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Report on the Analysis of Field Data Relating to the Reliability of Solar Hot Water Systems

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Abstract

Utilities are overseeing the installations of thousand of solar hot water (SHW) systems. Utility planners have begun to ask for quantitative measures of the expected lifetimes of these systems so that they can properly forecast their loads. This report, which augments a 2009 reliability analysis effort by Sandia National Laboratories (SNL), addresses this need. Additional reliability data have been collected, added to the existing database, and analyzed. The results are presented. Additionally, formal reliability theory is described, including the bathtub curve, which is the most common model to characterize the lifetime reliability character of systems, and for predicting failures in the field. Reliability theory is used to assess the SNL reliability database. This assessment shows that the database is heavily weighted with data that describe the reliability of SHW systems early in their lives, during the warranty period. But it contains few measured data to describe the ends of SHW systems' lives. End-of-life data are the most critical ones to define sufficiently the reliability of SHW systems in order to answer the questions that the utilities pose. Several ideas are presented for collecting the required data, including photometric analysis of aerial photographs of installed collectors, statistical and neural network analysis of energy bills from solar homes, and the development of simple algorithms to allow conventional SHW controllers to announce system failures and record the details of the event, similar to how aircraft black box recorders perform. Some information is also presented about public expectations for the longevity of a SHW system, information that is useful in developing reliability goals.

* The work described in this report was performed for Sandia National Laboratories under Purchase Order No. 95808.

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ACRONYMS

AANOVA	Analysis of Variance
APS	Arizona Public Service
FSEC	Florida Solar Energy Center
HECO	Hawaiian Electric Company
HETL	Hawaii Energy Test Laboratory
NABCEP	North American Board of Certified Energy Practitioners
NREL	National Renewable Energy Laboratory
SHWRT	Solar Hot Water Reliability Testbed
SMUD	Sacramento Municipal Utility District
SNL	Sandia National Laboratory
SRP	Salt River Project
SWAP	Source Water Assessment Program
SWH	Solar Hot Water
UNM	University of New Mexico

INTRODUCTION

Background

Over the past 40 years hundreds of field studies, laboratory tests, and computer simulations have provide a bounty of data and information about the energy performance of solar hot water (SHW) systems. During this same period only a handful of studies have been conducted to understand the reliability of these systems. However, as increasing numbers of these systems are become routinely installed in both new and existing homes, there is a growing need to understand their reliability characteristics.

Where rebate programs have spurred significant numbers of installations, utility planners have become interested in not only how much energy these systems produce but the duration of that production and whether performance might degrade with time. Planners in both electric and gas utilities are looking to be assured that initial reductions in load due to the installation of SHW systems will continue over the length of the agreements, and that systems will not fail in service or may not be repaired. If the SHW systems are sufficiently unreliable and the owners do not keep the systems in good working condition, the utilities would be compelled to essentially ignore the initial load reduction and plan to install equipment of sufficient size to carry the entire load, ignoring the solar contribution. Such a practice would negate the benefit from solar systems. In the absence of quality reliability data, this may be only recourse for utility planners.

Additionally, rebate programs at all levels of government as well as gas and electric utilities often use the certified energy performance ratings for SHW systems to determine the size of the installation rebate that is issued to the owner. The rebate is often based on the assumption that the SHW systems will continue to operate flawlessly at their rated performance for their assumed life, which can range from 15 to 25 years. Utility planners have begun to discuss methods to validate the reasonableness of this assumption.

Generally, this growing angst can be summarized in three important questions. First, what are the life cycle characteristics of SHW systems? Specifically, what are the mean times to failure for various system types? Second, how closely does the field performance of SHW systems compare with their certified energy production ratings and purported durability? Third, how many systems may be failed in the field without the owner's knowledge?

Prior Work

Answers to these questions and concerns are sparse and limited. However, last year, Sandia National Laboratories (SNL) sponsored a research effort to address these concerns and questions. A report on the effort was published in May 2009 [1]. That report described the comprehensive collection, organization, and analysis of some previous research and existing data regarding the reliability of SHW systems and components.

Four datasets were procured and analyzed and some important conclusions emerged. First, based on a detailed inspection of 10-year-old systems in Florida, half of those active systems had failed at the time of inspection. Second, valves were identified as the probable cause of a majority of active SHW failures, at least during the startup or warranty period. Third, integral storage and thermosiphon SHW systems have fewer startup failures than active ones, probably due to their simple design that employs few mechanical parts. Fourth, it is probable that the existing data about reliability do not reveal the full extent of fielded system failures because most of the data were based on trouble calls that were serviced during the startup or warranty period. Moreover, often a SHW system owner is not aware of a failure because the backup system silently continues to produce hot water. Thus, a repair event may not be generated in a timely manner, and sometimes not at all.

The most significant conclusion from the report is that with the exception of the 10-year field survey in Florida, there are few *measured* data to characterize the full lifetime characteristics of SHW systems, especially for the portion of their lifetimes that follow the startup/warranty period. Although some estimates of the lifetimes of systems and their components were gathered from interviews with technicians and manufacturers, their value is limited because data from these sources are often biased or grossly inaccurate (Hiller explains why [2]).

Some important recommendations emerged from the study. First, an alarm should be integrated into SHW controllers so that they can notify the owner of a failed system. Second, there is need to collect high-quality reliability data that can be used to properly characterize the reliability of SHW systems. Third, there should be some accelerated testing of those components that are identified as highly problematic and which cause repeated failures.

After that report was published, a number of individuals emerged to report that more reliability-related data existed in the solar community. As a result, a new contractual effort was initiated with a task to seek out and procure those additional data, integrate them into the database, analyze them, and report the results. This report documents the results of this contracted research.

REPORT ORGANIZATION

This report is organized into four sections.

The Technical Section 1 describes the fundamentals of reliability theory. The theory is used to create a fundamental understanding about reliability engineering that serves as a backdrop for the ensuing discussions. The theory helps to explain the data requirements for a full mathematical characterization of SHW system reliability. It lays the groundwork for explaining the shortcoming of in the current database and the data needed to rectify the situation.

Technical Section 2 discusses the new data that were collected in this contractual effort. It begins with a brief description about the database that was developed in the first reliability study (the database that hereafter is referred to as the *Phase 1 database*). Then it describes the new data that were collected. These data will hereafter be called the *Phase 2 data*. It also describes how these data were procured and how they were integrated into the Phase 1 database. After merging the Phase 2 data into the Phase 1 database, the resulting consolidated database is referred to as the *Phase 2 database*.

Technical Section 3 presents an analysis of the Phase 2 data and associated information. It begins with a report on the comparison of the Phase 2 data with comparable data in the Phase 1 database.

The section then proceeds to discuss the extraordinarily low number of warranty claims for SHW systems that were installed under an incentive program that was sponsored by the Hawaiian Electric Company (HECO). Some statistics are presented that show the effectiveness of a field data feedback program employed by HECO that apparently contributed to the dearth of startup problems that normally accompany system installations. (In the electronics industry, this startup phase is sometimes referred to as “burn-in time,” where the “bugs are worked out.”)

Technical Section 4 presents a case study of a failed valve, the first analysis of a physical specimen since this reliability project was incepted several years ago.

Technical Section 5 discusses how the existing data fit with the needs of reliability theory. Deficiencies are noted, specifically regarding the lack of measured data that define the end–of-life period of SHW systems. Some new ideas are presented for cost-effectively gathering additional data that could be used to fully define SHW system reliability.

Additionally, the section discusses alternative methods for achieving highly reliable SHW systems, most notably predictive techniques that would help avoid unscheduled downtimes for repairs.

Technical Section 6 presents information about consumer expectations of the lifetimes for SHW and similar systems. A system lifetime goal is an essential requisite for designing systems to a specific level of reliability. These expectations were gathered from surveys of a cross section of the public. The survey methods are described and summary statistics are presented. While not an official part of this contractual work, the results are important because they help to define reliability goals for SHW systems.

Summary comments and recommendations are presented in Technical Section 7.

Appendix A contains the result of an interview with a researcher and solar professional in Hawaii who explains some of the details of an extremely successful SHW program that experienced a very low number of startup failures for thousands of installations on the islands.

Appendix B contains tables that present the new data that were procured and helped to create the Phase 2 database.

TECHNICAL SECTION 1.
RELIABILITY THEORY†

Engineering reliability theory is a well-developed field of engineering and its use is ubiquitous in the creation, operation, and maintenance of many common systems, especially those whose life cycles are important to know. Automobile manufacturers use the theory to determine appropriate warranty periods to ensure profitability. Airline companies use it to schedule maintenance service for airplanes, producing one of the safest means of travel in spite of the inherent dangers of flight. It is used by component designers to ensure specific levels of reliability for products associated with critical activities, such as weapons.

To begin, reliability must be defined to provide a common point of reference. Webster [3] provides two definitions: (1) "The state of being reliable," with "reliable" meaning "dependable" or "giving the same results on successive trials," and (2) "the extent to which an experiment, test, or procedure yields the same results."

However, this dictionary definition is rather imprecise, leaving the reader with ambiguous ideas about its meaning. For example, if reliable means dependable, then what does dependable mean? The word association can continue in circular fashion endlessly. Moreover, the phrase "yields the same results..." also lacks precision.

In common engineering applications, "reliability" has a specific meaning. It can be defined mathematically and it can be measured. It can be estimated with specific precision and expected error based on statistical tables. It can be tested and verified with field measurements. For engineers, "reliability" is as real as the measured energy performance of a product or process.

Reliability measures begin with the design goals for specific equipment or processes. These goals include two factors: the minimal performance level for the equipment to produce a specific outcome and the minimal amount of time that the equipment must be available to meet that level of performance.

Reliability is measured against both factors. For example, an SHW system may be designed to produce an annual solar fraction of 70% and be available to do so in 92 percent of the years with an expected lifetime of 15 years. A solar system that precisely meets these objectives is reliable. One that produces an 80% solar fraction in 95% of the years for 15 years is equally reliable. However, one that produces a 62% solar fraction for 98% of the years is not reliable because it fails to meet the required solar fraction.

According to Bazovsky, a noted reliability theoretician, reliability is the probability that no performance failure will occur in a given time interval of operation. Probabilities can be computed based on statistical theory. Thus, reliability is basically as statistical measure.

† The theory presented here is adapted from Igor Bazovsky, *Reliability Theory and Practice*, Prentice Hall, Inc., Englewood Cliffs, NJ, 1961 [out of print], and P. Tobias and D. Trinadade, *Applied Reliability*, Van Nostrand Reinhold Company, NY, NY, 1986 [out of print].

At the most fundamental level, a system whose failure mechanism is due to pure chance[‡] has its reliability defined as

$$R(t) = e^{-\lambda t} \quad \text{(Eq. 1)}$$

where R is the probability that the device will not fail in the given time t, t is a specific operating time period, and λ is the constant, chance failure rate for that device.

Note that the failure rate in this period is constant.

Suppose that an SHW system randomly fails on average once every 100,000 hours of operation. Its failure rate is then one failure divided by 100,000, equaling 0.00001 failures per hour. Its reliability over *any* 8760 hours of operation (one year) is

$$R(t) = e^{-0.00001 \cdot 8760}$$

$$R(t) = 0.916$$

or about 91.6%. Thus, it has about a 92% probability that it will not fail over any one-year period of its theoretical operational life. If that solar system has an expected life of 12 years, then the probability that the solar system will not fail over its life is about 35%.

The time period t used in the examples above does not represent elapsed time. It represents only some time period in the life of the system.

For the purpose of definition, a common measure of failure rate is the mean time to failure. The mean time to failure (m) is defined as the reciprocal of the failure rate

$$m = \frac{1}{\lambda}. \quad \text{(Eq. 2)}$$

The derivation of the reliability function, R, is based on probability theory. The probability of failure of any device is computed by integrating under the curve of the probability density functions. For the exponential function, which was discussed above, the density function yields an expected instantaneous failure rate (f) as a function of t. The exponential density function is given as

$$f(t) = \frac{1}{m} e^{-t/m}. \quad \text{(Eq. 3)}$$

This function is represented in Figure 1 The curve represents the density at which component failures occur at that time t. The curve is presented for a mean time to failure equal = 1.0. The units of time are nondimensional. This is the standard density curve for the exponential function used in reliability work.

[‡] For the moment we will ignore the failures that occur during the startup of the device and those that occur as the device enters its end of life.

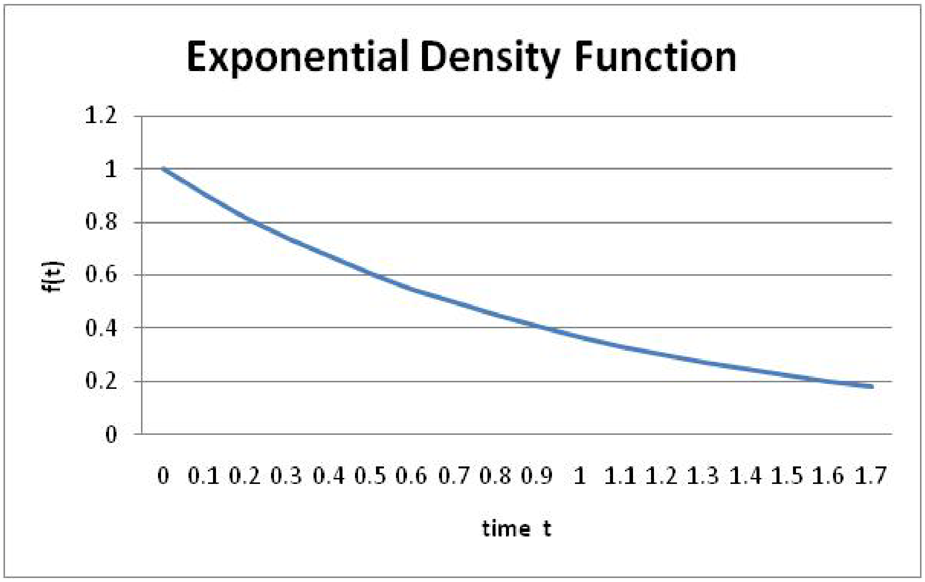

Figure 1. Exponential density function.

Note that for the exponential cumulative probability function when t = m, then f(t) = 0.368. Thus, the relative density of failures for survivors at the point equal to the mean time to fail is 0.368 or 36.8%.

The probability of a failure to time t is computed by integrating under the density curve to time t. The cumulative probability function is presented in Figure 2 (see the blue line). This line represents the cumulative probability of failure for any time t. Again, the time units are arbitrary.

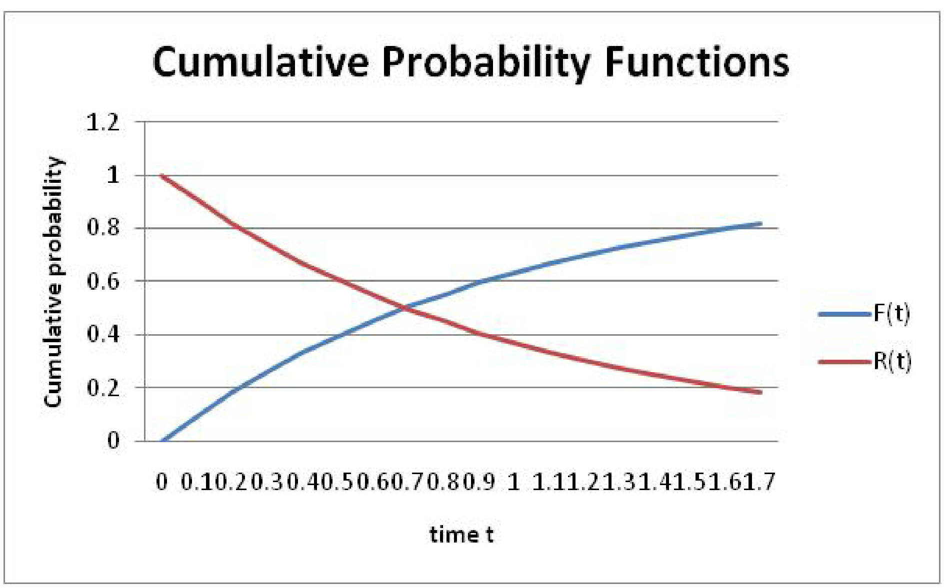

Figure 2. Cumulative probability functions.

In probability work there is often more interest in the probability of survival rather than failure. Thus, the function R is computed by the logical complement as follows:

$$R = 1 - F. \qquad \text{(Eq. 4)}$$

The line representing R, the cumulative probability of survival, is presented in red in Figure 2.

The instantaneous failure rate function, h, which is also called the hazard rate function, is then computed as follows

$$h(t) = \frac{f(t)}{R(t)}. \qquad \text{(Eq. 5)}$$

The assumption that a device, such as an SHW system, has a constant failure rate over its life is unrealistic. This assumption ignores what is commonly known about the life of any engineered product. That is, systems typically have a high rate of startup failures, followed by a reduced failure rate as it performs its intended function, and increasing failures as it draws near the end of its life.

The lifetime failure rate of nearly all devices follows a curve that is very commonly referred to in reliability engineering as the bathtub curve, and it looks like that shown in Figure 3.

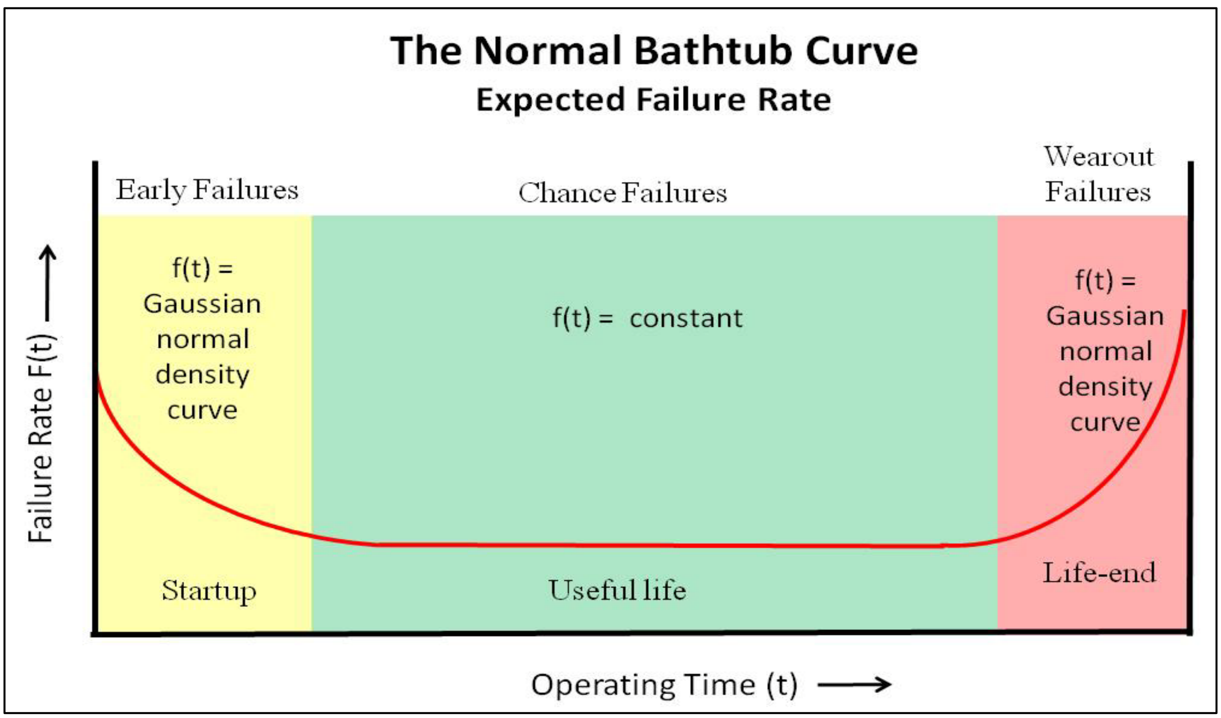

Figure 3. Normal bathtub curve, expected failure rate.

The failure rate early in the device's life is characterized by startup failures due to design flaws, faulty new equipment or components, installation errors, and misuse due to ignorance (yellow area). Once these initial problems are corrected, then the device enters its useful operational period where failures are due to chance occurrence (green area).

Later, as the device and its components age, the failures begin to increase because the system is wearing out. Failures start to slowly creep in and eventually the system fails (red area).

Note that both during the early failure and life-end periods, chance failure continues to operate and imposes additional random failures.

A constant failure rate is expected during the useful life period. During that time all of the components are operating well within their normal expected life and the startup problems have been solved. In this useful life period the applicable model for predicting failures is Equation 1.

Different mathematical models are used to describe the failure rate within the startup and life-end periods. The Gaussian distribution is a model that adequately explains the failure rate in these periods. It is easy to understand and apply and tabled values can be used to calculate its probabilities. It is defined by two key parameters, the mean and standard deviation of the failure rate as a function of operating time.

The Gaussian model does harbor one drawback in that its tails extend to infinity on both sides of the mean. Obviously, this makes little sense for systems that have limit to their life, but these extreme tails can be ignored as they are highly improbable or impossible. The ease of use and understanding of the Gaussian model outweighs these shortcomings and it is completely sufficient for applications put forth here, especially in explaining the concepts discussed below.

The Gaussian model is described by the equation for the normal density function as follows

$$f(T) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-(T-M)^2/2\sigma^2}. \qquad \text{(Eq. 6)}$$

where T is the age of system, M is the mean time to failure of system or component,[§] and σ is the standard deviation about the mean.

The density function is presented in Figure 4." The abscissa is represented by the z value, which is equivalent to a normalized standard deviation. The z value is analogous to a time metric because every device has a real lifetime that may be different from the mean life of similar systems. The differences are represented by standard deviations on both sides from the mean.

§ This mean should not be confused with the mean time between failures, m.

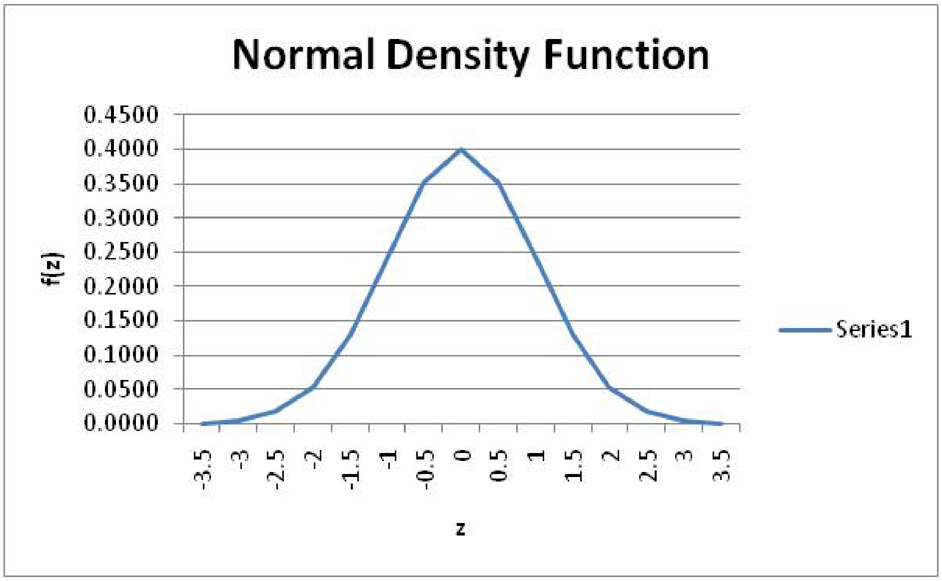

Figure 4. Nominal density function.

As with the exponential distribution, the hazard function can be computed by integrating under the curve of the normal density function. The normal cumulative density functions are plotted in Figure 5 next to the density curve. F represents the failure function and R represents the survival function. In both Figure 4 and Figure 5, the data were computed with Excel, but the same numbers could have been easily taken from statistical tables, which are ubiquitous.

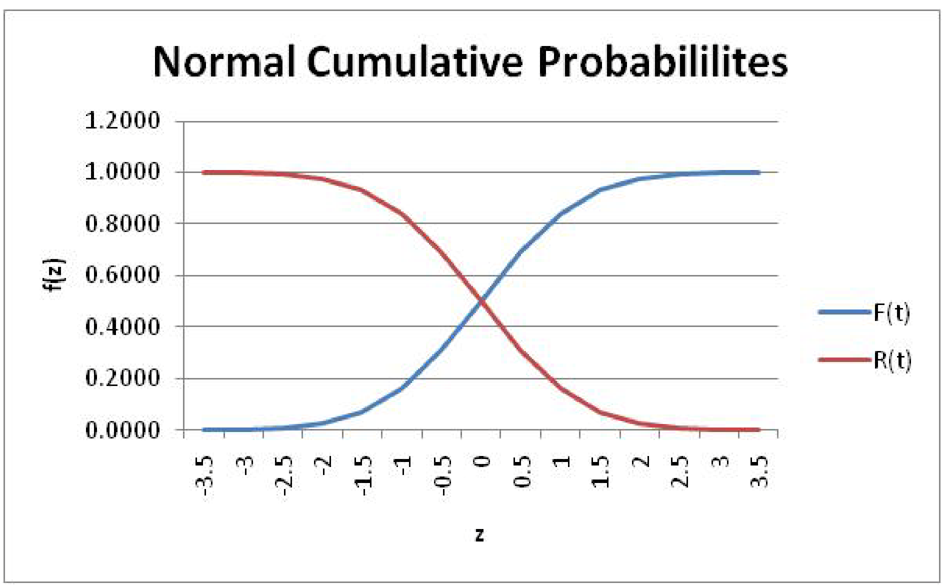

Figure 5. Normal cumulative probabilities.

Note that for the normal cumulative probability function, when z = m, then f(t) = 0.5. Thus, the relative density of failures for survivors at the point equal to the mean time to fail is 0.5 or 50%. Recall that the equivalent statistic in the exponential distribution was 36.8%.

The statistics used in these equations, the mean and the standard deviation, are derived empirically based on experiential measurements. Generally, the greater the sample size, the better defined will be the mean and standard deviation.

When all of the parameters are known for the three phases of life of a system—the means and standard deviations for the startup and life-end and the constant failure rate for the useful life period—the system's reliability is fully characterized. Thus, the life cycle of the system is completely defined. The models can be used with confidence to predict failure rates. The failure rates can be used to compute mean time to failures and probabilities for systems to operate within a specific period.

Using the mathematical characterizations outlined above, some important principles of reliability emerge. These principles imply that certain operational practices can be applied to systems to achieve very high system reliability.

At the outset of this section reliability was defined in engineering terms. One of the important measures of a system is its ability to meet the design performance goals. The probability of the system to do so defines its level of reliability.

A properly characterized system has its failure rates defined based on historical measures in the field or through experiment. The mean time to failure is defined by Equation 2 as being the reciprocal of the failure rate. The system availability is defined as follows:

$$Av = \frac{m}{m+Tm} \qquad \text{(Eq. 7)}$$

where Av is the availability of the system in a defined period,; m is the mean time between failure in the same unit as Av, and Tm is the average system down time in a defined period.

Clearly, an accurate measure of the failure rate for the system is essential to determining the availability of the system.

During the useful life of a system (the green area in the bathtub curve), the failure rates are typically very low, which means that the mean time to failure is very high. In many cases, the computed mean time to failure during this period is much higher than the expected life of the system. Obviously this make no sense unless it is understood that increasing failures will impose themselves upon the system as it enters its life-end stage, during which time the failure rates rise and mean times to failure fall.

Components in SHW systems are typically replaced after they have failed during the life-end period. At that time the system is operating well into the final hours of its life, a time when failure rates are high and rapidly rising and where corresponding mean times to failure are falling. Availability also is rapidly shrinking due to the increasing down times.

The key to high reliability and thus high availability of a system is, therefore, is to maintain the system so that it operates continuously in its useful life region. To do so requires that components be replaced before they approach their mean life span. Depending on the system, components that are replaced at two to three standard deviations before its expected mean end of life would be sufficient to indefinitely maintain very high overall system reliability.

This principle is demonstrated in Figure 6, which focuses on the life-end period. In the graph there are three lines. The blue line represents the normal density function; the red line represents the probability of survival, R; and the green line represents the normalized failure rate. The failure rate increases very rapidly as the system ages into its life-end period, especially as it passes its expected mean life.

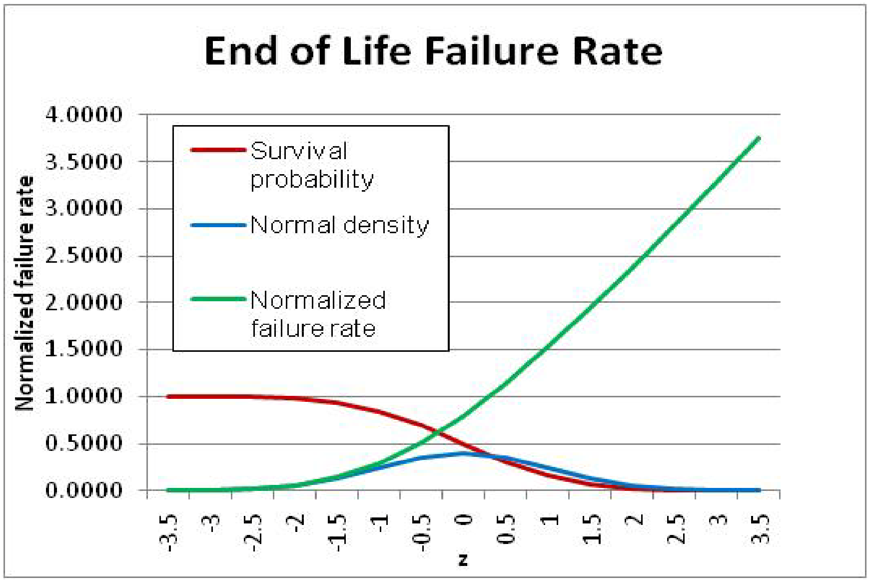

Figure 6. End-of-life failure rate.

If Equation 2 is applied, the result can be seen in Figure 7. The mean time to fail plummets rapidly as the failure rate grows, implying that the system is experiencing failures at an increasing rate.

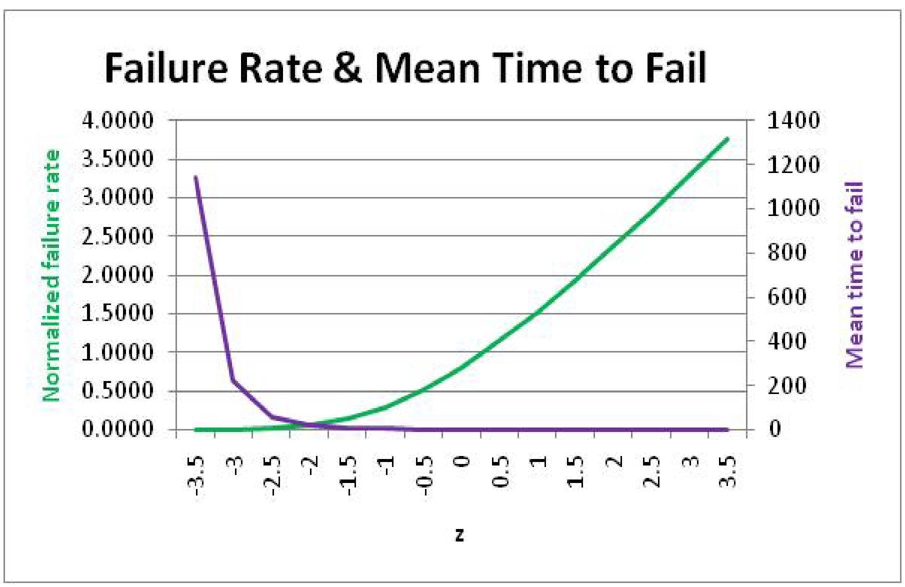

Figure 7. Failure rate and mean time to fail.

If system components can be replaced before they wear out, the low levels of reliability at the end of life can be substantially reduced or eliminated.

Suppose, for example, the life cycle of a component is well known, which means that its mean life and standard deviation have been estimated based on adequately sized samples to represent the population. Then that component can be replaced before it usually fails. If system availability is very critical, the component could be replaced at a time that is -3σ before the mean failure for that kind of component. If availability is not as critical and some occasional downtime could be tolerated for a miscalculation of replacement time, then a replacement at -1σ from the mean might suffice.

Typically, the replacement time is chosen so that the expected failure rate within the life-end period would be approximately equal to the failure rate in the useful part of the system's life. Figure 8 shows the area in the life of the systems when critical components must be replaced in order to assure continued high system reliability.

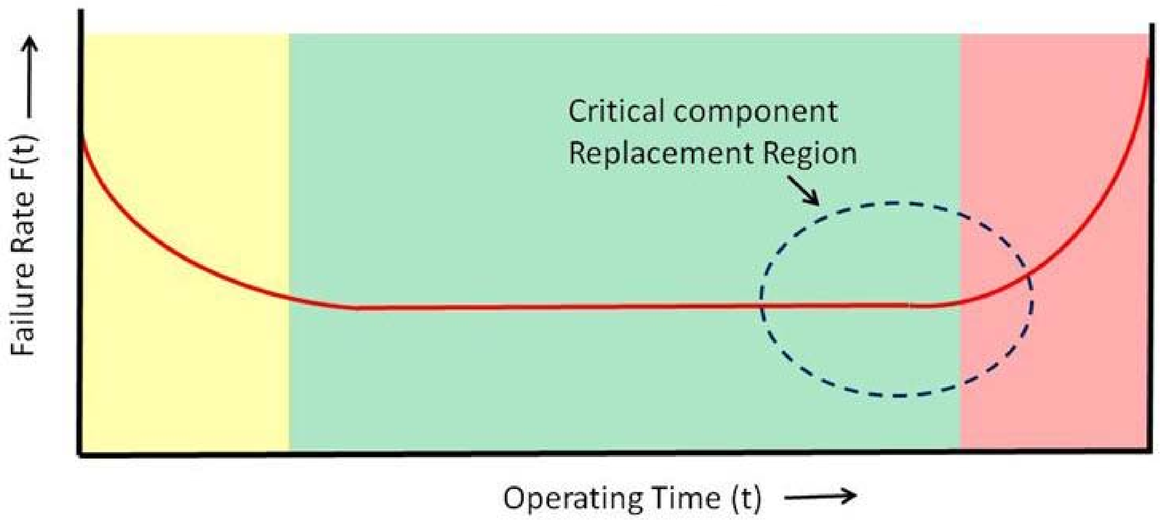

Figure 8. Normal bathtub curve, critical component replacement.

The useful life and life-end periods have been heavily discussed thus far with little mention about the startup period. The same principles that apply to the life-end period can apply to startup, but the solution is not early replacement of components. Rather, it is to install components with better initial reliability than those that have a tendency to fail early. Also, implementing improved installation practice can reduce early failures. These practices will help reduce initial failures and will be reflected in the bathtub curve with a flatter curve in the startup phase startup phase of the system.

A full statistical characterization of components at both the time of installation and during life-end is essential to gain value from the methods described above.

Figure 9 shows how the normal bathtub curve can change with a selective maintenance program coupled with an improved startup program. The early failure curve is flattened and the life-end period is sharply reduced to essentially the time when the system operator has decided that the system should be overhauled, redesigned and rebuilt, or taken out of service for a new system.

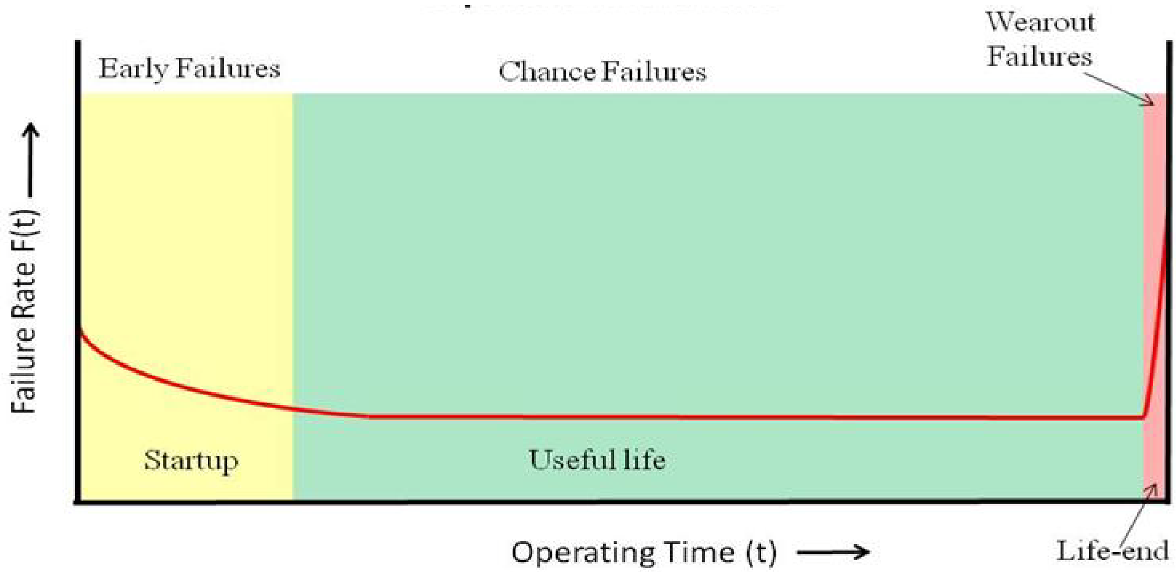

Figure 9. Normal bathtub curve with selective maintenance, expected failure rate.

Naturally, the replacement program would have to be applied to all components in the system, starting with those that have the shortest lifetimes. And the replacement program must be maintained indefinitely, at least for a period that is about equal to the design life of the system. In a solar system, that design life and its maintenance schedule are defined by economics based on how much energy the system saves versus the cost of maintaining it. At some point it is likely that critical and expensive components, such as the collector, will reach their ultimate life and necessitate a full system replacement. However, a properly maintained system that uses the component replacement methodology described above would have experienced very high reliability and availability up to the end of its service.

One of the best examples of the application of this methodology is the airline industry. Airplanes are some of the most reliable systems in society. Safety is their most important design goal and they deliver people safely to their destination repeatedly. In fact, there are over 5000 flight operations per day in the United States with lethal accidents being an extremely rare event. A significant portion of operational aircraft is relatively old, containing such relics as Boeing 727s and DC9s. Some very old aircraft, such as Boeing 707s and DC-3s operate routinely in many parts of the world. The reliability of aircraft today is so high that anyone can board nearly any commercially owed aircraft and be reasonably certain of safe passage to a destination.

Even more common systems, those similar to SHW ones, can also successfully achieve astounding reliability through proper maintenance procedures. This author's father owned and operated a 1946 Ford half-ton pickup truck as the main service vehicle for his auto repair shop for 39 years. The vehicle was finally retired with over 700,000 miles registered on the odometer; it was replaced only because all of the available replacement components from the state's salvage lots had been exhausted. Although the vehicle was heavily used for service calls during its normally scheduled six-and-a-half-day workweek, it almost never experienced unscheduled downtime. The secret to this astonishing performance was a maintenance program based on preemptive replacement of components. The component replacement schedule was developed through a rigorous collection and analysis of component failures gathered in the repair business.

TECHNICAL SECTION 2.
THE DEVELOPMENT OF THE PHASE 2 DATABASE

Phase 1 Database

The Phase 1 database holds three types of data. One type contains estimates of lifetimes of various components in an SHW system. These estimates were based on interviews of installers and manufacturers of SHW systems. Two sets of data were assembled. One was from a study by Arizona State University. The other was orchestrated by the National Renewable Energy Laboratory. In both cases the participants were asked for their opinions about the expected lifetimes of various SHW components; the results were recorded.

The second type of data consists of records about service that was rendered to SHW systems under warranty. These data were recorded by the Sacramento Municipal Utility District (SMUD) as part of their SHW incentive program that they operated in the 1990s. These warranty records contain information about the problems that were corrected in each service call, but do not record dates of the service nor of the system's installation. There were also a handful of records about warranty service in Hawaii. These data were discarded from the database and replaced with much more extensive data from HECO.

The third type of data consists of records of field inspections of ten-year-old SHW systems. The systems were originally installed as part of the Department of Energy's Solar Weatherization Program that was administered by the Florida Solar Energy Center (FSEC) in the early 1990s. FSEC conducted the survey and recorded the status of the systems.

All of the data were organized into a standard format in the Phase 1 database so that each type could be compared against one another. For example, the types of SHW components were organized into major categories including collectors, controllers, and sensors. Each major category was subdivided into subsystems. For example, the collector category contains items such as glazing, header tubes, etc. For each category, the number of problems encountered in the warranty period is recorded. Where applicable regarding the estimated lifetime data, estimates of component lifetimes are recorded in the database instead of records of problems.

The Phase 2 Data Sources

Data procurement was a major part of this recent effort. It began by identifying and contacting organizations throughout the country that might have data relating to SHW reliability and be willing to share them for this effort. Table 1 shows the organizations that were contacted, the actions required to interact with each one, and the result of the contact.

Two significant new sources of data were identified from this effort. One was in Hawaii; the data came from HECO. HECO had warranty service records relating to over 52,000 installations. A second data source was a large installer who agreed to supply records for over 900 installations, but with the stipulation that the name of the company along with names of their customers remain concealed. That company is referred to hereafter as *Anonymous Company*.

Table 1. Phase 2 Data Procurement.

Organization Contacted	Actions	Result
Hawaiian Electric CO	10 phone; 4 email conversations	Warranty records for 52,000 installations
USH2O	5 phone calls; 6 emails; notice to members	Numerous contacts and follow-ups
Lakeland Elec	1 phone call	Nothing
Florida Power & Light	2 phone calls	Nothing
San Diego Gas & Electric	SDG&E 5 phone calls; 2 email conversations	Nothing
Arizona Public Service	1 phone call	Nothing
Salt River Project	1 phone call	Nothing
American Solar Energy Society	3 phone calls	Nothing
Solar Rating Certification Corp.	1 phone call; 5 emails; notice to members	Nothing
California SEIA	2 phone calls; notice to members; 8 emails	Paper on surveys of early 1980s systems
Solar Energy Industries Association	1 phone call	Nothing
Maui Test Facility	2 phone calls; 4 email conversations	Info re field data feedback program/results
Barry Butler	1 phone call; 2 email conversations	Nothing
National Renewable Energy Lab	3 phone calls	Promise for data from future surveys
Davis Energy	4 phone calls; 3 email conversations	Promise for data from future surveys
Solar America program	4 phone calls; 3 email conversations	Nothing
U of Cal at Irvine	2 phone calls	Nothing
Interstate Renewable Energy Council	2 phone calls; 2 email conversations	Nothing
Florida Solar Energy Center	2 email conversations	Nothing
Portland General Electric	1 phone call	Nothing
Anonymous	6 phone calls; 8 email conversations	Warranty records for 900+ installations
University of NM library	Literature search	Paper on reliability of 1980 era system
Internet	Literature search	Nothing

The HECO database consisted of 484 service calls that were recorded as part of warranty service for the 52,218 systems that were installed over the period 1998 through 2004. Similarly, the Anonymous Company's supplied warranty records for 256 warranty service calls. The period of record is 2006 to 2009. Neither the exact date of warranty service nor the installation date of the system being serviced was included in the warranty records.

Additionally, significant information about HECO's warranty process was procured from Willy Bennett, who headed the Hawaii Energy Test Laboratory (HETL) on Maui. He supplied details about a program in which SHW system field problems were taken to his lab for systematic investigation. After testing and evaluation, Willy's team would propose an SHW design solution. Often these solutions were implemented in new SHW installations. More information about this program is included in the discussion below.

Phase 2 Data and Phase 2 Database

All of the data and information noted above were procured and were integrated into the Phase 1 database, creating the Phase 2 database.

It is important to note that all of the Phase 2 data represent the startup period for the SHW systems (i.e., the warranty period). Also, all of the data represent pumped, direct circulation systems only.[**]

[**] Interestingly, very few integral storage systems are installed on the Hawaiian islands, even though the mild climate is appropriate for them. The reason is that integral systems do not save as much energy as pumped ones and they are not included in the utility rebate program.

TECHNICAL SECTION 3. ANALYSIS OF THE PHASE 2 DATA AND PHASE 2 DATABASE

The SMUD dataset that is contained in the Phase 1 database is most similar to the HECO and Anonymous datasets because it is contains warranty repair records for pumped systems in the Sacramento area. Therefore, the SMUD data will be used for many of the comparisons presented below. All of these data pertain to the startup portion of the SHW system's life.

The two other types of data in the Phase 1 database include estimates of SHW component lifetime based on interviews of installers and manufacturers as well as records of field surveys of installed systems. These data are not directly applicable to warranty records because they pertain to the useful life and life-end portions of the SHW life cycle, which is past the startup period.

Comparisons and Trends

After all of the Phase 2 data from HECO and Anonymous Company were integrated into the Phase 2 database, summary statistics were computed. Figure 10 and Figure 11 show how the Phase 1 database was changed after the Phase 2 data were integrated. These plots, which contain summaries of all of the data in the database, show the distribution of problems attributed to the major component areas of SHW systems.

The additional data do not reveal any additional or new trends of interest. As can be seen, the most notable and consistent trend indicates that valves are apparently an enduring problem for SHW systems. But the data do not contain specific information about the type of valves that failed or their time to failure, both of which would help to characterize SHW system reliability and allow for deeper investigations into the causes of the problems.

The remaining differences are not significant and reflect possible biases that were introduced into the database due to a preponderance of problems that one company had with a specific product.

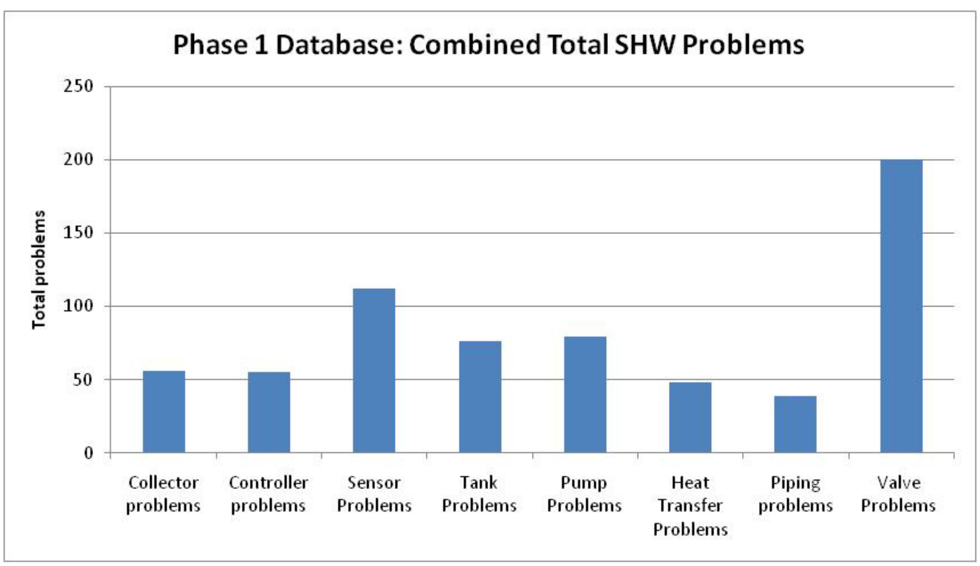

Figure 10. Phase 1 database.

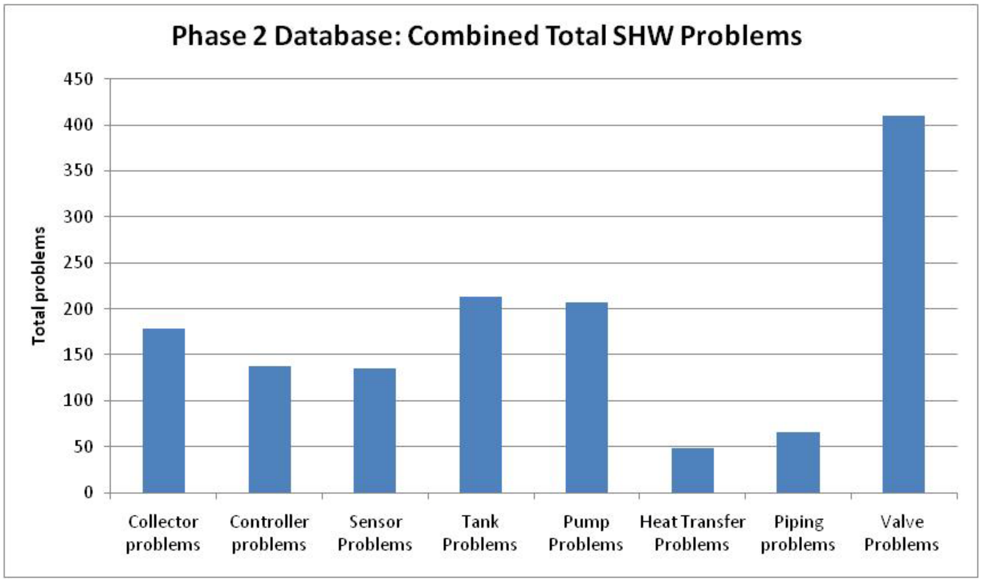

Figure 11. Phase 2 database.

For example, Anonymous Company tended to have problems with pumps and collectors, most of which related to specific quality issues with a certain product line and installation techniques. See Figure 12, which reflects the number of problems that prompted changes in the product. Once they changed to a different line of products, the problems were greatly diminished, but the legacy of that experience lives on in the database.

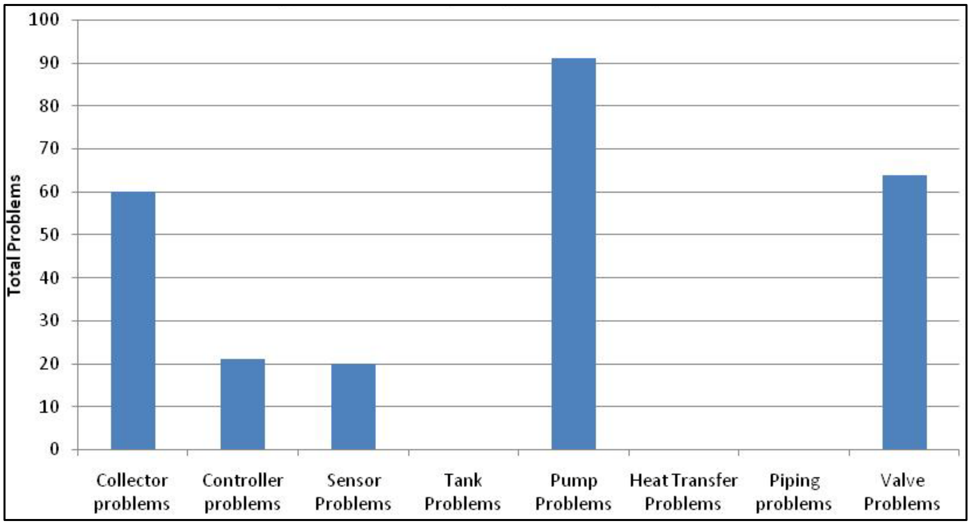

Figure 12. Anonymous Company warranty service.

Similarly, HECO experienced many problems with tanks, while they had many fewer problems with pumps. See Figure 13.

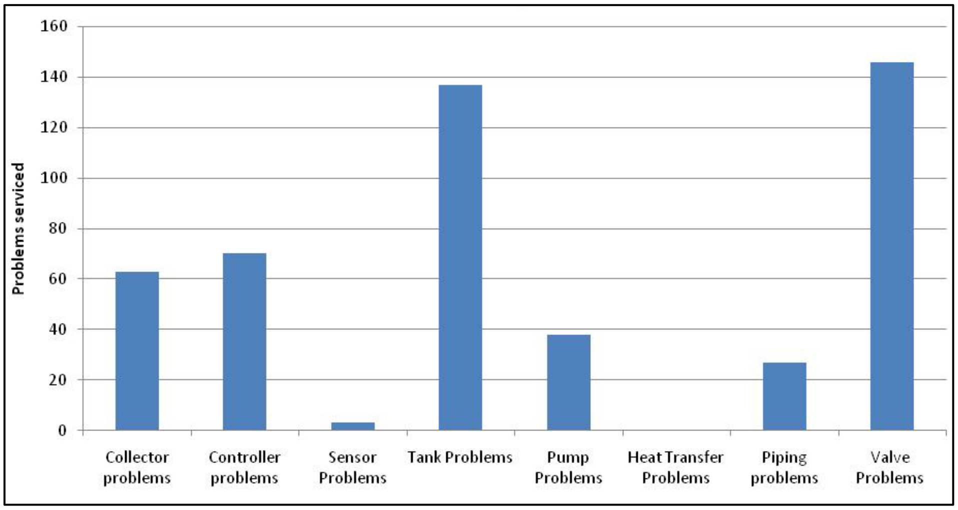

Figure 13. HECO warranty service.

In both cases, little true reliability information can be gleaned from the data because details of the warranty work, especially temporal data, were not recorded.

In general, there was little consistency among the three datasets regarding how the problems were allocated among the different major reliability categories. The only exception, as noted above, is in regard to valves. These components regularly created about 25% of all startup problems. Figure 14 shows the comparison visually.

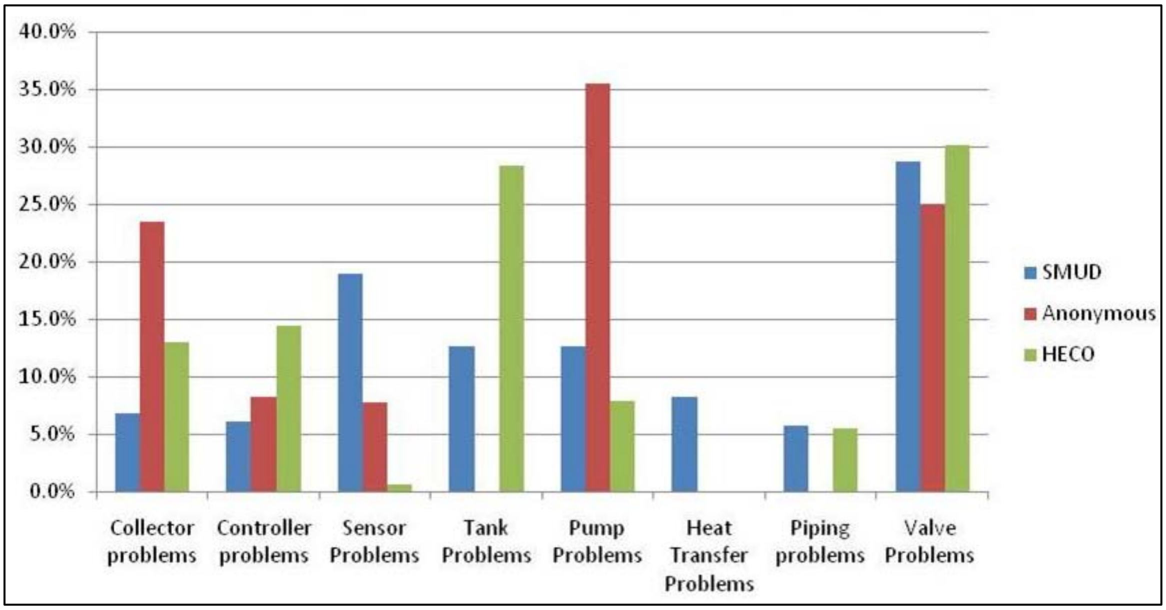

Figure 14. Dataset comparison of startup problems by category.

What the Data Show About Startup Failures During the Warranty Periods

Some interesting trends can be derived by examining the proportion of total startup failures for each of the three sets of warranty records. These proportions are computed by dividing the total failures in the warranty record by the total installations in that time period. The records for HECO and Anonymous Company show by year the number of number of systems that were installed and the number serviced under warranty. For SMUD, the total startup failures and total installations are known only for the entire period of record and are not broken out by year.

It must be noted that these computed values do not represent failure rates, in formal reliability terms, nor do they inform about the mean time to a startup failure because the exact time of delivery of the warranty service is unknown. To compute a failure rate, both the system installation data as well as the time of warranty service is needed.

Table 2 shows the comparison of the proportions of total startup failures relative to the total number of installations.

Table 2. Comparison of Startup Failure Proportions of Pumped Systems.

	SMUD	Anonymous	HECO
Total installed	1,889	1,893	53,218
Total probems	585	256	484
Percent problems	30.97%	13.52%	0.91%

These data suggest that there have been improvements in both quality of product and installation practice over time. The SMUD database represents systems that were installed in the mid 1990s. The SMUD and Anonymous data represent systems that were largely installed in the 2000s. It appears that the installers in Hawaii, who performed many of their installations after most of the SMUD systems were installed, may have learned lessons from that experience. No information is available to corroborate that possibility.

The newer installations may be the beneficiaries of manufacturing improvements and better-quality installations. Installation quality may have been induced by the inspections that were regularly conducted by HECO and the quality control program that is in use by Anonymous Company.

New contractor training programs may also have improved installations. Various programs have existed for at least a decade. The SHW contractor certification program developed by the North American Board of Certified Energy Practitioners (NABCEP) provides rigorous training for solar installers. It is unknown what installation training is actually required in Hawaii or by Anonymous Company.

The proportion of startup failures for the HECO systems is so extraordinarily low—an order of magnitude lower than those from Anonymous Company—that additional elucidation is needed. One possible explanation is that the systems that were installed on the islands are quite simple, at least with respect to pumped systems on the mainland. Since freezing is not an issue on the islands, the SHW collectors are configured without a heat exchanger; water from the hot water heating tank is pumped directly to the collector for heating and is then returned to the tank for storage.

These types of systems, often called *active direct* or *open loop*, always have water in the collector (see Figure 15). The collector and the tank operate at line pressure. They have single pumps, no heat exchanger, and very simple controls. Check valves are sometimes installed in the solar loop to prevent thermosiphoning at night, but the Hawaii Energy Test Lab found that a system with the solar return line connected to the bottom of the tank (called bottom connect) would perform about equally well whether or not a check valve was installed [4]. Systems like these cannot be installed in most areas of the continental United States.

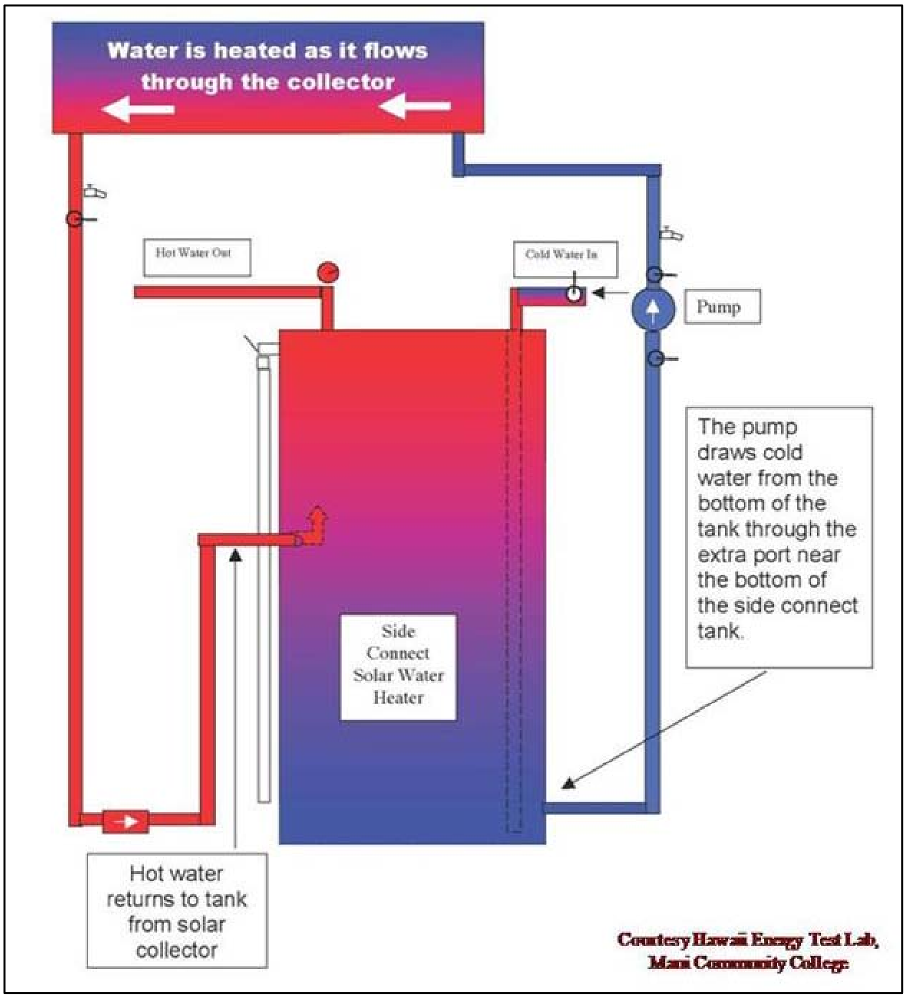

Figure 15. Typical SHW System Configuration in Hawaii.

Another possibility is that limited variation in system configurations allowed contractors to become well acquainted with the proper methods to install these systems. Lessons learned from the past were perhaps quickly integrated in new installations. Most of the components for these systems were purchased from only a few vendors who were located on the islands. This would limit the variety of components that were used in systems.

Another factor that favored high quality is that while training was mostly accomplished on the job by supervisors, 100% of the systems were rigorously inspected by trained city inspectors. These inspectors effectively provided training to installers when they rejected (red tagged) systems that failed to meet their standards.

Some additional comments about the Hawaii systems are provided in Appendix A. The information was taken from an interview with Willy Bennett, a solar professional in Maui and the former director of the HETL.

There HECO and Anonymous Company records can be analyzed in more detail than SMUD records because they contain a clear record of startup failures over time. The proportion of startup failure in the SMUD and records could not be determined because while there are records of installations by year, there is no corresponding breakout for the warranty service. Therefore, it was not possible to compute the proportion of warranty service as a function of time.

In the case of the Anonymous Company, two years of warranty records exist. Approximately the same number of installations occurred in both years, about 945. However, in the first year of record, 2008, 219 warranty claims were serviced, or a claim rate of around 23%. In 2009 the number of claims dropped to 53, representing about 5.6% of installations. Clearly the company had improved their installation practice and/or began to purchase better-quality components.

The percentage of annual warranty claims in the HECO is presented in Figure 16. It shows the trend over the seven-year period of record. As can be seen, there was a dramatic, nearly five-fold reduction in warranty claims after 2002.

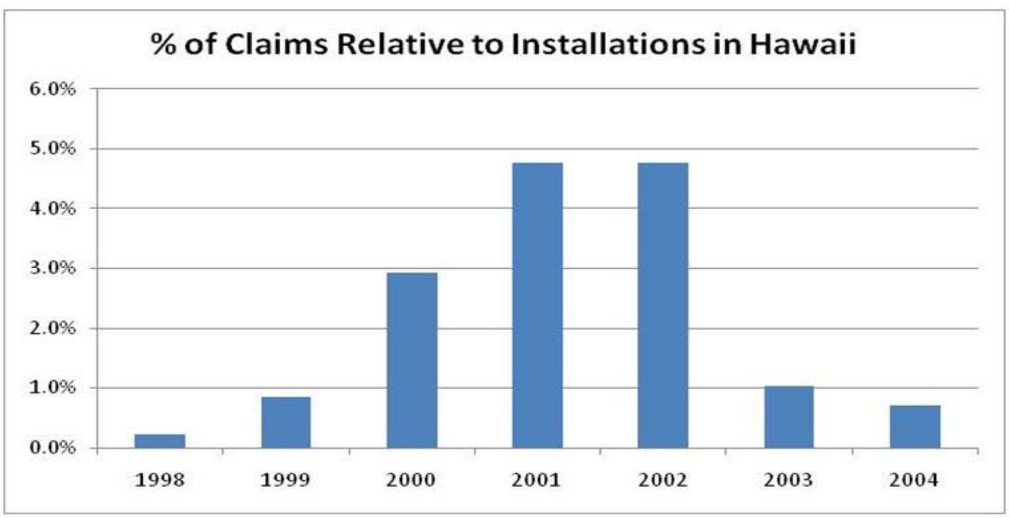

Figure 16. Percentage of claims versus installations in Hawaii.

Willy Bennett, former director of the HETL, suggests that the reduced startup failure rates were influenced by a feedback mechanism that fostered the flow of information about failed systems into his lab, where the problems were addressed. These data originated with HECO's warranty claim process, which recorded information about system failures. The information about failures was subsequently forwarded to the lab for analysis. The lab would investigate the problems, perform appropriate tests, and report the results, including suggestions for design or installation improvements. Many manufacturers and installers would use the information to improve the systems that they installed. Thus, newly installed systems would improve over time and this improvement would be reflected in a reduced number of warranty claims. Some of the testing work conducted by Bennett and his team can be found at http://oldweb.hawaiirdp.org/hetl/.

This feedback process was fostered by the limited physical area of Hawaii, which correspondingly had a limited number of component suppliers as well as installers. The work of HETL was well known and respected. Lessons that were learned in the laboratory were quickly adopted by the community and implemented in new systems. Additionally, relevant field lessons would also be adopted.

In summary, it appears that two factors have been instrumental in producing extraordinarily low startup failure proportions in the HECO SHW program: Simple system designs and a program to systematic identify the cause of failures, find solutions, and implement the solution into improved designs.

TECHNICAL SECTION 4. CASE STUDY OF AN SHW SYSTEM VALVE FAILURE

Among the thousands of data in SNL's Phase 2 reliability database, only valves have been identified as a consistent and significant problem area in SHW systems. However, there is little specific information about them, such as the kinds of valves that are failing and the conditions that lead to their failures.

In early January 2011, during an extraordinarily cold period in Albuquerque, NM, an air valve failed on the collector loop of the SNL/University of New Mexico (UNM) Solar Hot Water Reliability Testbed (SHWRT).[††] As a consequence, the solar collector return line did not properly drain, allowing the water inside it to freeze and rupture the copper tubing. The failure presented a unique opportunity to investigate a failed component that had been purported to be one of the banes of SHW systems.

The SHWRT was configured at the time in drainback mode for testing. Drainback systems are popular in many US areas and an air relief valve is often a critical component that allows air to vent into the collector loop when the solar pump is off, allowing the plain water in the collector and piping to drain into a tank. If the air valve fails, water can be air-locked in the loop and the collector and its supply/return lines can freeze. The vent also allows air to escape when the pump is turned on.

Figure 17 shows how the SHWRT is plumbed. Figure 18 shows how this popular valve is plumbed into the high point of the solar loop on the SHWRT.

This particular plumbing layout was required because of spatial considerations. As can be seen, because of the trap that is created between the solar return line and the inlet to the drain tank, a second air valve is required to allow air to escape in the line as water is draining from the heat exchanger into the drain tank.

A closeup of the design of the drain tank (Figure 19) offers an explanation as to why the valve is needed to drain the solar loop. As can be seen, the supply connection is connected to a dip tube inside the tank and that tube extends below the water level in the tank. Even when the solar system is operating, the end of the tube is immersed in the water.

After the system has run and the solar loop is completely full of water, the loop is closed and air is needed to break the vacuum to allow draining.

The purpose of the dip tube is to eliminate the noise associated with water as it enters the tank. Without the dip tube, the water would dribble down from the top and could create noise. At least one manufacturer routinely ships these tanks with the dip tube installed.

[††] The SHWRT is a collaborative effort between SNL and the UNM Mechanical Engineering Department. Its purpose is to provide a platform for testing a variety of thermal, physical, and control issues that directly or indirectly involve the reliability of SHW systems. It is the world's first and only such device.

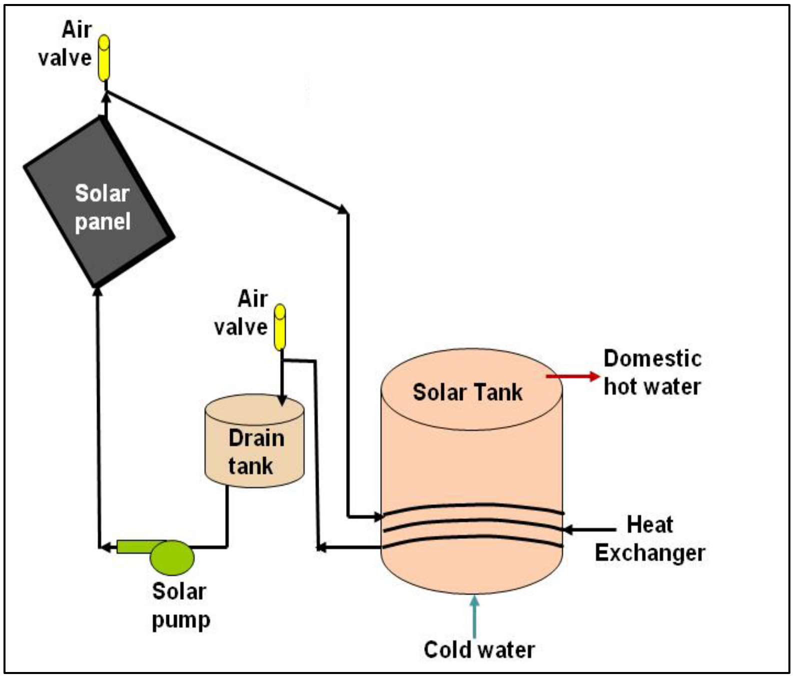

Figure 17. SHWRT drainback system.

Figure 18. Air valve at high point of solar loop.

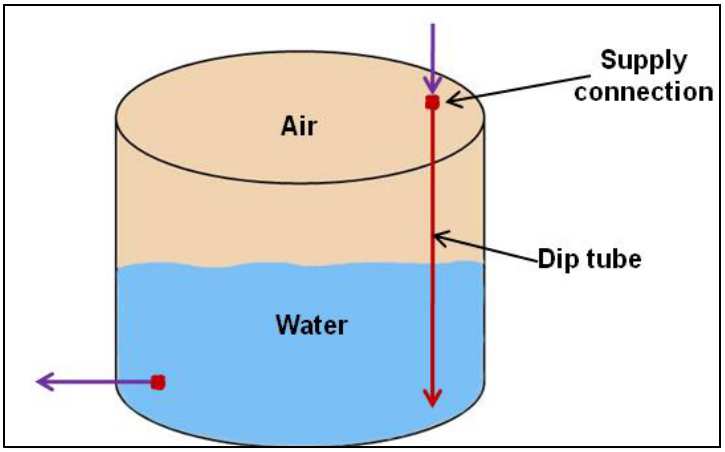

Figure 19. Standard drainback tank.

An air valve is critical component in a drainback SHW system. It permits air to vent into the collector loop when the solar pump is off, allowing the plain water in the collector and piping to drain into a tank. If the air valve fails, water can be air-locked in the loop and the collector and its supply/return lines can freeze. The vent also allows air to escape when the pump is turned on.

The failed valve was removed and dissected. The tiny air-bleed hole, a critical component in the valve, was clogged. Figure 20 shows a closeup view of the valve. The hole is covered by a loose-fitting threaded orifice cover for normal operation, but can be screwed in to manually close the vent. A vent orifice control will also close the vent hole and immobilize a float bob inside the valve that automatically closes the vent when water is flowing during normal operation, preventing water from leaking out of the vent hole.

Figure 20. Air valve.

The air-bleed hole is small, about 0.039 inch in diameter (991 microns), about the width of a typical hypodermic needle. Not only is this orifice prone to clogging from airborne particles, such as pollen or dust, but it can also freeze in very cold weather when moisture is sucked into the hole as the system drains.[‡‡] This kind of clogging is probable because the vent operates each time the solar pump is turned on or off, which is usually twice daily. Figure 21 shows a closeup view of the bleed hole.

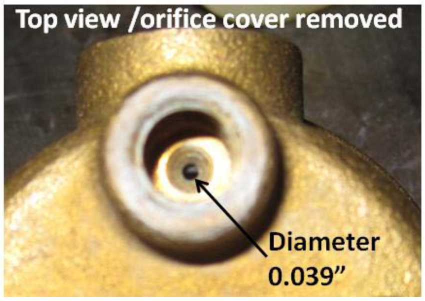

Figure 21. Bleed hole of air valve.

The analysis suggests that these types of vents should not be used outdoors, especially in areas that are dusty or prone to very cold conditions (such as Albuquerque). In this case, the valve failed in only four months. In any application, the vent hole should be periodically cleaned, but that is not practical for residential applications. Another solution is to use glycol in the solar loop, but that too is impractical because drainback systems are specifically designed to use low-cost tap water.

Other types of air vent valves are being studied to determine if they are more applicable to SHW drainback applications. The American Water Works Association has developed a standard for air valves. Identified as Standard C512-07, it lists the standards for three types of air valves: Air-Release, Air/Vacuum, and Combination Air Valves for Waterworks Service. There is no indication that the failed valve meets that standard.

It is advantageous to remove air valves from SHW drainback systems altogether. One design suggested by Chuck Marken, an experienced SHW system installer, suggests that if the dip tube is removed from the drain tank, then the system will automatically drain with no air relief because one side of the loop is longer than the other.[§§] Figure 22 shows such a design. However, it is essential that the solar loop is plumbed with no traps in either the supply or return lines.

A very similar design would place the drain tank and pump below the solar tank's heat exchanger, allowing the return line to feed the top of the heat exchanger and flow from there into the drain tank.

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‡‡ Pollens can range up to 1000 microns in diameter and often have jagged edges that easily cling to surfaces.

§§ Chuck Marken, personal communications with author.

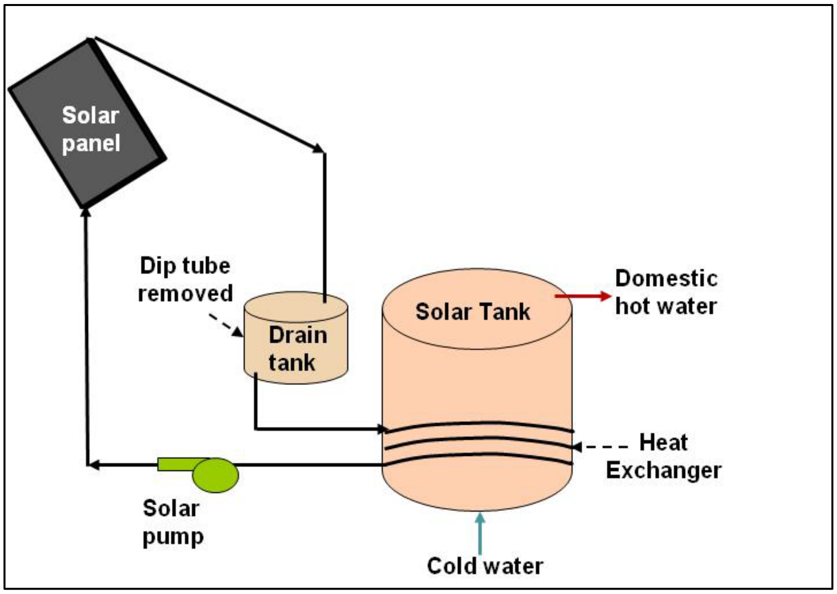

Figure 22. Drainback system with no air valve.

Figure 23 shows how the drain tank would appear with the dip tube removed. In this case the sound of the solar-heated water dribbling back to the tank would be audible. However, since most SHW systems are placed in garages or other closed spaces, it is unlikely that the additional noise will be a problem.

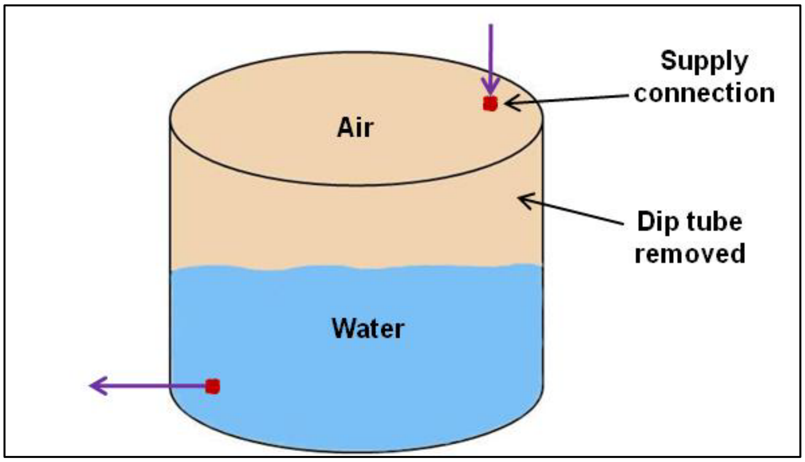

Figure 23. Modified drainback tank.

Stephen Neidigk of SNL suggested that instead of removing the dip tube that it be modified by drilling a few holes near the top of it.[***] This will allow most of the returning liquid to continue to flow inside the tube, thus eliminating the potential problem of noise. The holes will permit air to enter for draining, effectively allowing the system to operate as though the dip tube were removed. This appears to be the most effective approach.

[***] Stephen Neidigk, personal communications with author.

TECHNICAL SECTION 5. THE CHARACTERIZATION OF THE PHASE 2 DATABASE WITHIN THE CONTEXT OF RELIABILITY THEORY

As noted in Technical Section 2, highly reliable systems can be achieved by applying standard reliability techniques, but the successful application of these techniques depends on accurate data measures of the failure rates of systems. Well-timed, preemptive replacement of components is the key to high, sustained reliability, but the timing depends on predicted failures based on statistics that are derived through measurements at the end of the life of systems.

Classification of the Data in the Phase 2 Database

Most of the data that currently exist in the Phase 2 database, including the new ones that were recently collected, contain virtually no information to allow end-of-life statistics to be computed. For example, all of the SMUD, HECO, and Anonymous Company data are based on warranty records and thus provide information for the startup period. Moreover, the data contain records of total number of systems that were installed and those that were repaired under warranty. Unfortunately, the exact installation date for each of the repaired systems is usually not known. The exact date of the warranty service is also often unknown. If both of those dates were known for all of the systems, then statistics could be compiled for the early failure period. Thus, while valuable and interesting, these data have limited usefulness in characterizing the reliability of SHW systems.

The problem is that the existing SMUD, HECO, and Anonymous Company data were collected as by-products of warranty service, not for reliability work. Warranty records typically reflect a history of the system's startup period and could be used as the basis for computing startup failure rates, but only if the time to failure is meticulously recorded for each failed component.

Warranties usually cover a period of a year or two but the systems are expected to have an operational life of 15 to 20 years. Essentially, once a system is installed and has aged past the warranty period, it is forgotten in the field and subsequent problems are not recorded. None of the data were recorded at the end of system life, which is well beyond the warranty period.

None of the warranty-based databases hold information about the status of the systems following the warranty period. It is unknown, for example, how long each system operated without any problems, i.e., its useful life. It is also unknown when life-end failures began to be noticed and when those failures occurred. More importantly, no information is known about when components failed and in what order. Thus, no critical failure rates can be computed for the system's end of life.

A small percentage of data in the Phase 2 database is relevant to computing failure rates. However, most of this information is based on the opinions of installers who provided estimates of the time to end of life for major SHW components. Estimates such as these are notorious for inaccuracies, as suggested by Hiller [2]. This is especially the case when the estimates originate from industry representatives who have an interest in presenting the best possible scenario about products that they sell. This is not to suggest that the estimators deliberately deceive, only that they have a strong incentive to present the most optimistic picture of the products. In summary, essentially no reliable, measured data exist regarding the full life cycle of SHW systems.

The Source Water Assessment Program (SWAP) data collected by FSEC in the mid 2000s are the most valuable ones in the database for determining the failure rates during the useful life of the SHW systems. These measured data were based on field inspection of 10-year-old SHW systems. In this case each inspection record contains both the date of installation as well as the date of inspection. Thus, knowing both dates allows failure rates to be estimated and actual life cycle information about SHW systems.

However, even these excellent data represent interval data, which may be biased. The bias arises because it is uncertain when each failed system actually failed. Since the survey was conducted 10 years after installation, it is unknown whether a system failed one month after installation or nine years and 11 months after installation; all that is known is that it was in a failed state on the date of the survey. The computation of failure rates requires knowledge of the time to failure. For this computation, one could assume that the failure date is equal to the date of the survey. However, certainly all of the failed systems did not by coincidence fail just before the survey.

Another uncertainty is the number of failures that occurred during the warranty period and were never repaired and put back into service. As noted above, the reliability function for predicting failures in the warranty period is different from the one used to perform these predictions in the useful life period. Therefore, the data are biased and there exists no means to offset that bias.

Moreover, it has been a number of years since the survey was conducted. More systems have probably failed since that time, but it is unknown exactly how many there might be. Thus, while the one-time, 10-year survey provided probably the best reliability data that currently exist, they are of little use in computing the kind of measures that are needed to properly characterize the reliability of new SHW systems.

Reliability Sampling Techniques

Techniques for collecting reliability data are well developed, with their theoretical origins dating back to the late 19th century when railroads were burgeoning. Reliability was a tied to profitable and safe operation of rail equipment.

A reasonably thorough discussion about reliability sampling is presented by Tobias and Trinadade [5] and Leemis [6]. A summary of the information as it applies to SHW system reliability is presented below.

The goal of reliability data is to determine failure rates for various times in the life of a system. Failure rates are used to predict failures. To accomplish this the dates of failures must be carefully noted during the lives of the systems under study. The most important data are those that measure the time to life-end failures, particularly the specific system components that failed and when they failed.

In major industries such as airlines, defense, and automobiles, reliability engineers collect and organize data from the cradle to the grave for most of the components in the systems of interest. Airline companies must provide safe systems. Defense contractors must supply weapons that work only as needed and not at any other times. Electronic system manufacturers need to compute the optimal warranty periods for their products.

The types of reliability data fall into four general categories: Type I and Type II censored data, interval or grouped data, and a general form called multicensored[†††] data.

In the context of reliability data, censoring is a term that describes how the data collection exercises were terminated, such as whether the exact failure times are recorded or whether the data collection period was terminated before all of the systems or components under study had failed. Generally, the more censoring in the data collection, the less information the database will contain.

A good way to explain censoring is by example.

Type I censoring involves a test of *fixed length* in which units or systems under test are monitored during operation. All the units under test begin operation at the same time. The exact time of each failure is recorded. However, at the end of the test period, some units may not have failed, with their failures beyond the time allotted for the test.

Type II censoring involves a test of indeterminate length. As in the Type I test, all units begin operating at the same time and failures are noted as they occur. The test is terminated when a specified, predetermined number of failures are recorded.

Interval data are taken from a test in which the systems under test are operated for an interval without supervision. At the end of the interval the number of failed systems are identified and counted. The exact time to failure for each failed unit is not known.

Multicensoring involves data that incorporate a number of different kinds of censoring. Generally, multicensored data contain one or more of the following characteristics:

1. a run-time if the unit did not fail within the test period;
2. a time interval during which the unit failed; or
3. an exact failure time.

It is possible that a multicensored database will contain data with a mixture of these characteristics.

Table 3 summarizes the types of data censoring used in reliability data collection.

[†††] Multicensoring is a term used in reliability engineering that describes how the reliability data were collected and the shortcomings associated with them, especially for use in characterizing reliability for systems. More information about censored data is found later in the discussion.

Table 3. Comparison of Censoring Techniques in Reliability Data Collection.

Censoring Type	Length of Test	Number of failures allowed	Exact failure time known	Advantage	Disadvantage	Value for Reliability Work
Type I	fixed	unlimited	yes, for the ones that failed during the test, no for those that did not fail	test length is fixed so the test time can be easily planned	may result in an inadequate sample size	moderate
Type II	unlimitied	fixed	yes	the exact number of data can be planned in advance, insuring adequate sample	open ended test time can burden schedules and budgets; hard to plan	high
Interval	limited to lengh of the inspection interval	unlimited	no	tystems under test do not need to be constantly monitored for failures	the exact failure time is unknown; only known is the number of failures in the inpection interval	moderate
Multicensored	undetermined; multiple sampling times; different types of records of failures	Undetermined; includes variety of failure records	sometimes	flexibility in application	limited information; mixture of data types and record structures; may result in inadequte sample size	low

All of the available *measured* SHW reliability data in the Phase 2 database that are based on the warranty records (i.e., those from SMUD, HECO, and Anonymous Company) are multicensored because the only known parameter is the total number of failures within a poorly defined period.

The SWAP data recorded by FSEC are interval data. It is possible to estimate the failure functions for interval data, if the data can be assumed to have originated from the portion of their lifetimes where the distribution functions for that lifetime is known. For example, if a number of SHW systems are installed in an area and all were known to have been operating past their startup or warranty periods, then an inspection at some later time can assume that all of the observed failures were due to chance failures. Then the exponential function can be used to back-calculate the failure rate that must have been in play in order to produce those chance failures. Similarly, the failure rates for the startup and life-end periods can be back-calculated with end-of-interval information.

The other data, the installer's and manufacturer's *estimates* of SHW component lifetimes, do not fit into any reliability data category because they are not measured.

There currently exist thousands of data in the Phase 2 reliability database that has been assembled, but none of them is useful in determining with confidence the critical parameters that would allow a quantitative characterization of SHW reliability. Life-end data for SHW systems are needed for such a characterization. Only from this characterization can highly reliable systems be designed and maintained.

To illustrate the value of the current data for reliability work, some value estimators were computed for each of the five datasets within the Phase 2 database. A common set of attributes was developed for all the data based on their use in computing reliability measures. These attributes include the following:

- Data are measured or estimated;
- Data can or cannot be used to compute statistics, such a mean lifetimes;
- There is or is not potential bias in the data; and
- The data fit one of the four types of data censoring.

A value indicator was assigned to each attribute. This value ranged from 0.0 to 1.0 and was based on judgment. The assigned values are as follows:

- Measured data, 0.9; estimated data, 0.1.
- Data that can produce statistics, 0.9; other data, 0.1.
- Data harboring potential bias, 0.1; data with little or no bias, 0.9.
- Type II censoring, 0.9; Type I censoring, 0.7; Interval, 0.5; Multicensoring, 0.3, non-measured data (denoted as "N/A"), 0.1.

Table 4 presents the values assigned to each dataset. The last column, called net value data, shows the results from multiplying all of the values in each row.

Table 4. Qualitative Assessment of Value of Phase 2 Data for Engineering Reliability.

Data set	Application area	Measured	Censoring	stats	bias	Net data value
SMUD	startup	yes	Multi	no	no	0.0243
HECO	startup	yes	Multi	no	no	0.0243
Anonymous	startup	yes	Multi	no	no	0.0243
SWAP	life end	yes	Readout	yes	yes	0.0405
APS survey	life end	no	N/A	yes	yes	0.0009
NREL survey	life end	no	N/A	yes	yes	0.0009

Based on these metrics, the SWAP data are most valuable for reliability work while the estimates are least valuable. The SWAP data are considered to harbor some bias because it is unknown how many of the observed failures are due to startup problems or chance failures.

Possibilities for Collecting Appropriate Reliability Data

The Phase 2 database contains valuable information, but little of it can be used to mathematically characterize the life cycle of SHW systems using established reliability techniques. This shortcoming exists because there have been virtually no SHW reliability studies conducted for the purpose of understanding reliability.

Such studies would involve cradle-to-grave tracking of system operations. A number of systems could be monitored until they fail, producing Type II censored data. Critical measures, such as the installation data and the repair date, could be recorded as part of warranty service, which would produce mean failure times for components. Field surveys could be conducted more frequently, producing information about failure rates due to chance (useful life period). Failure information could be built into SHW controllers and extracted when a repair is made. These data could be used to develop critical end-of-life statistics leading to SHW reliability characterization. Alas, to date, few if any of these have been done or contemplated.

A probable reason for this situation is that data collection is an expensive prospect. For example, surveys, which produce high-quality interval data, require a physical inspection of systems in the field—not only a costly endeavor but laden with liability because homes need to be entered by the surveyor. To manage costs of future surveys, fewer systems could be monitored, but they could be more thoroughly monitored throughout their life by increasing the frequency of inspection. More complete data on fewer systems is preferable to less complete data for a greater number of systems.

A single system, properly monitored, could produce much data. The system would have to be continually monitored and if a failure occurs, it would be repaired and put back under test. Thus, a single system could continually yield information on reliability.

Candidate systems for such a monitoring program would be production units that are installed in solar manufacturers/installer facilities, universities, national labs, and other places where the systems can be carefully monitored and would be quickly repaired if they failed. It would be especially valuable to identify systems that have been operating for many years as they might be nearing their natural end of life and a record of any previous repairs may exist. For example, AAA Solar Inc. in Albuquerque has access to the history of several SHW systems that Have been operating for decades. Thoroughly monitoring the complete life cycle of a few systems is preferable to collecting and organizing large amounts of multicensored data that has limited value for reliability work.

It might be possible to tap into some existing programs that involve field surveys of SHW systems. Some utilities, such as the Arizona Public Service Company (APS) and the Salt River Project (SRP), have robust SHW incentive programs. They are actively conducting field surveys of installed SHW systems to ensure compliance with installation requirements. With some minor modifications to the survey methods, these surveys could produce a welter of reliability data that could be used to characterize the reliability of SHW systems. Utilities have an inherent interest in understanding reliability of these systems, so their cooperation in such an endeavor is certainly a possibility.

Although surveys tend to produce interval data because the survey is typically performed just once, the negative effects can be mitigated by selecting samples that include systems of varying ages. For example, if the population of fielded SHW systems is large and includes systems of varying ages, then a sampling procedure could be constructed to ensure that each inspection contains a representative number of systems of different ages. If the sample is properly designed and the surveys are conducted on shorter, regular intervals, a single survey could produce valuable data without re-inspecting any systems.

Three other techniques may produce useful reliability data. These possibilities include:

1) Photometric data collection based on aerial infrared photographs of SHW systems,
2) Development of algorithms for inclusion into conventional controllers that can identify and announce failures of SHW systems, and
3) Analysis of energy bills for homes with solar hot water systems.

The photometric technique is based on the fact that the glazing on an operating SHW system will retain a lower temperature than one that is in operational stagnation. Infrared cameras located on aircraft can fly over an area containing SHW systems and record the glazing temperatures. Systems that are apparently non-operational can be automatically assigned GPS coordinates. The technology currently exists to translate the GPS location to a street address.[‡‡‡] Utilities, such as APS and SRP, have records of SHW installations conducted under their rebate programs.

[‡‡‡] The Earth Data Analysis Center at UNM currently has the capability to do this translation automatically using a computer algorithm. They routinely do this and related tasks for Google Earth.

Therefore, if the flyover area is carefully selected, the GPS data could be used to determine when the systems were installed and time to failure for non-operational systems could be estimated.

Although these data would be of the interval type, a great deal of data could be cost-effectively collected. If successful, the data could be sufficient to fully characterize the reliability of SHW systems.

Another potential method of cost-effectively collecting a large of amount of data is to develop algorithms and/or devices that can announce a failure of a system and record critical information associated with the failure. Such a device would be similar to the black box recorders that are used on aircraft and which are being integrated into automobiles.

These devices could be integrated into SHW controllers or be placed on a system as a separate unit. Upon failure it could notify the owner of the system who could then contact appropriate personnel, which could be utility representatives. This failure even would then allow the extraction of critical data from the recording device. Since the device would have been continuously monitoring the system from its date of installation, the resulting data would be Type II censored, the best possible.

These data could not only lead to improved system reliability characterization, but could provide component failure information that might lead to the computation of critical statistics about their end of life. As noted in Technical Section 1 of this report, these kinds of statistics can be used to develop preemptive maintenance programs that would maintain high reliability for long periods. Such an effort to develop such a system is under way at the UNM, a project that is sponsored by SNL.

It might also be possible to generate reliability data by analyzing home energy bills. When an SHW system is properly installed, it can reduce the total energy load of a home by around 20%. That reduction, called the SHW energy signature, will continue to exist regardless of how the home is used and occupied. If the SHW system fails, the SHW signature disappears and should be noticeable in the home energy record.

Utilities that have SHW rebate programs know when an SHW system was installed on various homes. They also have records of energy consumption for those homes before and after the SHW systems were installed. If these records could be analyzed, and if SHW failures are identified, then failure rates could be computed. If successful, this method could generate large amounts of reliability data and information. Figure 24 shows the energy records for three homes before and after the installation of an SHW system.

While this approach is simple in concept, it is challenging in implementation because the variance in total energy use can be greatly affected by occupant living patterns and weather. Thus, noise in the data (i.e., data variability) could be considerable and would tend to disguise the SHW energy signature.

However, at least two analysis methods are applicable for managing the variance and following the SHW energy signature. The first is Analysis of Variance (ANOVA), a statistical method that has existed for many years. And the other is adaptive resonance theory, a form of neural networks. Both are designed to follow the SHW energy signature through the noise.

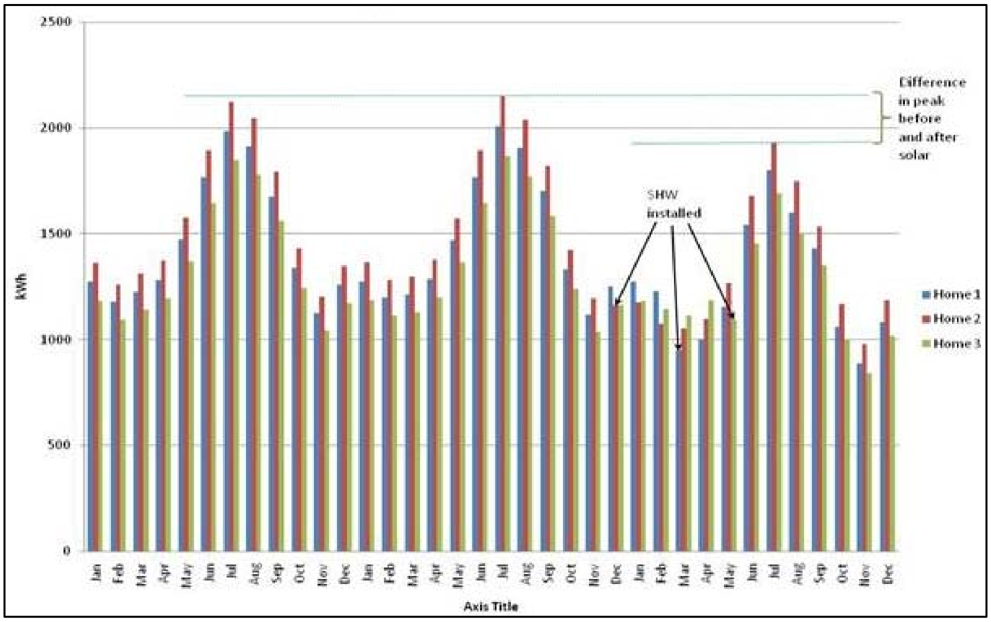

Figure 24. Energy use of three homes before and after installation of an SHW system.

Finally, in addition to the techniques that depend on statistics to predict failures, other predictive mechanisms could notify an owner when an SHW system is about to fail. These methods are based on various computerized self-learning methods and could be integrated into modern controllers. A warning of an impending failure of a component and/or system would allow action to be taken to address the system and record information about the situation. Thus, not only would such a capability prevent catastrophic failures, but it would simultaneously help to build a database of reliability information that would lead to increased reliability.

An effort to develop such a capability is under way at the UNM. The effort is co-funded by the university and SNL. Two methods are being tested. One is based on a theory developed by Jay Burch at the National Renewable Energy Laboratory (NREL) and involves the monitoring of the solar storage tank during operation. In this technique variations in the normal pattern of heating and cooling of the tank are used to identify potential problems.

Another technique is based on adaptive resonance theory, a system of self-learning neural networks that can be trained to artificially learn the patterns of a normally operating SHW system and then to identify patterns of aberrant behavior.

TECHNICAL SECTION 6. SURVEY OF USER EXPECTATIONS OF SHW LIFETIME[§§§]

In the course of this work many people were contacted and many discussions ensued about the reliability of SHW systems. Based on these many interactions it became clear that there were no clearly defined expectations about the expected lifetimes of SHW systems. Even among manufacturers and installers, there was a wide range of perceptions about what consumers desired in terms of the life of water heaters in general and solar water heaters in particular.

Lifetime expectations are important to know because they establish system lifetime goals for designers. These goals are used to define the reliability requirements for components.

A literature search identified a number of studies about water heaters, mostly commercial gas or electric ones. Several studies documented the actual lifetimes of many conventional water heaters. Some discussed how long a solar water heater should last, if it is properly designed (generally, these were mere speculations without any meaningful data as a basis). However, no studies were found that assessed the consumer's expectation of a solar system lifetime.

Due to the importance of system lifetime expectations relative to reliability work, an informal survey was developed with the objective of measuring consumer expectations for both conventional water heaters and solar water heaters.

It should be noted that the survey was not designed to the highest levels of statistical sampling rigor and was conducted during the personal time of the author, and without the use of SNL contract funds. Nonetheless, the methods were sound, the analysis of the data is reasonably thorough, and the results are informative and useful.

A copy of the survey form is found in Figure 25.

1. How much life do you expect from your gas or electric water heater (assuming an installation cost of $800)? _______yrs
2. What is the *minimal* expected time before the first repair of your gas or electric water heater (assuming a repair cost of $200)? _______yrs
3. Suppose you spent $3000 for an energy-efficiency device that reduces by 70% the amount of energy your gas or electric water heater uses. How much life do you expect from this device? _______yrs
4. What the *minimal* expected time to the first repair of your energy efficiency device (assuming a repair cost of $200)? ________yrs
5. Would you be willing to spend 5 minutes per month to inspect your energy efficiency device to ensure that it is saving energy? (___Yes, ___No)
6. Please circle one: I am an: energy professional, non-energy professional, tradesperson, other.

Figure 25. Residential Water Heating survey.

[§§§] This work was not part of the statement of work for this contractual effort and all of the effort was conducted by the author on his own time. No contractual resources were used in the conduct of this survey

As can be seen, questions 1 and 2 ask for estimates of the expected lifetime of a conventional water heater. Questions 3 and 4 ask about an "energy efficiency" device[****] that costs about as much as a solar water heater (one that is fully discounted with rebates and tax offsets) and saves about the same amount of energy. The term "solar water heater" was specifically avoided in the survey to help eliminate any bias associated with solar systems and to circumvent any confusion about the use of solar energy to heat water. Many people associate solar energy with electricity, not hot water.

Note also that the responder was asked for his or her profession and whether there was interest in expending a small amount of time monitoring their energy efficiency system, as would be typical with most of today's solar systems.

The survey was applied to friends, acquaintances, associates, guests, and others that the author encountered in different setting. For example, the author operates a Bed & Breakfast in Los Alamos, NM. Guests routinely rent the home for various purposes. Those guests were asked to complete the survey. To the greatest extent possible, a cross section of the public was invited to participate.

A total of 63 people responded to the survey. The results are summarized in Table 5.

Table 5. Survey Results.

Demographic information	
Total responders	63
Energy professional	14
Non-energy professional	24
Trades Person	7
Other	18

	Q1: Reg water heater life	Q2: Time to 1st repair	Q3: Hi effic device life	Q4: Time to 1st repair hi effic
Mean for all responders	16.1	11.7	24.5	14.7
Standard dev.	8.1	6.8	12.7	11.6
Mean Energy Prof.	14.8	8.0	20.5	8.9
Mean Non-Energy Prof	19.0	14.0	28.5	18.1
Mean Tradesperson	14.7	11.9	28.1	16.1
Mean Other	13.9	11.2	21.0	14.0

Among the 63 participants no single profession dominated the responding group. The largest group of responders was of non-energy professionals, which includes lawyers, accountants, medical doctor, etc.

It is instructive to learn that on average all of the responders expected the high-efficiency device should have a significantly longer lifetime than the regular water heater (see row one). That is

[****] In engineering parlance, the term "efficiency" usually refers to amount of energy that is converted from one source or form to another. But the subtleties of this term are frequently lost on the public. Generally the average person considers at solar system to be a high-efficiency device because it reduces the amount of conventional energy that would normally be used. "Efficiency," in its vernacular sense, is applied in this survey.

expected because the high-efficiency device costs significantly more than a standard water heater. The difference between the expected means life of 16.1 years for a standard water heater and 24.5 years for a high-efficiency device is statistically significant at the 5% level of significance.[††††]

The average expected lifetime for the regular water heater is 16.1 years, which is about 20% longer than the real lifetime of a standard water heater. But the expected lifetime of a high-efficiency device was, on average, 24.5 years. This is greater than most manufacturers and installers of solar systems would often assume, a normal expectation being about 20 years. Surprisingly, tradespeople who would be presumed to be some of the most knowledgeable of all responders on these matters provided the highest estimated lifetimes for the high-efficiency devices—28.1 years.

In general, the responders expected at least one repair within the lifetimes of both a normal and high-efficiency water heating device. While it is realistic to expect at least one repair to an SHW system within its life, it is unusual to expect any repairs with regular water heaters.

Finally, about two thirds of the responders reported that they would be willing to spend some time each month monitoring their energy efficiency device.

The survey suggests that most people expect a high-efficiency water heating device, a category that most people would use to classify a solar water heater, to have a significantly longer life than a normal water heater.[‡‡‡‡] They also expect at least one repair during that time. However, the expected lifetime for a high-efficiency water heater (24.5 years) is longer than the design life of most of these kinds of systems.

†††† This means that the probability of error in rejecting the null hypothesis is 5%. The null hypothesis is that there is no difference between the means and that both groups of data are derived from the same population.

‡‡‡‡ According to the survey, on average the expectation is 56% longer.

TECHNICAL SECTION 7.
SUMMARY AND RECOMMENDATIONS

This report documents an effort to collect additional reliability data concerning SHW systems. Two new sets of data were identified and added to the existing database. However, the new data were based on warranty information, which documents the reliability performance at the beginning of the life of SHW systems. While that is important, information about the end of life is essential if the reliability of SHW systems is to be properly characterized.

Reliability engineering is well developed but has been infrequently applied to SHW systems. The bathtub curve, part of reliability theory that describes graphically the expected failure rate of systems over their lifetimes, is presented and explained. This theory provides guidance in setting reliability goals and expectations for SHW reliability. It also presents guidance in assessing the value of existing data, and helps to identify additional data that are needed to quantitatively describe the reliability of SHW systems.

The report also outlines the value of reliability to the user community, especially utilities who are investing heavily in SHW technology and who are asking for quantitative measures of the expected lifetimes of these systems. As more systems are installed—and the installation rate is rising rapidly—the importance of understanding reliability increases commensurately.

The following are significant conclusions and recommendations from this study.

1. The Phase 2 database now contains presumably the bulk of the available data that relate to the reliability. However, most of the data reflect system failures in the startup periods of SHW systems' lives. While important, more and better information is needed regarding the life-end period. Life-end data are needed to allow a complete characterization of the reliability of SHW systems.
2. The records of FSEC's survey of 10-year-old systems in Florida are probably of the highest quality of all of the data in the Phase 2 database. First, the data reflect measured failures in the field. Second, the exact times of SHW installation and the time interval to the survey are known. Third, the survey was completed after the warranty period. Therefore, many of the failures occurred in the useful life period of the systems.
3. The other sets of data, those based on interviews of installers and manufacturers, speak to the end-of-life period of SHW systems. However, they have limited value because they are potentially biased and do not represent independently measured values of system wearout failures.
4. The analysis of the Phase 2 data confirmed that valves of all types are problematic in SHW systems. But they did not provide enough details to identify the exact failure mechanisms, the types of valves that typically fail, or the conditions that led to failures.
5. Field experience, if properly folded back into the design and installation process, can dramatically improve SHW system startup reliability. The experiences of HECO and HETL provide guidance on how such a feedback program can be operated.
6. According to standard reliability theory, if a system's critical components can be replaced before they fail, a system can be indefinitely maintained in a state of very high reliability.

To plan these preemptive replacements, measured data are needed to define the life cycle (i.e., the bathtub curve) of critical system components.

7. New data can be cost-effectively collected by tapping into some existing field survey work that is being conducted by some utilities. These surveys would produce interval data that would complement those that were collected by FSEC and would allow failure rates to be estimated for the useful life and life-end periods of SHW systems.
8. Infrared photos of homes with solar collectors may be a significant source of reliability information that can help to define failure rates of SHW systems. These efforts should be planned and executed in cooperation of utilities who are involved with SHW installations and who hold critical information—such as SHW system installation dates and locations. These data are keys to the success of these collection methodologies because they provide a time to failure, an essential element in estimating failure rates for the life periods beyond startup.
9. Other techniques that could be built into standard SHW controllers could identify and announce system failures and record important information surrounding any failure events. This approach could provide a plethora of data. Since these data would contain exact times of failure, they would be classified as Type II censored, the highest quality of reliability data.
10. The application of proven statistical techniques, such as ANOVA, and newer techniques involving computerized self-learning systems, such as Adaptive Resonance Theory, might provide the ability to recognize and follow over time the reduction in total home energy use due to the installation of an SHW system. Utilities hold these energy records. Thus, failures could be noted without the need for site inspections. Using these techniques, many data could be cost-effectively collected in a very short period of time. The data resulting from this effort could be of high quality, Type II censored.
11. Informal surveys suggest that consumers expect 24.5 years of life from an SHW system and similar high-efficiency water heating devices. Only one repair is expected in the lifetime. If these data are correct, then SHW systems should be designed to meet these reliability goals. A scientifically designed survey should be organized and conducted to determine consumer expectations more accurately.

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APPENDIX A. Quotations from Willy Bennett, Solar Professional, and former Director of the Hawaii Test Lab, Maui, Hawaii

The comments below are taken verbatim from and interview with Willy Bennett in March 2010. He graciously provided them without remuneration, for which the author is grateful. Clarifying comments are provided in footnotes, along with a website reference where additional information is available.

> Most systems are open loop with the collectors and tanks using potable water under county water pressure. A few are thermosiphon systems using a heat exchange fluid, aluminum panels, and a wrap-around tank heat exchanger.
>
> 90% of the systems are open loop pumped systems with the tank on the ground. The pump is 120 or 240 volts controlled by a differential controller or a 12 volt pump directly connected to a 12 volt PV panel.
>
> There is a timer that can be set to turn on the backup element in the tank from 4 to 5 PM and 4 to 5 AM or used as a manual control. There is usually only one element that electrically heats just the top 1/3 of the tank.
>
> The top-, side-, and bottom- connect pumped systems and a thermosiphon system produced and stored overnight the same amount of hot water when they were working properly.[§§§§] When the check valve failed on the top connect system it lost considerable amounts of heat as shown in the attached test report[*****]. The bottom-connect and side connect systems lost much less. The side connect system didn't lose a lot of heat in this test, but it has in the field, so it is not used very much.
>
> On Maui, about 1/2 of the systems are top connect even though I proved that the design was faulty in 2000. They are still allowed by the solar rebate program. Most companies don't install them, but two do. They install them on new houses and don't do repairs, so they don't see the problems. The few of us that perform inspections and repairs do what we can to fix the problem, but it isn't easy. I find that a really good spring check or electric valve is needed to stop the forward siphoning. A Rheem[†††††] representative told me that California contractors only order top connect tanks for open systems even though I reported my findings in talks at the American Solar Energy Society conferences.
>
> I still see lots of the top connect systems when I do energy audits or system maintenance. Many people do not realize there is a problem as the Hawaiian standards oversize most systems and the heat loss is not as noticeable. This is a significant factor as people complain more about cold water or high energy bills than they do about water that is too hot.
>
> Oahu doesn't have as many problems as Maui with the top connect tanks as they caught on sooner that they didn't work well. I'm not sure about the overheating problem on that island.

[§§§§] This refers to the location in the solar/hot water tank where the return line is connected.
[*****] This test report can be found at http://oldweb.hawaiirdp.org/hetl/hetlschedule.htm.
[†††††] Rheem is a major hot water tank manufacturer and supplier of many solar tanks.

The funny thing is that with all of the design problems, the Hawaii solar water heating program is very successful. I believe it is due to:

- Unavailability of natural gas in Hawaii.
- High electricity and propane rates.
- Dedicated contractors and other solar professionals.
- Designs that produce very hot water.
- Utility promotion of solar water heating.
- State rebates.

APPENDIX B. Summary of SHW Warranty Records from the Hawaiian Electric Company and Anonymous Company

Combined SWAP/HECO/Sacramento/Company High-Level Summary of Problems

	SYSTEM TYPE						
	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
Problem Areas	TOTAL REPORTED PROBLEMS						
Collector Problems	27	179	6	1	82	71	366
Controller Problems	0	138	0	1	17	25	181
Sensor Problems	0	135	1	0	26	76	238
Tank Problems	0	213	11	0	0	74	298
Pump Problems	0	207	0	1	6	68	282
Heat Transfer Problems	0	48	3	0	1	14	66
Piping Problems	1	66	2	0	1	21	91
Valve Problems	7	410	28	3	40	155	643
Totals	**35**	**1396**	**51**	**6**	**173**	**504**	**2165**

Problem Areas	PROBLEMS AS A PERCENTAGE OF TOTAL						
Collector Problems	77.1%	12.8%	11.8%	16.7%	47.4%	14.1%	16.9%
Controller Problems	0.0%	9.9%	0.0%	16.7%	9.8%	5.0%	8.4%
Sensor Problems	0.0%	9.7%	2.0%	0.0%	15.0%	15.1%	11.0%
Tank Problems	0.0%	15.3%	21.6%	0.0%	0.0%	14.7%	13.8%
Pump Problems	0.0%	14.8%	0.0%	16.7%	3.5%	13.5%	13.0%
Heat Transfer Problems	0.0%	3.4%	5.9%	0.0%	0.6%	2.8%	3.0%
Piping Problems	2.9%	4.7%	3.9%	0.0%	0.6%	4.2%	4.2%
Valve Problems	20.0%	29.4%	54.9%	50.0%	23.1%	30.8%	29.7%
Totals	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

ASU Survey – High-Level Summary

Summary of Estimates

ASU survey, March 1988
24 participants in study

Survey Results Representing All System Types

Component Areas	First Failure (average yrs)	Lifetime (average yrs)	Reliability Index (average)
Collector	10.9	20.2	8.6
Controller	7.5	13.0	8.5
Sensors	5.5	11.0	7.5
Tanks	6.6	10.5	7.6
Pumps	6.0	9.0	7.5
Heat Transfer	4.0	6.0	6.0
Piping	8.5	11.3	6.5
Valves	4.7	6.9	6.2
Averages	6.7	11.0	7.3

Experience of Participants in Years	
ICS	6
Drainback	14
Indirect Thermosiphon	0
Pool	2
Not Specified	7
Total	29

ASU Survey – Detailed

Summary of Estimates

ASU survey, March 1988
24 participants in study

	Survey Results Representing All System Types		
	First Failure (ave yrs)	Lifetime (ave yrs)	Reliability Index (ave)
Collector	**10.9**	**20.2**	**8.6**
Passage blocked	11.0	19.0	9.0
Copper collector painted	10.0	18.5	8.5
Copper collector selective surface	10.5	21.0	9.0
Aluminum collector painted	7.5	17.0	7.5
Aluminum collector selective surface	6.5	17.0	8.0
Fluid passages	9.0	19.0	8.5
Collector cover	16.0	30.0	9.5
Collector enclosure	15.0	25.0	9.0
Collector gaskets	13.0	15.0	8.5
Controller	**7.5**	**13.0**	**8.5**
Sensors	**5.5**	**11.0**	**7.5**
Tanks	**6.6**	**10.5**	**7.6**
Solar storage tank glass	7.5	11.0	7.5
Solar storage tank steel	7.0	11.0	6.5
Solar storage tank thermostat	6.0	11.0	8.5
Expansion tank	6.0	9.0	8.0
Pumps	**6.0**	**9.0**	**7.5**
Horizontal shaft pumps	6.5	10.0	8.0
Vertical shart pumps	5.5	8.0	7.0
Heat Transfer	**4.0**	**6.0**	**6.0**
Glycol fluid	4.0	6.0	6.0
Piping	**8.5**	**11.3**	**6.5**
Piping insulation painted	8.0	8.0	9.0
Piping insulation w/AL tape	9.0	14.5	4.0
Piping insulation untreated	3.0	6.0	6.0
Valves	**4.7**	**6.9**	**6.2**
Valve, air vent	4.0	6.5	6.0
Valve, draindown	3.5	6.0	5.5
Valve, spring check valve	5.0	7.5	6.5
Valve, flapper check valve	5.0	7.0	6.0
Valve, drain ball valve	7.0	8.5	8.0
Valve, vent	4.5	6.5	6.0
Valve, mix or tempering	3.5	5.5	4.5
Valve, P&T	4.5	7.0	6.5
Valve, pressure	5.5	8.0	7.0
Totals	6.7	11.0	7.3

Experience of Participants in Years

ICS	6
Drainback	14
Indirect Thermosiphon	0
Pool	2
Unknown	7
Total	29

FSEC Survey – High-Level Summary

Summary of Estimates

FSEC survey, March 1988
Five participants in study

Component Areas	Lifetime (average yrs)
Collector	26.0
Controller	10.1
Sensors	no data
Tanks	9.7
Pumps	10.9
Heat Transfer	9.7
Piping	20.0
Valves	8.2
Averages	13.5

FSEC Survey – Detailed

DHW SYSTEM COMPONENT LIFETIME SURVEY

Survey of Industry Conducted by John Harrison, Florida Solar Energy Center (1993)

Respondent: Type of industry activity (5 individual respondents)	Company A Distributor Installer	Company B Manufacturer	Company C Manufacturer Distributor Installer	Company D Installer	Company E Manufacturer Distributor Installer		
SYSTEM COMPONENT	**ANTICIPATED LIFETIME – IN YEARS**					**COMPONENT AVERAGE**	**AVERAGE BY CATEGORY**
Flat Plate Collector	30 (20+)	30.0	30.0	40.0	15.0	29.0	
ICS Collector		30.0	30.0	9 (8-10)		23.0	26.0
Pump DC	12.5 (10-15)	12.5 (10-15)	7.0	9 (3-15)	8.0	9.8	
Pump AC	12.5 (10-15)	10 (8-12)	15.0	12.5 (10-15)	10.0	12.0	10.9
Storage Tank – Solar	12.5 (10-15)	9.5 (7-12)	8.5 (7-10)	7.5 (5-10)	9.0	9.4	
Storage Tank – Conventional	12.5 (10-15)	9.5 (7-12)	8.5 (7-10)	7.5 (5-10)	9.0	9.4	9.4
Controller – Differential	9 (8-10)	7 (4-10)	10.0	6.5 (8-13)	12.0	8.9	
Controller – PV	10.0	20.0	17.5 (15-20)	10+		14.4	
Controller – Timer	10.0	10.0	10.0		8.0	9.5	
Controller – Snap Switch			7.0		8.0	7.5	10.1
Heat Exchanger (Internal)	12.5 (10-15)	10+	8.0	10+		10.1	
Heat Exchanger (External)	15 (10-20)	10.0	10.0	10+	9.0	10.8	
Expansion Tank	7.5 (5-10)	10.0	7.0	7.5 (5-10)	10.0	8.4	9.7
Freeze Prevention Valves	4 (3-5)	3.0	5.0	5.0		4.3	
Air Vent	4 (3-5)	3.5 (3-4)	7.0	5.0	8.0	5.5	
Pressure/Temp Relief Valve	10.0	10 (1-10)	8.0	10.0	7.0	9.0	
Pressure Relief Valve	10.0	10 (1-10)	20.0	10.0	8.0	11.6	
Vacuum Breaker	4 (3-5)	6.5 (5-8)	5.0	5.0	15.0	7.1	
Isolation Valve – Gate		9 (8-10)	0.5	3 (2-4)	10.0	5.6	
Isolation Valve – Ball	15 (10-20)	12.5 (10-15)	10.0	12.5 (10-15)	15.0	13.0	
Drain Valve	10.0	20.0	20.0	8.5 (7-10)	15.0	14.7	
Check Valve – Vertical	6 (5-7)	6.5 (3-10)	2.0	5.0	10.0	5.9	
Check Valve – Horizontal	6 (5-7)	6.5 (3-10)	1.0	2.0	10.0	5.1	
Check Valve – Motorized	10+		10.0	6 (5-7)		8.6	8.2
Piping – Copper	20+	20+	20.0	20+	20+	20.0	20.0

NREL Survey – High-Level Summary

Summary of Estimates

NREL Survey of Installers

Component Mean Lifetime Estimates—Overall Averages

Component Areas	Average Years
Collector	22.5
Controller	20.0
Sensors	15.0
Tanks	18.5
Pumps	9.5
Heat Transfer	3.0
Piping	7.0
Valves	8.6
Averages	

NREL Survey – Detailed

NREL Survey of Sacramento Contractors 1994
Data as presented in draft NREL report

Component Mean Lifetime[1] Estimates

Component	Best Conditions (i.e., properly installed and maintained) Low[2]	Best Conditions High[3]	Best Conditions Average	Worst Conditions (i.e., poor water qual, over temp) Low[2]	Worst Conditions High[3]	Worst Conditions Average	Overall Average
Collector							
Glass cover	30	60	45	30	60	45	45
Polycarbonate cover	5	20	12.5	5	20	12.5	12.5
Plastic films (Tedlar)	5	20	12.5	5	20	12.5	12.5
Copper absorber	20	60	40	10	30	20	30
EPDM absorber	5	20	12.5	5	20	12.5	12.5
Glycol fluid (heat transfer)	5	10	7.5	3	6	4.5	6
Tanks							
Glass-lined	8	25	16.5	5	20	12.5	14.5
Polypropylene (unpress.)	20	40	30	10	20	15	22.5
Pumps	5	20	12.5	3	10	6.5	9.5
Controller							
Current models	10	30	20	10	30	20	20
Sensors	10	20	15	10	20	15	15
Loop Regulation (Valves)							
Mixing valve, no trap	3	7	5	2	5	3.5	4.25
Mixing valve, trapped	5	30	17.5	5	10	7.5	12.5
Check valves	10	40	25	5	10	7.5	16.25
Vent valve	3	8	5.5	2	6	4	4.75
Vacuum relief	3	10	6.5	2	6	4	5.25
Draindown valve	3	9	6	2	6	4	5
Expansion tank	5	20	12.5	2	6	4	8.25
Pressure relief valve	10	25	17.5	4	12	8	12.75
Pipe Insulation							
Painted	2	8	5	2	8	5	5
Aluminum tape	8	10	9	8	10	9	9

Notes:
1) Mean lifetime: Defined as the time for 50% of the population of operating units to fail.
2) Low: lowest estimate provided by contractors.
3) High: highest estimate provided by contractors.

SWAP – High-Level Summary of Problems

Installations, 1993-1997;			SYSTEM TYPE				
Inspections in 2003	**ICS**	**Pumped[1]**	**Thermo**	**PV Control**	**Pool**	**Unknown**	**Totals**
Total Installed systems	393	406	2	no data	0	0	801
Total attempted inspections	80	81		8			169
Total actual inspections	76	67		8			151
Total operational systems	62	32		6			100
Total non-operational systems	14	35		2			51
Percent of operational systems	81.6%	47.8%		75.0%			66.2%
Sample proportion of problems relative to total inspected	18.4%	52.2%		25.0%			
Lower 95% confidence limits on proportion	8.0%	37.0%		8.0%			
Upper 95% confidence limits on proportion	24.0%	65.0%		48.0%			
Problem Areas			TOTAL REPORTED PROBLEMS FOR ALL INSPECTIONS				
Collector Problems	14	16		0			30
Controller Problems	0	11		0			11
Sensor Problems	0	1		0			1
Tank Problems	0	2		0			2
Pump Problems	0	4		1			5
Heat Transfer Problems	0	0		0			0
Piping Problems	1	5		0			6
Valve Problems	6	32		2			40
Totals	**21**	**71**		**3**			**95**
Problems per Inpected System	3.6	0.9		2.7			1.6
Problem Areas			PROBLEMS AS A PERCENTAGE OF TOTAL				
Collector Problems	66.7%	22.5%		0.0%			31.6%
Controller Problems	0.0%	15.5%		0.0%			11.6%
Sensor Problems	0.0%	1.4%		0.0%			1.1%
Tank Problems	0.0%	2.8%		0.0%			2.1%
Pump Problems	0.0%	5.6%		33.3%			5.3%
Heat Transfer Problems	0.0%	0.0%		0.0%			0.0%
Piping Problems	4.8%	7.0%		0.0%			6.3%
Valve Problems	28.6%	45.1%		66.7%			42.1%
Totals	100.0%	100.0%		100.0%			100.0%

			Total Installed Systems				
	ICS	**Pumped[1]**	**Thermo**	**PV Control**	**Pool**	**Unknown**	**Totals**
NUMBER OF SYSTEMS INSTALLED	**393**	**406**	**2**				**801**

Notes:

1. An undetermined number of these were PV control systems.

SWAP		
Upper 95% confidence limit	24.0%	65.0%
Lower 95% confidence limits	8.0%	37.0%
Proporation of problems as % installed	18.4%	52.2%

SWAP – Mid-Level Summary of Problems

SWAP installs, 1993-1997; 200 inspects	ICS	Direct Circ	Thermo	PV Control	Pool	Unknown	Totals
			SYSTEM TYPE				
SYSTEMS INSTALLED	393	406	2				
INSPECTED SYSTEMS W/PROBLEMS	73	68	0	8	0	0	149
Collector Problems	14	16	0	0	0	0	30
Faulty Collector Problem Totals	9	16	0	0	0	0	25
Collector Mounting Problem Totals	5	0	0	0	0	0	5
Controller Problems	0	11	0	0	0	0	11
Diff Controller Problem Totals	0	7	0	0	0	0	7
PV Controller Problem Totals	0	0	0	0	0	0	0
Timer Controller Problem Totals	0	4	0	0	0	0	4
Sensor Problems	0	1	0	0	0	0	1
Sensor Failure Totals	0	1	0	0	0	0	1
Sensor Wiring Problem Totals	0	0	0	0	0	0	0
Tank Problems	0	2	0	0	0	0	2
Solar Storage Water Heater Problem Totals	0	2	0	0	0	0	2
Electric Auxiliary Water Heater Problem	0	0	0	0	0	0	0
Gas Auxiliary Water Heater Problem Totals	0	0	0	0	0	0	0
Drainback Tank Problem Totals	0	0	0	0	0	0	0
Pump Problems	0	4	0	1	0	0	5
Pumps Problem Totals	0	4	0	1	0	0	5
Heat Transfer Problems	0	0	0	0	0	0	0
Heat Exchanger Problem Totals	0	0	0	0	0	0	0
Heat Transfer Fluid Problem Totals	0	0	0	0	0	0	0
Piping Problems	1	5	0	0	0	0	6
Piping Problems Totals	1	5	0	0	0	0	6
Insulation Exterior Problem Totals	0	0	0	0	0	0	0
Valve Problems	6	32	0	2	0	0	40
Valve, Air Vent Problem Totals	0	14	0	1	0	0	15
Valve, Automatic Draindown Totals	0	0	0	0	0	0	0
Valve, Anti-Scald Problem Totals	0	8	0	0	0	0	8
Valve, Check Problem Totals	0	2	0	0	0	0	2
Valve, Fill Drain Problem Totals	0	0	0	0	0	0	0
Valve, Freeze Totals	6	5	0	0	0	0	11
Valve, Isolation and Supply Totals	0	0	0	0	0	0	0
Valve, Mixing/Temp Problem Totals	0	1	0	0	0	0	1
Valve T&P Collector Loop Problem Totals	0	2	0	1	0	0	3
Valve, Vacuum Breaker Problem Totals	0	0	0	0	0	0	0
Totals	21	71	0	3	0	0	95

SWAP – Detailed Summary of Problems

	System Type						
SWAP, 1993-1997; 200 inspections 2003-2004	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
SYSTEMS INSTALLED	393	406	2				
INSPECTED SYSTEMS W/PROBLEMS	73	68		8			149
Collector Problem Totals	9	16	0	0	0	0	25
-defective collector							0
-leaking	8	5					13
-leaking (source unknown)							0
-header tubes leaking							0
-header tube leaking		3					3
-riser to header connection leaking							0
-riser tubes leaking							0
-leaking due to freeze damage		1					1
-glazing is broken							0
-O-rings defective							0
-plug on pool panel defective							0
-panels blew off roof							0
-enclosure structural problem							0
-no fluid flow in collector							0
-glazing extremely dirty							0
-structural damage to roof from collector leak							0
-collector bypassed							0
-collector removed for re-roofing							0
-collector removed permanently	1	6					7
-unknown problem		1					1
Collector Mounting Problem Totals	5	0	0	0	0	0	5
-collector not firmly attached to roof							0
-defective mounting	1						1
-mounting bolts not secured							0
-improper structural mounting method	1						1
-improper roof flashing used							0
-flashing not sealed							0
-roof penetration not sealed	1						1
-leak at mounting points	1						1
-collector not tilted for drainage							0
-improper orientation (azimuth)	1						1
-unknown problem							0
Diff Controller Problem Totals	0	7	0	0	0	0	7
-defective controller		6					6
-switch on "on" position							0
-high temp limit setting inaccurate							0
-loose connections at sensor terminal							0
-improperly programmed							0
-controller stays on all the time							0
-controller operates only in manual mode							0
-system shuts off at wrong high limit or runs continuously							0
-no power to the controller		1					1
-unknown problem							0
PV Controller Problem Totals	0	0	0	0	0	0	0
-PV module shaded							0
-PV module too small for head							0
Timer Controller Problem Totals	0	4	0	0	0	0	4
-defective timer		4					4

			System Type				
SWAP, 1993-1997; 200 inspections 2003-2004	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
SYSTEMS INSTALLED	393	406	2				
INSPECTED SYSTEMS W/PROBLEMS	73	68		8			149
-wrong on/off time							0
-current time incorrect							0
-unplugged from power source							0
Sensor Failure Totals	0	1	0	0	0	0	1
-defective sensor							0
-defective collector sensor							0
-defective tank sensor							0
-collector sensor not properly attached/secured							0
-tank sensor not properly attached/secured							0
-improper connection method							0
-improper mounting location (collector)							0
-sensor not protected from environment		1					1
-sensor not installed (required)							0
-sensor and controller not compatible							0
-defective snap switch							0
-unknown problem							0
-defective temp gauge							0
-leaking at body of gauge							0
-defective transformer							0
Sensor Wiring Problem Totals	0	0	0	0	0	0	0
-defective sensor wiring							0
-defective wire connections							0
-open collector sensor wiring							0
-shorted collector sensor wiring							0
-open water heater sensor wiring							0
-shorted water heater sensor wiring							0
-sensor wires reversed							0
-sensor wire run not secured							0
-sensor wires not connected							0
-sensor wires crimped							0
-sensor wires chaffed from obstructions							0
-wiring insulation chewed off by rodents							0
-line cord problem							0
-roof wiring penetrations not sealed properly							0
-unknown problem							0
Solar Storage Water Heater Problem Totals	0	2	0	0	0	0	2
-defective water heater		1					1
-tank fitting leak							0
-internal tank leak							0
-thermosiphon tank leak							0
-defective element							0
-defective thermostat							0
-defective thermostat wiring							0
-thermostat set too low		1					1
-thermostat tripped (overheating)							0
-voltage to water heater inadequate							0
-defective circuit breaker							0
-thermosiphon tank shell coming apart							0
-tank outer shell cracked							0
-white deposits in storage tank							0
-solar blocked from tank bottom calcification							0

SWAP, 1993-1997; 200 inspections 2003-2004	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
			System Type				
SYSTEMS INSTALLED	393	406	2				
INSPECTED SYSTEMS W/PROBLEMS	73	68		8			149
-unknown problem							0
Electric Auxiliary Water Heater Problem	0	0	0	0	0	0	0
-defective tank							0
-internal tank leak							0
-defective element							0
-leak at element bolt							0
-defective thermostat							0
-thermostat tripped							0
-upper thermostat set too low							0
-lower thermostat set too low							0
-no electrical power to tank							0
-old water heater inefficient without solar							0
-not properly insulated							0
-unknown problem							0
Gas Auxiliary Water Heater Problem Totals	0	0	0	0	0	0	0
-defective tank							0
-internal tank leak							0
-defective thermocouple							0
-loose thermocouple connection							0
-failure to ignite							0
-pilot light off							0
-pilot valve defective							0
-unknown problem							0
Drainback Tank Problem Totals	0	0	0	0	0	0	0
-defective tank							0
-tank leaks							0
-level indicator leaks							0
-tank is empty of fluid							0
-tank water level low							0
-improper fluid level							0
-tank overfilled							0
-unknown problem							0
-expansion tank problem							0
Pumps Problem Totals	0	4	0	1	0	0	5
-pump failure		3		1			4
-defective pump							0
-defective rotor							0
-defective gasket							0
-motor failure							0
-defective capacitor							0
-replaced cartridge							0
-bearing dry (need lubrication)							0
-leak in pump		1					1
-leak at pump connections							0
-loose pump mounting flanges							0
-air trapped in pump							0
-improperly installed							0
-required pump not installed							0
-unknown problem							0
-stuck shaft, impeller, or coupling							0
-pressure problem							0

SWAP, 1993-1997; 200 inspections 2003-2004	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
				System Type			
SYSTEMS INSTALLED	393	406	2				
INSPECTED SYSTEMS W/PROBLEMS	73	68		8			149
-no pressure							0
-no collector loop pressure							0
-pressure too high, pool sweep runs with solar on							0
Heat Exchanger Problem Totals	0	0	0	0	0	0	0
-heat exchanger leak							0
-inefficient due to clogging							0
-isolated from system							0
-defective heat exchanger							0
-air in heat exchanger							0
-unknown problem							0
Heat Transfer Fluid Problem Totals	0	0	0	0	0	0	0
-insufficient glycol mixture							0
-loss of chemical stability							0
-loss of fluid due to a leak							0
-fluid level low							0
-no fluid in system							0
-low pressure in loop							0
-no pressure in heat transfer loop							0
-recharge of fluid required							0
-wrong type of glycol used							0
Piping Problems Totals	1	5	0	0	0	0	6
-entrapped air							0
-leak in piping		1					1
-leak at roof piping penetration	1	4					5
Insulation Exterior Problem Totals	0	0	0	0	0	0	0
-defective insulation							0
-insulation deteriorating (non-UV)							0
-UV protective foil tape deteriorating							0
-new insulation needed							0
-animals destroying insulation							0
-wrong type (foam/plastic) insulation used							0
-not used (required)							0
Valve, Air Vent Problem Totals	0	14	0	1	0	0	15
-defective air vent		14		1			15
-internal leak							0
-air in hot water line							0
-needs air vent							0
-leak at plumbing fitting							0
-not operating (air in system)							0
-not installed (required)							0
-inoperative due to freeze							0
-unknown problem							0
Valve, Automatic Draindown Totals	0	0	0	0	0	0	0
-valve defective							0
-does not open or close fully							0
-valve stuck in drain position							0
-valve stuck in fill position							0
-O-rings defective							0
-noisy operation							0

SWAP, 1993-1997; 200 inspections 2003-2004	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
			System Type				
SYSTEMS INSTALLED	393	406	2				
INSPECTED SYSTEMS W/PROBLEMS	73	68		8			149
-unknown problem							0
Valve, Anti-Scald Problem Totals	0	8	0	0	0	0	8
-defective valve		8					8
-needs internal rebuilding							0
-unknown problem							0
Valve, Check Problem Totals	0	2	0	0	0	0	2
-defective valve		2					2
-leaking							0
-valve stuck open – internal leak							0
-not installed (required)							0
-unknown problem							0
Valve, Fill Drain Problem Totals	0	0	0	0	0	0	0
-valve defective							0
-internal leak at seals							0
-packing nuts loose							0
-not installed (required)							0
-unknown problem							0
Valve, Freeze Totals	6	5	0	0	0	0	11
-valve defective	1	5					6
-valve leaking	5						5
-freeze plug problem							0
-unknown problem							0
Valve, Isolation and Supply Totals	0	0	0	0	0	0	0
-defective valve							0
-leak at seats							0
-improper setting (position)							0
-not installed (required)							0
-defective motorized pool valve							0
-isolation valve not sealing completely							0
-unknown problem							0
-internal leak at seal							0
Valve, Mixing/Temp Problem Totals	0	1	0	0	0	0	1
-defective valve		1					1
-leaking							0
-needs internal rebuilding							0
-improper temperature setting							0
-loose packing nut							0
-stuck due to deposits							0
-required – due to water being too hot							0
-unknown problem							0
Valve T&P Collector Loop Problem Totals	0	2	0	1	0	0	3
-defective collector valve		2		1			3
-leaking collector valve							0
-discharge not routed to proper location							0
-leaking at port – did not reseal after opening							0
-unknown problem							0
-defective water heater valve							0
-internal leak on water heater valve							0

	System Type						
SWAP, 1993-1997; 200 inspections 2003-2004	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
SYSTEMS INSTALLED	393	406	2				
INSPECTED SYSTEMS W/PROBLEMS	73	68		8			149
Valve, Vacuum Breaker Problem Totals	**0**	**0**	**0**	**0**	**0**	**0**	**0**
-defective valve							0
-leaking							0
-valve has been plugged							0
-unknown problem							0
Summary	**21**	**71**	**0**	**3**	**0**	**0**	**95**
Checksum							**95**

Anonymous Company – High-Level Summary of Problems

2006-2009	ICS	Direct Circ	Thermo	PV Control	Pool	Unknown	Totals
			SYSTEM TYPE				
Total Installed		1893					
Service Calls	0	0	0	0	0	0	0
Calls as Percentage of Total	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Problem Areas			TOTAL REPORTED PROBLEMS				
Collector Problems	0	60	0	0	0	0	60
Controller Problems	0	21	0	0	0	0	21
Sensor Problems	0	20	0	0	0	0	20
Tank Problems	0	0	0	0	0	0	0
Pump Problems	0	91	0	0	0	0	91
Heat Transfer Problems	0	0	0	0	0	0	0
Piping Problems	0	0	0	0	0	0	0
Valve Problems	0	64	0	0	0	0	64
Totals	**0**	**256**	**0**	**0**	**0**	**0**	**256**
Problems per Service Call	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Problem Areas		PROBLEMS AS A PERCENTAGE OF TOTAL	
Collector Problems	23.4%		23.4%
Controller Problems	8.2%		8.2%
Sensor Problems	7.8%		7.8%
Tank Problems	0.0%		0.0%
Pump Problems	35.5%		35.5%
Heat Transfer Problems	0.0%		0.0%
Piping Problems	0.0%		0.0%
Valve Problems	25.0%		25.0%
Totals	100.0%		100.0%

HECO – High-Level Summary of Problems

HECO records, 1998-2004	SYSTEM TYPE						
	ICS	Direct Circ	Thermo	PV Control	Pool	Unknown	Totals
Total Installed	**0**	**53218**	**0**	**0**	**0**	**0**	**14099**
Service Calls	0	467	0	0	0	0	467
Calls as Percentage of Total	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Problem Areas	TOTAL REPORTED PROBLEMS						
Collector Problems	0	63	0	0	0	0	63
Controller Problems	0	70	0	0	0	0	70
Sensor Problems	0	3	0	0	0	0	3
Tank Problems	0	137	0	0	0	0	137
Pump Problems	0	38	0	0	0	0	38
Heat Transfer Problems	0	0	0	0	0	0	0
Piping Problems	0	27	0	0	0	0	27
Valve Problems	0	146	0	0	0	0	146
Totals	**0**	**484**	**0**	**0**	**0**	**0**	**484**
Problems per Service Call	N/A	1.04	N/A	N/A	N/A	N/A	1.04
Problem Areas	PROBLEMS AS A PERCENTAGE OF TOTAL						
Collector Problems		13.0%					13.0%
Controller Problems		14.5%					14.5%
Sensor Problems		0.6%					0.6%
Tank Problems		28.3%					28.3%
Pump Problems		7.9%					7.9%
Heat Transfer Problems		0.0%					0.0%
Piping Problems		5.6%					5.6%
Valve Problems		30.2%					30.2%
Totals		100.0%					100.0%

HECO – Mid-Level Summary of Problems

				SYSTEM TYPE			
HECO records, 1998-2004	**ICS**	**Pumped**	**Thermo**	**PV Control**	**Pool**	**Unknown**	**Totals**
TOTAL INSTALLED							
SERVICE CALLS		**467**		**0**		**0**	**467**
Collector Problems	**0**	**63**	**0**	**0**	**0**	**0**	**63**
Faulty Collector Problem Totals	0	63	0	0	0	0	63
Collector Mounting Problem Totals	0	0	0	0	0	0	0
Controller Problems	**0**	**70**	**0**	**0**	**0**	**0**	**70**
Diff Controller Problem Totals	0	36	0	0	0	0	36
PV Controller Problem Totals	0	0	0	0	0	0	0
Timer Controller Problem Totals	0	34	0	0	0	0	34
Sensor Problems	**0**	**3**	**0**	**0**	**0**	**0**	**3**
Sensor Failure Totals	0	3	0	0	0	0	3
Sensor Wiring Problem Totals	0	0	0	0	0	0	0
Tank Problems	**0**	**137**	**0**	**0**	**0**	**0**	**137**
Solar Storage Water Heater Problem Totals	0	0	0	0	0	0	0
Electric Auxiliary Water Heater Problem	0	137	0	0	0	0	137
Gas Auxiliary Water Heater Problem Totals	0	0	0	0	0	0	0
Drainback Tank Problem Totals	0	0	0	0	0	0	0
Pump Problems	**0**	**38**	**0**	**0**	**0**	**0**	**38**
Pumps Problem Totals	0	38	0	0	0	0	38
Heat Transfer Problems	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Heat Exchanger Problem Totals	0	0	0	0	0	0	0
Heat Transfer Fluid Problem Totals	0	0	0	0	0	0	0
Piping Problems	**0**	**27**	**0**	**0**	**0**	**0**	**27**
Piping Problems Totals	0	27	0	0	0	0	27
Insulation Exterior Problem Totals	0	0	0	0	0	0	0
Valve Problems	**0**	**146**	**0**	**0**	**0**	**0**	**146**
Valve, air vent Problem Totals	0	4	0	0	0	0	4
Valve, automatic draindown Totals	0	0	0	0	0	0	0
Valve, anti-scald Problem Totals	0	0	0	0	0	0	0
Valve, check Problem Totals	0	0	0	0	0	0	0
Valve, fill drain Problem Totals	0	0	0	0	0	0	0
Valve, freeze Totals	0	0	0	0	0	0	0
Valve, isolation and supply Totals	0	6	0	0	0	0	6
Valve, mixing/temp Problem Totals	0	2	0	0	0	0	2
Valve T&P collector loop Problem Totals	0	134	0	0	0	0	134
Valve, Vacuum breaker Problem Totals	0	0	0	0	0	0	0
Totals	**0**	**484**	**0**	**0**	**0**	**0**	**484**

Sacramento – High-Level Summary of Problems

Sacramento Data				System Type			
		SMUD			Murray		
Total Installations	423	1889	907	unknown	unknown	unknown	3219
Percent of Total Installations	13.1%	58.7%	28.2%				
Service Calls	31	298	61	3	242	495	1130
Proporation of problems as % of total installed	7.3%	15.8%	6.7%				
Lower 95% confidence limits for proportion	5%	14%	5%				
Upper 95% confidence limit for proportion	9%	17%	8%				
Percent of total service calls	2.7%	26.4%	5.4%	0.3%	21.4%	43.8%	100.0%
Problem Areas			**TOTAL REPORTED PROBLEMS**				
Collector Problems	13	40	6	1	82	71	213
Controller Problems	0	36	0	1	17	25	79
Sensor Problems	0	111	1	0	26	76	214
Tank Problems	0	74	11	0	0	74	159
Pump Problems	0	74	0	0	6	68	148
Heat Transfer Problems	0	48	3	0	1	14	66
Piping Problems	0	34	2	0	1	21	58
Valve Problems	1	168	28	1	40	155	393
Totals	**14**	**585**	**51**	**3**	**173**	**504**	**1330**
Problems per Service Call	0.5	2.0	0.8	1.0	0.7	1.0	1.2
Percent of problem per total installed	3.3%	31.0%	5.6%				
Problem Areas			**PROBLEMS AS A PERCENTAGE OF TOTAL**				
Collector Problems	92.9%	6.8%	11.8%	33.3%	47.4%	14.1%	16.0%
Controller Problems	0.0%	6.2%	0.0%	33.3%	9.8%	5.0%	5.9%
Sensor Problems	0.0%	19.0%	2.0%	0.0%	15.0%	15.1%	16.1%
Tank Problems	0.0%	12.6%	21.6%	0.0%	0.0%	14.7%	12.0%
Pump Problems	0.0%	12.6%	0.0%	0.0%	3.5%	13.5%	11.1%
Heat Transfer Problems	0.0%	8.2%	5.9%	0.0%	0.6%	2.8%	5.0%
Piping Problems	0.0%	5.8%	3.9%	0.0%	0.6%	4.2%	4.4%
Valve Problems	7.1%	28.7%	54.9%	33.3%	23.1%	30.8%	29.5%
Totals	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Notes:
1 Includes only ICS, Pumped and Thermosiphon totals

Sacramento – Mid-Level Summary of Problems

Sacramento Data	System Type						
		SMUD			Murray		
TOTAL INSTALLED	**423**	**1889**	**907**	**unknown**	**unknown**	**unknown**	
SERVICE CALLS	**31**	**298**	**61**	**3**	**242**	**495**	**1130**
Collector Problems	**13**	**40**	**6**	**1**	**82**	**71**	**213**
Faulty Collector Problem Totals	11	28	2	1	62	59	163
Collector Mounting Problem Totals	2	12	4	0	20	12	50
Controller Problems	**0**	**36**	**0**	**1**	**17**	**25**	**79**
Diff Controller Problem Totals	0	29	0	0	16	23	68
PV Controller Problem Totals	0	0	0	1	0	1	2
Timer Controller Problem Totals	0	7	0	0	1	1	9
Sensor Problems	**0**	**111**	**1**	**0**	**26**	**76**	**214**
Sensor Failure Totals	0	82	1	0	19	54	156
Sensor Wiring Problem Totals	0	29	0	0	7	22	58
Tank Problems	**0**	**74**	**11**	**0**	**0**	**74**	**159**
Solar Storage Water Heater Problem Totals	0	30	9	0	0	50	89
Electric Auxiliary Water Heater Problem	0	27	1	0	0	7	35
Gas Auxiliary Water Heater Problem Totals	0	1	1	0	0	14	16
Drainback Tank Problem Totals	0	16	0	0	0	3	19
Pump Problems	**0**	**74**	**0**	**0**	**6**	**68**	**148**
Pumps AC Problem Totals	0	74	0	0	6	68	148
Heat Transfer Problems	**0**	**48**	**3**	**0**	**1**	**14**	**66**
Heat Exchanger Problem Totals	0	9	0	0	0	2	11
Heat Transfer Fluid Problem Totals	0	39	3	0	1	12	55
Piping Problems	**0**	**34**	**2**	**0**	**1**	**21**	**58**
Piping Problems Totals	0	1	0	0	1	2	4
Insulation Exterior Problem Totals	0	33	2	0	0	19	54
Valve Problems	**1**	**168**	**28**	**1**	**40**	**155**	**393**
Valve, Air Vent Problem Totals	0	14	0	0	0	44	58
Valve, Automatic Draindown Totals	0	72	0	0	0	9	81
Valve, Anti-Scald Problem Totals	0	1	0	0	0	2	3
Valve, Check Problem Totals	0	8	0	0	7	8	23
Valve, Fill Drain Problem Totals	1	8	0	0	2	4	15
Valve, Freeze Totals	0	1	8	1	1	18	29
Valve, Isolation and Supply Totals	0	6	0	0	30	20	56
Valve, Mixing/Temp Problem Totals	0	46	5	0	0	24	75
Valve T&P Collector Loop Problem Totals	0	7	7	0	0	15	29
Valve, Vacuum Breaker Problem Totals	0	5	8	0	0	11	24
Totals	**14**	**585**	**51**	**3**	**173**	**504**	**1330**

Sacramento – Detailed Summary of Problems

Sacramento Data — **System Type**

		SMUD			Murray		
Bergquam and Murray records, 1991-1999, SMUD	**ICS**	**Pumped**	**Thermo**	**PV Control**	**Pool**	**Unknown**	**Totals**
TOTAL INSTALLED	**423**	**1889**	**907**	**unknown**	**unknown**	**unknown**	**3219**
SERVICE CALLS	**31**	**298**	**61**	**3**	**242**	**495**	**1130**
Collector Problem Totals	**11**	**28**	**2**	**1**	**62**	**59**	**163**
-defective collector	1	3	0		6	2	12
-leaking		1	0		1		2
-leaking (source unknown)	2	6	0	1	24	13	46
-header tubes leaking		0	0		3	3	6
-header tube leaking		0	1				1
-riser to header connection leaking		8	0				8
-riser tubes leaking		0	0		3	2	5
-leaking due to freeze damage	2	3	0		6	20	31
-glazing is broken	5	3	0			3	11
-O-rings defective		0	1		8	1	10
-plug on pool panel defective		0	0		2		2
-panels blew off roof		0	0		1		1
-enclosure structural problem		2	0			1	3
-no fluid flow in collector		2	0				2
-glazing extremely dirty		0	0			2	2
-structural damage to roof from collector leak		0	0			1	1
-collector bypassed		0	0			1	1
-collector removed for re-roofing	1	0	0		2	3	6
-collector removed permanently		0	0		1	1	2
-unknown problem		0	0		5	6	11
Collector Mounting Problem Totals	**2**	**12**	**4**	**0**	**20**	**12**	**50**
-collector not firmly attached to roof		1	0		5		6
-defective mounting	1	4	0		10	4	19
-mounting bolts not secured		1	1				2
-improper structural mounting method		2	0		1	1	4
-improper roof flashing used		1	0			1	2
-flashing not sealed	1	1	1			1	4
-roof penetration not sealed		0	0		1	3	4
-leak at mounting points		1	2			1	4
-collector not tilted for drainage		0	0			1	1
-improper orientation (azimuth)		1	0				1
-unknown problem		0	0		3		3
Diff Controller Problem Totals	**0**	**29**	**0**	**0**	**16**	**23**	**68**
-defective controller		23	0		10	16	49
-switch on "on" position		1	0				1
-high temp limit setting inaccurate		0	0			1	1
-loose connections at sensor terminal		0	0			1	1
-improperly programmed		0	0		2		2
-controller stays on all the time		0	0			1	1
-controller operates only in manual mode		1	0			2	3
-system shuts off at wrong high limit or runs continuously		1	0			1	2
-no power to the controller		2	0				2
-unknown problem		1	0		4	1	6
PV Controller Problem Totals	**0**	**0**	**0**	**1**	**0**	**1**	**2**
-PV module shaded		0	0	1			1
-PV module too small for head		0	0			1	1

Sacramento Data	System Type						
		SMUD			Murray		
Bergquam and Murray records, 1991-1999, SMUD	ICS	Pumped	Thermo	PV Control	Pool	Unknown	Totals
TOTAL INSTALLED	423	1889	907	unknown	unknown	unknown	3219
SERVICE CALLS	31	298	61	3	242	495	1130
Timer Controller Problem Totals	**0**	**7**	**0**	**0**	**1**	**1**	**9**
-defective timer		2	0			1	3
-wrong on/off time		0	0		1		1
-current time incorrect		4	0				4
-unplugged from power source		1	0				1
Sensor Failure Totals	**0**	**82**	**1**	**0**	**19**	**54**	**156**
-defective sensor		11	0		8	30	49
-defective collector sensor		30	0		2	7	39
-defective tank sensor		11	0		1	1	13
-collector sensor not properly attached/secured		5	0			1	6
-tank sensor not properly attached/secured		2	0				2
-improper connection method		2	0			5	7
-improper mounting location (collector)		0	0		5	3	8
-sensor not protected from environment		2	0		1	3	6
-sensor not installed (required)		1	0			1	2
-sensor and controller not compatible		0	0			1	1
-defective snap switch		0	0			1	1
-unknown problem		2	0		1		3
-defective temp gauge		1	1				2
-leaking at body of gauge		0	0		1		1
-defective transformer		15	0			1	16
Sensor Wiring Problem Totals	**0**	**29**	**0**	**0**	**7**	**22**	**58**
-defective sensor wiring		7	0		2	9	18
-defective wire connections		7	0		1	1	9
-open collector sensor wiring		2	0				2
-shorted collector sensor wiring		4	0		1		5
-open water heater sensor wiring		1	0				1
-shorted water heater sensor wiring		2	0				2
-sensor wires reversed		3	0			1	4
-sensor wire run not secured		1	0		1		2
-sensor wires not connected		0	0		1	1	2
-sensor wires crimped		0	0			1	1
-sensor wires chaffed from obstructions		0	0			1	1
-wiring insulation chewed off by rodents		1	0				1
-line cord problem		0	0			1	1
-roof wiring penetrations not sealed properly		0	0			1	1
-unknown problem		1	0		1	6	8
Solar Storage Water Heater Problem Totals	**0**	**30**	**9**	**0**	**0**	**50**	**89**
-defective water heater		3	0			5	8
-tank fitting leak		10	2			7	19
-internal tank leak		3	0			8	11
-thermosiphon tank leak		0	1				1
-defective element		5	2			9	16
-defective thermostat		2	2			4	8
-defective thermostat wiring		0	0			1	1
-thermostat set too low		2	0				2
-thermostat tripped (overheating)		1	0			5	6
-voltage to water heater inadequate		0	0			1	1
-defective circuit breaker		0	0			1	1
-thermosiphon tank shell coming apart		0	1				1
-tank outer shell cracked		0	0			1	1

Sacramento Data

	System Type						
	SMUD			Murray			
Bergquam and Murray records, 1991-1999, SMUD	**ICS**	**Pumped**	**Thermo**	**PV Control**	**Pool**	**Unknown**	**Totals**
TOTAL INSTALLED	**423**	**1889**	**907**	**unknown**	**unknown**	**unknown**	**3219**
SERVICE CALLS	**31**	**298**	**61**	**3**	**242**	**495**	**1130**
-white deposits in storage tank		1	0				1
-solar blocked from tank bottom calcification		0	0			1	1
-unknown problem		3	1			7	11
Electric Auxiliary Water Heater Problem	**0**	**27**	**1**	**0**	**0**	**7**	**35**
-defective tank		4	0			3	7
-internal tank leak		1	0				1
-defective element		8	1				9
-leak at element bolt		0	0			1	1
-defective thermostat		4	0			1	5
-thermostat tripped		2	0				2
-upper thermostat set too low		4	0				4
-lower thermostat set too low		1	0				1
-no electrical power to tank		1	0				1
-bad wiring on thermostat		0	0				0
-old water heater inefficient without solar		1	0				1
-not properly insulated		0	0			1	1
-unknown problem		1	0			1	2
Gas Auxiliary Water Heater Problem Totals	**0**	**1**	**1**	**0**	**0**	**14**	**16**
-defective tank		0	1				1
-internal tank leak		0	0			1	1
-defective thermocouple		0	0			1	1
-loose thermocouple connection		0	0			1	1
-failure to ignite		0	0			2	2
-pilot light off		0	0			3	3
-pilot valve defective		0	0			2	2
-unknown problem		1	0			4	5
Drainback Tank Problem Totals	**0**	**16**	**0**	**0**	**0**	**3**	**19**
-defective tank		1	0				1
-tank leaks		2	0				2
-level indicator leaks		1	0				1
-tank is empty of fluid		1	0				1
-tank water level low		5	0			1	6
-improper fluid level		2	0				2
-tank overfilled		1	0				1
-unknown problem		1	0			1	2
-expansion tank problem		2	0			1	3
Pump AC Problem Totals	**0**	**74**	**0**	**0**	**6**	**68**	**148**
-pump failure		4	0			2	6
-defective pump		35	0		4	36	75
-defective rotor		21	0				21
-defective gasket		1	0				1
-motor failure		0	0			2	2
-defective capacitor		0	0			1	1
-replaced cartridge		2	0			1	3
-bearing dry (need lubrication)		1	0				1
-leak in pump		0	0			3	3
-leak at pump connections		4	0			4	8
-loose pump mounting flanges		0	0			1	1
-air trapped in pump		1	0			5	6

Sacramento Data

	System Type						
	SMUD				Murray		
Bergquam and Murray records, 1991-1999, SMUD	**ICS**	**Pumped**	**Thermo**	**PV Control**	**Pool**	**Unknown**	**Totals**
TOTAL INSTALLED	**423**	**1889**	**907**	**unknown**	**unknown**	**unknown**	**3219**
SERVICE CALLS	**31**	**298**	**61**	**3**	**242**	**495**	**1130**
-improperly installed		1	0				1
-required pump not installed		1	0				1
-unknown problem		1	0		1	10	12
-stuck shaft, impeller, or coupling		1	0				1
-pressure problem		0	0			1	1
-no pressure		0	0			2	2
-no collector loop pressure		1	0				1
-pressure too high, pool sweep runs with solar on		0	0		1		1
Heat Exchanger Problem Totals	**0**	**9**	**0**	**0**	**0**	**2**	**11**
-heat exchanger leak		4	0				4
-inefficient due to clogging		1	0				1
-isolated from system		1	0				1
-defective heat exchanger		2	0			1	3
-air in heat exchanger		0	0			1	1
-unknown problem		1	0				1
Heat Transfer Fluid Problem Totals	**0**	**39**	**3**	**0**	**1**	**12**	**55**
-insufficient glycol mixture		17	1				18
-loss of chemical stability		1	0				1
-loss of fluid due to a leak		4	0		1	3	8
-fluid level low		1	0				1
-no fluid in system		1	1				2
-low pressure in loop		3	0				3
-no pressure in heat transfer loop		2	0			1	3
-recharge of fluid required		9	1			8	18
-wrong type of glycol used		1	0				1
Piping Problems Totals	**0**	**1**	**0**	**0**	**1**	**2**	**4**
-entrapped air		1	0				1
-fluid leak in piping		0	0		1		1
-leak at roof piping penetration		0	0			2	2
Insulation Exterior Problem Totals	**0**	**33**	**2**	**0**	**0**	**19**	**54**
-defective insulation		6	1			2	9
-insulation deteriorating (non-UV)		4	0			2	6
-UV protective foil tape deteriorating		17	0			3	20
-new insulation needed		1	0			6	7
-animals destroying insulation		1	0				1
-wrong type (foam/plastic) insulation used		1	0				1
-not used (required)		3	1			6	10
Valve, Air Vent Problem Totals	**0**	**14**	**0**	**0**	**0**	**44**	**58**
-defective air vent		13	0			26	39
-internal leak		1	0			2	3
-air in hot water line		0	0			1	1
-needs air vent		0	0			1	1
-leak at plumbing fitting		0	0			1	1
-not operating (air in system)		0	0			1	1
-not installed (required)		0	0			2	2
-inoperative due to freeze		0	0			9	9
-unknown problem		0	0			1	1
Valve, Automatic Draindown Totals	**0**	**72**	**0**	**0**	**0**	**9**	**81**
-valve defective		57	0			8	65

Sacramento Data

	System Type						
		SMUD			Murray		
Bergquam and Murray records, 1991-1999, SMUD	**ICS**	**Pumped**	**Thermo**	**PV Control**	**Pool**	**Unknown**	**Totals**
TOTAL INSTALLED	**423**	**1889**	**907**	**unknown**	**unknown**	**unknown**	**3219**
SERVICE CALLS	**31**	**298**	**61**	**3**	**242**	**495**	**1130**
-does not open or close fully		1	0				1
-valve stuck in drain position		5	0				5
-valve stuck in fill position		3	0			1	4
-O-rings defective		1	0				1
-noisy operation		1	0				1
-unknown problem		4	0				4
Valve, Anti-Scald Problem Totals	**0**	**1**	**0**	**0**	**0**	**2**	**3**
-defective valve		1	0				1
-needs internal rebuilding		0	0			1	1
-unknown problem		0	0			1	1
Valve, Check Problem Totals	**0**	**8**	**0**	**0**	**7**	**8**	**23**
-defective valve		4	0		5	2	11
-leaking		0	0			1	1
-valve stuck open – internal leak		1	0				1
-not installed (required)		2	0		2	1	5
-unknown problem		1	0			4	5
Valve, Fill Drain Problem Totals	**1**	**8**	**0**	**0**	**2**	**4**	**15**
-valve defective		2	0		1	2	5
-internal leak at seals		1	0				1
-packing nuts loose		2	0				2
-not installed (required)	1	1	0		1	2	5
-unknown problem		2	0				2
Valve, Freeze Totals	**0**	**1**	**8**	**1**	**1**	**18**	**29**
-valve defective		0	6	1		10	17
-valve leaking		1	1		1	6	9
-freeze plug problem		0	1				1
-unknown problem		0	0			2	2
Valve, Isolation and Supply Totals	**0**	**6**	**0**	**0**	**30**	**20**	**56**
-defective valve		2	0		7	10	19
-leak at seats		0	0			1	1
-improper setting (position)		2	0			2	4
-not installed (required)		1	0		4	2	7
-defective motorized pool valve		0	0		16		16
-isolation valve not sealing completely		0	0		1		1
-unknown problem		0	0		2	5	7
-internal leak at seal		1	0				1
Valve, Mixing/Temp Problem Totals	**0**	**46**	**5**	**0**	**0**	**24**	**75**
-defective valve		18	3			8	29
-leaking		1	1			1	3
-needs internal rebuilding		15	0			12	27
-improper temperature setting		6	0			2	8
-loose packing nut		1	0				1
-stuck due to deposits		4	0				4
-required – due to water being too hot		0	0			1	1
-unknown problem		1	1				2
Valve T&P Collector Loop Problem Totals	**0**	**7**	**7**	**0**	**0**	**15**	**29**
-defective collector valve		3	2			5	10
-leaking collector valve		1	0			1	2
-discharge not routed to proper location		0	0			2	2

Sacramento Data

Bergquam and Murray records, 1991-1999, SMUD	System Type SMUD ICS	Pumped	Thermo	PV Control	Murray Pool	Unknown	Totals
TOTAL INSTALLED	423	1889	907	unknown	unknown	unknown	3219
SERVICE CALLS	31	298	61	3	242	495	1130
-leaking at port – did not reseal after opening		0	0			1	1
-unknown problem		0	0			1	1
-defective water heater valve		3	4			2	9
-internal leak on water heater valve		0	1			3	4
Valve, Vacuum Breaker Problem Totals	0	5	8	0	0	11	24
-defective valve		5	5			4	14
-leaking		0	2			4	6
-valve has been plugged		0	0			1	1
-unknown problem		0	1			2	3
Summary	14	585	51	3	173	504	1330
Checksum							1330

SMUD – Solar Hot Water Installation Records

SMUD Solar Hot Water Installation Records

Total Models Installed 1991-2008

Model Number	Manufacturer	System Type	Total Installed
300 series	Solahart	Thermosiphon	662
2001	American Solar Network	Pumped	146
444A	Copper Heart or Fafco	ICS	50
AETC	Alternate Energy Tech	Pumped	88
ASN	Anerican Solar Net.	Pumped/drainback	519
CC1B	Sage Copper Cricket	Thermosiphon	20
GOB1408	Heliodyne	Pumped	3
HP141080ACSHE	Heliodyne	Pumped	159
HV80	Heliodyne	PV pumped	1
JKP	Solarhart	Thermosiphon	246
PK20	Nippon	ICS	361
PT40	TCT	ICS	14
SX1000	Solmax	Pumped	707
SX3000	Solmax	Pumped	412
TE40C-80-1	Sun Earth	Pumped?	92
Unknown			3
Grand Total			**3483**

Total Installed by System Type 91-08

Sytem Type	Total Installed
ICS	425
Pumped	2127
Thermosiphon	928
Unknown	3
Total	3483

Total Installed by System Type 91-99

System Type	Total Installed
ICS	423
Pumped	1889
Thermosiphon	907
Unknown	3
Total	3222

NREL – Review by Model

NREL Survey (Data from individual graphs of problems for each system)

These data were not used in the analysis

Survey of 221 Systems	SYSTEM MODEL										
	Solmax SX1000	Solmax SX3000	ASN2	SunFamily PK20	Heliodyne HP141080	Solahart 302K	ASN 3	Solahart JKP1	AET C8040	Not Known	Totals
Total Systems Surveyed	80	55	25	17	14	11	6	4	3	6	221
Type of System	Pumped indirect	Pumped indirect	Drain-back	Pumped indirect	Pumped indirect	Thermo-siphon	Drain-back	Thermo-siphon	Pumped indirect	n/a	
Problem Areas	TOTAL OBSERVED PROBLEMS										
Heat Transfer Problems	26	22	2	0	6	0	0	0	0	1	57
Sensor Problems	31	3	2	0	8	0	2	0	2	2	50
Wiring Problems	15	0	0	0	0	0	1	1	0	0	17
Valve Problems	11	0	7	10	3	6	1	4	2	1	45
Insulation Problems	10	0	0	0	0	0	0	0	0	0	10
Controller Problems	24	20	8	6	3	3	0	0	0	0	64
Pump Problems	10	48	4	5	0	0	0	0	1	1	69
Collector Problems	16	3	8	2	3	0	0	0	2	3	37
Tank Problems	11	11	6	2	0	3	2	0	0	1	36
Piping Problems	6	0	0	0	0	0	0	0	1	1	8
Other	9	0	0	11	3	5	2	0	0	0	30
Totals	169	107	37	36	26	17	8	5	8	10	423
% problems per system	211.3%	194.5%	148.0%	211.8%	185.7%	154.5%	133.3%	125.0%	266.7%	166.7%	191.4%
Problem Areas	PROBLEMS AS A PERCENTAGE OF TOTAL										
Heat Transfer Problems	15.4%	20.6%	5.4%	0.0%	23.1%	0.0%	0.0%	0.0%	0.0%	10.0%	13.5%
Sensor Problems	18.3%	2.8%	5.4%	0.0%	30.8%	0.0%	25.0%	0.0%	25.0%	20.0%	11.8%
Wiring Problems	8.9%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	20.0%	0.0%	0.0%	4.0%
Valve Problems	6.5%	0.0%	18.9%	27.8%	11.5%	35.3%	12.5%	80.0%	25.0%	10.0%	10.6%
Insulation Problems	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.4%
Controller Problems	14.2%	18.7%	21.6%	16.7%	11.5%	17.6%	0.0%	0.0%	0.0%	0.0%	15.1%
Pump Problems	5.9%	44.9%	10.8%	13.9%	0.0%	0.0%	0.0%	0.0%	12.5%	10.0%	16.3%
Collector Problems	9.5%	2.8%	21.6%	5.6%	11.5%	0.0%	0.0%	0.0%	25.0%	30.0%	8.7%
Tank Problems	6.5%	10.3%	16.2%	5.6%	0.0%	17.6%	25.0%	0.0%	0.0%	10.0%	8.5%
Piping Problems	3.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	10.0%	1.9%
Other	5.3%	0.0%	0.0%	30.6%	11.5%	29.4%	25.0%	0.0%	0.0%	0.0%	7.1%
Totals	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

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