Improved Hot Water Code Calculation

Florida Solar Energy Center

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FLORIDA SOLAR ENERGY CENTER®

Creating Energy Independence

Improved Hot Water Code Calculation

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Executive Summary

The purpose of this research project is fourfold:

- Identify domestic hot water (DHW) waste sources
- Characterize the implications of climatic differences on hot water use
- Characterize the energy impacts of hot water recirculation systems and controls
- Recommend Florida-specific methods that can be employed in the Florida Energy Conservation Code for residential hot water use and energy consumption calculations.

Results of a DHW distribution literature review performed for this project paralleled previous research that showed that a number of significant factors impinging on hot water energy use are not considered by standard DHW energy use calculations in building energy codes, including the Florida Energy Conservation Code. These factors include climate variation effects on hot water use, DWH distribution system design and recirculation system pump control.

An interactive DHW energy consumption calculation spreadsheet that incorporates climate variation effects, DWH distribution system design and recirculation system pump control was adapted for Florida use. The spreadsheet was used to evaluate the impacts of including these additional DHW factors in energy use calculations. The same expanded calculation procedure was then incorporated into EnergyGauge® USA energy simulation software to evaluate the impacts of these additional DHW factors on performance energy code compliance.

One of the most significant improvements provided by the new DWH calculation procedure stems from a better accounting of how the water mains temperatures impact the average daily quantity of hot water use (gallons per day). Figure E-1 shows that because the proposed (new) calculation procedure includes climatic considerations, the quantity of hot water use is significantly lower for Florida's warm climate than it is using the current (old) calculation procedure. A spreadsheet evaluation showed the new calculation procedure to provide corresponding DHW energy use savings.

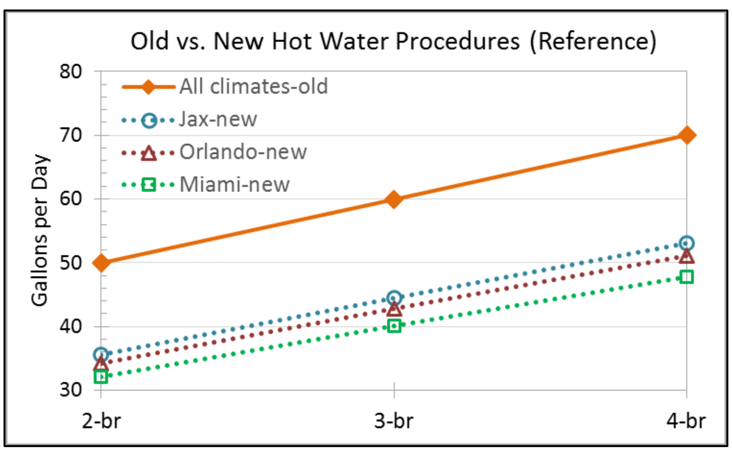

Figure E-1. Hot water use quantity in gallons per day (gpd) predicted by current (old) and proposed (new) DHW calculation procedures

In addition to better accounting of how water mains temperatures affect hot water use, the new calculation procedure includes five hot water system characteristics that are currently not considered in residential Florida Energy Code hot water calculations:

- Recirculation DHW distribution systems
- Pipe insulation
- Fixture flow efficiency (standard or "low-flow")
- Pipe length
- Drain water heat recovery (DWHR).

EnergyGauge USA simulations were run to assess the impacts of including both the climate-based water temperature changes and these additional characteristics in performance energy code calculations. Figure E-2 provides a sample of the results, showing current and new procedure performance compliance e-Ratios for a 3 bedroom Orlando example house for each of nine cases analyzed.

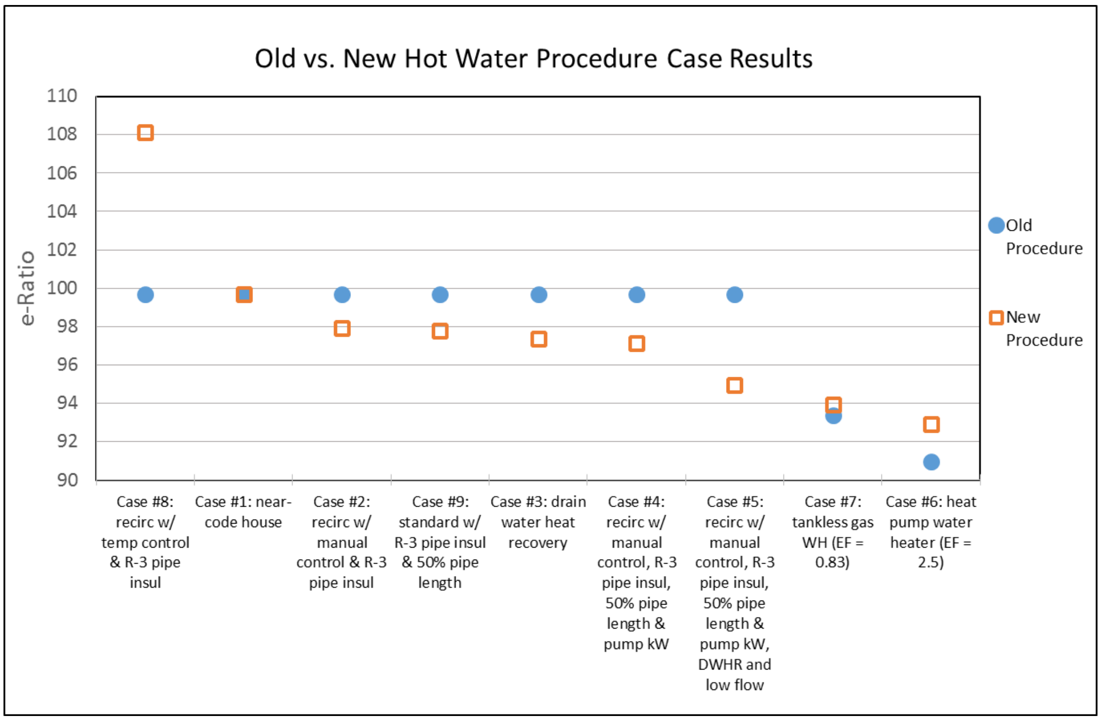

Figure E-2. Total e-Ratios predicted by current (old) and proposed (new) DHW calculation procedures for nine hot water distribution design and equipment efficiency variation cases analyzed, organized from left to right by proposed procedure (new) e-Ratio.

Finally, code change language that would incorporate the new DWH calculation procedure into the Florida Energy Conservation Code is provided for consideration by the Florida Building Commission.

Contents

Introduction

The purpose of this research project is fourfold:

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- Characterize the implications of climatic differences on hot water use
- Characterize the energy impacts of hot water recirculation systems and controls
- Recommend Florida-specific methods that can be employed in the Florida Energy Conservation Code for residential hot water use and energy consumption calculations.

The study includes a literature review, research report and recommendations suitable for consideration by the Florida Building Commission in determining the most appropriate Florida-specific methods, procedures and calculations for determining the energy use effectiveness of DHW systems in the Florida Energy Code for Residential Buildings.

Specific activities include four main tasks:

- Task 1) Literature review of NREL, LBNL, ASHRAE, DOE Building America databases and general search of “hot water distribution” and “energy” key words: A listing of documents reviewed for this task is included in the Appendix and a summary of the literature review findings is included below.
- Task 2) Draft DHW calculation procedure: A draft interactive DHW energy consumption calculation spreadsheet and corresponding draft proposed code language changes were provided with the interim project report and are included in the Appendix of this report (the spreadsheet is presented as a separate deliverable; a “cover sheet” example of the energy consumption calculation from the spreadsheet is included here).
- Task 3) DHW energy use comparison: DHW energy use for 2, 3, and 4-bedroom homes in Miami, Orlando and Jacksonville calculated with the proposed new calculation procedure is compared with DHW use determined by the current code calculation procedure.
- Task 4) Energy Code performance comparison: An EnergyGauge® USA simulation comparison of overall energy code performance scores (e-Ratios) using the current DHW procedure verses the proposed new DHW procedure is included in this report.

Task 1 Literature Review

A literature review was performed searching on "hot water distribution" and "energy" terms in the National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), ASHRAE and Department of Energy (DOE) Building America databases. A general “hot water distribution” and “energy” Google search was also performed. A listing of pertinent documents identified via these searches is included in the Appendix.

Findings from the literature review and background hot water systems research show that a number of significant factors impinging on hot water energy use are not considered by standard DHW energy use calculations in building energy codes, including the Florida Building Code for

Energy Conservation. There are three principal factors that are not adequately considered by standard building energy code hot water calculations:

- The fact that service water temperatures (T_{mains}) vary from climate location to climate location is not adequately considered in determining the quantity of hot water use (gallons per day) by standard models (Burch and Christensen 2007), (Burch and Thornton 2012), (Parker et al. 2015)
- The fact that domestic hot water distribution system design significantly impacts both the hot water use quantity (hot water waste) and hot water energy consumption (piping heat loss) is not adequately considered by standard models (Lutz 2011), (Shein 2016)
- The fact that devices like hot water recirculation pumps, which can reduce the quantity of hot water use (by up to 15%), can dramatically increase hot water energy use (by up to 250%) is not adequately considered by standard models (Klein 2014a).

Measurement of hot water energy use in the field shows a distinct climatic influence on hot water energy use. The field research consistently shows that seasons and locations with lower outdoor temperatures have larger hot water energy use and seasons and locations with higher outdoor temperatures have smaller hot water energy use (Parker et al. 2015). Figure 1 presents an example from research conducted by Merrigan in Florida between 1982 and 1983 (Merrigan 1988). As illustrated in Figure 1, the estimated service water temperature (T_{mains}) varies inversely with the amount of hot water needed to produce a use temperature commensurate with showering and other human needs ($T_{use} \approx 105$ F). Thus, as illustrated in Figure 1, when T_{mains} temperatures are high, it takes much less hot water to reach this T_{use} temperature than when T_{mains} temperatures are low.

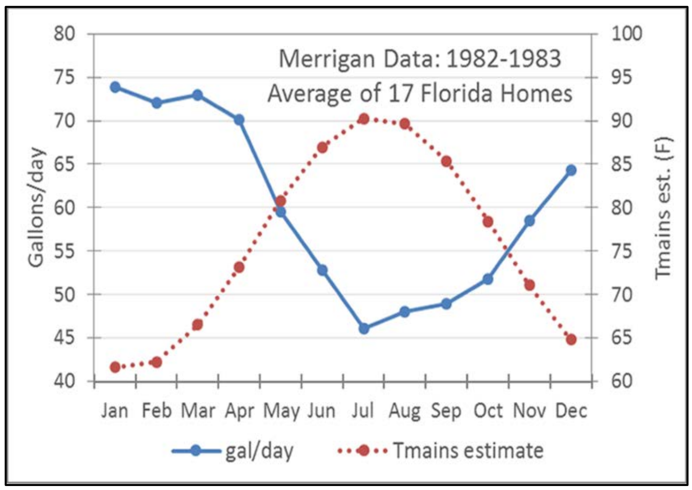

Figure 1. Measured DHW gallons per day in 17 Florida Homes from research conducted in 1982-1983.

DHW research also shows that hot water use includes significant wasted hot water use due to DHW system distribution system losses. Typical hot water distribution system losses are estimated to be about 20% of typical hot water energy consumption or about 10 gallons per day as a national average (Lutz 2005), (Van Decker 2014). The quantity of hot water waste depends on three principle factors (Parker et al. 2015):

- The length and diameter of the hot water piping (i.e. the volume of hot water left in the piping) (Klein 2014b)
- The amount of hot water piping insulation (Shein 2015), (NAHB 2010)

- The time between multiple hot water events that use the same hot water piping (Lutz and Melody 2012), (Burch and Thornton 2012), (Klein 2014c).

Parker goes on to explain:

> The first two of these factors are self-evident but the third factor can be more difficult to grasp. The time interval between multiple hot water events that use the same piping is important because it determines the quantity of heat that will be lost from the piping between hot water events. If two hot water events follow one another within a very short time period (e.g. two showers, one right after another), the hot water waste quantity will be very similar to a single event. However, if sufficient time elapses between two events, then all of the residual hot water left in the piping following both events will be lost to the surroundings.

As noted above, hot water recirculation systems can reduce the quantity of hot water used but can also dramatically increase energy use depending on if or how they are controlled. It is therefore important that both the benefits and potential drawbacks of these systems also be accounted for in code calculation procedures. A monitored 2014 Building America study (Henderson and Wade 2014) and 2015 forum presentation (Klein 2015) provide further discussion on recirculation system benefits and drawbacks.

The literature review identified additional factors that affect hot water energy use such as household demographics (Parker et al. 2015) and variability of daily hot water use (Lutz et al. 2011). Although these factors may improve predicting the DHW energy use of a specific existing household, the application to codes that apply to new unoccupied houses is limited and therefore not considered for this study.

Task 2 Draft Calculation Procedure

Hot water distribution system efficiency factors and pertinent conservation measures are largely addressed in the industry vetted ANSI/RESNET 301-2014 Addendum A-2015 (ANSI/RESNET 2015), (BSR/RESNET 2014). As a result, this Addendum was used as the starting point for the new Florida hot water calculation procedure. Florida-specific adaptations to the RESNET procedure include calculation by month and Florida climate adjustment.

In addition to better accounting of how water mains temperatures affect hot water use, the new calculation procedure includes five hot water system characteristics that are currently not considered in residential Florida Energy Code hot water calculations:

- Recirculation DHW distribution systems
- Pipe insulation
- Fixture flow efficiency (standard or “low-flow”)
- Pipe length
- Drain water heat recovery (DWHR).

An interactive hot water energy consumption calculation spreadsheet that uses the new calculation procedure and corresponding draft proposed code language changes were provided with the interim project report. The spreadsheet is presented as a separate deliverable. A "cover sheet" example of the energy consumption calculation from the spreadsheet is included in the Appendix of this report. The energy consumption spreadsheet provides an interactive means of comparing estimated hot water energy use using the new procedure with estimated hot water energy use from the current, or "old" procedure. The energy use changes with project location, hot water distribution characteristics and conservation measures. The draft of our proposed code language is included in the Appendix.

Existing Florida Energy Code hot water conservation credits such as solar thermal collectors and heat recovery units (HRUs) are addressed "upstream" of the new calculation procedure so credit remains for these options if the new procedure is approved for code use.

Task 3 Energy Use Comparison

The hot water energy consumption calculation spreadsheet described above was used to compare the estimated annual hot water energy use of a sample house using the current DHW calculation procedure with the energy use resulting from using the new calculation procedure.

The comparison used two, three and four bedroom, 2,000 sq. ft., one-story sample houses with baseline efficiency electric water heaters in three Florida cities: Miami, Orlando and Jacksonville. Pertinent sample house characteristics are shown in Table 1.

Table 1. Energy Use Comparison Sample House Characteristics.

Component	Entry for All Cities
Conditioned floor area (ft^2)	2,000
Number of stories	1
Number of bedrooms*	2 / 3 / 4
Water heater size (gallons)	50
Water heater EF (Electric)	0.948
Hot water distribution	Non-recirculation
Hot water pipe length (ft.)	99.44
Hot water pipe insulation	None
Hot water fixture flow	Standard
Drain water heat recovery	No

* Each house was run with 2, 3 and 4 bedrooms with no additional changes to the inputs.

Table 2 shows the hot water energy use results in each of the three modeled Florida cities. The negative differences between the current and new procedure mean that, owing to its climate-specific hot water use calculation, the new procedure estimates lower hot water energy use in each Florida case. The same results are shown graphically in Figure 2. It is important to point out that these results are almost entirely due to the fact that the quantity of hot water use in current code procedures is based solely on the number of bedrooms in the home such that the gallons per day (gpd) of hot water use equals 30 + 10 * number of bedrooms. Thus, 50 gpd, 60 gpd and 70 gpd for 2, 3 and 4 bedroom homes, respectively. Because the proposed new calculation procedure includes climatic considerations, the quantity of hot water use is significantly lower for Florida's warm climate than a national average. Figure 3 illustrates this fact graphically.

Table 2. Sample House Hot Water Energy Use Estimates for Current (Old) vs. New Calculation Procedures.

City	2 Bedroom			3 Bedroom			4 Bedroom	
	Energy Use (kWh)	Change (new-old)		Energy Use (kWh)	Change (new-old)		Energy Use (kWh)	Change (new-old)
Jax-old	2,105			2,515			2,925	
Jax-new	1,692	-413		2,101	-414		2,497	-428
Orl-old	1,942			2,320			2,698	
Orl-new	1,515	-428		1,879	-441		2,232	-466
Mia-old	1,730			2,066			2,403	
Mia-new	1,283	-447		1,590	-477		1,887	-516

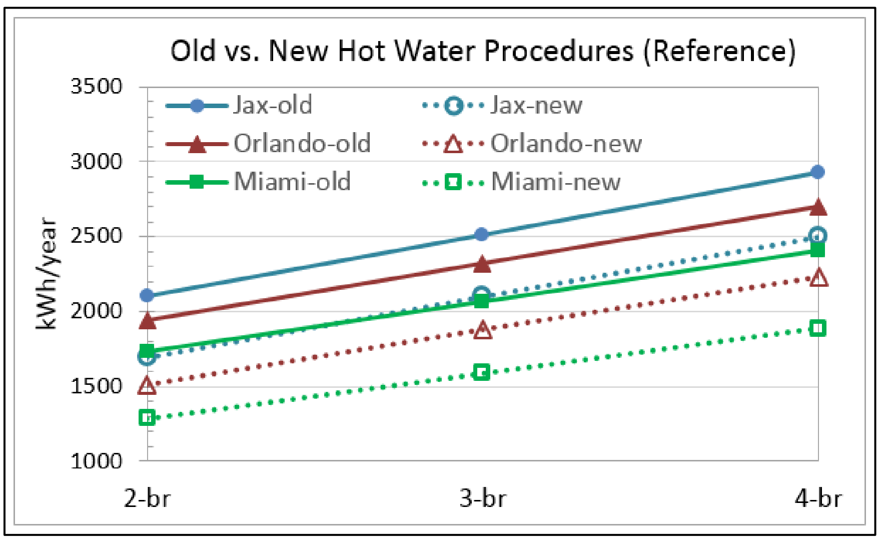

Figure 2. Sample house electric hot water energy use estimates for current vs. new calculation procedures.

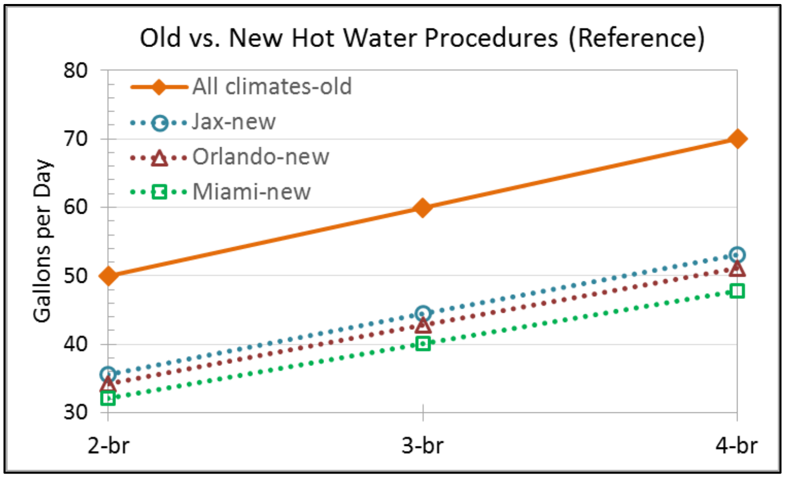

Figure 3. Hot water use quantity in gallons per day (gpd) predicted by current (old) and proposed (new) DHW calculation procedures.

Task 4 Energy Code Performance Score Comparison

EnergyGauge USA energy simulation software, which is currently used for 2014 Florida Energy Code compliance calculations, was used for the comparison of overall energy code performance scores (e-Ratios) using the current hot water calculation procedure compared with the new procedure.

The comparison used an all-electric, 2,000 sq. ft., single family, "near-code" sample house modeled in three Florida cities: Miami, Orlando and Jacksonville. The sample house characteristics are shown in Table 3.

Table 3. Near-Code Sample House Characteristics.

Component	Location		
	Miami	**Orlando**	**Jacksonville**
Conditioned floor area (ft^2)	2,000	2,000	2,000
Number of stories	1	1	1
Foundation type	SOG	SOG	SOG
Floor perimeter R-value	0	0	0
Wall type	Wood Frame	Wood Frame	Wood Frame
Wall insul. R-value	13	13	13
Wall solar absorptance	0.75	0.75	0.75
Window area (ft^2)	300	300	300
Window U-factor	0.5	0.4	0.4
Window SHGC	0.25	0.25	0.25
Roofing material	Comp. Shingles	Comp. Shingles	Comp. Shingles
Roof solar absorptance	0.75	0.75	0.75
Attic ventilation	Vented 1/300	Vented 1/300	Vented 1/300

Ceiling insul. R-value	30	38	38
Envelope ACH50 (air chng/hr @ 50pa)	5	5	5
HP SEER / HSPF	14 / 8.2	14 / 8.2	14 / 8.2
AHU location	Garage	Garage	Garage
Duct insul. R-value	8	8	8
Duct location	Attic	Attic	Attic
Duct leakage	Qn_{out}= 0.04	Qn_{out}= 0.042	Qn_{out}= 0.048
Heating / Cooling set points (°F)	72 / 75	72 / 75	72 / 75
Number of bedrooms*	2 / 3 / 4	2 / 3 / 4	2 / 3 / 4
Water heater size (gallons)	40	40	40
Water heater EF (Electric)	0.948	0.948	0.948
Water heater location	Garage	Garage	Garage
Water heater heat trap	Yes	Yes	Yes
Hot water piping length	99.44 ft.	99.44 ft.	99.44 ft.
Hot water pipe insul.	None	None	None
Hot water fixture flow	Standard	Standard	Standard
Hot water distribution	Non-recirculation	Non-recirculation	Non-recirculation

* Each house was run with 2, 3 and 4 bedrooms without any additional changes to the conditioned floor area or other envelope characteristics.

Energy code compliance simulation runs included the near-code sample house and eight hot water distribution design and equipment efficiency variation cases:

1) Near-code sample house (standard hot water distribution system)
2) Recirculation system with manual control and R-3 pipe insulation (recirculation system with manually controlled on/off, 178.89 ft. loop length, 10 ft. branch piping length and 50 Watt pump)
3) Drain water heat recovery (DWHR); no other changes from Case #1 near-code house
4) Recirculation with manual control and 50% pipe length and pump power, and R-3 pipe insulation
5) Same as Case #4 plus DWHR and low-flow fixtures
6) Heat pump water heater (HPWH) with EF = 2.5; no other changes from Case #1 house
7) Tankless natural gas water heater with EF = 0.83; no other changes from Case #1 house
8) Recirculation with temperature control (recirculation on/off controlled via temperature sensor instead of manual control) and R-3 pipe insulation
9) Standard distribution system with 50% pipe length and R-3 pipe insulation.

After each house was entered in EnergyGauge USA, performance code compliance calculations were run to estimate cooling, heating and water heating reference and proposed home loads and corresponding e-Ratios for the current, or “old” hot water calculation procedure and for the proposed, or "new" calculation procedure. An e-Ratio of 100 or less is required to pass the performance compliance method[1].

Table 4 shows the total combined (cooling, heating and water heating) e-Ratio results for all nine cases in each of the three modeled Florida cities. Positive differences between the old (current) and new procedure e-Ratio values mean that the new procedure has a higher e-Ratio than the old procedure while negative differences mean the new procedure provides a lower e-Ratio.

Table 4. Old and New Hot Water Calculation Procedure e-Ratio Comparison for Sample House with Nine Hot Water Distribution, Equipment Efficiency and Conservation Measure Variations.

Case			2 Bedroom			3 Bedroom			4 Bedroom	
			e-Ratio	Change (new-old)		e-Ratio	Change (new-old)		e-Ratio	Change (new-old)
#1 Near-Code House		Jax-old	99.67			99.68			99.67	
		Jax-new	99.64	-0.03		99.67	-0.01		99.67	-0.01
		Orl-old	99.63			99.68			99.60	
		Orl-new	99.62	-0.01		99.67	-0.01		99.59	-0.01
		Mia-old	100.46			100.24			100.05	
		Mia-new	100.47	0.01		100.22	-0.02		100.05	0.00
#2 Recirc. w/ manual control and R-3 pipe insulation		Jax-old	99.67			99.68			99.67	
		Jax-new	97.86	-1.81		97.59	-2.09		97.38	-2.30
		Orl-old	99.63			99.68			99.60	
		Orl-new	98.11	-1.52		97.92	-1.76		97.65	-1.95
		Mia-old	100.46			100.24			100.05	
		Mia-new	99.57	-0.89		99.15	-1.09		98.87	-1.18
#3 Drain water heat recovery		Jax-old	99.67			99.68			99.67	
		Jax-new	97.34	-2.33		96.80	-2.88		96.26	-3.41
		Orl-old	99.63			99.68			99.60	
		Orl-new	97.77	-1.86		97.37	-2.31		96.87	-2.74
		Mia-old	100.46			100.24			100.05	
		Mia-new	99.46	-1.00		98.93	-1.31		98.53	-1.53
#4 Recirc. w/ manual control, R-3 pipe ins., 50% pipe length and pump kW		Jax-old	99.67			99.68			99.67	
		Jax-new	97.12	-2.55		96.71	-2.97		96.34	-3.34
		Orl-old	99.63			99.68			99.60	
		Orl-new	97.48	-2.15		97.15	-2.53		96.79	-2.81
		Mia-old	100.46			100.24			100.05	
		Mia-new	99.18	-1.28		98.68	-1.56		98.33	-1.72

[1] Section R405 of Florida Energy Conservation Code provides more information on calculating performance compliance e-Ratios.

Case			2 Bedroom e-Ratio	Change (new-old)		3 Bedroom e-Ratio	Change (new-old)		4 Bedroom e-Ratio	Change (new-old)
#5 Recirc. w/ manual control, R-3 pipe ins., 50% pipe length and pump kW, DWHR and low flow		Jax-old	99.67			99.68			99.67	
		Jax-new	94.96	-4.71		94.01	-5.67		93.12	-6.55
		Orl-old	99.63			99.68			99.60	
		Orl-new	95.74	-3.89		94.95	-4.72		94.16	-5.44
		Mia-old	100.46			100.24			100.05	
		Mia-new	98.21	-2.26		97.43	-2.81		96.83	-3.22
#6 Heat pump water heater (EF = 2.5)		Jax-old	91.57			89.99			88.53	
		Jax-new	93.52	1.96		91.86	1.86		90.37	1.84
		Orl-old	92.33			90.97			89.54	
		Orl-new	94.31	1.98		92.91	1.94		91.47	1.93
		Mia-old	95.51			94.33			93.20	
		Mia-new	97.16	1.65		95.94	1.62		94.89	1.70
#7 Tankless gas WH (EF = 0.83)		Jax-old	93.16			92.58			92.02	
		Jax-new	93.76	0.60		93.09	0.51		92.47	0.45
		Orl-old	93.91			93.36			92.82	
		Orl-new	94.56	0.65		93.93	0.57		93.34	0.53
		Mia-old	96.64			96.06			95.53	
		Mia-new	97.22	0.58		96.58	0.52		96.05	0.53
#8 Recirc. w/ temperature control and R-3 pipe ins.		Jax-old	99.67			99.68			99.67	
		Jax-new	107.74	8.07		109.45	9.77		111.10	11.42
		Orl-old	99.63			99.68			99.60	
		Orl-new	106.61	6.98		108.12	8.44		109.44	9.84
		Mia-old	100.46			100.24			100.05	
		Mia-new	104.87	4.40		105.54	5.30		106.29	6.24
#9 Standard w/ R-3 pipe ins. and 50% pipe length		Jax-old	99.67			99.68			99.67	
		Jax-new	97.76	-1.91		97.44	-2.24		97.16	-2.52
		Orl-old	99.63			99.68			99.60	
		Orl-new	98.03	-1.60		97.77	-1.91		97.47	-2.13
		Mia-old	100.46			100.24			100.05	
		Mia-new	99.50	-0.96		99.05	-1.18		98.75	-1.30

A comparison showing current and new procedure e-Ratios for the 3 bedroom Orlando house for each case analyzed is provided in Figure 4 organized from left to right from the highest new e-Ratio to the lowest new e-Ratio.

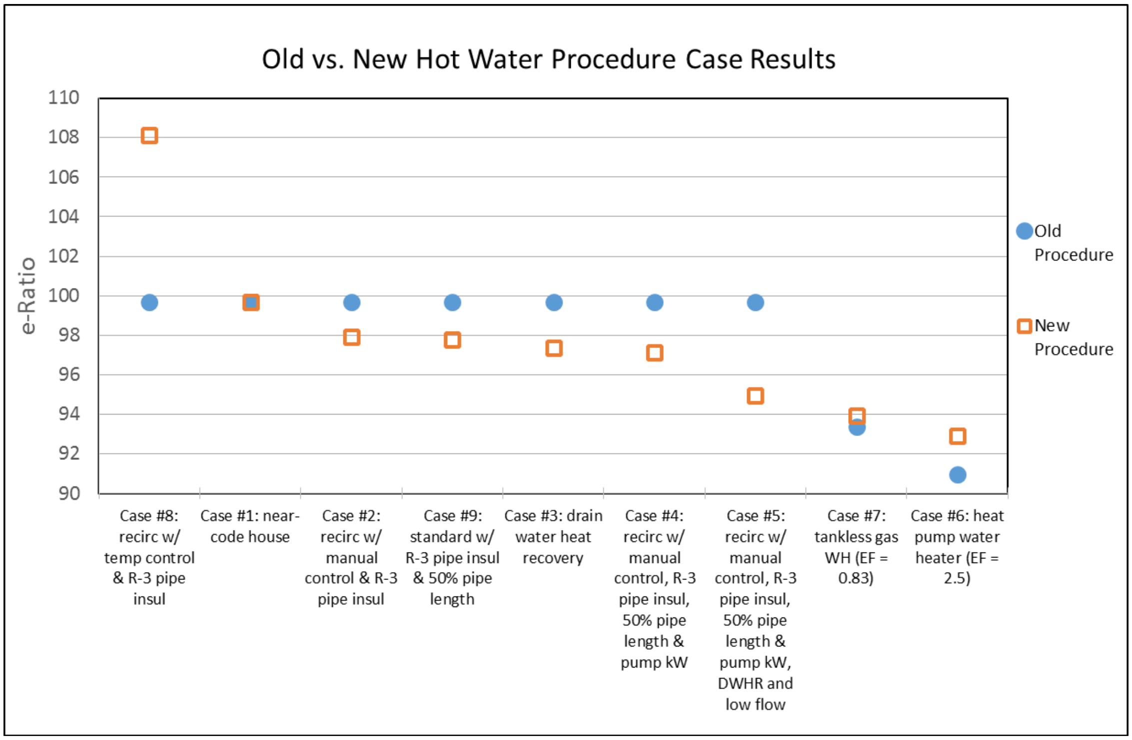

Figure 4. Total e-Ratios predicted by current (old) and proposed (new) DHW calculation procedures for the nine hot water distribution design and equipment efficiency variation cases analyzed, organized from left to right by proposed procedure new e-Ratio.

Discussion

Code Performance Score Comparisons

The summary of Task 4 energy code performance score comparison results (Table 4 above) shows total, combined (cooling, heating and water heating) e-Ratio impacts for the various distribution, equipment efficiency and conservation measures analyzed. These results are further discussed by Case # below.

The Case #1 e-Ratio comparison for the near-code house shows only insignificant e-Ratio differences between the old (current) calculation procedure and new procedure. Both the reference and proposed design hot water loads are equally lower for the new procedure. The slight differences in the Case #1 results are due to hot water having slightly less weight in the combined (cooling, heating and water heating) new procedure and to rounding error.

Cases #2 provides total e-Ratio results for a recirculation system with manual control and R-3 pipe insulation and Case #4 is the same system with 50% pipe length and pump power use. The new procedure lowers the total e-Ratio for these distribution options by 0.89 points for the Case #2 two bedroom house in Miami to 3.34 points for the Case #4 four bedroom house in Jacksonville. Code adoption of the new DHW calculation procedure would provide a small to moderate performance compliance credit for manually controlled recirculation with R-3 pipe insulation as compared with to the current DHW procedure.

The Case #3 total e-Ratio comparison results for the drain water heat recovery system show the new procedure to lower the total, combined e-Ratio from 1.00 point for the two bedroom house in Miami to 3.41 points for the four bedroom house in Jacksonville. Code adoption of the new DHW calculation procedure would provide a small to moderate performance compliance credit for drain water heat recovery relative to the current DHW procedure.

The Case #5 total e-Ratio comparison shows results for adding a drain water heat recovery system and low flow fixtures to the Case #4 manually controlled recirculation distribution system with R-3 pipe insulation and 50% pipe length and pump power. This configuration combines all potential DHW saving measures. The new procedure lowers the total, combined e-Ratio for this distribution system from 2.26 points for the two bedroom house in Miami to 6.55 points for the four bedroom house in Jacksonville. Code adoption of the new DHW calculation procedure would provide a moderate to large performance compliance credit for this distribution system and conservation measure combination relative to the current DHW procedure.

Comparison Cases #6 and #7 provide total e-Ratio results for specifying an EF-2.5 heat pump water heater and EF-0.83 tankless gas water heater respectively (with no distribution system or conservation measure changes from the Case #1 near-code house). The new DHW procedure with these equipment options increase the total, combined e-Ratio. The tankless gas water heater gains between 0.45 and 0.65 e-Ratio points and the heat pump water heater gains between 1.62 and 1.98 e-Ratio points. The overall impact of current hot water system improvements will be slightly less in the new procedure as water heating becomes a smaller fraction of the overall e-Ratio. Impact for heat pump water heaters is greater than for tankless gas systems because the normalized DHW load for the tankless gas water heater is larger than the normalized DHW load for the heat pump system but the reference DHW load is the same for both. As a result, the e-Ratio is larger for the tankless gas water heater in both the current and the new DHW calculations but the difference between the old and new calculation is less for the tankless gas system than for the heat pump system. Code adoption of the new DHW calculation procedure would increase performance compliance total e-Ratios for tankless gas equipment by a small amount and heat pump water heaters by a somewhat larger amount compared with the current DHW procedure.[2]

The Case #8 total e-Ratio comparison shows the results for the same distribution system used in Case #2-- recirculation system and R-3 pipe insulation-- except instead of manual control for the recirculation system that was specified for Case #2, the recirculation system for Case #8 is temperature controlled. Note that the draft 6th edition 2017 code does not allow this type of recirculation control. We calculated it in the event it is considered or perhaps to indicate why it is not allowed. This change in control strategy significantly increases the total, combined e-Ratios for all new DHW procedure runs, from 4.40 points for a two bedroom house in Miami to 11.42 points for a four bedroom house in Jacksonville. Code adoption of the new DHW calculation procedure would significantly increase performance compliance total e-Ratios for temperature controlled recirculation distribution systems, if allowed, as compared with the current DHW procedure.

The Case #9 total e-Ratio comparison shows results for a standard distribution system with R-3 pipe insulation and 50% pipe length. The new procedure lowers the total, combined e-Ratio for this distribution and conservation measure option from 0.96 points for the two bedroom house in Miami to 2.52 points for the four bedroom house in Jacksonville. Code adoption of the new DHW calculation procedure would provide a small to moderate performance compliance credit for R-3 pipe insulation and 50% pipe length relative to the current DHW procedure. This distribution option can be compared with the manually controlled recirculation distribution option with R-3 pipe insulation and 50% pipe length and pump power (Case #4), which provides slightly greater performance compliance credit.

<u>Controls for Recirculation Systems</u>

One additional observation is made regarding the language used in the draft 6th Edition (2017) Florida Energy Conservation Code regarding controls for hot water recirculation systems. The mandatory circulation system control requirements in Section R403.5.1.1 (below) are not explicit, leaving questions as to what is intended by phrases such as “the identification of a demand” and “at the desired temperature.”

> **R403.5.1.1 Circulation systems.** Heated water circulation systems shall be provided with a circulation pump. The system return pipe shall be a dedicated return pipe or a cold water supply pipe. Gravity and thermosyphon circulation

[2] The heat pump analysis is for a 40 gallon tank. Once the tank size is greater than 55 gallons the reference house has the efficiency of a heat pump and savings due to heat pumps will be less.

> systems shall be prohibited. Controls for circulating hot water system pumps shall start the pump based on the identification of a demand for hot water within the occupancy. The controls shall automatically turn off the pump when the water in the circulation loop is at the desired temperature and when there is no demand for hot water.

In Section R403.5.2, the draft 2017 code provides control requirements for demand recirculation systems:

> **R403.5.2 Demand recirculation systems.** A water distribution system having one or more recirculation pumps that pump water from a heated water supply pipe back to the heated water source through a cold water supply pipe shall be a *demand recirculation water system*. Pumps shall have controls that comply with both of the following:
>
> 1. The control shall start the pump upon receiving a signal from the action of a user of a fixture or appliance, sensing the presence of a user of a fixture or sensing the flow of hot or tempered water to a fixture fitting or appliance.
> 2. The control shall limit the temperature of the water entering the cold water piping to 104^{o}F (40^{o}C).

Since Section R403.5.2 provides clarification of recirculation system control requirements, Section R403.5.1.1 should stipulate controls be in accordance with Section R403.5.2:

> **R403.5.1.1 Circulation systems.** Heated water circulation systems shall be provided with a circulation pump. The system return pipe shall be a dedicated return pipe or a cold water supply pipe. Gravity and thermosyphon circulation systems shall be prohibited. Controls for circulating hot water system pumps shall start the pump based on the identification of a demand for hot water within the occupancy. The controls shall automatically turn off the pump when the water in the circulation loop is at the desired temperature and when there is no demand for hot water. <u>Controls shall be in accordance with Section R403.5.2.</u>

Recommendations

The intent of the Florida Energy Conservation Code is to regulate the design and construction of buildings to effectively use and conserve energy over each building's useful life, while also permitting innovative approaches and techniques (Section R101.3). As shown in this report, climate-specific effects on domestic hot water use, the hot water distribution system type employed, and the use of conservation measures can significantly affect residential energy use and conservation. The draft proposed code change language delivered in the Appendix of this report provides a vetted, comprehensive means of accounting for these factors in performance energy code calculations, and is therefore recommend for adoption during the next Florida Building Code modification cycle.

As outlined in the Discussion section above, the authors also believe there is a need to clarify circulation system control requirements in Section R403.5.1.1 of the draft 6th Edition (2017) Florida Energy Conservation Code. This clarification can be made by adding a stipulation to Section R403.5.1.1 that "controls shall be in accordance with Section R403.5.2," which provides specific hot water pump and temperature control requirements.

Acknowledgements

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APPENDIX

- Literature Review Documents List
- DHW Energy Consumption Calculation Spreadsheet Cover Page
- Draft Proposed DHW Code Language Changes

Literature Review Documents List

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DHW Energy Consumption Calculation Spreadsheet Cover Page

Example Hot Water System Calculations

User input fields are yellow	
TMY City	Orlando
Distribution system type	re, man
HW pipe Insulation	none
Fixture flow efficiency	std
Std sys pipe length	99.44
Recirc sys loop length	178.89
Recirc sys branch length	10.00
Recirc pumpWatts	50.00
DW heat recovery?	no
PipeL %	100%

Ref std sys pipe length = 99.44
Ref recirc sys loop length = 178.89
HW Climate factor = 10.2%

Δ gpd	Variable Name	Proposed (PD)	Reference (RD)
-6.01	HWgpd	36.8	42.8
0.00	Fgpd	25.6	25.6
0.00	CWgpd	3.9	3.9
0.00	DWgpd	4.3	4.3
-6.01	sWgpd	0.8	6.8
0.00	oWgdp	2.3	2.3
	WD_{eff}	0.1	1.0
	E_{waste}	43.2	32.0
	ED_{eff}	1.070	1.00
Δ MBtu	kWh/y	1736.1	1878.8
-0.470	pumpkWh/y	5.0	0.0
	Δ Water	-14.0%	w.r.t. RD
	Δ HW Energy *	-7.3%	w.r.t. RD
	Δ e-Ratio **	-0.74	w.r.t. RD

Home characteristics:

CFA	2000
Nbr	3
Nfl	1
Bsmt	0
Ndu	1

Water heater:

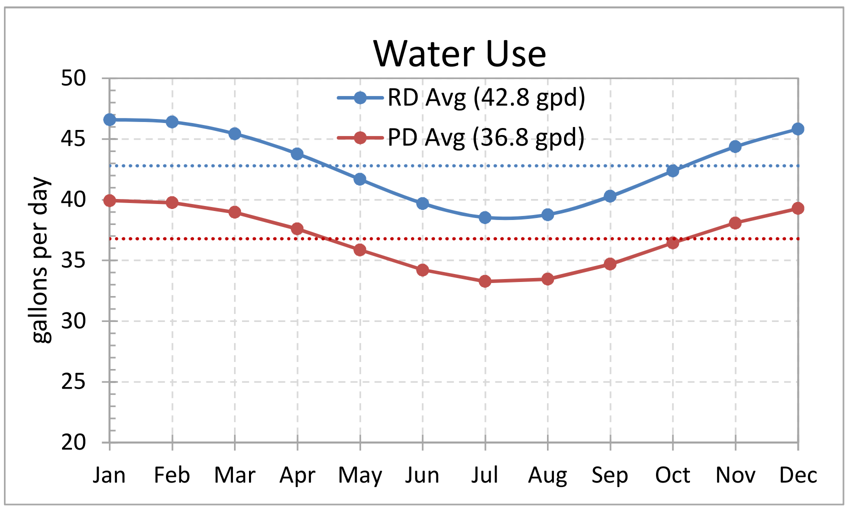
Fuel type	elec

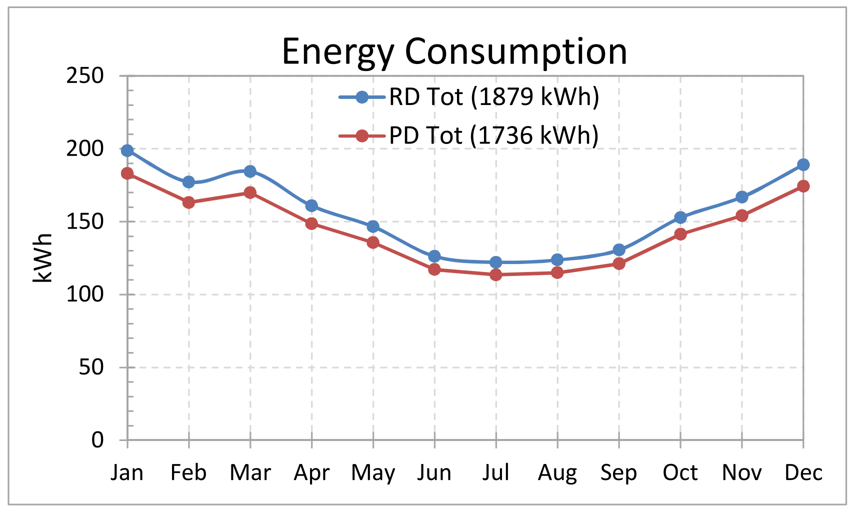
Drain Water Heat Recovery:

Showers connected	all
Equal flow?	yes
CSA 55.1 $DWHR_{eff}$	54.0%

WHinTadj = 0.00
WHinT = 77.5
EFuse = 0.948
Tmains = 77.54

* Calculated using Florida Code nMEUL method
** Estimate only. Actual Δ e-Ratio will depend on a large number of home configuration variables.





rated EF gas	0.83
rated EF elec	1.70
use rated EFs?	no

PROPOSED DOMESTIC HOT WATER SYSTEM CHANGES

[Adapted from ANSI/RESNET 301-2014 Addendum A-2015]

TABLE R405.5.2(1)— SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS. Modify as follows:

TABLE R405.5.2(1)
SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

BUILDING COMPONENT	STANDARD REFERENCE DESIGN	PROPOSED DESIGN
Service water Heating[d, e, f, g]	~~As proposed~~ Fuel Type: Same as proposed Use (gal/day): ~~same as proposed design~~ determined in accordance with Appendix # Efficiency: in accordance with prevailing Federal minimum standards Energy Consumption: determined in accordance with Appendix #.	Fuel Type: As proposed Use (~~G~~gal/day):~~= 30 + (10 × N_{br})~~ determined in accordance with Appendix # Efficiency: As proposed Energy Consumption: determined in accordance with Appendix #.

[All other parts of the table to remain unchanged.]

Add new Appendix # to read as follows:

APPENDIX #

CALCULATION OF HOT WATER ENERGY CONSUMPTION

#-1 Domestic Hot Water (DHW) System Modeling. Domestic hot water energy consumption shall be modeled and simulated monthly or more frequently using monthly or more frequent simulation time steps in accordance with Sections #-1.1 through #-2.2. Annual domestic hot water energy consumption shall be set equal to the sum of the simulated monthly values.

#-1.1 Standard Reference Design Hot Water Use. Domestic hot water system use in gallons per day for the Standard Reference Design shall be determined in accordance with Equation #-1

$$HWgpd = (refDWgpd + refCWgpd + F_{mix} * (refFgpd + refWgpd)) * Ndu \qquad \text{Eq. \#-1}$$

where:

HWgpd = gallons per day of hot water use
refDWgpd = reference dishwasher gallons per day = ((88.4+34.9*Nbr)*8.16)/365
refCWgpd = reference clothes washer gallons per day =
(4.52*(164+46.5*Nbr))*((3*2.08+1.59)/(2.874*2.08+1.59))/365

$F_{mix} = 1 - ((T_{set} – T_{use})/ (T_{set} – T_{mains}))$
where
T_{set} = Water heater set point temperature = 125 F
T_{use} = Temperature of mixed water at fixtures = 105 F
$T_{mains} = (T_{amb,avg} + offset) + ratio * (\Delta T_{amb,max} / 2) * \sin (0.986 * (day\# - 15 - lag) - 90)$
where
T_{mains} = temperature of potable water supply entering residence (ºF)
$T_{amb,avg}$ = annual average ambient air temperature (ºF)
$\Delta T_{amb,max}$ = maximum difference between monthly average ambient air temperatures (e.g., $T_{amb,avg,july} – T_{amb,avg,january}$) (ºF)
0.986 = degrees/day (360/365)
day# = Julian day of the year (1-365)
offset = 6°F
ratio = $0.4 + 0.01 (T_{amb,avg} – 44)$
lag = $35 – 1.0 (T_{amb,avg} – 44)$

refFgpd = 14.6 + 10.0*Nbr = reference climate-normalized daily fixture water use (in gallons per day)

refWgpd = $9.8 * Nbr^{0.43}$ = reference climate-normalized daily hot water waste due to distribution system losses (in gallons per day)

where
Nbr = number of bedrooms in each dwelling unit
Ndu = number of like dwelling units

#-2 Proposed Design Hot Water Use. Domestic hot water system use in gallons per day for the Proposed Design shall be determined in accordance with Equation #-2

$$HWgpd = (DWgpd + CWgpd + F_{eff} * adjF_{mix} * (refFgpd + oWgpd + sWgpd * WD_{eff})) * Ndu \quad \text{Eq. \#-2}$$

where:
HWgpd = gallons per day of hot water use in Rated home
DWgpd = dishwasher gallons per day = ((88.4+34.9*Nbr)*8.16)/365
CWgpd = clothes washer gallons per day = (4.52*(164+46.5*Nbr))*((3*2.08+1.59)/(2.874*2.08+1.59))/365
F_{eff} = fixture effectiveness in accordance with Table #(1)

Table #(1) Hot water fixture effectiveness

Plumbing Fixture Description	F_{eff}
Standard-flow: showers ≤2.5 gpm and faucets ≤2.2 gpm	1.00
Low-flow: all showers and faucets ≤2.0 gpm	0.95

$adjF_{mix} = 1 – ((T_{set} – T_{use})/ (T_{set} – WH_{in}T))$
where
T_{set} = 125 ºF = water heater set point temperature
T_{use} = 105 ºF = temperature of mixed water at fixtures
$WH_{in}T$ = water heater inlet temperature
where
$WH_{in}T = T_{mains} + WH_{in}T_{adj}$ for DWHR systems and where $WH_{in}T_{adj}$ is calculated in accordance with equation #-5
$WH_{in}T = T_{mains}$ for all other hot water systems
T_{mains} = temperature of potable water supply entering the residence calculated in accordance with Section #-1
refFgpd = reference climate-normalized daily fixture water use calculated in accordance with Section #-1.1

$oWgpd = refWgpd * oFrac * (1-oCD_{eff})$ Eq. #-3

where

$oWgpd$ = daily standard operating condition waste hot water quantity

$oFrac$ = 0.25 = fraction of hot water waste from standard operating conditions

oCD_{eff} = Approved Hot Water Operating Condition Control Device effectiveness (default = 0.0)

$sWgpd = (refWgpd – refWgpd * oFrac) * pRatio * sysFactor$ Eq. #-4

where

$sWgpd$ = daily structural waste hot water quantity

$refWgpd$ = reference climate-normalized distribution system waste water use calculated in accordance with Section #-1.1

$oFrac$ = 0.25 = fraction of hot water waste from standard operating conditions

$pRatio$ = hot water piping ratio

where

for Standard systems:

$pRatio = PipeL / refPipeL$

where

PipeL = measured length of hot water piping from the hot water heater to the farthest hot water fixture, measured longitudinally from plans, assuming the hot water piping does not run diagonally, plus 10 feet of piping for each floor level, plus 5 feet of piping for unconditioned basements (if any)

$refPipeL = 2*(CFA/Nfl)^{0.5} + 10*Nfl + 5*Bsmt$ = hot water piping length for Reference Home

where

CFA = conditioned floor area

Nfl = number of conditioned floor levels in the residence, including conditioned basements

Bsmt = presence =1.0 or absence = 0.0 of an unconditioned basement in the residence

for recirculation systems:

$pRatio = BranchL /10$

where

BranchL = measured length of the branch hot water piping from the recirculation loop to the farthest hot water fixture from the recirculation loop, measured longitudinally from plans, assuming the branch hot water piping does not run diagonally

sysFactor = hot water distribution system factor from Table #(2)

Table #(2) Hot Water Distribution System Insulation Factors

Distribution System Description	**sysFactor**	
	No pipe insulation	≥R-3 pipe insulation
Standard systems	1.00	0.90
Recirculation systems	1.11	1.00

WD_{eff} = distribution system water use effectiveness from Table #(3)

Table #(3) Distribution system water use effectiveness

Distribution System Description	**WD_{eff}**
Standard systems	1.00
Recirculation systems	0.10

Ndu = number of dwelling units

#-2.1 Drain Water Heat Recovery (DWHR) Units

If DWHR unit(s) is (are) installed in the Rated Home, the water heater potable water supply temperature adjustment ($WH_{in}T_{adj}$) shall be calculated in accordance with Equation #-5.

$WH_{in}T_{adj}$ =Ifrac*($DWHR_{in}T$-T_{mains})*$DWHR_{eff}$*PLC*LocF*FixF **Eq. #-5**

where

$WH_{in}T_{adj}$ = adjustment to water heater potable supply inlet temperature (°F)

Ifrac = 0.56 + 0.015*Nbr – 0.0004*Nbr^2 = fraction of hot water use impacted by DWHR

$DWHR_{in}T$ = 97 °F

T_{mains} = calculated in accordance with Section #-1.1

$DWHR_{eff}$ = Drain Water Heat Recovery Unit efficiency as rated and labeled in accordance with CSA 55.1

where

$DWHR_{eff}$ = $DWHR_{eff}$ *1.082 if low-flow fixtures are installed in accordance with Table #(1)

PLC = 1 - 0.0002*pLength = piping loss coefficient

where

for standard systems:

pLength = pipeL as measured accordance with Section #-2

for recirculation systems:

pLength = branchL as measured in accordance with Section #-2

LocF = a performance factor based on the installation location of the DWHR determined from Table #(4)

Table#(4) Location factors for DWHR placement

DRHR Placement	**LocF**
Supplies pre-heated water to both the fixture cold water piping and the hot water heater potable supply piping	1.000
Supplies pre-heated water to only the hot water heater potable supply piping	0.777
Supplies pre-heated water to only the fixture cold water piping	0.777

FixF = Fixture Factor

where

FixF = 1.0 if all of the showers in the home are connected to DWHR units

FixF = 0.5 if there are 2 or more showers in the home and only 1 shower is connected to a DWHR unit.

#-2.2 Hot Water System Annual Energy Consumption

Service hot water energy consumption shall be calculated using Approved Software Tools and the provisions of Section #-1, Section #-2 and Section #-2.1 shall be followed to determine appropriate inputs to the calculations.

If the Proposed Design includes a hot water recirculation system, the annual electric consumption of the recirculation pump shall be added to the total hot water energy consumption. The recirculation pump kWh/y shall be calculated using Equation #-6

pumpkWh/y = pumpW * Efact **Eq. #-6**

where:

pumpW = pump power in watts (default pumpW = 50 watts)

Efact = factor selected from Table #(5)

Table #(5) Annual electricity consumption factor for hot water recirculation system pumps

Recirculation System Description	**Efact**
Recirculation without control or with timer control	8.76

Recirculation with temperature control	1.46
Recirculation with demand control (presence sensor)	0.15
Recirculation with demand control (manual)	0.10

Results from standard hot water energy consumption calculations considering only tested Energy Factor data ($stdEC_{HW}$) shall be adjusted to account for the energy delivery effectiveness of the hot water distribution system in accordance with equation #-7.

$EC_{HW} = stdEC_{HW} * (E_{waste} + 128) / 160$ Eq. #-7

where E_{waste} is calculated in accordance with equation #-8.

$E_{waste} = oEW_{fact} * (1-oCD_{eff}) + sEW_{fact} * pEratio$ Eq. #-8

where

$oEW_{fact} = EW_{fact} * oFrac$ = standard operating condition portion of hot water energy waste

where

EW_{fact} = energy waste factor in accordance with Table #(6)

oCD_{eff} is in accordance with Section #-2

$sEW_{fact} = EW_{fact} – oEW_{fact}$ = structural portion of hot water energy waste

pEratio = piping length energy ratio

where

for standard system: pEratio = PipeL / refpipeL

for recirculation systems: pEratio = LoopL / refLoopL

and where

LoopL = hot water recirculation loop piping length including both supply and return sides of the loop, measured longitudinally from plans, assuming the hot water piping does not run diagonally, plus 20 feet of piping for each floor level greater than one plus 10 feet of piping for unconditioned basements.

refLoopL = 2.0*refPipeL - 20

Table #(6) Hot water distribution system relative annual energy waste factors

Distribution System Description	**EW_{fact}**	
	No pipe insulation	≥R-3 pipe insulation
Standard systems	32.0	28.8
Recirculation without control or with timer control	500	250
Recirculation with temperature control	375	187.5
Recirculation with demand control (presence sensor)	64.8	43.2
Recirculation with demand control (manual)	43.2	28.8