Revisions to the SRCC Rating Process for Solar Water Heaters

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J. Burch
National Renewable Energy Laboratory

J. Huggins and S. Long
Solar Rating and Certification Corporation

J. Thornton
Thermal Energy System Specialists, Inc.

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REVISIONS TO THE SRCC RATING PROCESS FOR SOLAR WATER HEATERS

Jay Burch
National Renewable Energy Laboratory
1617 Cole Blvd., MS52-02
Golden, CO 80401
e-mail: jay.burch@nrel.gov

Jeff Thornton
Thermal Energy System Specialists, Inc.
22 North Carroll Street, Suite 370
Madison, Wisconsin 53703
Email: thornton@tess-inc.com

Jim Huggins
Solar Rating And Certification Corporation
400 High Point Drive, Suite 400
Cocoa, Florida 32926

Steven Long, P.E.
Solar Rating and Certification Corporation
14001 Summit Dr.
Whittier, CA 90602
e-mail: stevenlong1@charter.net

ABSTRACT

In the United States, annual performance ratings for solar water heaters are computed with component-based simulation models driven by typical meteorological year weather and specified water draw. Changes in the process are being implemented to enhance credibility through increased transparency and accuracy. Changes to the process include using a graphical rather than text-based model-building tool, performing analytical tests on all components and systems, checking energy balances on every component, loop, and system at every time step, comparing the results to detect outliers and potential errors, and documenting the modeling process in detail. Examples of changes in ratings are shown, along with analytical and comparative testing results.

Keywords: solar water heaters, ratings, solar water heater models, analytical testing.

1. INTRODUCTION

Annual performance ratings for solar water heaters (SWHs) at hundreds of sites across the United States are issued by the Solar Rating & Certification Corporation (SRCC) under its OG300 Guidelines (1).[1] The ratings give the solar system annual savings relative to a standard conventional system, under specific draws and weather from typical meteorological years (TMY3, (2)). As in Fig. 1, there are two rating paths (3): i) *component* test path; and ii) *system* test path. As indicated in Fig. 1, both paths yield calibrated simulation models that are used to generate ratings. In the component path, the key components (collectors (4), tanks, and heat exchangers (5), at the least) are tested according to standards yielding the input parameters for corresponding validated literal component-based models. A literal SWH model has a one-to-one correspondence to the real system, by components and hookups. A literal model must exist for the component path to make sense. Ideally, the model is validated over the range of rated systems sizes, and analytically tested for input errors. Actual systems are not tested (keeping rating costs low). The component path is very similar to ISO 9459-Part 4 (6), with the key exception that in the ISO standard the system must be physically assembled and tested to validate the system model. This makes the ISO component path expensive.

If a validated literal system model does not exist (e.g., as for various self-pumping systems) or any component model is not well-validated with prescribed tests for inputs (e.g., a heat pump water heater), the component path cannot be used. In this case, the system as a whole must be tested. A model that is "close" to the system is then fit to the system test data, yielding an "effective" model. A thermosiphon system, for example, might be chosen to model a self-pumping system, which is then calibrated to the data. This path is very similar to ISO 9459, part 5 (7), where a highly-simple model is used for all active systems. System path models result in "effective" models, with the regressed parameters subsuming the modeling mismatches in unknown ways. As a result, models from system tests cannot be easily extrapolated to similar systems of different sizes. In this paper we focus on the component path, and do not discuss the system path further.

[1] The SRCC "one-day" ratings are not of concern here, and are not discussed further.

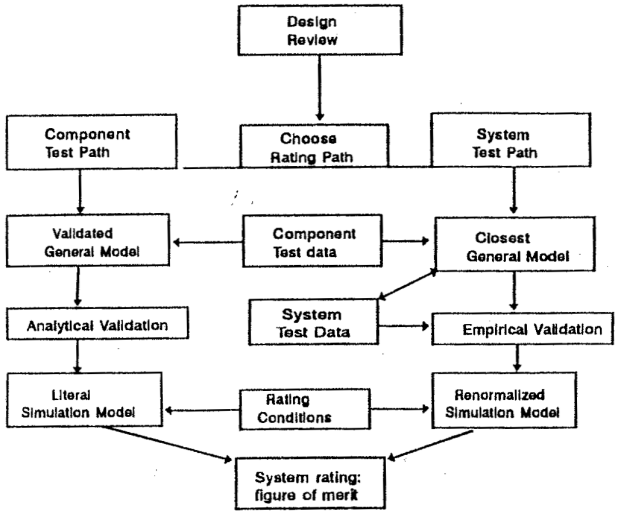

Fig. 1. Two paths available for rating: component tests and system tests, both followed by simulation of the ratings.

SRCC has stated a desire that ratings be accurate to better than 10%, although there is really no clear definition of accuracy, nor is there any process or database to verify that desire. Accuracy of the ratings is a basic issue for all stakeholders. Stakeholders, in increasing order of concern about accuracy of ratings, include: i) *consumers*, comparing performance for possible purchase of a unit; ii) *analysts*, comparing SWHs with other advanced technologies for policy and R&D planning; iii) *incentive organizations*, calculating performance-based rebates based on the ratings; iv); *suppliers*, comparing their SWHs to other SWHs and using ratings in sales; and v) *rating organizations*, such as SRCC and the International Association of Plumbing and Mechanical Officials, that generate and maintain the ratings. Incentive organizations and suppliers have the highest accuracy desires among users, as significant money hinges on the ratings.

A rating system must be *credible* with all the stakeholders. Credibility is founded on **accuracy** and **transparency**. *Accuracy* should be consistent across all system types, with no biases toward any technology or location vs. others. It should be accurate enough for use by all stakeholders (e.g., error < 10%). The modeling accuracy should be well-validated on a component and a system level. Without a systematic program of validation demonstrating accuracy, it is not possible to maintain rating credibility. The system should have inherent *transparency*, so that the process is open to scrutiny at varying levels, depending on stakeholder needs. This paper presents a new ratings modeling framework that enhances credibility through increased accuracy and transparency.

We first lay out the existing SRCC component path process and its attendant problems. In section 3, we consider analytical and numerical validation generally, indicating the vast array of possible validation tests and what they mean. Validation (like "truth") is an ambiguous, multi-faceted beast that cannot ever be tamed. In section 4, we present a proposed ratings procedure featuring high levels of validation and inherent transparency. In section 5 we give examples of early results from the system, and indicate the change in ratings from the old to the new framework. Lastly, conclusions and future efforts are given in Section 6.

2. CURRENT SRCC RATING PROCESSES

Both the current and proposed ratings structures are based on the modeling environment TRNSYS (8), because it is modular, extensible, and well-developed. *Modularity* means it allows any components to be hooked up with any other components; there are few hardwired connections, and system configurations are very easy to change (important as suppliers innovate). This modularity also means components can easily be wrongly connected. The tool, similar to MatLab and other equation solvers, is *extensible*, facilitating modeling of any component whose governing energy algorithms are known. It has a *well-developed* library of component models needed for modeling almost all SWHs and hydronic systems.

2.1 Ratings framework

The framework includes the model generation process and the input generation process. The draw must be specified, including the time profile and the mains temperature, as in (9).

The deckwriter. SRCC/OG300 system ratings began in 1991, when TRNSYS system models consisted of text files called "decks" specifying which components are present and how they are connected. The deck is a simple, flexible way to implement simple systems. Unfortunately, an SWH deck representing the relevant features of a functioning SWH can go beyond 30 pages. The prospect of creating and maintaining thousands of such decks was daunting. A *deckwriter* was coded to automatically write the decks, based on a brief list of system components and their parameters. A structured syntax for input/output variable names was constructed to automatically couple inputs and outputs. The deckwriter also facilitated changes in component models. Revised component model descriptions with their named input and outputs are written only once, in the deckwriter. The system has worked well, as models have been generated and maintained for ~20 years, with currently ~2000 SWHs in the database (most of the 2000 are variations in system size).

Draw specification. The impacts on the annual ratings of the assumed draw profile and mains temperature functions m(t) and $T_{mains}(t)$ are discussed in a companion paper (9). It is shown that the current SRCC T_{mains}

algorithm leads to ~8% upward bias in performance, depending mainly on collector F_rU_l. The temperature bias does not change the rank order of technology savings, but updated algorithms are needed for incentivizers.

Basic model validation. When OG300 began and implemented Fig. 1, a few system types and a small number of basic components were thought to be needed. A glycol and a drainback system were tested at a university over a range of component sizes (10). Physical models for the systems were assembled in TRNSYS and validated. These (and literally thousands of other SWH tests) indicate that a literal, component-based simulation model (using existing component models with key inputs derived from test data) adequately describes the system performance of conventional SWHs. The component and system modeling algorithms have proven to be sufficiently accurate. Having said this, testing for correct implementation of both the physical modeling and the input process remains a need.

2.2 Shortcomings of the current rating structure

Model validation. The two SWH configurations tested in (10) supported the premise that modeling can adequately represent SWH performance. We make two assumptions when extrapolating to similar models using the same algorithms: i) the **model** correctly formulates the relevant physics and solves the coupled equations; and ii) no errors are made in preparing the **inputs**. It is impractical to do actual tests on all configurations. No procedures were laid out for the current SRCC process as to when and how to test and check the models for input errors and coding bugs, and further validation was not done.

Transparency. Text files are a numbing mind-death when they go on for thousands of lines, as illustrated in Fig. 2. Parameter values are buried in the text. Combined with an unwieldy variable syntax, the model is inscrutable. As a result, even a simple examination of the component models or their couplings becomes very difficult. Transparency is lacking.

Documentation/consistency. The modeling assumptions have limited documentation and have not always been applied consistently. For example, tank losses in stratified auxiliary tanks with solar pre-heat were overestimated because of too-few nodes, causing underestimation of electric system savings (11). A problem not with the rating process so much as with SRCC practice lies in what data were considered acceptable. Collectors are always formally tested under Standard100/ ISO9806, but tank and heat exchanger data, as required in (5), were not always provided. Work-arounds and simplifying assumptions follow that decision. Consequently there is varying and unknown accuracy in tank and heat exchanger component models. In addition, documentation of the process for deriving inputs is spotty or non-existent.

Fig. 2. The first 6 pgs of a TRNSYS deck. Extended text files are inscrutable, as is this figure.

Internal checks. Simulation models pose tradeoffs between convergence tightness, time step, noding, and simulation speed. Internal checks were not always made, so relaxing criteria to speed computation time became risky and led to occasional energy imbalances. Checking the model's energy balances catches these errors.

User error. It is difficult to ferret out user errors when there is limited checking of results. As an example of a user error, the lower deadband on controllers was set to 0, due to stability issues in one-day simulations, and was not reset for the annual runs. This implies that the solar loop pump is pumping inappropriately on warm nights, increasing the parasitics by 50%. Although not detectable in savings (it decreased savings only a few percent), comparison of pump on times between PV-powered and ΔT-controlled pumps will catch such an error.

3. VALIDATION OF SWH MODELS: GENERAL

Validation of the underlying SWH models is essential to build credibility in the ratings. Validation is akin to "truth" in that it is uncertain what is precisely meant and it is certain one will never answer all the questions. However, its difficulty should not be a deterrent. Without validation, reasonable but unanswerable questions remain, even if the physical modeling basis is accepted.

Some general sources of error in simulation modeling are given in Table 1 (12). There are many levels of validation, depending on the degree of control exercised over the possible sources of error in a simulation. For our case, the first two errors are eliminated by *rating process definitions* of weather and draw for ratings. As previously discussed, the physical algorithms are generally not in question, although physical tests are important for systems having novel features not previously well-validated.

TABLE 1. TYPES OF SIMULATION ERRORS[1]

Errors external to the model
Actual weather and use conditions vs. assumed
Actual properties/characteristics vs. assumed
User error in inputs
Errors internal to the model
Incorrect algorithms for energy mechanisms/ couplings
Incorrect solution of algorithms
Coding error

1. Adapted from (12).

There are three broad approaches to validation (12): i) **analytical:** the model results are compared to an analytical solution of the coupled equations the model purports to solve; ii) **comparative**: the model results are compared to other simulations solving the same problem, or model results for similar systems are compared; and iii) **empirical**: the model results are compared to measured system performance, using the measured weather and draws and measured component parameters. Empirical validation is the only way to test the accuracy of the assumed physical algorithms; the other tests assume the physical algorithms are correct, and test the solution and input process. It is part of a future international effort toward a validation standard as in (12) for building models. The analytical/empirical validation implemented here is a first step toward developing such a standard. Analytical and comparative tests uncover both internal and external error.

4. PROPOSED RATING PROCESS

The proposed structure is mostly unchanged from that presently used. The same modeling environment is used, the same- or very similar- component models are used, and the processes for deriving inputs are essentially the same. Changes were made to promote transparency and increase accuracy, as summarized in Table 2. Change in ratings is discussed in Section 5.

4.1 Rating process basics

Before modeling began, it was necessary to define a systematic simulation protocol, structure a database that enables maintenance of models and documents results of tests, and define the generic SWH configurations in the SRCC OG300 database that must be modeled.

Simulation protocol. A simulation protocol specifies how to develop rating models and their inputs. The processes will be documented here similar to the house simulation protocol in (13). The protocol document will be written on a general and technical level, to allow scrutiny appropriate to different stakeholders.

TABLE 2. RATING PROCESS CHANGES

Accuracy-related	
New draw	New T_{mains} and $m_{draw}(t)$; 3 draw levels
↓Tolerance	Tight energy balances maintained
↑Noding	Correct heating elements placement
Energy balances	Key component, fluid loop, and system energy balance checked every time step
Transparency-related	
Graphical modeling	Components and their interconnection are clear and visible
Traceability	All component and system models are accessible; versioning and ratings history
Documented tests	Results of all analytical and numerical tests are accessible; versioning history

Ratings database. The ratings database will hold all models and test results. It will be modular, so that stakeholders can have access to the specific parts of interest, as appropriate. A component supplier (collector or tank manufacturer) has access to those files relating to his component. An OG300 system supplier has access to files related to his system. System suppliers will automatically generate the relevant parameter file as part of their OG300 application in the near future. Similarly, testing laboratories and manufacturers will use supplied software to translate their test data into model inputs.

Configurations. A *configuration* is a generic system model that explicitly defines all components, their interconnections, and the driving forces. A configuration class is all SWHs modeled by changing only parameter values in a given configuration. Configurations result from a unique choice of components and their interconnections. As of this writing, there are 130 configurations in the database, and about 100 of the configurations have been completed and passed analytical testing. Each configuration produces annual ratings, one-day ratings, or validation test results, as set by a switch in the system include file.

4.2 Transparency features

The new modeling is *inherently* transparent because the system construction is graphical, with linked icons representing discrete components. Fig. 3 shows the model for a flat plate glycol SWH with a solar tank and an electric auxiliary tank, an external solar loop heat exchanger, and a differential controller. Model components are icons and are easily grasped. Compare to Fig. 2. Couplings are also graphical; couplings between any input and output variables in any two components are accessible.

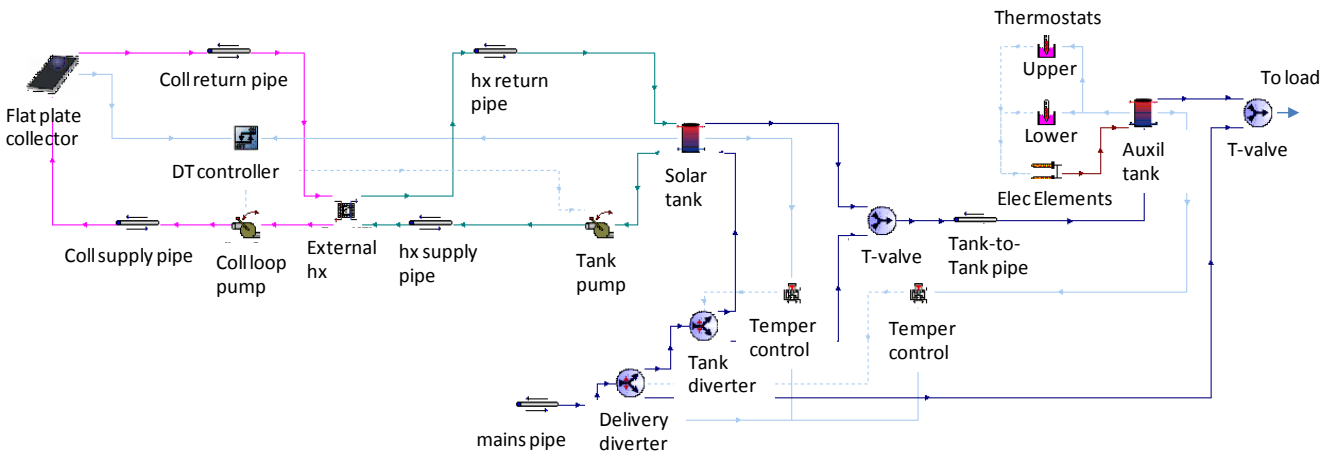

Fig. 3. Graphical representation of a flat plate SWH, showing interconnected icons. (Two tempering valves allow the simulated valve location to vary with auxiliary type.)

Structured parameter files. The modeling is structured for vetting of inputs by SWH and component suppliers. Each system model has two files: one that contains all the parameters peculiar to his system, and one that specifies the simulation internal parameters. Having a compact list, *a SWH supplier can check that all his system's parameters are entered correctly.*

Tanks and heat exchangers should have test data submitted as in (5). In cases of tanks, model parameters are extracted by a regression on the data (e.g., tuning of immersed heat exchanger models, or collector/tank parameters). In others, the test results are the input themselves, such as the performance map required in (5). The data and the tools applied to that data will be archived in the database, documenting these input derivations. Any changes in the data will be tracked in a versioning scheme.

Supplier results. Results are available at any time step desired, but hourly, monthly, and annual intervals are useful. Hourly files rapidly grow large and must be limited to small samples. Hourly files might cause excess staff time responding to questions, as hourly data is quite complex. Monthly/annual files are of most interest, and will be provided to all suppliers for all their systems. Suppliers will examine monthly data for their systems, certainly, and they could use that data in sales tools. Fees could be charged for supplier access to more details, such as voluminous hourly or even one-minute files. The supplier could be furnished with an un-modifiable version of the model itself, for optimization of his system.

4.2 Accuracy checks

Internal coding errors and external user errors are tested for. No empirical tests are used here.

Analytical validation. Analytical tests will be done on each component and each configuration. Examples of the tests done are listed in Table 3. Both *components* and *whole systems* are validated. The goal is that every component and every system is tested. Tests and their analysis will be automated. Analytical testing is facilitated by the validation port placed in the model, allowing any drivers for sun, ambient temperature, draw, etc.

Component tests were implemented without expectation of finding issues. Unfortunately, that was not entirely true, illustrating the power of these tests. Collector models failed the test that collector outlet temperature must approach the stagnation temperature at very low flows. This led to a revision of the theory for the heat removal factor appropriate for collectors modeled with a quadratic efficiency equation (14). The F_r equations developed for a collector with linear efficiency equation were used with a quadratic collector curve. The error is small under normal operation, so no one had noticed the inconsistency.

TABLE 3. ANALYTICAL TEST EXAMPLES

Component tests	
Coll. stagnation	Very low flows $\Rightarrow T_{coll,out} \rightarrow T_{stag}$?
Coll. T_{out}	Design flows, $T_{coll,out} = T_{predicted}$?
Tank decay	Time constant = Mc_p/UA_{total}?
Temper. valve	Given γ^1, T_{out}, $m_{out,1}$, $m_{out,2}$= predicted?
Pump	Given γ^1, power & flow = predicted?
System tests	
Constant draw	m_{draw}, I, T_{amb} fixed; $T_{sysout}=T_{predicted}$?

Note 1: γ is the control signal to the component

System tests have not been developed much to date. A simple case is shown in Table 3. This test does provide a fairly stringent test on the model. The system validation is assured mainly through implementation of energy balances.

Energy balances. An energy balance proceeds by defining a system of interest, and checking how well energy conservation is obeyed:

$$\sum_i Q_{in,i} + \sum_i Q_{out,i} = \Delta Q_{stored}$$

Energy balances are done on components, all loops (such as a solar-heat exchanger-pump loop), and the system. *When energy balances are tightly maintained, there is high confidence that the solution is proceeding correctly.* Component models were modified as necessary to output energy flows. All energy balances are checked at every time step. Time-step imbalances and their annual average and maximum value must be less than a specified tolerance.

Configuration comparison (CC). The CC test compares all configurations, running a standard system in all configurations. The collector area/type/orientation, and tank volume are kept constant. Other parameters are adjusted to be as equivalent as possible. CC finds errors large compared to typical variations between configurations. It allows systematic differences between configurations to be seen, such as differences between drainback and glycol systems. Examples are shown below. The tool to do these comparisons may be made available on the SRCC web site.

System intercomparisons. It is useful to intercompare the ratings to look for outliers and show how a given system competes with other systems of similar configuration. This test will be implemented when the ratings data base is fully populated. To account for system size and compare across climates, savings can be plotted versus a normalized variable, such as $H_{day,avg}A_{coll}$. Each supplier can be provided plots of his systems against all other similar systems. He can see if he is doing well, or needs to improve his design.

5. INITIAL RESULTS

Fig. 4 shows the CC test results for one system of each configuration for five cities: Phoenix, Washington DC, Denver, Chicago and Seattle. , indicating noticeably higher savings for some configurations. The data can be displayed via two independent filters. Fig. 5 shows savings for systems with tankless or boiler backup vs. all other systems. It is evident that the tankless/boiler auxiliary induces a large increase in savings. The reference is a standard gas storage tank water heater, implying that the solar savings is added with savings from a better auxiliary. Savings has to be understood as (solar+tankless) vs. gas storage water heater. Fig 6 shows the savings of all configurations with gas auxiliary, versus all configurations with electric auxiliary. It is evident that the gas case saves more than the electric case. Notice the difference is constant across configurations. The difference is due to two effects: i) the conversion efficiency $\eta_{gas,conv} = \sim 0.8$, whereas $\eta_{elec,conv} \equiv 1.0$, implying gas fuel saved for a given solar therm in the tank (which TRNSYS computes) is 25% higher; and ii) the electric tank bottom element is ~ 8" above the tank bottom, implying increased tank losses of order several hundred kWh with solar, which also decreases savings (11). These two effects are mostly independent of the solar system, so we expect the gas-electric difference to be mostly constant, independent of the solar pre-heat system, as shown. This is a severe test of modeling accuracy, which is passed by the proposed system.

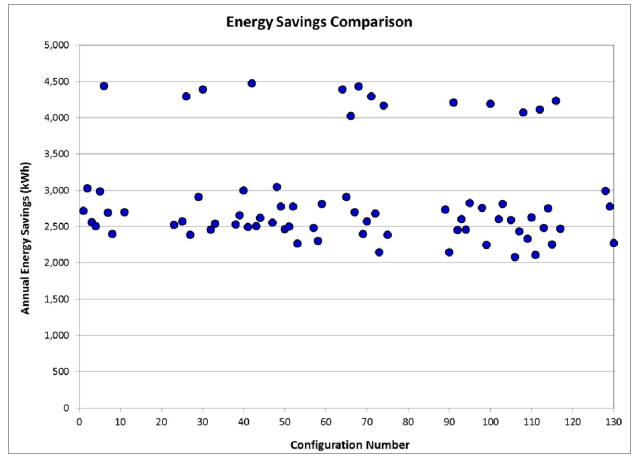

Fig. 4. Savings for a standard system in all configurations modeled to date. Note the grouping around 4,200 kWh.

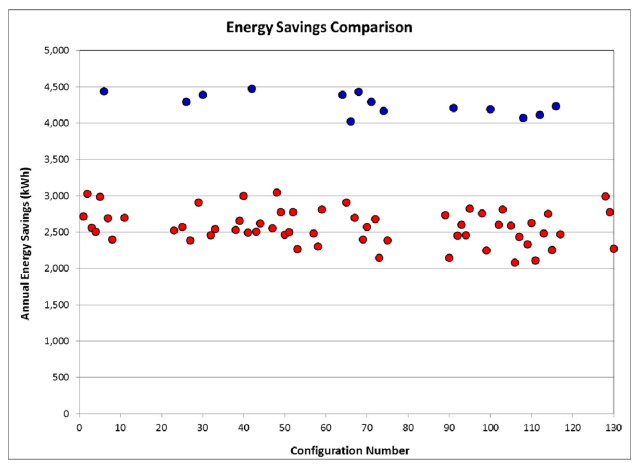

Fig. 5. The upper blue dots are all SWH with tankless auxiliary, and the lower red dots are all other SWH.

A scatterplot showing agreement between the current and the proposed system is shown in Fig. 7. In general, there is consistent reduction in savings, averaging 8% for this subset of systems. Some systems show decreases up to 40%. There is no noticeable trend in percent rating change with savings level, as shown in Fig. 8. The main causes for the change in ratings are the draw changes (9), both in changing to mostly tempered draws and in increasing the mains water temperature by about 5 ^{o}F. Other causes for the change in outliers have been investigated in a few cases, but it is

arduous to do so and won't be done routinely. Energy balance errors and thermostat placement in current models were two problems identified. Part of the disagreement is caused by the differences between TMY2 and TMY3 radiation data. Differences on total horizontal incidence are shown in Fig. 9. Beam radiation increased slightly, and diffuse radiation decreased. Although the differences are low on average (1%), some significant irradiance differences will show up in new-old comparisons.

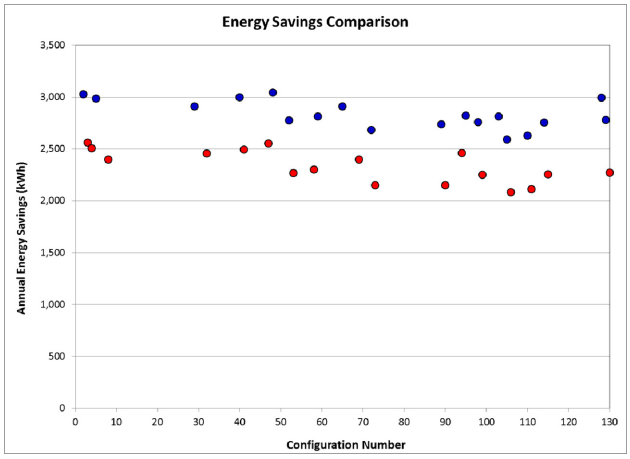

Fig. 6. Upper blue dots are for SWH with gas storage tank auxiliary, and lower red dots have electric storage tank auxiliary.

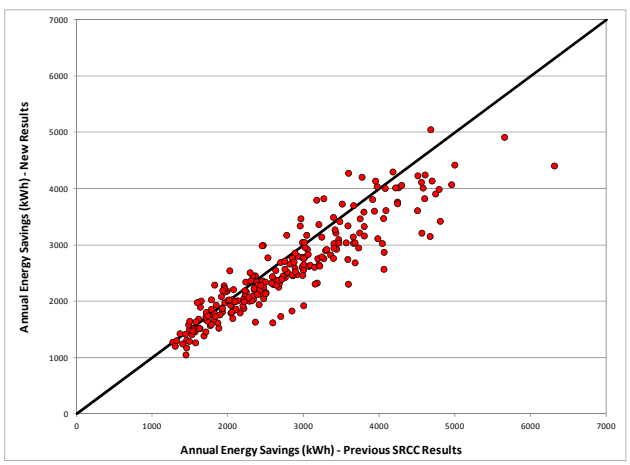

Fig. 7. Agreement between savings for current and proposed ratings.

6. CONCLUSIONS AND FUTURE WORK

The current SRCC ratings structure has functioned well for over 20 years, providing models for ~2000 rated systems in about a hundred configurations. However, its shortcomings in transparency and validation became apparent in several instances investigating rating accuracy, and a change was in order.

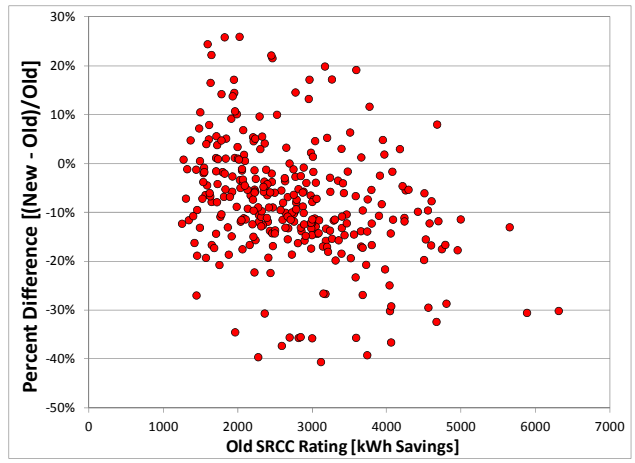

Fig. 8. Percent change in the ratings vs. the old SRCC rating.

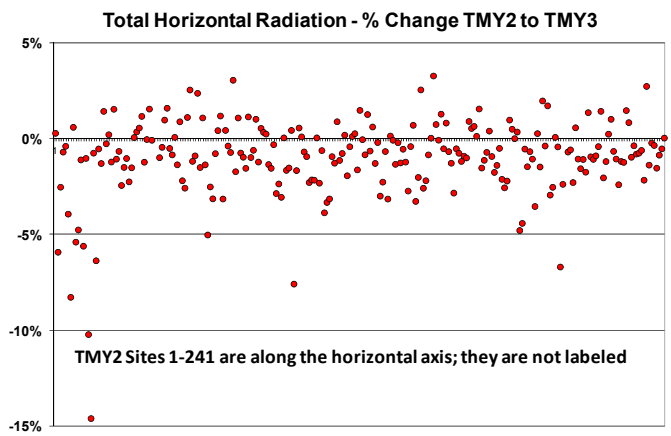

Fig. 9. Percent change in H_{horiz}, between TMY2 and TMY3 weather files; $\Delta \equiv (H_{TMY3} - H_{TMY2})/ H_{TMY2}$.

A new rating structure has been developed and is in the process of being implemented. It is inherently transparent, as the components and couplings are graphical and models can be understood relatively easily. A ratings database is being constructed that embodies all the component and system models, and documents all the analytical and comparative testing done on the components and systems. A key aspect of the new models is a systematic application of energy balance checks on every component, every fluid loop, and the total system. The level of accuracy has been improved to allow consistent and meaningful cross-comparisons and checks.

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8. NOMENCLATURE

Symbols:

c_p	= specific heat
F_r	= Heat removal factor
H	= Solar incidence over some period (energy/area)
I	= Solar irradiance (power/area)
m	= mass flow rate
M	= mass
Q_{sav}	= Energy saved
T	= Temperature
U_l	= Collector loss coefficient
γ	= control signal
η	= Efficiency (collector or system)
Δ	= Difference

Subscripts

amb	= ambient condition
ann	= annual, or annual average
col	= collector
conv	= input fuel conversion efficiency
elec	= electric auxiliary "fuel"
gas	= natural gas fuel
in	= incoming
inc	= incident solar on collector
mains	= water mains inlet
out	= outgoing
predict	= predicted value
stored	= stored energy with system boundary

Acronyms

BTP	= Buildings Technology Program
CC	= configuration comparison test
DOE	= U.S. Department of Energy
SRCC	= Solar Rating and Certification Corporation
SWH	= solar water heater(s)
TMY	= Typical meteorological year
TRNSYS	= Transient system simulation

9. REFERENCES

(1) *SRCC Operating Guidelines OG-300: Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems*, available at http://www.solar-rating.org/certification/standards.html.

(2) TMY3. Description and manuals are available at: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

(3) Burch, Jay, J. Thornton, J. Huggins, and S. Long, "Simulation-based Ratings for Solar Hot Water Systems", American Solar Energy Society, Annual conference 1993.

(4) ISO 9806: *Test methods for solar collectors- Parts 1,2, & 3.* Available from the International Organization for Standardization (ISO), www.iso.org.

(5) *TM-1: Solar Domestic Hot Water System and Component Test Protocols* Available from SRCC at http://solar-rating.org/certification/standards.html

(6) ISO 9459, Part 4. *System performance characterization by means of component tests and computer simulation.* Available from the International Organization for Standardization (ISO), www.iso.org

(7) ISO 9459, Part 5. *System performance characterization by means of whole system tests and computer simulation.* Available from the International Organization for Standardization (ISO), www.iso.org

(8) Sandy Klein et al. TRNSYS; A Transient System Simulation Program; Solar Energy Laboratory, University of Wisconsin-Madison: Madison, WI, 2006.

(9) Burch, Jay, and J. Thornton, "A Realistic Draw Specification for Rating Solar Water Heaters", ASES/WREF2012, Denver, CO, May 13-19.

(10) Davidson, J.H., W. Carlson, and W. Duff, "Impact of Component Selection and Operation on Thermal Ratings of Drain-Back Solar Water Heaters," _ASME J. Solar Energy Engineering, V114, 4, 219-226, 1992.

(11) Burch, Jay, "Deriving Simulation Parameters from Rating Data for Stratified Storage Tank Water Heaters", American Solar Energy Society, Annual conference 2011.

(12) Ron Judkoff, Wortman, D., O'Doherty, B. and Burch, J. "A Methodology for Validating Building Energy Analysis Simulations."Technical report NREL/TP-550-42059, April 2008.

(13) Hendron, R. and C. Engebrecht, *Building America House Simulation Protocols*, 2010, Golden, CO. NREL/TP-550-49246.

(14) Thornton, J., private communication; to be published.