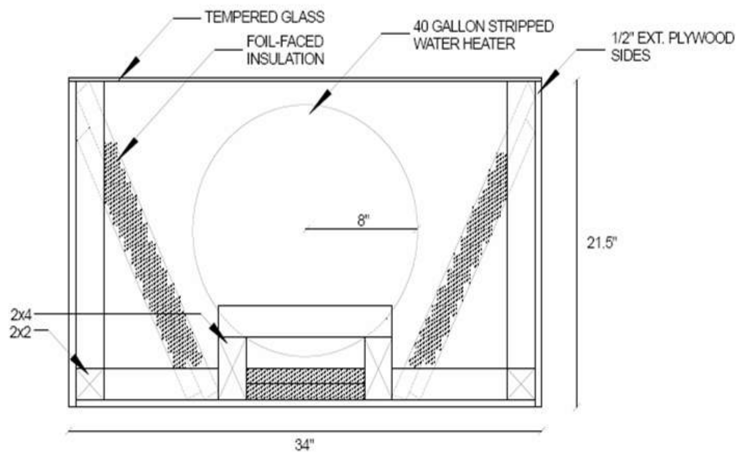

Fig. 3.3: ICS Device Top/Bottom Cut-Out Viewpoint

Construction began by stripping the core metal tank from the insulation and metal sheathing that encased it and pressure-teating it for leaks. A reinforced wooden cradle was built to support the 40 gallon tank which would reach 350lbs when full. The tank's boxed enclosure was sized according to the dimensions of the tank and glass and constructed. Inlet and outlet piping holes were prepared through the enclosure and insulation before the final placing of the tank. The tank was set in place, plumbing fittings were connected and the interior foil-faced insulation sheets were positioned and sealed to best direct incoming solar radiation onto the tank. A level foundation was laid and the reinforced leg support and bracing were built and attached. Weather-stripping was applied around the enclosure's top perimeter and the sheet of tempered glass was bracketed on. Joints were caulked and the exterior wood was primed and painted. The device was set along the foundation, piping runs were fitted to the inlet and outlet valves and the solar water heater was filled with water, ready for heating. In accordance with the primary basis of a successfully sustaining community-based technological adoption, this construction process is well-documented to educate residents how to effectively build the system.

The prototype solar water heating device was built and installed at the John T. Lyle Center for Regenerative Studies at Cal Poly Pomona. The Lyle Center served to provide the necessary foundation for examining how suitable the ICS Solar Water Heater was for off-grid applications. The system was plumbed and installed to a 350ft ² structure, as illustrated in Figures 3.2 and 3.4, called the "Tijuana House," an off-grid prototype that provides Masters Students and professors the grounds for testing renewable systems. The off-grid circumstances existing at the Lyle Center effectively provided the ideal context for constructing and customizing the device and simulating its usage to poor and off-grid communities.

Fig. 3.4: ICS Solar Water Heater & "Tijuana House"

3.4 <u>Design Features</u>

Efforts to maximize the performance of the ICS Solar Water Heater occurred both in its initial construction phase and after testing the system's ability to heat water. The device was oriented true south and built to have a tilt of geographical latitude, that being 34° in Los Angeles, to effectively receive year-round solar exposure at varying solar altitudes. As illustrated in Figures 3.1 and 3.2, the bottom end of the solar water heater's boxed enclosure was constructed to have a 30°outward tilt to increase solar exposure to the tank's coldest section during winter months. The solar water heater's interior walls, as illustrated in Figure 3.3, have foil-faced polystyrene insulation angled inward in a parabolic shape to best concentrate received light onto the tank. Lastly, as it is known and was demonstrated in performance, ICS Solar Water Heaters experience significant nighttime heat losses as a result of combining water storage and heat collection into one unit. To best mitigate against these losses, a hinged shutter-like system was constructed and connected to provide an insulated, sealed enclosure over the device's glass during nightfall. The hinged shutters, by the way they were designed to sit while open, also serve to reflect and concentrate incoming sunlight onto the tank. These incorporated design features served to effectively facilitate the environmental processes that together worked to maximize system performance.

3.5 <u>System Customization</u>

Unlike that of conventional households which have a constant supply of pressurized running water and electricity powered water pumps, off-grid households need to employ other means of circulating water to effectively facilitate the processes of solar water heating. This limitation, serving as the greatest restraint off-grid households face in their capacity to use and benefit from such systems, marks the need to customize the system to suit that of lacking running water. This led to installing a cold water storage container shelved at a height of 9½ feet attached to the prototype structure's exterior wall. As the container was piped downward into the tank's cold water inlet valve, it provided the solar water heater with a pressurized water source, mimicking that of a constant water supply. This was possible by the principal of static pressure, which confirms that for a particular drop in feet of pressure, measured from that of a liquid running through conduit, an equal rise in feet or pressure naturally results. In this respect, it became known that the higher the cold water storage container was from the tank's cold water inlet valve, the more pressurized the system's circulation became for transporting hot water. The 9½ foot drop from the container to the tank, as illustrated in Figure 3.5, therefore resulted in an identical 9½ foot rise, allowing for steady circulation in and throughout the prototype structure. This relationship proved that any drops in pressure due to that of friction within the tank and piping were negligible. Succeeding in facilitating this process, in turn laid a foundation for furthering the efforts toward customizing the ICS Solar Water Heater to suit the conditions facing poor and off-grid communities.

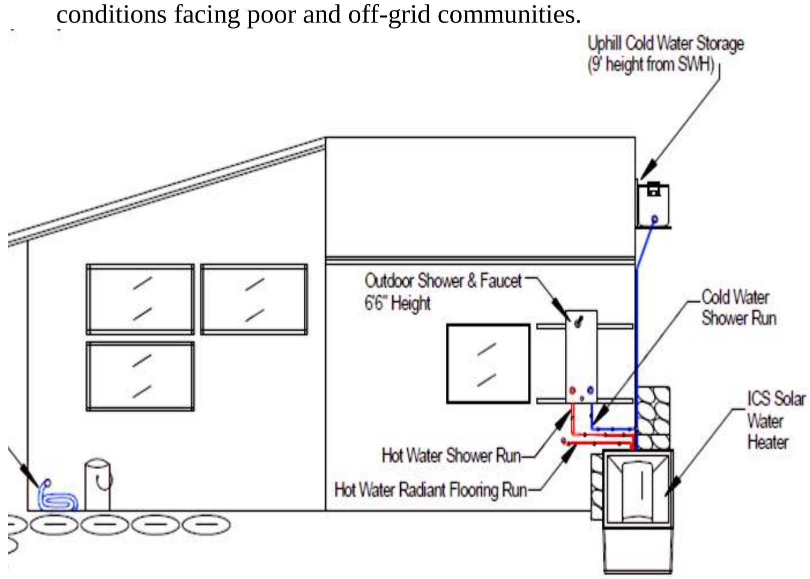

Fig. 3.5: ICS System Circulation with Usage Applications

After manually achieving the steady flow of running water to pressurize the solar water heater's need for circulation, the design and construction of hot water applications followed. The basis for going ahead with the efforts of application was affirmed by gaining favorable results during system performance trials, which recorded water temperatures as high as 160°F (71°C) in spring and summertime months. In acknowledgement that bathing would be a dominant application for the ICS Solar Water Heater and that reasonable bathing temperatures of 90° to 100° (F) would be needed, an outdoor shower system was built and installed to the structure. This came by piecing together plumbing fittings from a basic shower kit to the ICS Solar Water Heater. The structural constraints of available interior space and adequate drainage led the shower to be installed outdoors. Unlike the shower's front location and open setup, as illustrated in Figures 3.5 and 3.6, which serves to provide for simulated demonstration, a community applied shower system would be situated more appropriately to user preferences. As for the shower system's plumbing, piping was run from the solar water heater's hot water outlet valve to the shower's hot water nozzle and a secondary cold water run was spliced from the main cold water run to the shower's cold water nozzle. Experimentation showed that in order to receive adequate shower pressure, the showerhead needed to be approximately $2/3^{rds}$ the height of the cold water storage container. At equal heights, the hot water outlet serves only to dribble out, whereas at lower heights relative to the cold water storage container, the hot water outlet increases in pressure. Since showerheads are typically installed at around 6½ feet, the cold water storage container needed to be at least 9 feet to facilitate shower pressure, and so, by design was the installed height.

Aside from showering, the system was designed to suit various domestic hot water applications. As off-grid communities often bathe by that of a "dip and pour" technique, the shower system has a faucet-like spigot to provide for a more rapid fill-up. The spigot may also be attached to a hose bib to run a hot water line anywhere needed. Since the spigot is only $1/3^{rd}$ the height of the cold water storage container, it serves to provide high-pressured water for miscellaneous household applications such as cooking, cleaning and laundering. In addition, secondary hot water lines may be sourced directly from the device to such applications around the house. As illustrated in Figure 3.6, a second hot water line was run from the solar water heater to the prototype structure's slab-embedded radiant flooring system. In the effort of space-heating, heated water was drawn through the slab, but its results proved ineffective due to unsuitable radiant floor piping material and too low of hot water temperatures to affect change. These efforts to tailor the ICS Solar Water Heater's hot water applications to that of poor and off-grid communities remained in line with their expected needs and constraints, suggesting a well-suited and favorable technological integration.

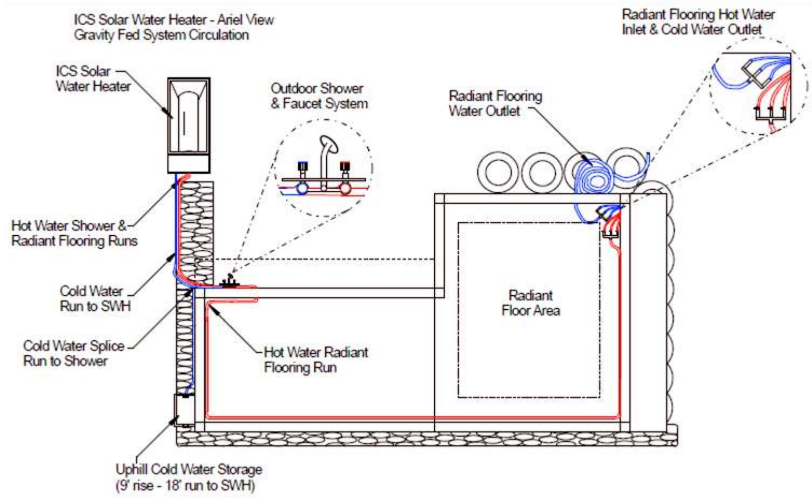

Fig. 3.6: ICS System Circulation with usage Applications

4. SYSTEM TESTING / DATA COLLECTION

System testing was conducted to analyze how the ICS Solar Water Heater performed under differing weather and seasonal conditions. Its performance results served to represent the system's overall efficiency in heating water as well as to illustrate the effect that improvement measures had on its ability to heat water. Such improvement efforts involved various construction modifications and altered hot water usage behaviors. In addition to data-gathering providing the means for customizing a high-performing device, it provided a year-round performance expectation that supports the grounds for a well-informed effort to community-integration. The resulting ICS Solar Water Heating device that came from these testing trials and improvement measures serves to provide the model of reference for future, community-adopted systems.

4.1 Testing Methods

Two overlapping testing methods were utilized to evaluate the ICS Solar Water Heater's system performance. The first involved manually drawing hot water from the solar water heater's shower system, as illustrated in figure 4.1, in a simulated hot water usage schedule. Adhering to this daily schedule served to both evaluate the system's performance as to its expected household usage and to reveal other useful operational information about the system. During testing periods, volumes of hot water were drawn first thing each morning to both assess what water temperatures residents could expect and to reveal how much nighttime heat loss had occurred since the prior day. The next simulated hot water draw took place at the end of the afternoon, again to assess what water temperatures residents could expect. A 5°- 10° (F) drop consistently occurred from one 5gallon hot water draw to the next, giving predictability to the tank's stratified water levels. A total of 24 gallons of heated water was drawn from the 40 gallon solar water heater on each day of testing, simulating a reasonable consumption schedule. These simulated hot water drawings were necessary for having accurate performance measures, since temperatures otherwise would increase and be falsely inflated. A 5 gallon water storage medium and thermometer provided the necessary tools for this method of testing.

Fig. 4.1: ICS Solar Water Heater Shower System

The other testing method employed involved the use of digital devices called HOBO data loggers to read the ICS Solar Water Heater's system performance. These devices, able to read multiple performance variables, were placed within the solar water heater's interior at both the upper and lower regions of the tank to measure both surface and ambient temperatures. Another device was situated outside the solar water heater to provide a means for comparing system performance measures to that of outdoor conditions. The resulting data provided for a very comprehensive and detailed analysis of the correlations existing between its variables. These correlations, as illustrated in Figure 4.1, spoke loudly of the weight that environmental processes and resident usage played upon performance, leading to inferences that resulted in improvements to system design and usage behavior. The data logging devices provided an effective means for assessing the inner workings of the ICS Solar Water Heater's operation. This method, together with that of the simulated hot water volume drawings, provided the testing approach necessary for affirming favorable system performance.

4.2 Data Results & Conclusions

The results and conclusions that led from the two testing methods were bolstered by efforts to observe and analyze the underlying environmental factors that influenced system performance. As the ICS Solar Water Heater's performance correlates greatly with that of external factors, its results proved most favorable during spring and summer months. These results, reaching water temperature highs of 160°F (71°C), can be attributed to the increased number of sun hours and hotter temperatures characteristic of such seasons. Though system performance is most directly correlated with that of clear, unobstructed solar exposure, it is also correlated with outdoor temperature. This occurs as the result of hotter outdoor environments not pulling as much heat out from within the solar water heater as colder environments do. This speaks to the natural processes of heat transfer and temperature stabilization, which serves to balance out temperatures of adjoining environments.

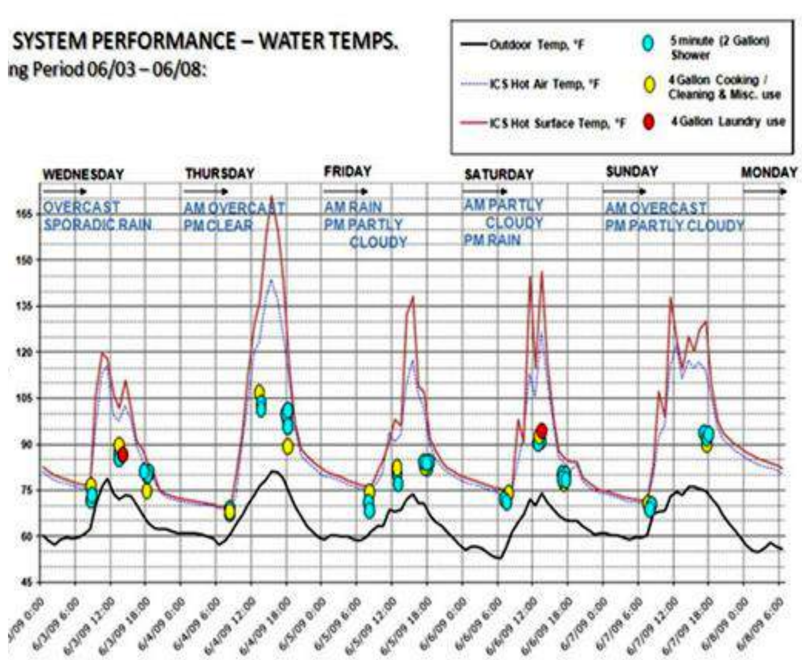

Fig. 4.3: ICS Solar Water Heater System Performance

Another winter-specific aspect that the solar water heater accounts for has to do with the initial supply of cold water needing to be heated. Testing showed that the water supply filling the solar water heater's cold water storage container had temperatures in the mid 50's (F) over winter months and temperatures in the mid 60's over summer months, an approximate 10°F differential that the solar water heater accounts for. Though performing solar water heating in the wintertime has its environmental disadvantages, data results from testing the ICS Solar Water Heater's performance during such months have proven favorable. Manual temperatures drawn in early February, as illustrated in Figure 4.2.2, consistently reached temperature highs of 125°F. Such temperatures serves to provide sufficient heating for the hot water applications of bathing, cleaning, laundering and preliminary water heating for cooking. In tests conducted during weather conditions of little to no sunshine, as illustrated in Figure 4.2, the system effectively heated water from 70°F to 90° and 105°F, demonstrating the system's ability to even perform under conditions of overcast and diffuse lighting. Proportionate to external conditions, the ICS Solar Water Heater is best suited for hotter and sunnier climates; however its performance versatility shows that it should not be excluded from other type environments.

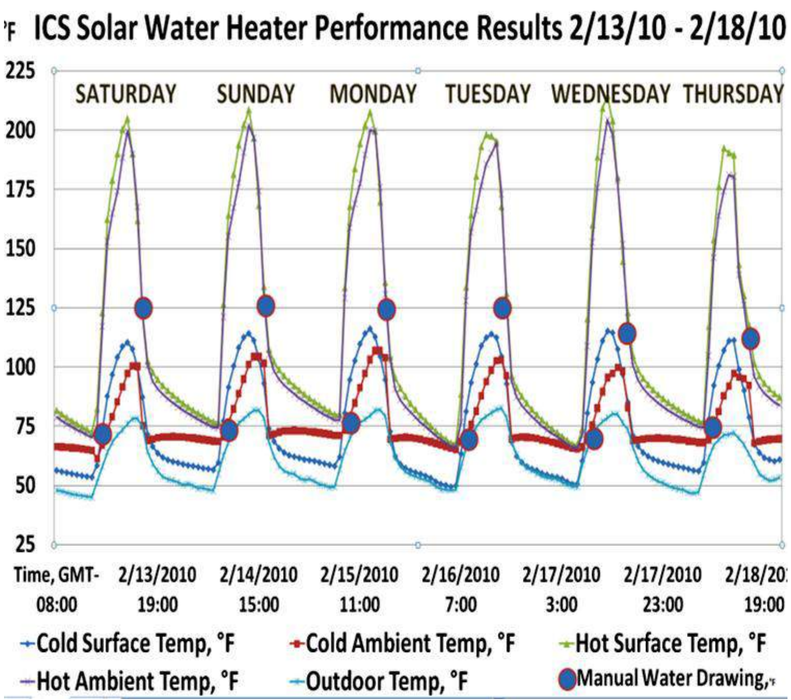

Fig. 4.4: ICS Solar Water Heater System Performance

The many variables that the data loggers tested for served to provide many useful correlations and time-specific performance behaviors for effectively recognizing overall system operation. In the case of the hinged, shutter system that was designed and constructed to reduce nighttime heat-loss, data recordings illustrated that on the two nights that were not sealed and covered, that being Monday and Tuesday, noticeably unfavorable declines in temperatures resulted. As illustrated in Figure 4.1, all performance variables resultantly experienced rapid temperature declines to record lows as opposed to other nights that had less drastic declines. The graph's data also pointed out that the temperature declines in the solar water heater's performance consistently began at 3pm, revealing that the last hour and a half of sunlight was ineffectual, in turn suggesting that the device be sealed and covered not at sundown but at 3pm in the month of February or October to slowdown nighttime heat loss. In the same respect, telling by the data's recorded peak temperature time each day, household usage of hot water would best occur at 2pm. Many such insights were inferred from these data results, bringing the comprehensive systems approach of analyses to the efforts of successfully maximizing system performance. Manually drawing simulated hot water volumes while recording the system's performance variables over ranging seasons has served to provide a well-informed understanding for the ICS Solar Water Heater's expected performance. Accomplishing this has in turn served to provide the most well-suited prototype device and well-informed approach toward the efforts of community-wide technological adoption.

5. COMMUNITY INTEGRATION PLANNING

Implementing this works' comprehensive approach to system customization, usage simulation and performance testing has effectively affirmed the ICS Solar Water Heater's suitability for poor and off-grid communities. These proven findings have effectively laid the foundation necessary for confidently directing future efforts toward community integration. Like that of assuring suitable system customization, coordinating effective community integration has its own set of criteria. In addition to exhausting locally-based reused supply chains and modifying system setup to suit household specifications, effective community integration requires the active participation of residents in the workings of system construction and utilization. Resident involvement serves as the primary basis for successful technological adoption within poor, off-grid communities. Other respective community-based criterion that serves to assist and facilitate successful technological adoption is that of adequate community organization and representation. Serving its objective, this work has effectively moved forward from the efforts of confirming system suitability to the concluding extent of planning the preliminary coordination of community integrated ICS Solar Water Heaters.

Planning for community-based technological adoption involved selecting the community through the support of a collaborative partnership and organizing the main approach for system construction and utilization through implementing methods for activating resident involvement. Community selection was facilitated by a nongovernmental organization named "Corazón," a collaborator in this work. With Corazón having academic ties to Cal Poly Pomona, whereby this academicallybased work was offered a direction of implementation, a partnership resultantly ensued. As Corazón's operative mission is to strengthen community cohesion and self-sufficiency of several communities around Tijuana and Tecate, they readily supported the basis of this work, since sharing similar objectives. One of the informal communities they serve, "Valle de Las Palmas," located in the rural foothills of Tecate, Mexico, became the community selected to represent this works' technological adoption of ICS Solar Water Heaters. Chosen for its proactive and collaborative community-building efforts, Valle de Las Palmas provides the base of analysis for preparing a suitable approach for activating community-wide participation toward technological adoption. As each of the communities Corazón serves has a community center and representing council to assemble and communicate community affairs with, this works' efforts for gathering household data and seeking community involvement will operate through these existing chains of communication. Announcing scheduled ICS Solar Water Heater instructional workshops, for example, will serve to activate resident participation for effectively passing the knowledge of constructing and utilizing the systems over to the community. Providing reference materials to support these instructional efforts, will serve to show everything from equipment makeup and construction sequences to system utilization and troubleshooting tips. ICS Solar Water Heating system construction will begin by building an operable demonstration device at the Valle de Las Palmas community center to establish system familiarity among community residents as well as train an initial construction team the process of construction and operation. This construction team, to be made up of two Corazón personnel and several Valle de Las Palmas residents, will then assist in leading the construction efforts of future household ICS Solar Water Heating installations. This approach, dependent upon community participation, serves to facilitate a self-sustaining technological adoption. These outlined methods serve to structure the framework for conducting this works' subsequent efforts of community-wide integration of ICS Solar Water Heating systems within Valle de Las Palmas.

6. CONCLUSION:

This work serves to contribute toward the greater effort of facilitating the access of basic domestic amenities for residents of poor and off-grid communities through the adoption of renewable technologies and practices. By customizing an Integrated Collector Storage Solar Water Heater to suit the conditions facing poor and off-grid communities, access to a clean, reliable and abundant supply of hot water was facilitated, thereby aiding resident well-being and demonstrating the effect community customization can have upon the delivery of renewable systems and practices. The effectively customized, high performing ICS Solar Water Heating prototype provided the basis for moving forward to community-wide technological adoption. Combining the solar water heating device with a community integrated approach that emphasizes resident participation concludes this works' efforts. This successful merging of device and community commences the subsequent efforts of coordinating the technological implementation of ICS Solar Water Heater's within the community of Valle de Las Palmas.

7. ACKNOWLEDGEMENTS:

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