Measure Information Template: Tankless Gas Water Heaters

2008 California Building Energy Efficiency Standards

Proposer: Davis Energy Group, Inc
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Purpose

This document proposes changes to the modeling of tankless gas water heaters under the Title 24 Residential Building Standards. Current ACM modeling rules for tankless water heaters overvalue their performance by not accounting for the impact of small hot water draws and heat exchanger "cool down" on overall performance.

Overview

Description	Instantaneous, or tankless gas water heaters have the potential to significantly improve the efficiency of residential water heating due to higher combustion efficiencies and the elimination of standby losses common to the gas storage water heaters. In the last decade a new breed of instantaneous gas water heaters with Energy Factors (EF) of 0.80 or higher have been introduced to the market. These units are considerably more efficient that standard gas storage water heaters (~0.60 EF) and they represent a significant improvement over units of twenty to thirty years ago in terms of both eliminating standing pilots and by integrating sophisticated controls that vary burner capacity to meet supply water setpoints under varying flow rates. Over the past five years tankless water heaters are starting to achieve some penetration in the residential market. Economics are generally good in new construction applications. In retrofit applications, associated installation costs (expensive vent system and frequent need for upsizing of the gas line) often become a major barrier for most homeowners. The proposed change for tankless water heaters is to more accurately describe their performance in the ACM. This proposal is for all building types included under the residential standards.
Type of Change	The proposal represents a change in the Residential ACM modeling rules. Appendix RG of the ACM manual would need to be modified to reflect the proposed changes.
Energy Benefits	The benefit would be increased accuracy in the modeling of tankless gas water heaters within the Title 24 Standards.
Non-Energy Benefits	Reduced natural gas consumption equates to improved air quality.
Environmental Impact	Since approximately 85% of California homes have gas storage water heaters, the long-term savings impact is significant. Most tankless units require an electric connection for controls and combustion air blower. The added electrical demand is small (~5 Watts per unit), but continuous. Air quality benefits would accrue from reduced gas consumption.

Technology Measures	Measure Availability and Cost Not required for modeling rule change. Useful Life, Persistence and Maintenance This is one area of uncertainty with tankless water heaters. In areas with hard water, scale deposits will start to build on the heat exchanger. To date, there is no data on how significant a problem mineral deposits are. Manufacturers recommend flushing the heat exchange with a mild acid solution at one or two year intervals, depending on water quality.
Performance Verification	Not required.
Cost Effectiveness	Not required.
Analysis Tools	The proposed changes can be easily implemented in the ACM.
Relationship to Other Measures	The proposed change would reduce the current credit for tankless gas water heaters.

Methodology

Both tankless and storage gas water heaters are tested under procedures defined by the U.S. Department of Energy (Federal Register 10 CFR, Chapter II, Pt. 430, Subpt. B, App. E). The test procedure prescribes six equal hot water draws (volume of ~10.7 gallons per draw) at one-hour intervals. The remainder of the 24-hour test period is used to account for standby losses. Unlike storage water heaters, the standby portion of the test minimally impacts tankless water heater performance. However, the number, timing, and frequency of draws affect tankless units since the heat exchanger must be raised to temperature for each draw event.

Evaluating tankless water heater performance was one of the elements of the PIER-funded study addressing water heating research issues and Title 24. To evaluate the performance of tankless gas water heaters, Davis Energy Group (DEG) monitored two units currently on the market. One unit was monitored in an existing home (occupied by a working couple) and the second was tested at DEG's shop facility. The schematic shown in Figure 1 depicts the system configuration at the house[1]. Installed monitoring equipment included a high resolution flow meter (FLDHW), a gas meter with a 20 pulse per ft^3 digital output (GAS), and immersion thermocouples on the inlet and outlet of the tankless heater (TDC and TDH, respectively).

A Data Electronics DT-50 datalogger was used to monitor and log data in the field. The datalogger was configured to log temperatures, hot water flow, gas consumption, and heating capacity on 15-second intervals whenever hot water flow occurred. Each hot water draw event could then be characterized by a start time and end time, volume of

[1] A similar monitoring configuration was used in the testing at DEG's shop facility.

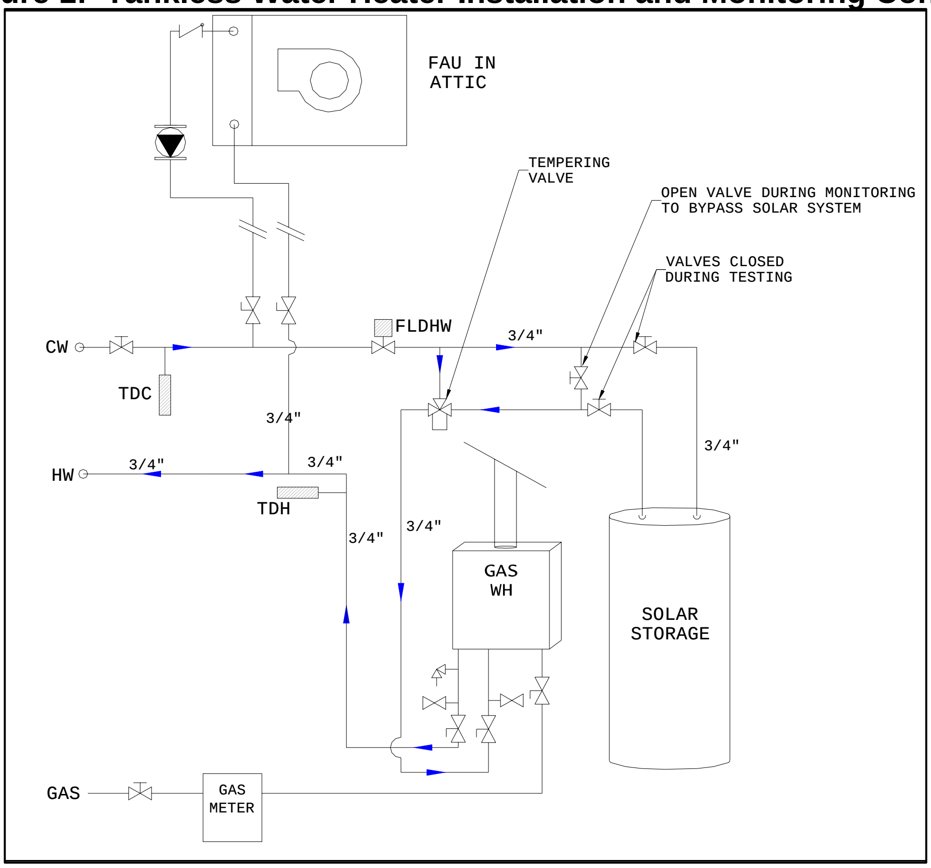
water drawn from the water heater, Btu's delivered from the water heater, and gas consumption.

Efficiency was defined as follows:

Efficiency = Q_{out} / Q_{in} (Equation 1)

Where Q_{out} = Draw volume in gallons x 8.3 x (TDH – TDC)
Q_{in} = Gas ft^3 x 1013 Btu/ft^3

Figure 1: Tankless Water Heater Installation and Monitoring Configuration



As part of the field testing, a conventional gas storage water heater was monitored prior to replacement with the tankless unit. Field results indicated trends that suggested additional lab testing would be useful in further understanding system performance. Under the PIER project, a second tankless unit was obtained for testing at Davis Energy Group's shop/test facility. The primary goal of the lab testing was to evaluate the performance of a tankless unit under more controlled conditions allowing data collection at various flow rates, hot water draw volumes, and time interval between draws. Performance characteristics of the units monitored in the lab and field are summarized in Table 1.

Table 1: Performance Characteristics of Tested Units

	Unit # 1 (field)	Unit # 2 (lab)
Energy Factor	0.82	0.81
Thermal Efficiency	82%	81.6%
Min Capacity (Btuh)	15,000	19,500
Max Capacity (Btuh)	180,000	140,000
Default Temperature Setting	120°F	122°F

Analysis and Results

This section provides a brief summary of the PIER tankless study results. Full details of the study can found in the PIER "Field and Laboratory Testing of Tankless Gas Water Heater Performance" report.

Figure 2 compares monitoring data for both the storage gas water heater (pre-retrofit) and tankless unit (post-retrofit) at the field site. The storage water heater data shows efficiency approaching zero at very low daily hot water usage rates. As loads increase (the Q_{out} term in Equation 1), standby loss term becomes a smaller fraction of the overall energy consumption. The trend of the storage water heater efficiency curve fit suggests that as water loads approach the 64.3 gallons used in the Energy Factor test, the monitored efficiency converges to a value close to the rated Energy Factor. The instantaneous water heater demonstrates a very different relationship. As hot water consumption decreases, the daily efficiency falls slightly. What is more significant is the large variation that exists for days with similar hot water usage. For example, the three data points around 25 gallons/day demonstrate efficiencies ranging from about 55% to 82%. This large variation suggests that differences in hot water use characteristics affects the calculated daily efficiency.

Testing was performed at the Davis Energy Group shop to better understand the impacts of draw volume size, flow rate, and time intervals between draws on overall efficiency. Figure 3 plots data from a series of tests with varying flow rates (1.2 to 2.3 gpm) and varying time intervals between hot water draws (5 and 45 minutes[2]). The data clearly depicts the impact of "cool down" time on system efficiency. The "5 minutes between draw" tests show a 10-15 percentage point drop in efficiency at draw volumes of 1 gallon (relative to larger 10 or 15 gallon draws), while the "45 minutes between draws" show a much more significant drop. This efficiency disparity is largest at small volumes and approaches zero at about 4 gallon draw volumes. The impact of flow rate appears to be negligible for the "5 minute" data, although the "45 minute" interval data does demonstrate some variation due to flow rate. This may be due to the effect of the lower flow rate allowing the heat exchanger more time to fully come to temperature than at a higher flow rate.

[2] At 45 minutes, the heat exchanger had essentially cooled to room temperature.

Figure 2: Comparison of Daily Water Heater Efficiency

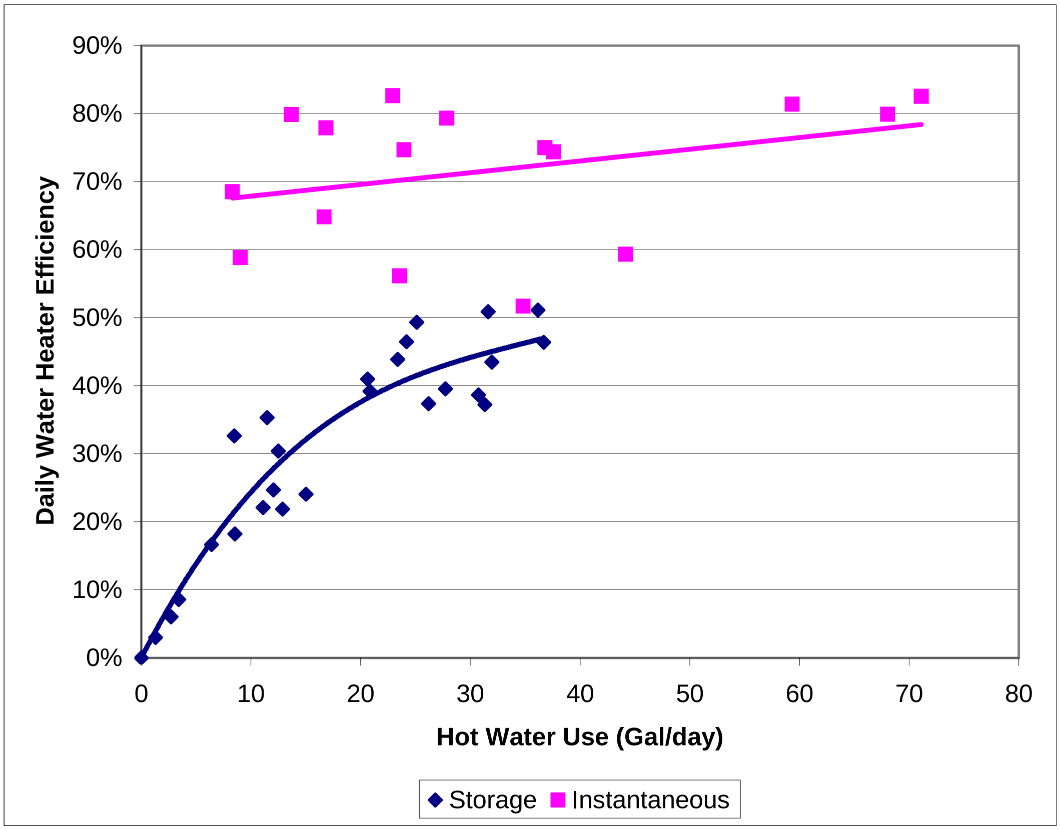


Figure 3: Monitored Lab Efficiency of Tankless Water Heater #2

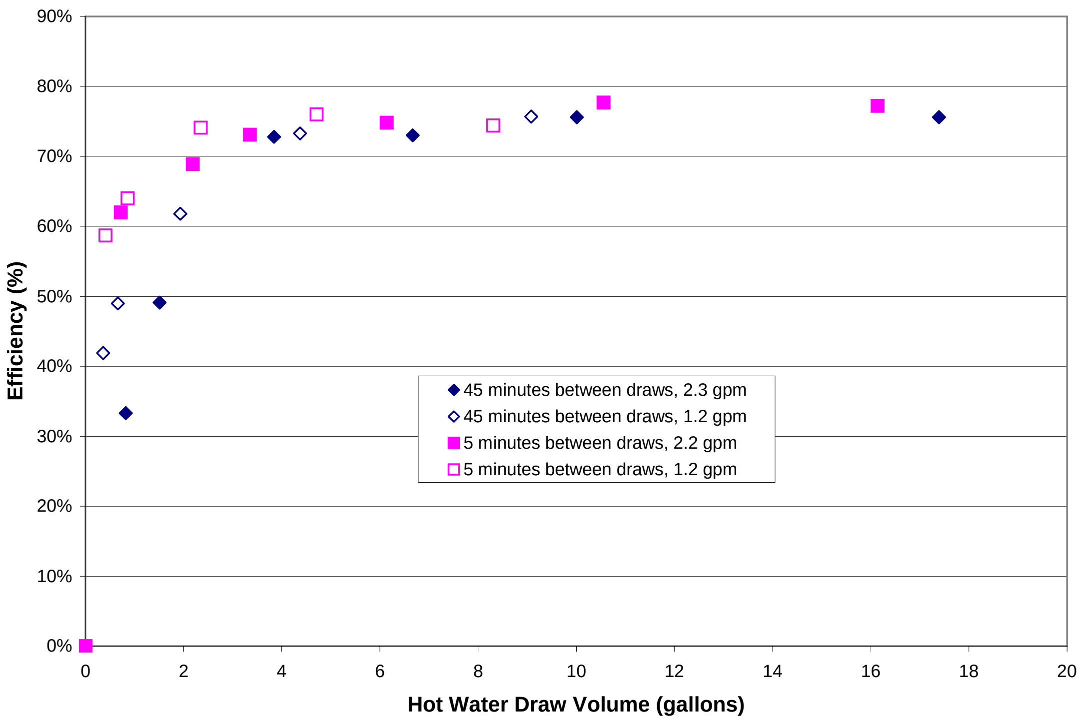
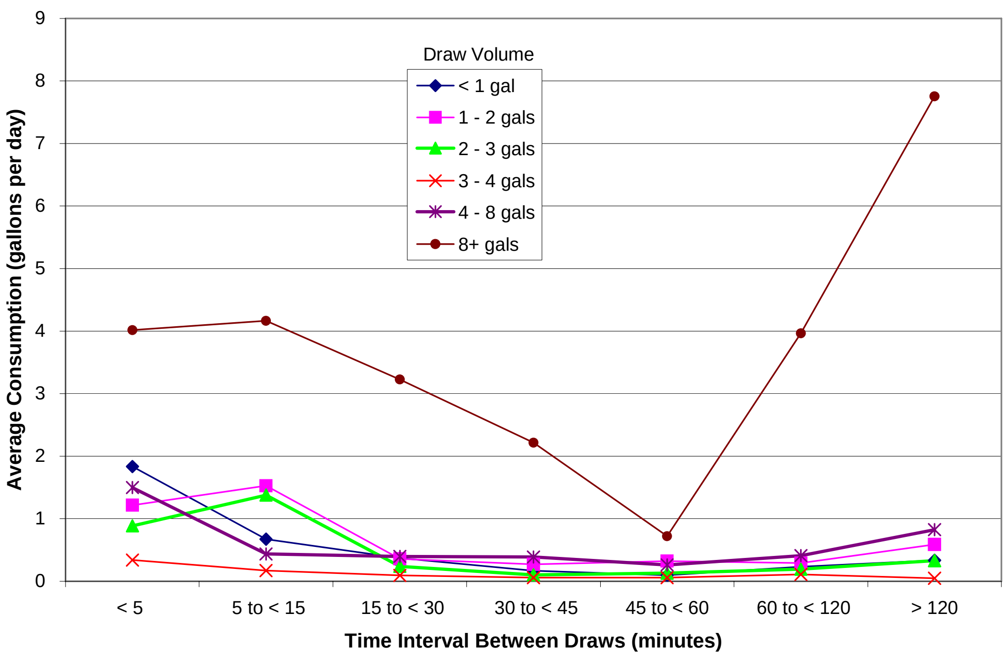


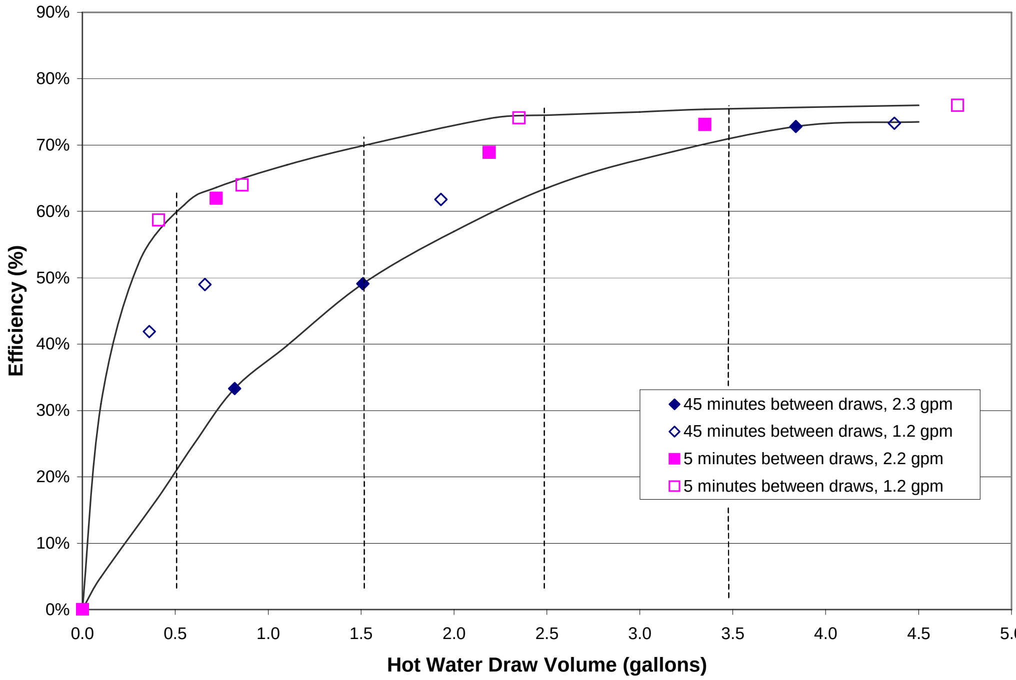
Figure 3 clearly demonstrates how system efficiency is affected by both the size of the hot water draw and how much the heat exchanger has cooled since the prior draw. This is valuable information, but to draw conclusions on full-year performance, representative hot water draw schedules must by applied. Currently this is the weak link. There is very little good data available characterizing hot water usage in California homes. For this study we relied on two sources: 1) a typical hot water usage profile used in the residential distribution system analysis for the 2005 Title 24 Standards, and 2) eleven months of detailed hot water usage data collected during 2003-2004 at a Building America monitoring site in Elk Grove, CA. The 2,070 ft^2 single-story Elk Grove house was occupied by a working couple during the monitoring period. Hot water usage during the eleven months averaged 43 gallons per day. In addition to monitoring the total hot water usage, data were collected on the draw characteristics of each hot water draw (start time, end time, average flow rate, and temperatures). Figure 4 disaggregates the Building America hot water usage data by both draw volume and time interval between draws.

Figure 4: Characterization of Hot Water Loads at Building America Site



With a basis for defining hot water usage, we can now look more closely at tankless performance. Figure 5 focuses on tankless performance at hot water draw volumes less than 5 gallons (subset of data in Figure 3), since this is the region where performance is subject to the greatest degradation. For the zero to four gallon draw volume range we propose to evaluate performance under two “cool down” levels: 5 minute “cool down” and 45 minute “cool down” (at the 2.3 gpm flow rate). Figure 5 shows a smoothed curve through the lab monitored data points. In addition vertical lines are shown at 0.5, 1.5, 2.5, and 3.5 gallons. A representative efficiency is defined where the vertical lines intercept the curve. For example, at 0.5 gallons, efficiencies of 21% and 60% are estimated, for 45 and 5 minute intervals, respectively.

Figure 5: Efficiency as a Function of Volume and Time Between Draws



The final step in developing an estimate of typical full-year tankless water heater performance involves applying the efficiency curves to the assumed load profiles. Table 2 disaggregates the assumed hot water load into one-gallon bins. An assumption is made that at an eleven gallon hot water draw volume, the thermal efficiency of a tankless unit is equal to the nominal efficiency[3], in this case 81.6%. Estimated efficiencies for draws of four gallons or less are based on Figure 5. From five through ten gallons, a linear relationship is assumed. From eleven gallons on up, the nominal 81.6% efficiency is assumed. As shown in the weighted efficiency columns in Table 2, virtually all of the degradation occurs at draw volumes less than four gallons due to the lower efficiencies and considerable usage at low volume. The difference between hot (77.3%) and cold start (70.3%) efficiencies is fairly significant when compared the assumed nominal 81.6% efficiency.

In reality, the expected degradation will lie somewhere between the hot and cold start conditions. Table 3 summarizes the “waiting time between draws” data from both the Elk Grove Building America data and the 2005 Title 24 hot water usage pattern assumptions. Based on these two points, we propose applying a 40% weighting factor to “cold” and a 60% weighting to “hot”. The resulting annual efficiency is calculated to be 74.5%, or 8.8% below the nominal 81.6% efficiency.

[3] Eleven gallons corresponds to the draw volume used in the Energy Factor test (1/6 of 64.3 gallons).

Table 2: Projected Typical Tankless Performance (Cold and Hot Start)

Hot Water Draw Vol (gallons)	% of Total Load	"Cold Start" Estimated Thermal Efficiency	Weighted Efficiency	"Hot Start" Estimated Thermal Efficiency	Weighted Efficiency
1	9.0%	***21.0%***	1.9%	***60.0%***	5.4%
2	10.0%	***49.0%***	4.9%	***70.0%***	7.0%
3	7.0%	***63.0%***	4.4%	***74.0%***	5.2%
4	5.0%	***71.0%***	3.6%	***76.0%***	3.8%
5	2.0%	72.5%	1.5%	76.8%	1.5%
6	2.0%	74.0%	1.5%	77.6%	1.6%
7	1.0%	75.5%	0.8%	78.4%	0.8%
8	4.0%	77.1%	3.1%	79.2%	3.2%
9	5.0%	78.6%	3.9%	80.0%	4.0%
10	5.0%	80.1%	4.0%	80.8%	4.0%
11	6.0%	81.6%	4.9%	81.6%	4.9%
12	8.0%	81.6%	6.5%	81.6%	6.5%
13	8.0%	81.6%	6.5%	81.6%	6.5%
14	8.0%	81.6%	6.5%	81.6%	6.5%
15	5.0%	81.6%	4.1%	81.6%	4.1%
16	4.0%	81.6%	3.3%	81.6%	3.3%
17	3.0%	81.6%	2.4%	81.6%	2.4%
18	3.0%	81.6%	2.4%	81.6%	2.4%
19	3.0%	81.6%	2.4%	81.6%	2.4%
20	2.0%	81.6%	1.6%	81.6%	1.6%
Overall Efficiency			70.3%		77.3%

Table 3: Summary of Time Intervals Between Low Volume Draws

	Time Interval Between Draws (minutes) <5	5 to < 15	15 to < 45	> 45
Building America data	34%	31%	13%	22%
2005 Standards (HWSIM)	14%	35%	29%	22%

Recommendations

Our recommendations for updating ACM rules for tankless water heaters includes the following:

1. The ACM should degrade the listed Energy Factor for gas tankless water heaters by 8.8%.

2. For units with a continuously burning pilot, 500 Btu/hour of pilot energy should be assumed, unless a value is available in the CEC's Appliance Directory for small natural gas instantaneous water heaters.

The proposed 8.8% Energy Factor degradation would be uniformly applied in the ACM, regardless of the magnitude of the hourly hot water load. Although this approach is technically not accurate on a "per draw" basis (smaller draws have larger performance degradation and large draws have little or no degradation), the proposed approach provides accurate results on a daily or annual time scale. Given the current lack of knowledge on hot water usage patterns in California, it is premature to propose a more detailed modeling methodology that would hopefully utilize shorter time steps than the current one hour interval used in the ACM.

Material for Compliance Manuals

The following represents existing language in Appendix RG.4.2 of the ACM.

RG.4.2 Small Gas or Oil Instantaneous

The hourly energy use for instantaneous gas or oil water heaters is given by the following equations.

Equation RG-25

$$WHEU_j = \left(\frac{HARL_j}{EF_j} + PILOT_j \right) \times WSAF_j$$

where

$WHEU_j$ =	*Hourly fuel energy use of the water heater (Btu), adjusted for wood stove boilers.*
$HARL_j$ =	*Hourly adjusted recovery load.*
EF_j =	*Energy factor from the DOE test procedure (unitless). This is taken from manufacturers literature or from the CEC Appliance Database.*
$PILOT_j$=	*Energy consumption of the pilot light (Btu/h). Default if no information provided in manufacturer's literature or CEC Appliance Database is 500 Btu/hr.*
$WSAF_j$ =	*Wood stove boiler adjustment factor for the j^{th} water heating system. This is an optional capability and is set to 1.00 for ACMs without wood stove boiler modeling capability.*

Based on the data presented in this template, we propose the following modification for the definition of EF_j.

EF_j =	Adjusted Energy Factor to account for cycling performance degradation. EF_j is calculated by multiplying the listed EF (taken from manufacturers literature or from the CEC Appliance Database) by 0.912.

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