Docket No. 13-BSTD-01:

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Notice to Staff Workshop RE:
Water Heating Systems

In the matter of:
Scoping Water Heating Systems for Future Building Energy Efficiency Standards

Purpose:
Correct bias errors in Domestic hot water Energy Load calculations while including energy savings credits from both Drain Water Heat Recovery (DWHR) systems and Hot Water Distribution Efficiency (HWDE).

BACKGROUND

Water heating is the second or first largest energy load in homes; its contribution to total home energy load has increased in recent years as building envelops and mechanical systems improvements have resulted in significant reduced energy consumption. Domestic water heating and delivery technology have also improved; The State of California recognizes many of these improvements. However, energy credits for DWHR and HWDE systems have yet to be recognized. Such building energy code credits are available in the Ontario, Canada, France, the United Kingdom and France. Furthermore, because of their longevity (100+ year life) and ease of installation during new construction, DWHR and HWDE should be considered to be a part of the “infrastructure” of the home.

One current fundamental problem is that the typical calculations for Domestic Hot Water Energy Load is rather constant across climate zones and these don’t easily allow for changes to hot water load itself. The good news is that it by using the water heater’s rated Energy Factor and Recovery Efficiency (or Recovery COP), one can easily correct the water heating system performance and, hence, hot water energy load for actual site conditions to accurately calculate annual, monthly or even daily energy loads.

This methodology uses the HERS rating system and can easily be adapted for the State of California. Furthermore, the methodology presented can be used to accurately “adjust” hot water system energy performance (i.e. Modified System Energy Factor, called “Energy Ratio” herein) either on an annual, monthly or even daily basis.

This same methodology has been submitted to RESNET for adoption.

Hot Water Load and Mains Water Temperature

The annual domestic hot water energy load for the HERS Reference Home and the HERS Rated Home is calculated according as:

$$LOAD_{DHW} = \frac{C_p \bullet (30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right) \bullet 365}{E_f}$$

Where: C_p is the Specific Heat of Water.
E_f is the water heater's rated energy factor
T_{mains} is the supply fresh mains water temperature. It is not specified by HERS (could not be found in the manual) but is believed to currently be 58.0°F (which is used to determine E_f according to DOE procedure).

However, T_{mains} does vary by location across the United States and it also varies by time of year. By using a fixed value for T_{mains} regardless of location, annual hot water load will usually needlessly be over estimated or under estimated. It is therefore **recommended** that HERS includes a firm location-specific specification for T_{mains}, thereby no longer allowing one fixed temperature to be used across all climate zones. Either of the following is recommended:
1) T_{mains} shall be the average monthly or average annual mains water temperature according to established local conditions, OR
2) T_{mains} shall be the Average Annual Ambient Temperature - 6.0°F.[2] That is, $T_{mains} = T_{ambient}$ - 6.0°F.
NOTE: It is also possible to reasonably predict the monthly average annual mains water temperature with a model provided in the same paper. [2]

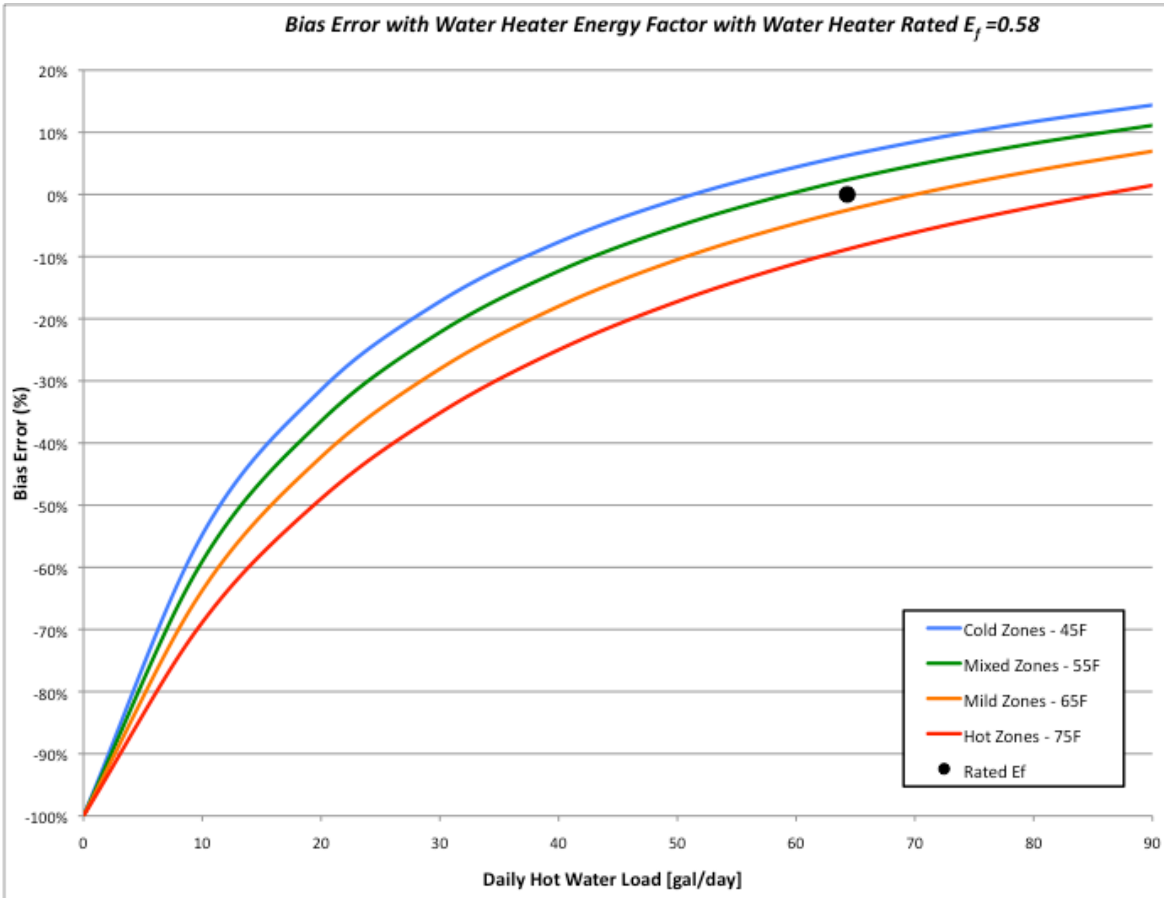
Energy Factor (E_f)

According to the HERS Standard equipment performance ought to be adjusted according to local conditions as stated here:
"303.5.1.4 Manufacturer's Equipment Performance Ratings (e.g., HSPF, SEER, AFUE) shall be corrected for local climate conditions and miss-sizing of equipment………."

Currently, HERS does not use a correction procedure for E_f. Since the water heater Energy Factor (E_f) test procedure requires an fixed hot water load and fixed temperatures, it does not represent what a water heater's true annual coefficient of performance (i.e. Energy Factor) will be for a given home in a given location. The same cannot be said for furnace AFUE, which is corrected. A water heater's actual annual coefficient of performance (which is Energy Factor, E_f) is highly dependent upon occupancy (hot water volume load), mains water temperature, and delivery temperature, because E_f itself is primarily dependent upon a water heater's recovery efficiency and standby losses.

Domestic Hot Water Energy Load - Bias Error

The following graph illustrates the actual Bias Error that is currently introduced into domestic hot water load calculations by assuming that E_f is constant, as a function of Hot Water Load in gallons/day and for different average annual mains water temperatures:

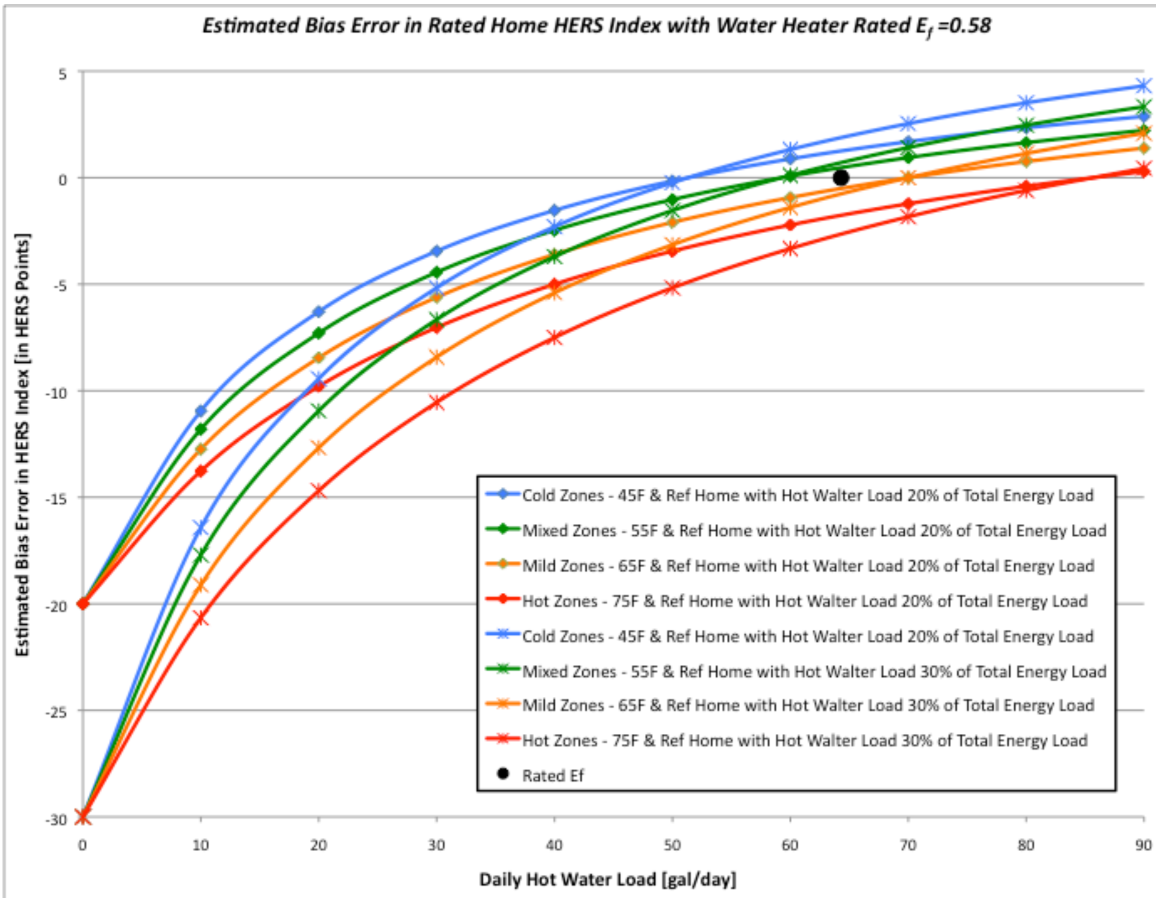


HERS Index - Bias Error

By nature of how the HERS Index and hot water energy load are both calculated, it is now easy to assess the potential Bias Error with the HERS score itself, based upon the hot water energy load's contribution (as a percent) to the total HERS reference energy load. The reason for this is that the hot water contribution to the HERS Index can be reduced and expressed as this simple ratio: $HERSerror_{DHW} = \frac{E_{r\_rated}}{E_{r\_reference}} \bullet \%DHWofTotalEnergyLoad$

Note that this ratio assumes that the volume of hot water use is the same between the reference and the rated home.

The next graph shows this bias error in the HERS score as a function of daily hot water load, based upon hot water load being 20% and 30% of total energy load for the reference house (i.e. %DHWofTotalEnergyLoad = 20% and 30%). For example, if the modeled house has an hot water load of 40 gallons per day and service water heating accounts for 30% of total load in the reference home in a hot climate zone, the HERS Index for the rated home is about 7 points lower than it ought to be if the Energy Ratio (E_r) were used.



ADJUSTING THE USE OF ENEGY FACTOR:
INTRODUCTION TO THE “ENERGY RATIO”

The term “Energy Factor” (E_f) is Federally regulated and therefore one must be mindful about how it is used, especially in publications and modeling. In the January 1st version of the “Mortgage Industry National Home Energy Rating Systems Standards”, it is defined as follows:
“Energy Factor or EF –A standardized measure of water heater energy efficiency as determined under Department of Energy Regulations, 10 CFR 430.23(e)(2)(ii).”

In order to avoid confusion and other issues that could arise by using the term Energy Factor to describe a “modified” or “adjusted” performance number for water heating, the term “Energy Ratio” (E_r) is now used here when correcting for site-specific water heating energy load conditions. Both E_f and E_r are used in the same manner for estimating annual (or other time period) hot water energy load. Fortunately, the site-specific Energy Ratio (E_r) is easily determined by this comprehensive equation, which includes Drain Water Heat Recovery[1] technology:

$$E_r = \frac{\eta_{r\_test}}{1 + \left[\frac{\eta_{r\_test}}{E_{f\_test}} - 1\right] \bullet \left[\frac{T_{del\_site} - T_{a,stby\_site}}{T_{del\_test} - T_{a,stby\_test}}\right] \bullet \left[\frac{V_{test} \bullet \left(T_{del\_test} - T_{in\_test}\right)}{HWDE_r \bullet V_{site} \bullet \left(T_{del\_site} - T_{in\_site}\right)}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

Where:

-η_{r_test} is the primary water heater’s rated recovery efficiency or 0.98 for electric resistive water heaters or the recovery COP for heat pump water heaters
-E_{f_test} is the primary water heater’s rated Energy Factor as per test

-T_{del_site} is the actual water heater set-point temperature, 120 °F
-$T_{a,stby\_site}$ is the actual room temperature, assume 67.5 °F
-T_{del_test} is the test water heater set-point temperature, 135 °F
-$T_{a,stby\_test}$ is the test room temperature, 67.5 °F

-V_{test} is the test hot water draw, 64.3 gallons per day
-T_{in_test} is the test mains water temperature, 58.0 °F
-V_{site} is the actual hot water draw [gallons per day], which is: 30*Ndu + 10*Nbr, where Ndu is the number of dwelling units and Nbr is the number of bedrooms
-T_{in_site} is the actual mains water temperature, site specific

-η_{r_DWHR} is the Drain Water Heat Recovery unit efficiency in accordance to:
CSA B55.1 and listed by a recognized agency (e.g. UL, ETL)
It is zero if there is no DWHR unit present.
-C_{DWHR} is the Drain Water Heat Recovery Coefficient,
1) 0.432 if all of the showers in the home are connected to the DWHR unit or units
2) 0.216 if there are 2 or more showers in the home and only 1 shower is connected to a DWHR unit or units
3) 0.0 for the reference house
-$HWDE_f$ is the Hot Water Distribution Efficiency factor. $HWDE_f$ is set to 1.0 for both the Reference House and the Rated House until there is an approved model as part of a separate submission to RESNET.

PROPOSAL A – Full Equation

The authors think the full equation is the most appropriate to adopt because it corrects many current problems with domestic hot water energy modeling. It can be used for any modeling time period (e.g. daily, monthly, annual, etc.). However it might be considered too complex to adopt by initially. Therefore two additional alternate proposals are also made herein, as follows.

PROPOSAL A – Simplified Energy Ratio Equation

If it were decided that hot water load, mains water temperature and set-point water temperature should not be considered in the Energy Ratio at this time, then we arrive at two simple equations, which provide for a simple credit calculation for DWHR:

$$E_{r\_reference} = E_f$$

and

$$E_{r\_rated} = \frac{\eta_{r\_test}}{\left[\dfrac{\eta_{r\_test}}{E_{f\_test}}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

It should be mentioned that CRESNET (Canadian RESNET) uses these equations and this approach is included within the Canadian version of REM/Rate, specifically to provide credit for DWHR systems. Natural Resources Canada (NRCan) has also used this equation within the EnergyStar for New Homes Ontario program since 2006.

One may think that using DWHR should only result in a simple multiplier on Energy Factor to arrive at Energy Ratio, but this is not the case because DWHR systems do not directly save anything on standby losses. This equation reflects reality, is conservative and it also accounts for differences when operating with different water heater types.

It might be preferable to adopt this equation in a timely fashion in order to include an energy credit for DWHR, as CRESNET has done.

PROPOSAL B – Reduced Energy Ratio Equations

Part 1) - HERS Reference Home E_r Equations

We can also substitute all of the constant parameters into the comprehensive E_r equation to arrive at much simpler equations to use in practice, by water heater type.

For example, with Fuel-based (e.g. Natural Gas, Propane, Oil, etc.) Primary Water Heaters, if the baseline water heater has E_{f_test}=0.58 & η_{r_test}=79% then the new Reference Home Energy Ratio reduces to:

$$E_{r\_reference} = \frac{0.76}{1+\left[\frac{1394}{(30+10*Nbr)\bullet\left(120°F-T_{mains}\right)}\right]}$$

Also, for Electric Resistive Primary Water Heaters, if the baseline water heater has E_{f_test}=0.92 & η_{r_test}=98% then the Reference Home Energy Ratio reduces to:

$$E_{r\_reference} = \frac{0.98}{1+\left[\frac{251}{(30+10*Nbr)\bullet\left(120°F-T_{mains}\right)}\right]}$$

Finally, for Heat Pump Water Heaters the actual reference water heater may be either a natural gas water heater or an electric resistive water heater, as per above. However, if the reference water heater is a heat pump water heater, then the next equation applies. The recovery COP (akin to recovery efficiency) is not specifically reported or labeled on Heat Pump Water Heaters. However, based upon standard tank insulation levels, one can use the ratio of: Recovery Efficiency to Energy Factor for a typical tank electric resistive water heater to calculated a reasonable recovery COP as: $COP_{r\_test} = E_{f\_test}$*0.98/0.92. If the baseline water heater has E_{f_test}=2.4 then, for example, $COPr_{\_test} = \eta_{r\_test}$ = 3.56 then the Reference Home Energy Ratio reduces to:

$$E_{r\_reference} = \frac{2.56}{1+\left[\frac{251}{(30+10*Nbr)\bullet\left(120°F-T_{mains}\right)}\right]}$$

These equations still fulfill the requirements of *430.23(e)(2)(ii)* because they provide correction for load (i.e. sizing) and for local conditions (i.e. hot water set-point temperature at 120 °F and T_{mains}).

It should be noted that if or when there are changes to the fixed parameters (e.g. base water heater E_f), these reduced conditions would also have to be changed. This might not be an issue as RESNET is always updating models based upon the most current data.

<u>Part 2) - HERS Rated Home E_r Equations</u>

In like manner, by substituting all of the constant parameters into the comprehensive E_r equation, the Rated Home equations are very similar.

For Fuel-based Primary Water Heaters with above assumptions:

$$E_{r\_rated} = \frac{0.76}{1+\left[\frac{1394}{(30+10*Nbr)\bullet\left(120°F - T_{mains}\right)}\right] - \eta_{DWHR}\bullet C_{DWHR}}$$

For Electric Primary Water Heaters with above assumptions:

$$E_{r\_rated} = \frac{0.98}{1+\left[\frac{251}{(30+10*Nbr)\bullet\left(120°F - T_{mains}\right)}\right] - \eta_{DWHR}\bullet C_{DWHR}}$$

For Heat Pump Water Heaters with above assumptions:

$$E_{r\_rated} = \frac{2.56}{1+\left[\frac{251}{(30+10*Nbr)\bullet\left(120°F - T_{mains}\right)}\right] - \eta_{DWHR}\bullet C_{DWHR}}$$

HOT WATER LOAD CALCALATIONS

Now, the new Reference Home Hot Water Energy Load is:

$$LOAD_{DHW\_reference} = \frac{C_p\bullet(30+10*Nbr)\bullet\left(120°F - T_{mains}\right)\bullet 365}{E_{r\_reference}}$$

And the new Rated Home Hot Water Energy Load looks virtually the same:

$$LOAD_{DHW\_rated} = \frac{C_p\bullet(30+10*Nbr)\bullet\left(120°F - T_{mains}\right)\bullet 365}{E_{r\_rated}}$$

But they each use a different Energy Ratio. T_{mains} is as proposed above.

As previously explained above, the change in the HERS Index is the key determining factor for crediting changes in hot water system efficiency, assuming there is no change in the volume of hot water use. However, the volume of hot water certainly play a role in determining the %DHWofTotalEnergyLoad, which certainly affects the change in HERS score for water heating.

DRAIN WATER HEAT RECOVERY: BACKGROUND AND COMMENTS

A Drain Water Heat Recovery (DWHR) device is a heat exchanger, which uses outgoing warm drain water to pre-heat incoming cold freshwater. It is rated for efficiency and pressure loss according to CSA B55.1 and complies with CSA B55.2.

CSA B55.2 is a Safety compliance Standard that is specific to Drain Water Heat Recovery units. It specifies the minimum types of copper that are permitted in fabrication and that all units must be pressure tested at 160 PSI to ensure there are no leaks. It also requires that all units are DOUBLE-WALL-VENTED.

CSA B55.1 is a Performance Standard, which rates the PRESSURE LOSS and EFFICIENCY of Drain Water Heat Recovery units at an equal flowrate of 2.5 gallons per minute. These 2 Standards are referenced in the Ontario Building Code.

In North America, DWHR units are installed in over 25,000 homes and for over 10,000 apartment, hotel suites and dorms as well as in many Recreation Facilities, Restaurants and Laundry Facilities. There are at least 3 North American Manufacturers and all known manufacturers have units that comply with the clause submitted. Home Depot sells these systems on-line.

CSA B55.2 compliant units have no moving parts and require no maintenance. The “Board of Examiners of Plumbers and Gas Fitters of Massachusetts” has approved this technology for over 5 years now.

To ensure safety and water supply in the home, the State of California may consider adopting the follow statement:
“Drain water heat recovery units shall comply with CSA 55.2. Drain water heat recovery unit efficiency shall be in accordance with CSA 55.1. Where more than one Drain water heat recovery unit is used, the average efficiency shall be applied. Potable water-side pressure loss of drain water heat recovery units shall be less than 3 psi (20.7 kPa) in accordance with CSA B55.1. There shall be a permanent label be affixed to each DWHR unit and to facilitate verification, a second duplicate label shall be located within 10 feet (3 meters) of the water heater, which will also detail where the DWHR unit is located.”
A very similar statement has been approved for inclusion in the 2015 IECC.

REFERENCES

1. “Introduction to a Method for Calculating Site-Specific & Seasonal Water Heating Energy Factor”; presented at the May 2012 ACEEE Hot Water Forum, Gerald Van Decker, RenewABILITY Energy Inc. *(available online)*

2. “TOWARDS DEVELOPMENT OF AN ALGORITHM FOR MAINS WATER TEMPERATURE”, Jay Burch and Craig Christensen, National Renewable Energy Laboratory *(available online)*

Introduction to the Method for Calculating Site-Specific Hot Water Energy Loads

Presented by:

Rod Buchalter

RenewABILITY ENERGY INC.

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Hot Water is Important: it is a Big Load and is Often Equal to Space Heating

The E_f Testing & Rating Method for Water Heaters assumes:

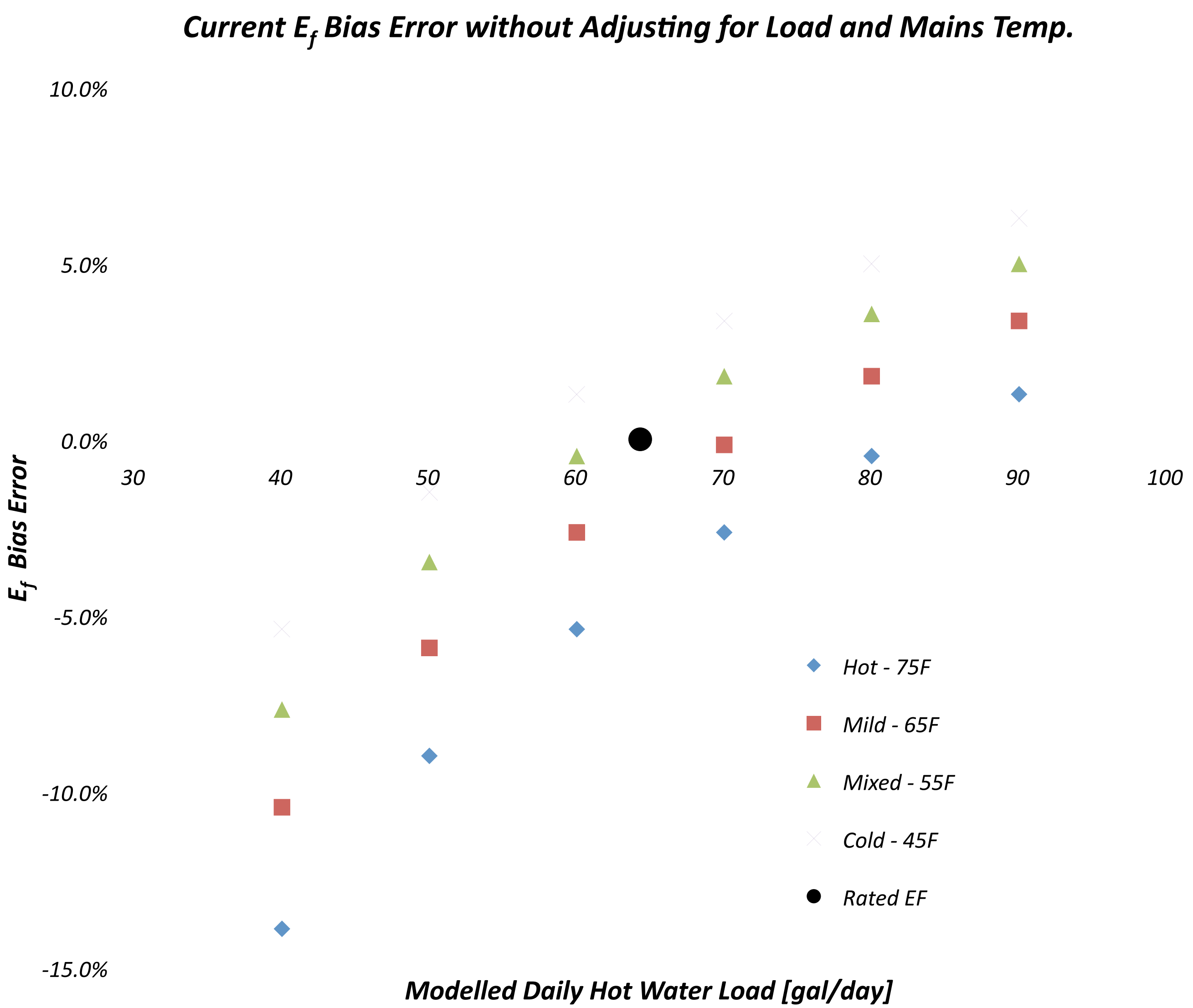
1) an Average Climate (T_{mains} = 58.0°F),
2) an Average Load (64.3 gallons per day), and
3) a Water Heater Set-point temperature of 135°F, while HERS uses 120°F

Using an Average Energy Factor (E_f) for calculation of Water Heating Energy Load is like using:

"average climate data and average house size to calculate Space Heating Load for Every HERS rated home regardless of actual design and location"

The assumptions for Water Heater E_f are Fundamentally INCOMPATIBLE with both HERS Assumptions and with Reality, thereby introducing Bias Error

The E_f Bias Error will result in errors in hot water load



The Good News:

1) The principal of adjusting Water Heating E_f has been used for over 7 years to calculate Drain Water Heat Recovery (DWHR) credits in the US and Canada

2) It is very simple to Adjust the E_f and, thereby, eliminate this Bias Error in HERS

Drain Water Heat Recovery (DWHR)

In residential, DWHR works by using the outgoing warm drain water (mostly the shower) to HEAT the incoming cold fresh water

Installed DWHR Unit

Picture taken at a site in Traverse City, Michigan

Ontario Experience: Homes with DWHR

- Well over 200 builders include DWHR as a standard in all their homes
- Another 200 builders offer the DWHR as an option in their homes
- Over 7,000 new homes had DWHR installed in 2012 which is almost 20% of the Ontario housing starts
- Over 25,000 DWHR units installed in North America ….and counting

Sample DWHR Partners in the US

DWHR Credit in US Energy Star® for Homes Version 2

The EPA's Energy Factor (E_f) Enhancement

e.g. 0.67 EF gas water heater without DWHR to 0.93 EF with DWHR Efficiency of 57% at 2.25gpm

Limitation / Be Aware:

-Does not give actual energy savings

-Ensure that home energy simulation software does not reduce space heating with increased input Water Heating E_f

Advantage:

-On a level playing field with other water heating technologies (e.g. Tankless)

-Easy to compare technologies

-Is widely applicable for Residential labeling programs (e.g. Energy Star)

DWHR Credit in US Energy Star® for Homes Version 2

Glenn T. Chinery EPA **ENERGY STAR® for Homes** March 2004

Policy Recommendations for the HERS Community to Consider regarding HERS point credit for Waste Water Heat Recovery Devices

Electric: 52-gallon tank, EF_{DOE} ranging from 0.80 to 0.94

EF enhancement factor = (HXeff/0.5)^1.15 * (1.35 + 0.285 * Ln { $EF_{DOE}^{0.8}$ * $gpd^{0.06}$ / $[(T_{main}+453)/453)]^{5.6}$ })

- So, GFX-enhanced new energy factor = old energy factor * EF enhancement factor
- How to use in HERS Calculations: Multiply the water heater's EF_{DOE} by the EF

enhancement factor and enter this new value as the EF_{DOE} in the HERS rating algorithm (i.e., as a HERS rating software input). ($R^{2>}$=0.95)

Gas: 40-gallon tank, EF_{DOE} ranging from 0.54 to 0.68

EF enhancement factor = (HXeff/0.5)^1.18 * (1.3015 + 0.284 * Ln { $EF_{DOE}^{0.86}$ / $RE^{0.8}$ * $gpd^{0.095}$ * $[(T_{main}+453)/453)]^{5.18}$ })

- So, GFX-enhanced new energy factor = old energy factor * EF enhancement factor
- How to use in HERS Calculations: Multiply the water heater's EF_{DOE} by the EF

enhancement factor and enter this new value as the EF_{DOE} in the HERS rating algorithm (i.e., as a HERS rating software input). ($R^{2>}$=0.95)

NOTE: Drain Water Heat Recovery is the "industry accepted term" and not Waste Water Heat Recovery. GFX is a the brand-name for one DWHR product.

Example: Natural Gas Water Heating and DWHR

Mixed Climates with Natural Gas Water Heating

DWHR Rated Effectiveness	Gas Tank Mixed Climate 2 bedrooms	Gas Tank Mixed Climate 3 bedrooms	Gas Tank Mixed Climate 4 bedrooms	Gas Tank Mixed Climate 5 bedrooms
42.0%	0.960	0.964	0.967	0.970
44.0%	1.014	1.018	1.022	1.025
46.0%	1.069	1.073	1.077	1.080
48.0%	1.124	1.128	1.132	1.136
50.0%	1.179	1.184	1.188	1.192
52.0%	1.235	1.240	1.244	1.248
54.0%	1.291	1.297	1.301	1.305
56.0%	1.348	1.353	1.358	1.362
57.0%	1.376	1.382	1.387	1.391
58.0%	1.405	1.411	1.416	1.420
60.0%	1.462	1.468	1.473	1.478
62.0%	1.520	1.526	1.531	1.536
64.0%	1.578	1.584	1.590	1.595
66.0%	1.636	1.643	1.649	1.654
68.0%	1.695	1.702	1.708	1.713
70.0%	1.754	1.761	1.767	1.773
72.0%	1.813	1.821	1.827	1.833

For example, with a DWHR efficiency of 57% and with a Gas Water Heater having an E_f=0.67, the Combined E_f for Water Heating is now **E_f=0.93** (which is 0.67*1.387) according to EPA methodology for a 4 Bedroom Home on Gas Water Heating in a mixed climate zone

Example: Electric Water Heating and DWHR

Mixed Climates with Electric Water Heating

DWHR Rated Effectiveness	Electric Tank Mixed Climate 2 bedrooms	Electric Tank Mixed Climate 3 bedrooms	Electric Tank Mixed Climate 4 bedrooms	Electric Tank Mixed Climate 5 bedrooms
42.0%	0.996	0.999	1.001	1.003
44.0%	1.051	1.054	1.056	1.058
46.0%	1.106	1.109	1.111	1.113
48.0%	1.162	1.165	1.167	1.169
50.0%	1.217	1.221	1.223	1.226
52.0%	1.274	1.277	1.280	1.282
54.0%	1.330	1.334	1.336	1.339
56.0%	1.387	1.390	1.393	1.396
57.0%	1.415	1.419	1.422	1.425
58.0%	1.444	1.448	1.451	1.454
60.0%	1.501	1.505	1.509	1.511
62.0%	1.559	1.563	1.567	1.569
64.0%	1.617	1.621	1.625	1.628
66.0%	1.675	1.680	1.683	1.686
68.0%	1.734	1.738	1.742	1.745
70.0%	1.793	1.797	1.801	1.805
72.0%	1.852	1.856	1.860	1.864

For example, with a DWHR efficiency of 57% and with an Electric Water Heater having an E_f=0.92, the Combined E_f for Water Heating is now **E_f=1.31** (which is 0.92*1.422) according to EPA methodology for a 4 Bedroom Home on Electric Water Heating in a mixed climate zone

DWHR Credit in CDN Energy Star® for Homes Version 3

3.10.2. Drainwater Heat Recovery (DHR)

(1) Drainwater Heat Recovery (DHR) technology has demonstrated a significant potential to reduce energy use and peak loads for water heating and is eligible for credits in ENERGY STAR qualified new homes using one of the options below:
   (a) Under Section 3.11 Electrical and Appliances Savings Requirements, or under Section 3.12 Fuel Savings Credits.
   (b) Using a combined energy factor (EF) with a hot water heater, it may meet the EF requirements for water heaters in the Alternative Building Packages described in Section 4.
   (c) Using a combined EF with a hot water heater, or as an Energy Credit, it may be part of alternate compliance using EGNH software as described in Section 5.1.

(2) The combined EF may be calculated as shown in the paper "Drainwater Heat Recovery Credits for ENERGY STAR Qualified New Homes", Energy Building Group Ltd., 21 March, 2006.

(3) The product must be labeled: "Approved for Potable Water". The product must be certified by a Canadian licensed certification company such as ULC, CSA, ETL, etc.

(4) The product must be tested for heat exchange effectiveness at 9.5 lpm flow using hot water drain at 41.0C and entering water supply no greater than 9.5C.

(5) The product must be installed according to the manufacturer's instructions.

(6) Where a single DHR unit is installed in a house with two or more stacks the credit must be reduced by 1/3 if not connected to all the showers in the house.

Note: This Method was developed based upon First Principles and Energy Balance but the results are very similar to the EPA Method

New Terminology is Now Introduced:

The term "Energy Factor" (E_f) is Federally regulated.

In order to avoid confusion and other issues with the use of Energy Factor, the term "Energy Ratio" (E_r) is now proposed when correcting for site-specific water heating energy load conditions.

Both E_f and E_r are used in the same manner for calculating annual hot water energy load.

Energy Ratio – Used by CRESNET and NRCan, simplified:

$$E_{r\_rated} = \frac{\eta_{r\_test}}{\left[\frac{\eta_{r\_test}}{E_{f\_test}}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

Where:

A) η_{r_test} is the primary water heater's Recovery Efficiency

B) η_{r_DWHR} is the rated DWHR unit's efficiency according to CSA B55.1: "Test method for measuring efficiency and pressure loss of drain water heat recovery units"

Note: it is conservative to use CSA B55.1 because it is at 2.5gpm. Lower flow rates (which are more common) would yield higher efficiency

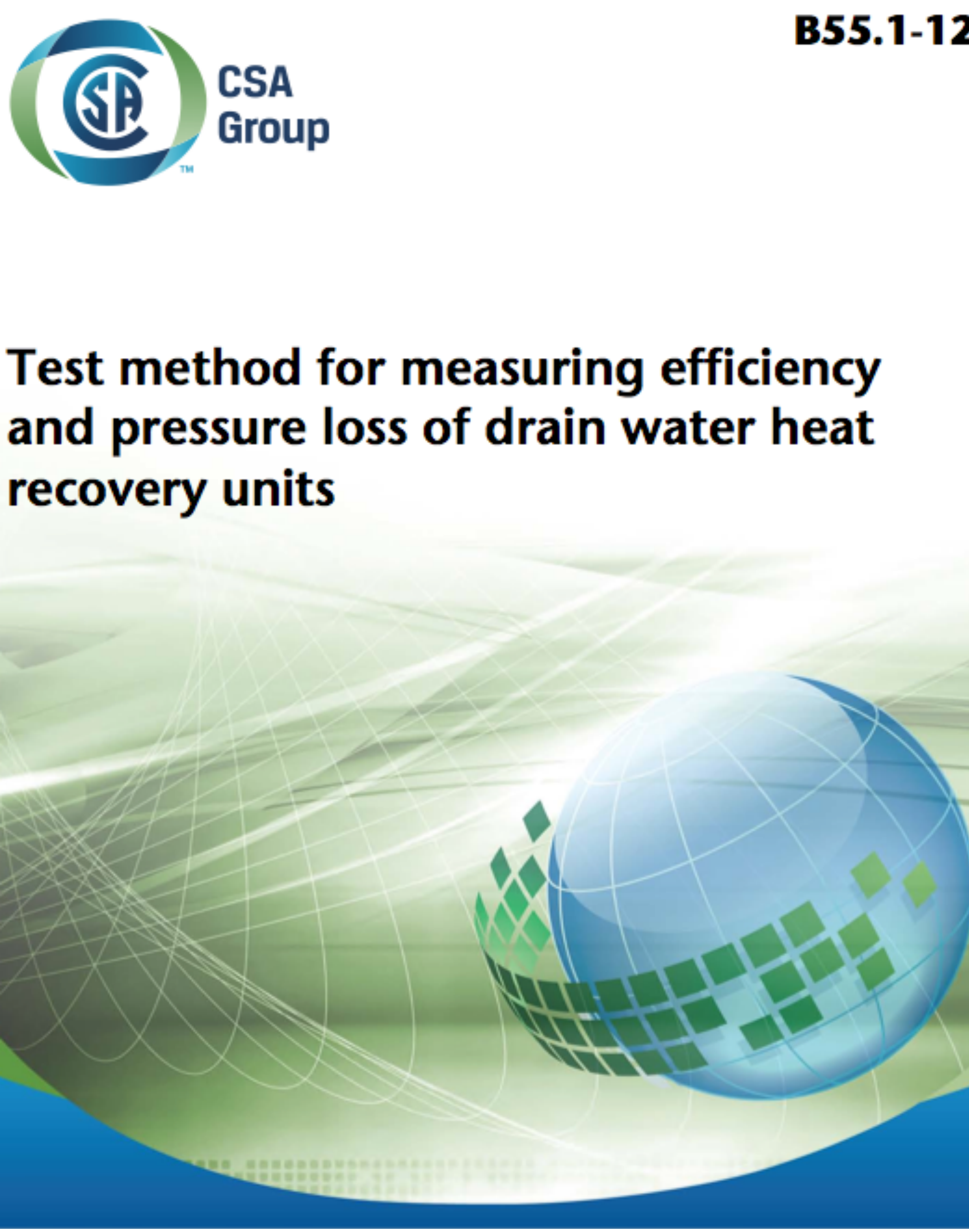
C) C_{DWHR} is determined by:

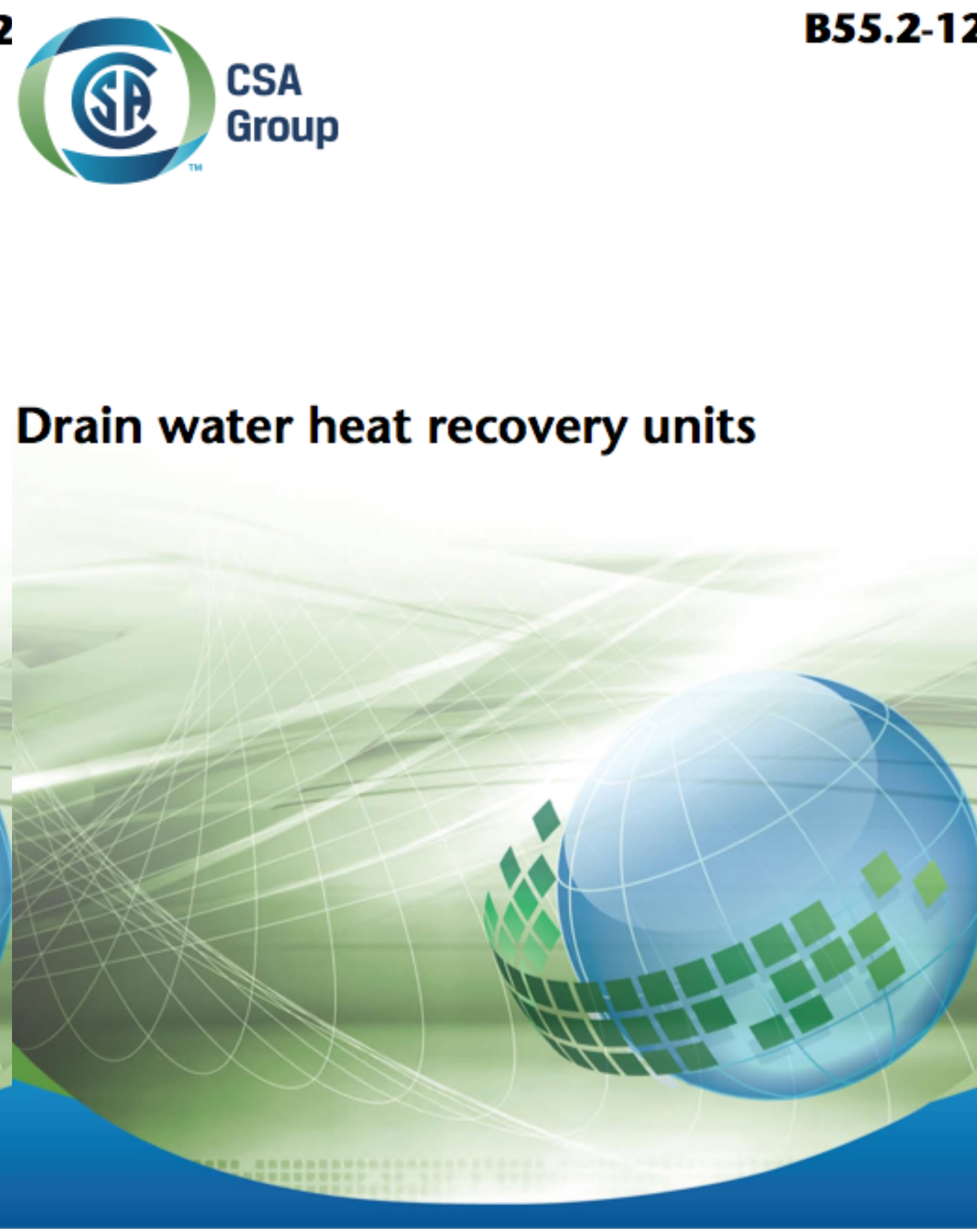
1) If all of the showers in the home are connected to the DWHR unit or units, then the DWHR Connection Factor, C_{DWHR} is 0.432.

2) If there are 2 or more showers in the home and only 1 shower is connected to a DWHR unit, then the DWHR Connection Factor, C_{DWHR} is 0.216.

Note: these factors both assume unequal flow and are therefore conservative, on average

CSA Standards for DWHR Performance and Safety





Comparison of “Energy Ratio” Methods

Both Methods:

1) were developed Independently

2) have the same Purpose

3) give very similar Results

However:

1) The US EPA Method includes Climate Zone (mains water temperature) and Hot Water Load (Occupancy)

2) The Canadian Method is based upon First Principles and Energy Balances, resulting in a Simpler Equation(s) and it works for <u>all</u> water heaters and <u>all</u> DWHR Efficiencies

Moving Forward…

We have very recently **<u>Proposed</u>** a comprehensive Method to RESNET for Calculating Site-Specific:

1) "Reference Home": $E_{r\_reference}$ & Hot Water Energy Loads
2) "Rated Home": E_{r_rated} & Hot Water Energy Loads

Which is based upon: Rated Water Heater Energy Factor & Recovery Efficiency, Climate Zone, Actual Load, and absence/presence of DWHR

-This **Site Specific Energy Ratio E_r** also easily accounts for the energy savings from having "<u>Efficient Hot Water Distribution Systems</u>", because a Reduced Load is easily included in both the Energy Ratio and Direct Load Calculation

-It is a based upon a big, yet straightforward equation for calculating Energy Ratio (E_r), which is an expanded form of the equation currently used by CRESNET and NRCan

The Complete “Energy Ratio” Equation:

Based upon an Energy Balance Analysis of the Entire Water Heating System, the following equation has been derived by G.W.E. Van Decker as:

$$E_r = \frac{\eta_{r\_test}}{1 + \left[\frac{\eta_{r\_test}}{E_{f\_test}} - 1\right] \bullet \left[\frac{T_{del\_site} - T_{a,stby\_site}}{T_{del\_test} - T_{a,stby\_test}}\right] \bullet \left[\frac{V_{test} \bullet \left(T_{del\_test} - T_{in\_test}\right)}{V_{site} \bullet \left(T_{del\_site} - T_{in\_site}\right)}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

Where:

T_{del_site} is the actual water heater set-point temperature, 120 ˚F

$T_{a,stby\_site}$ is the actual room temperature, assume 67.5 ˚F

T_{in_site} is the actual mains water temperature, site specific

V_{site} is the actual hot water draw [gallons per day], which is: 30*Ndu + 10*Nbr

T_{del_test} is the test water heater set-point temperature, 135 ˚F

$T_{a,stby\_test}$ is the test room temperature, 67.5 ˚F

T_{in_test} is the test mains water temperature, 58.0 ˚F

V_{test} is the test hot water draw, 64.3 gallons per day

η_{r_test} is the primary water heater’s rated recovery efficiency as per test

E_{f_test} is the primary water heater’s rated Energy Factor as per test

η_{r_DWHR} is the Drain Water Heat Recovery unit efficiency in accordance to CSA B55.1 and listed by a recognized agency (e.g. UL, ETL).

C_{DWHR} is:

1) 0.432 if all of the showers in the home are connected to the DWHR unit or units

2) 0.216 if there are 2 or more showers in the home and only 1 shower is connected to a DWHR unit or units

The HERS Reference Home E_r Equations are simplified:

For Fuel-based (e.g. Natural Gas, Propane, Oil, etc.) Primary Water Heaters, if the baseline water heater has E_{f_test}=0.58 & η_{r_test}=79% then the new Baseline Energy Ratio reduces to:

$$E_{r\_reference} = \frac{0.76}{1 + \left[\frac{1195}{(30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right)} \right]}$$

For Electric Primary Water Heaters, if the baseline water heater has E_{f_test}=0.92 & η_{r_test}=98% then the Baseline Energy Ratio reduces to:

$$E_{r\_reference} = \frac{0.98}{1 + \left[\frac{251}{(30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right)} \right]}$$

...and the HERS Rated Home E_r Equations are:

For Fuel-based (e.g. Natural Gas, Propane, Oil, etc.) Primary Water Heaters, if the baseline water heater has E_{f_test}=0.58 & η_{r_test}=79% then the new Baseline Energy Ratio reduces to:

$$E_{r\_rated} = \frac{0.76}{1 + \left[\frac{1195}{(30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right)}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

For Electric Primary Water Heating, if the baseline water heater has E_{f_test}=0.92 & η_{r_test}=98% then the Baseline Energy Ratio reduces to:

$$E_{r\_rated} = \frac{0.98}{1 + \left[\frac{251}{(30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right)}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

Reference and Rated Hot Water Energy Loads:

Now the new Reference Home Hot Water Energy Load is:

$$LOAD_{DHW\_reference} = \frac{C_p \bullet (30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right) \bullet 365}{E_{r\_reference}}$$

And the new Rated Home Hot Water Energy Load looks virtually the same:

$$LOAD_{DHW\_rated} = \frac{C_p \bullet (30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right) \bullet 365}{E_{r\_rated}}$$

…….BUT they each use a different Energy Ratio

NOTE: C_p is the specific heat of water

Note Also:

This calculation can be done in any of the following time-steps:

Annual

Monthly

and even, Daily

That means that these equations can be used to calculate the Hot Water Energy Load Dynamically if desired.

For example, if the hot water draws and mains water temperature changes throughout the year, the Hot Water Load can be calculated accordingly.

Mains water temperature is as per local conditions and as annual average, monthly average or even daily temperature.

If data is not available, calculate average annual mains water temperature as Average Annual Ambient Temperature less 6.0°F.[1]

1. "TOWARDS DEVELOPMENT OF AN ALGORITHM FOR MAINS WATER TEMPERATURE", Jay Burch and Craig Christensen, National Renewable Energy Laboratory (available online)

Energy Ratios (E_r) Example

Water Heater E_f Test Conditions			
Rated Energy Factor	E_f	0.670	
Recovery Efficiency	η_r	79%	
Water Heater Temperature	$T_{test,del}$	135	°F
Cold Water Temperature	$T_{test,in}$	58	°F
Room Temperature	T_{room}	67.5	°F
Volume Per Day	V_{test}	64.3	gal

Water Heater Site Conditions			
Energy Ratio	E_r	TBD	
Recovery Efficiency	η_r	79%	
Water Heater Temperature	$T_{site,del}$	120	°F
Annual Ave Cold Water Temp.	$T_{site,in}$	55	°F
Room Temperature	T_{room}	67.5	°F
Volume Per Day	V_{site}	70.0	gal

Energy Ratio without DWHR	$E_{r\_baseline}$	0.686	
DWHR Rated Efficiency		57.0%	
Plumbing Factor		1.000	
Energy Ratio with DWHR	$E_{r\_enhanced}$	0.946	

E_r Examples - Cold Climate

Energy Ratio E_r with and without Drain Water Heat Recovery						
Zone: "Cold" Climate		Average Annual Water Mains Temperature:			45	°F
Rated Energy Factor:	EF=	0.67		Recovery Efficiency:	η_r=	79%
House Detail:	1 Bedroom	2 Bedrooms	3 Bedrooms	4 Bedrooms	5 Bedrooms	6 Bedrooms
Hot Water Load [gal/day]	40	50	60	70	80	90
DWHR Efficiency						
None	0.634	0.660	0.679	0.693	0.703	0.712
30%	0.732	0.767	0.792	0.811	0.826	0.838
40%	0.772	0.811	0.839	0.860	0.877	0.891
50%	0.816	0.860	0.891	0.916	0.935	0.950
60%	0.866	0.915	0.951	0.979	1.001	1.018

E_r Examples - Mixed Climate

Energy Ratio E_r with and without Drain Water Heat Recovery						
Zone: "Mixed" Climate		Average Annual Water Mains Temperature:			55	°F
Rated Energy Factor:	EF=	0.67	Recovery Efficiency:		η_r=	79%
House Detail:	1 Bedroom	2 Bedrooms	3 Bedrooms	4 Bedrooms	5 Bedrooms	6 Bedrooms
Hot Water Load [gal/day]	40	50	60	70	80	90
DWHR Efficiency						
None	0.619	0.647	0.667	0.682	0.694	0.703
30%	0.712	0.749	0.776	0.797	0.813	0.826
40%	0.749	0.791	0.821	0.844	0.862	0.877
50%	0.791	0.837	0.871	0.897	0.918	0.935
60%	0.837	0.890	0.928	0.958	0.981	1.001

E_r Examples - Mild Climate

Energy Ratio E_r with and without Drain Water Heat Recovery						
Zone: "Mild" Climate		Average Annual Water Mains Temperature:			65	°F
Rated Energy Factor:	EF=	0.67	Recovery Efficiency:		η_r=	79%
House Detail:	1 Bedroom	2 Bedrooms	3 Bedrooms	4 Bedrooms	5 Bedrooms	6 Bedrooms
Hot Water Load [gal/day]	40	50	60	70	80	90
DWHR Efficiency						
None	0.600	0.630	0.652	0.669	0.682	0.693
30%	0.687	0.727	0.756	0.779	0.797	0.811
40%	0.722	0.766	0.799	0.824	0.844	0.860
50%	0.761	0.810	0.847	0.875	0.897	0.916
60%	0.804	0.859	0.900	0.932	0.958	0.979

E_r Examples - Hot Climate

Energy Ratio E_r with and without Drain Water Heat Recovery						
Zone: "Hot" Climate		Average Annual Water Mains Temperature:			75	°F
Rated Energy Factor:	EF=	0.67		Recovery Efficiency:	η_r=	79%
House Detail:	1 Bedroom	2 Bedrooms	3 Bedrooms	4 Bedrooms	5 Bedrooms	6 Bedrooms
Hot Water Load [gal/day]	40	50	60	70	80	90
DWHR Efficiency						
None	0.577	0.610	0.634	0.652	0.667	0.679
30%	0.657	0.700	0.732	0.756	0.776	0.792
40%	0.689	0.736	0.772	0.799	0.821	0.839
50%	0.724	0.776	0.816	0.847	0.871	0.891
60%	0.763	0.821	0.866	0.900	0.928	0.951

Examples….

Given: A Water Heater with Rated E_f=.67:

The Energy Ratio, E_r, ranges from:

0.610 (hot climate, 2 bedroom home)

to

0.703 (cold climate, 5 bedroom home)

Given: A Water Heater with Rated E_f=.67 and **DWHR Rated Efficiency=60%**:

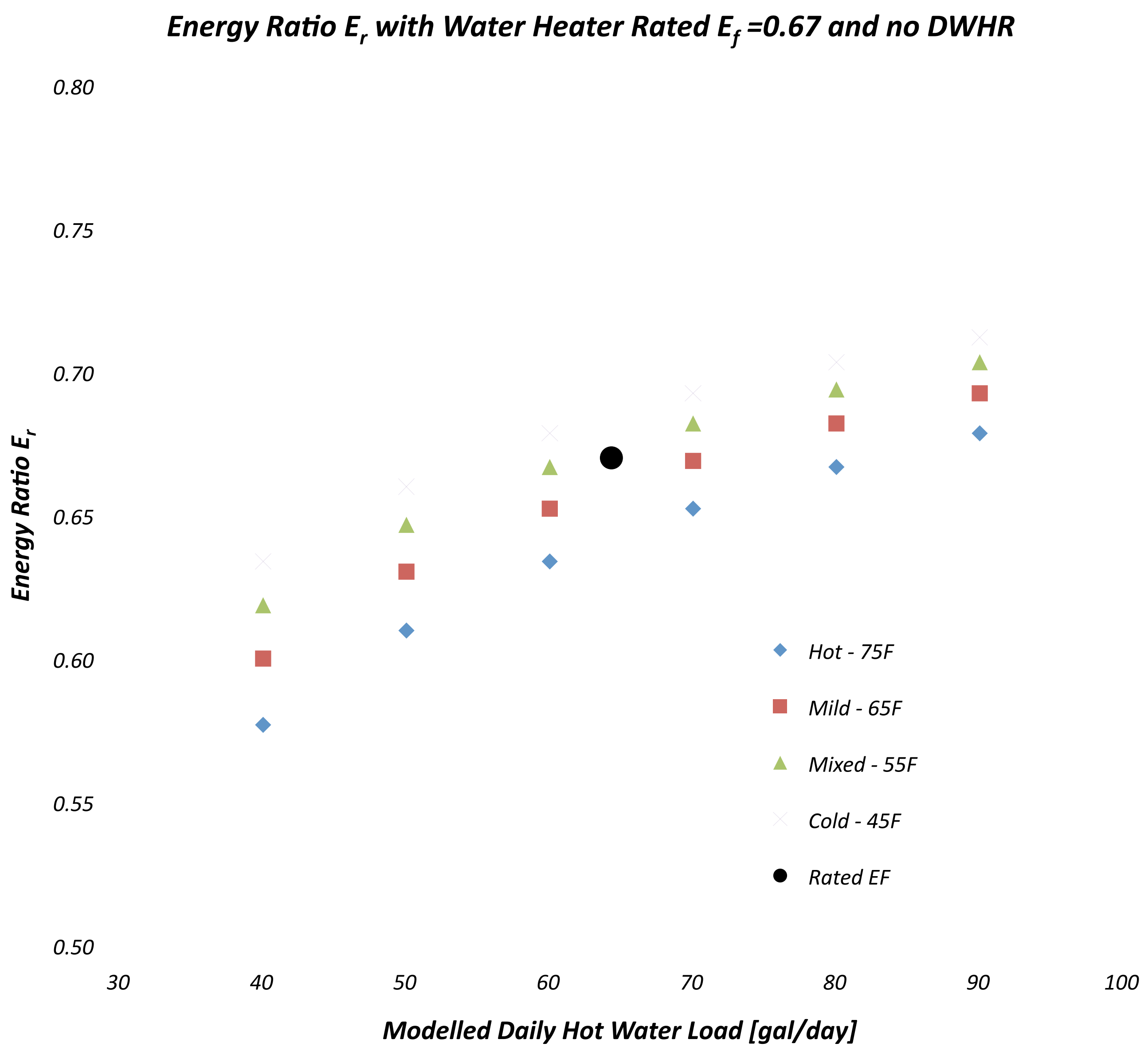
The Energy Ratio, E_r, ranges from:

0.821 (hot climate, 2 bedroom home)

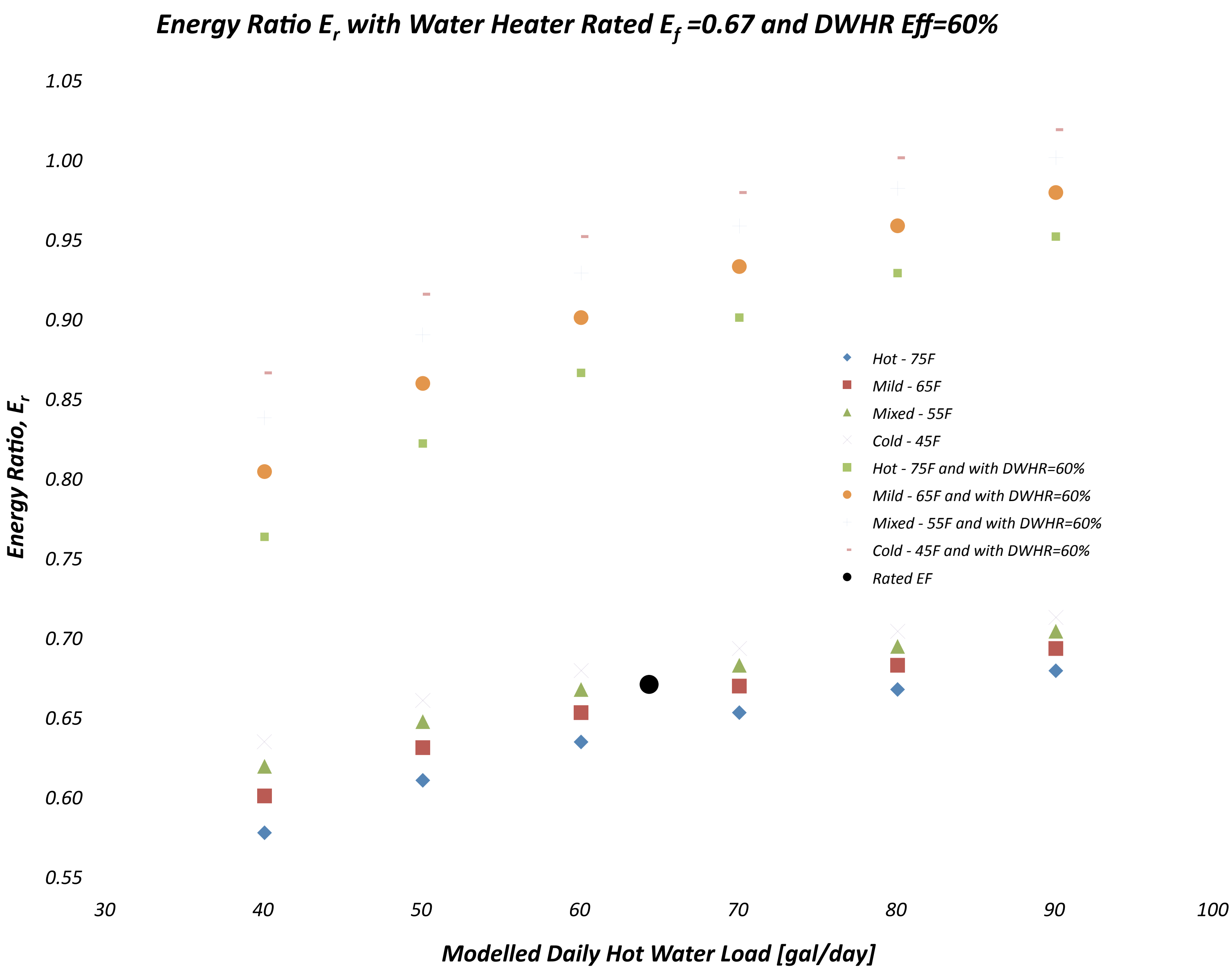
to

1.001 (cold climate, 5 bedroom home)

Energy Ratio (E_r) Across a Broad Range of Conditions



Energy Ratio (E_r) Across the same range with DWHR



Hot Water Distribution Efficiency is also easy to Include

With the new Energy Ratio Approach, RESNET may also adopt a reduced load approach. This can easily be put in to the Enhanced Energy Ratio equations.

For Fuel-based Primary Water Heaters:

$$E_{r\_rated} = \frac{0.76}{1 + \left[\frac{1195}{HWDE_r \bullet (30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right)}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

For Electric Primary Water Heaters:

$$E_{r\_rated} = \frac{0.98}{1 + \left[\frac{251}{HWDE_r \bullet (30 + 10 * Nbr) \bullet \left(120°F - T_{mains}\right)}\right] - \eta_{DWHR} \bullet C_{DWHR}}$$

Where Hot Water Distribution Efficiency factor, $HWDE_f$ is:

= 0.80 where a demand recirculation water system is installed for the hot water distribution system and the volume in the piping from the circulating hot water piping to the termination of the fixture supply for every fixture is less than or equal to 0.19 gallons (0.71 liters).

= 0.90 where the water volume in the piping from the water heater to the termination of the fixture supply for every fixture is less than or equal to 0.5 gallons (1.89 liters).

= 1.0 where neither condition above is met.

So in Summary....

There can be significant Bias Error in the current calculation of Hot Water Energy Loads because Energy Factor is based upon an average condition for America

The concept of Energy Ratio easily allows for HERS Reference Home and HERS Rated Home calculation of Hot Water Energy Loads very accurately based upon actual mains water temperature and actual daily hot water draws

It is now very easy and accurate to provide credit for Drain Water Heat Recovery and Hot Water Distribution Efficiency in the calculation of HERS Rated Home Hot Water Energy Loads

The data is all there to do this!

Questions & Discussion

Thank You for Attending!

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