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

Presented by:

Rod Buchalter

RenewABILITY ENERGY INC.

www.renewability.com

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:

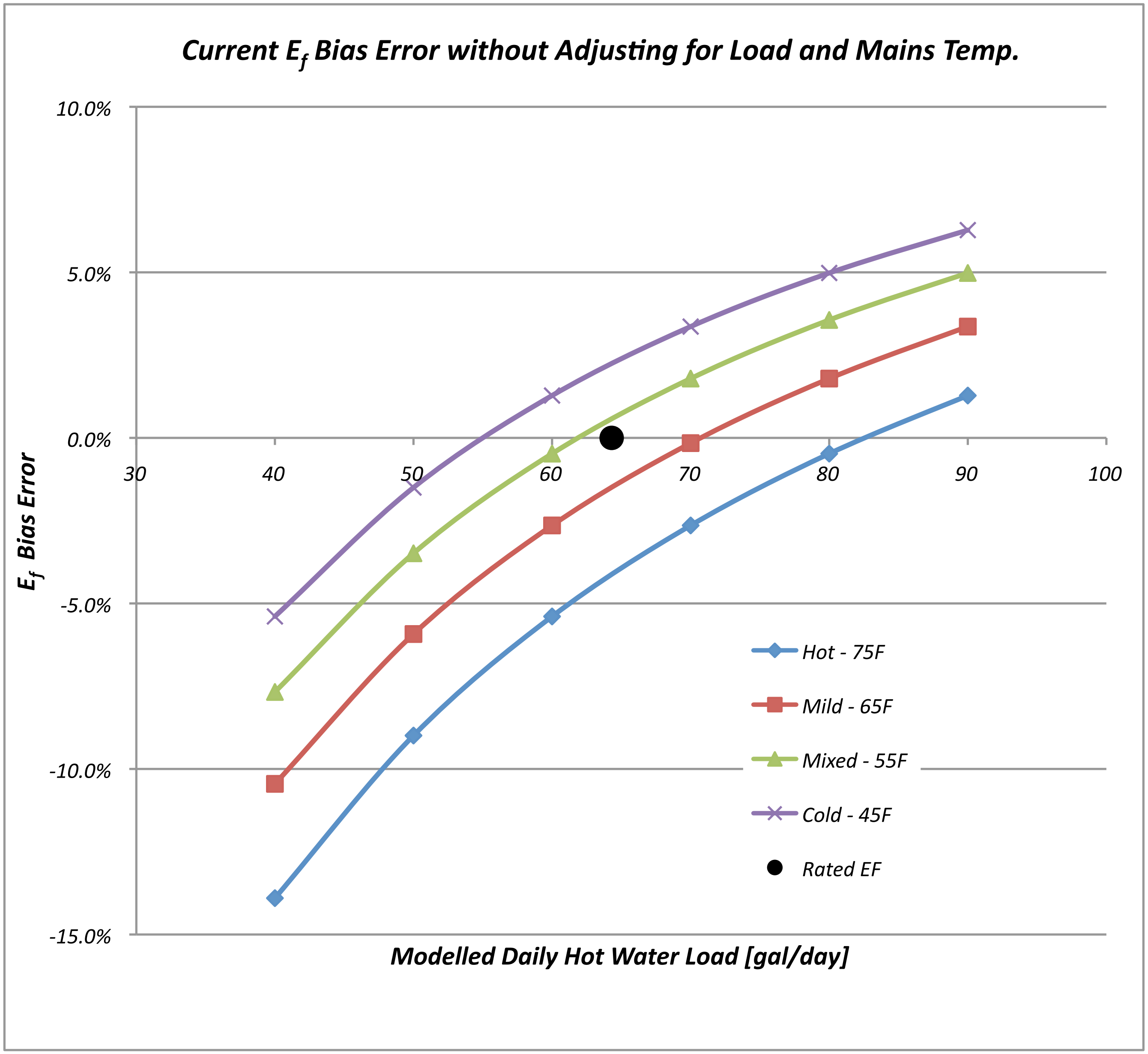
1) an Average Climate (T_{mains} = 58.0°F),
2) an Average Load (64.3 gallons per day), and
3) a Water Heater Set-point temperature of 135°F, while HERS uses 120°F

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

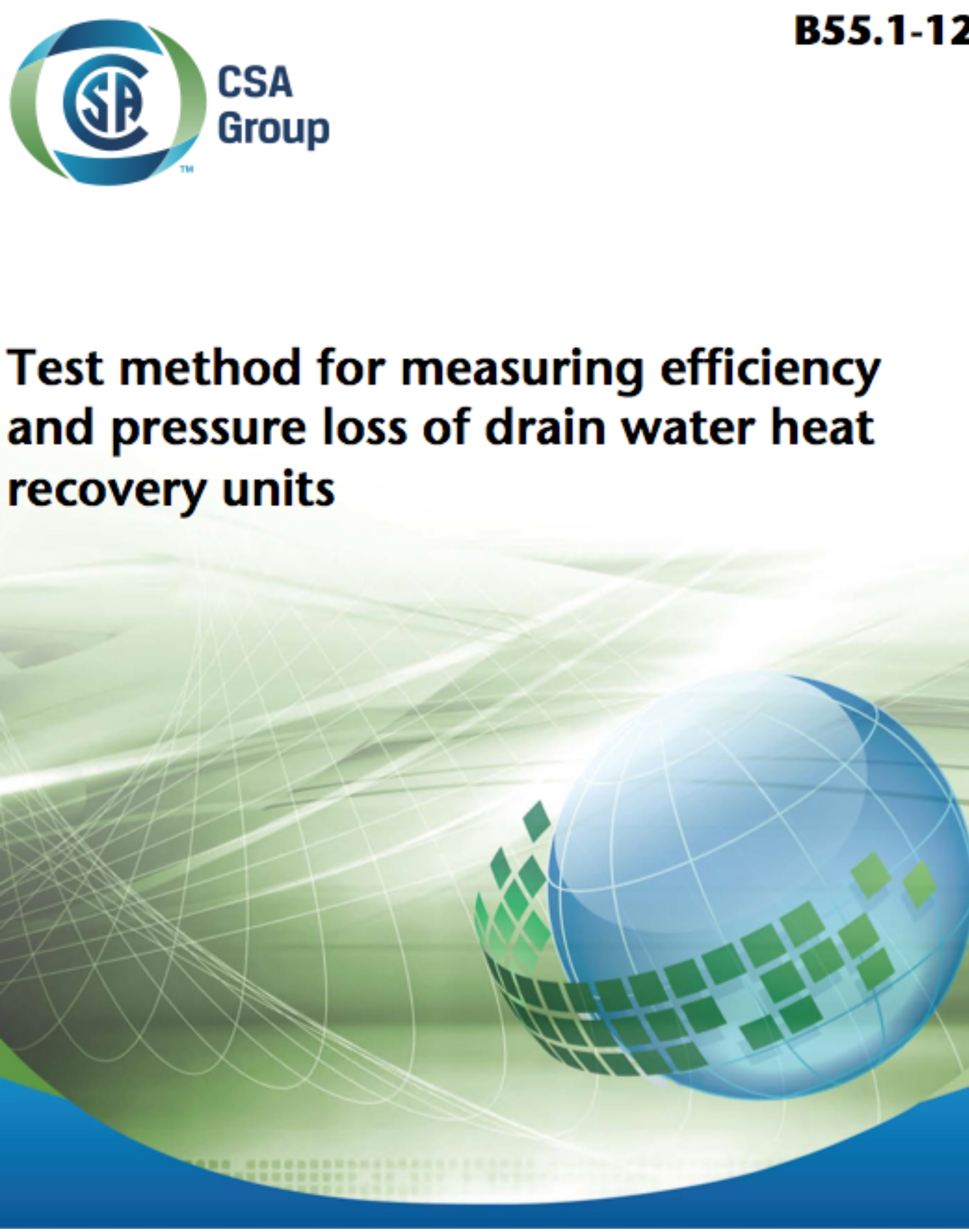
C) C_{DWHR} is determined by:

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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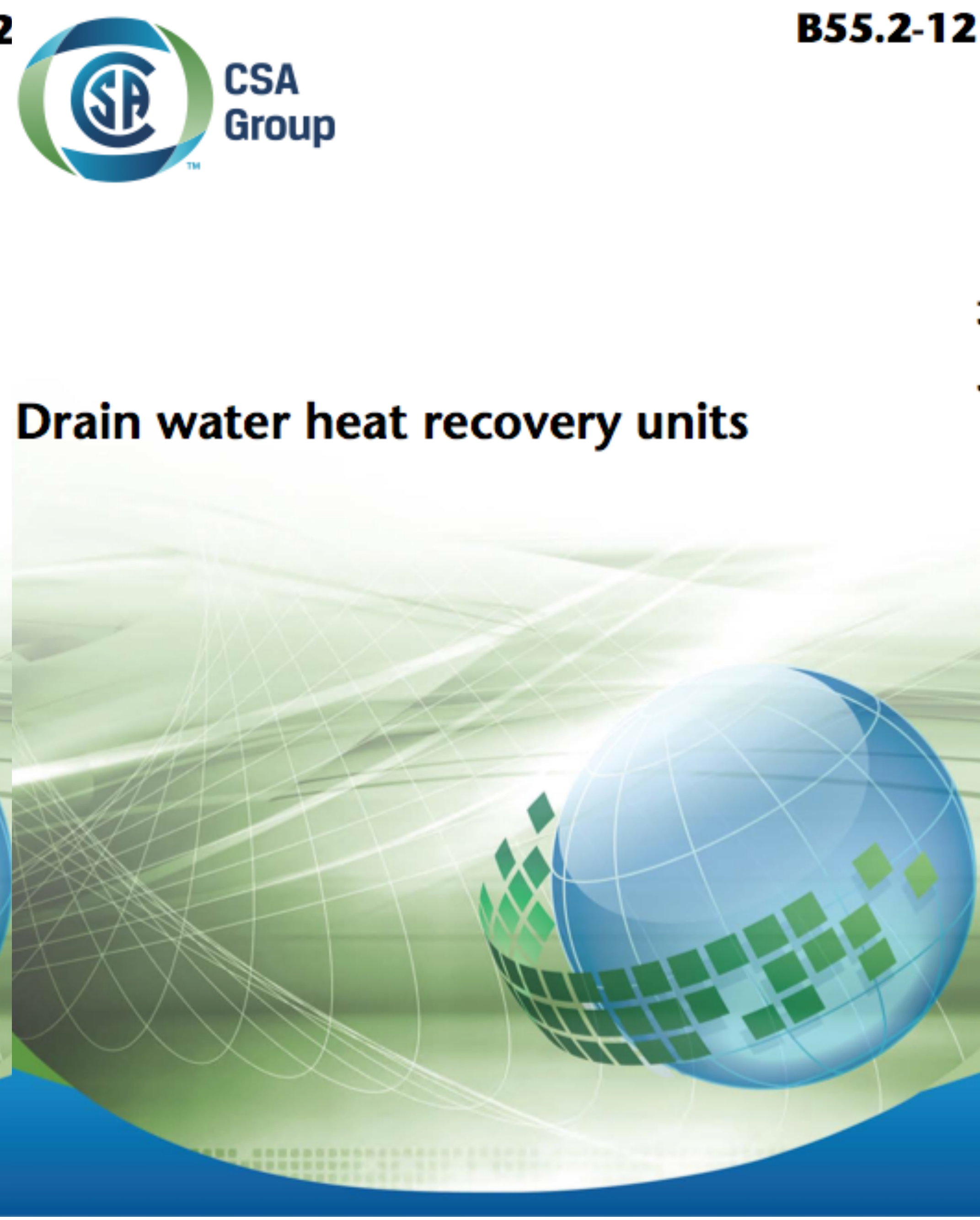
CSA Group

Test method for measuring efficiency and pressure loss of drain water heat recovery units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CSA Group

Drain water heat recovery units

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:

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

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

CDWHR 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:

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

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:

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

…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:

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

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:

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

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%**:

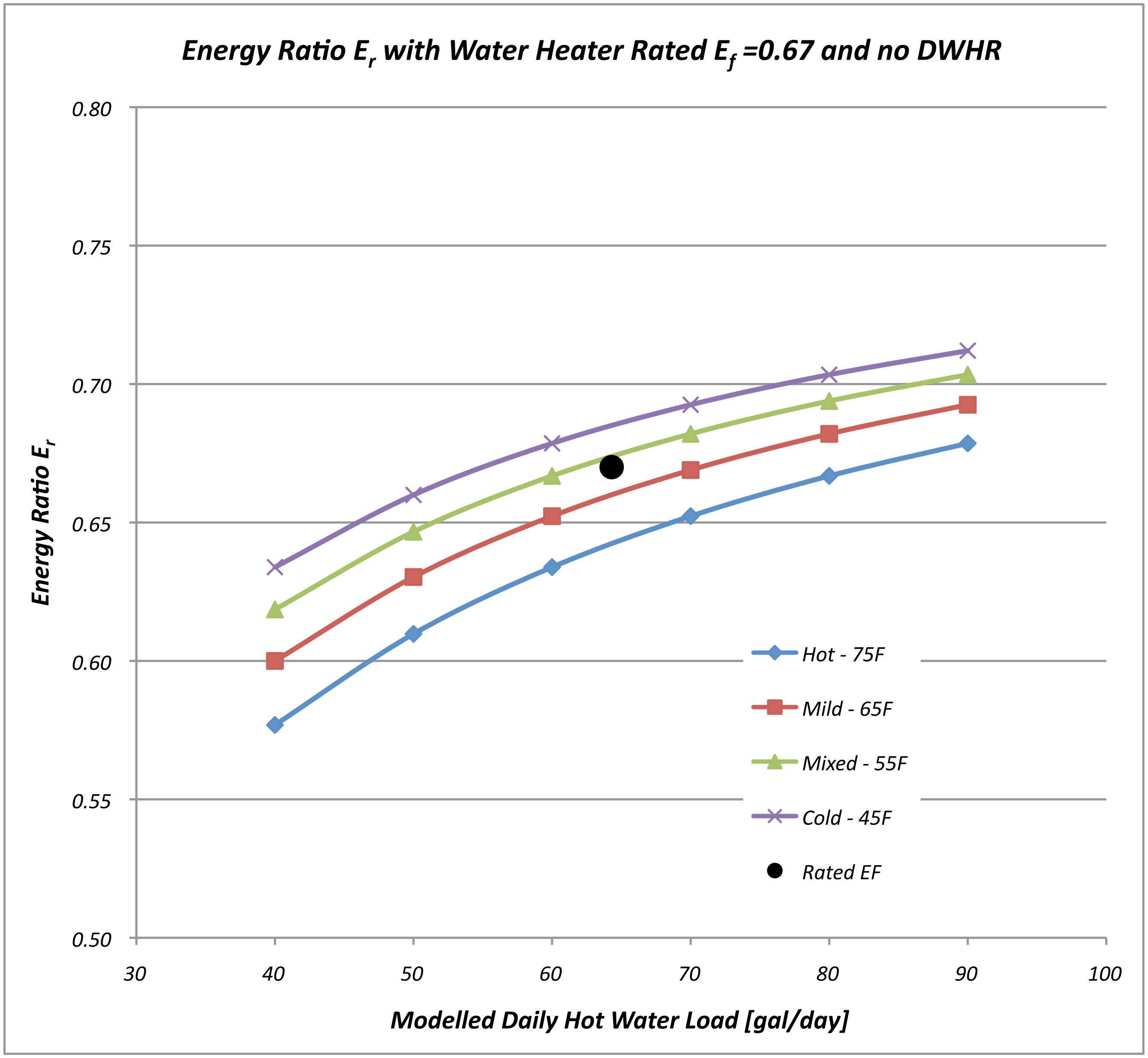
The Energy Ratio, E_r, ranges from:

0.821 (hot climate, 2 bedroom home)

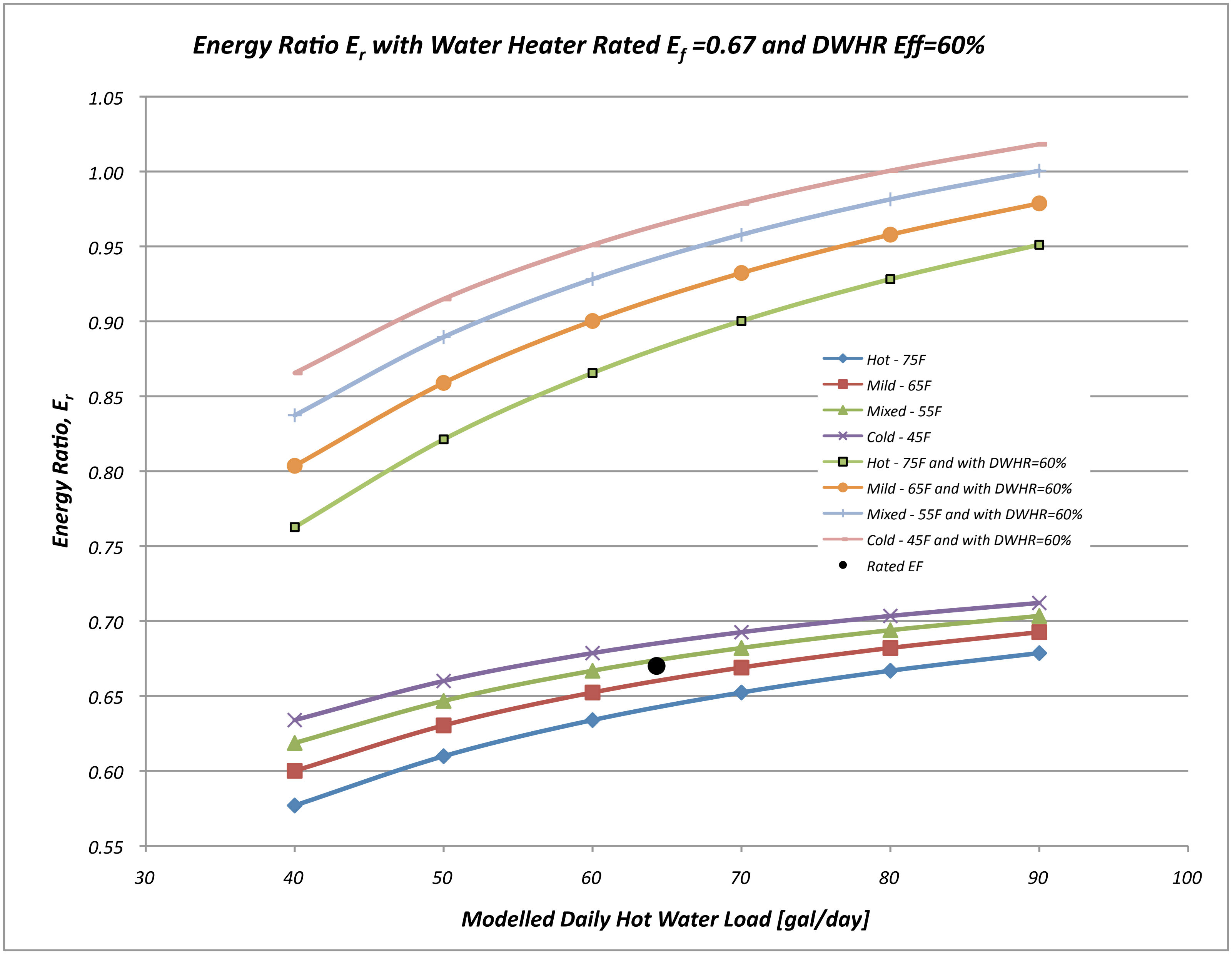
to

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!

www.RenewABILITY.com