

Uncertainty in the Residential Water Heater Test Procedure

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June 2, 2008
ACEEE Forum on Water Heating and Use
Sacramento, CA

Sources of Uncertainty

Uncertainty



Instrument

Procedural

Operational

Instruments – Primary Measurements

$$\eta = \frac{Q_{delivered}}{E_{consumed}} = \frac{mc_p (T_{out} - T_{in})}{E_{elec} + E_{fuel}}$$

Quantity	Tolerance in DOE procedure
Mass of water removed	±1 %
Inlet and outlet water temperatures	±0.1 °C (±0.2 °F)
Electricity consumption	±1 %
Fossil fuel consumption	±1 %
Heat content of fuel	±1 %

- An example of this effect: Consider an electric water heater with a “true” EF = 0.90. What if the measured electricity consumption is inaccurate by -1 %?, i.e. the measured value is too low:

$$EF_{measured} = 0.909 \approx 0.91$$

Instruments – Secondary Measurements

- Ambient Temperature, RH
- Tank Water Storage Temperature
- Tank Volume
- Gas Pressure
- Water Flow Rate

Generally, these measurements are used to normalize conditions to a standard set of operating conditions (e.g. ambient conditions, flow rates, etc.)

Despite the “secondary” nature, errors in some of these measurements can cause big problems

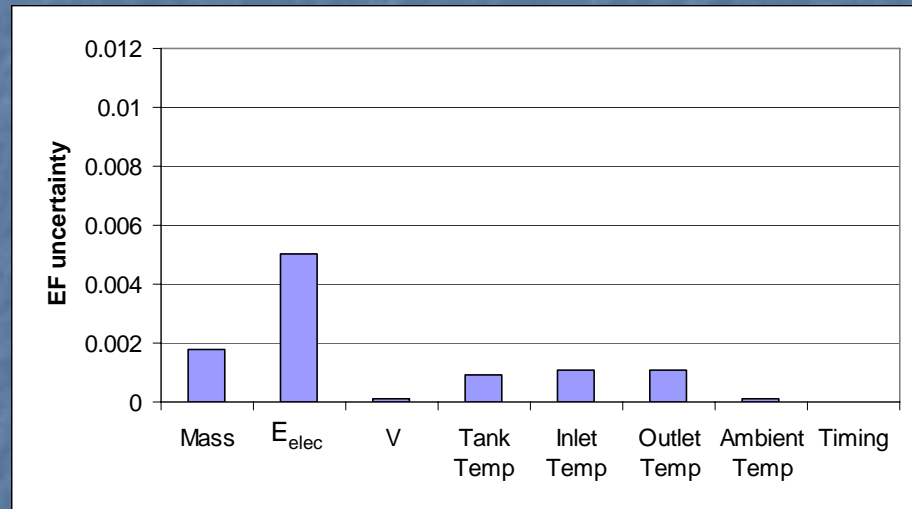
Operational Uncertainty, I

- Random variability in testing
 - Our test lab has shown $\sigma = 0.0023$ in the EF determined for electric storage water heaters
- A thorough uncertainty analysis on the EF with both the random errors and instrument errors included:
 - our lab: ± 0.012 (95 % confidence interval)¹
 - worst case: ± 0.028

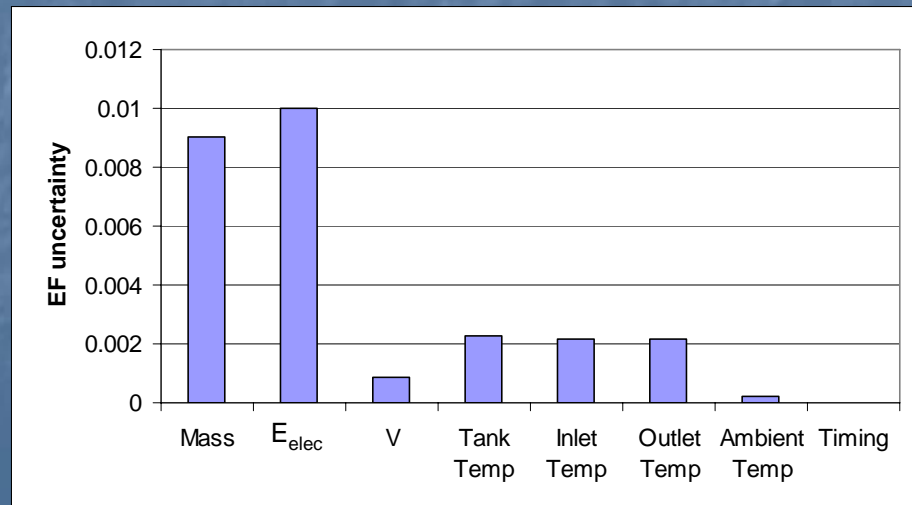
¹Healy, Lutz, and Lekov, 2003 "Variability in Energy Factor Test Results for Residential Electric Water Heaters" HVAC&R Research 9.

Example of Contributions to Uncertainty

Our Lab

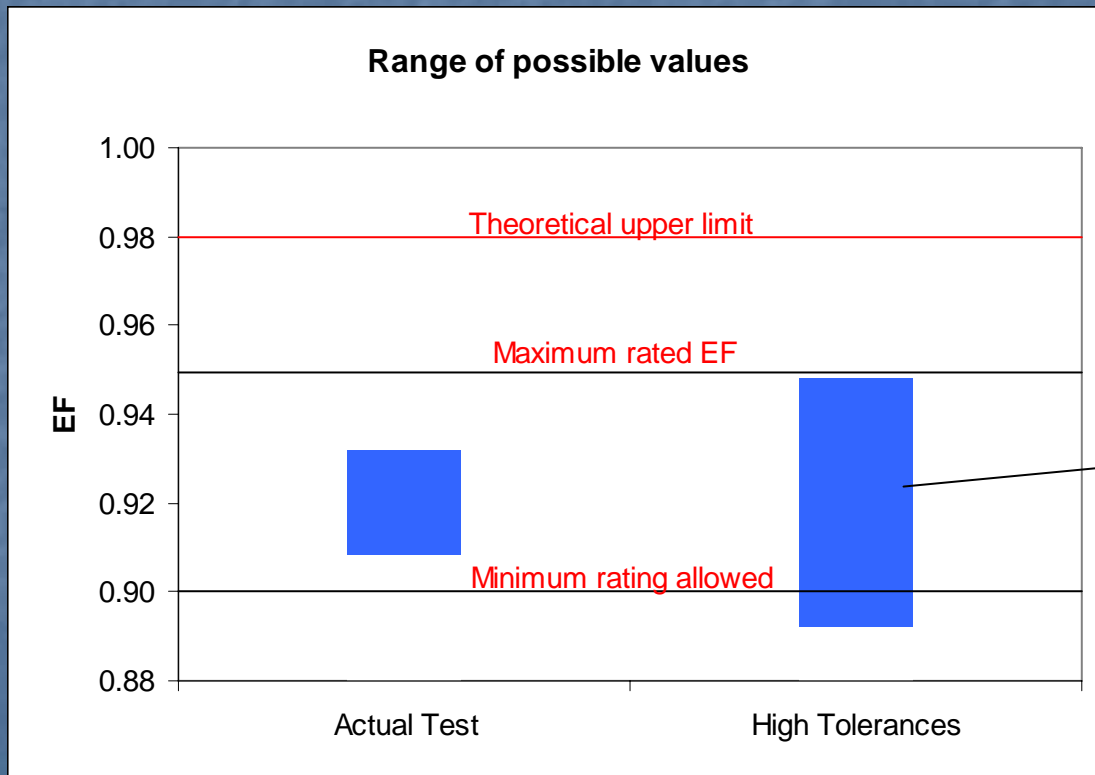


Worst Case



Example of Confidence Interval of EF

- Confidence intervals on results from a test with actual instrument tolerances and one with high tolerances



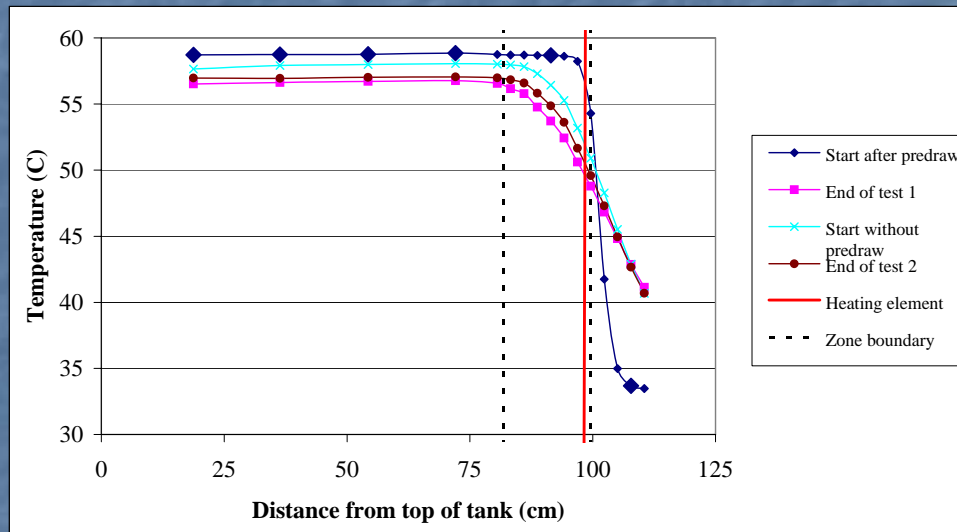
Nearly spans
the range of all
known Energy
Factors!!!

Operational “Uncertainty”, II

- Challenge: Create a test that mimics pseudo-steady state operation that can be achieved from box → result in ~2 days
- Flexibility afforded in current procedure and steps to help initiate the test. For example
 - Predraws
 - Startup method
 - Tank thermocouple placement

Predraws

- A pre-conditioning step in which water is drawn into water heater before start of test until burner turns on. Tank recovers, then the 24-hour simulated-use test begins.
- Problem...predraw puts water heater in much different state at beginning of 24 hour test than at end of test



- This difference creates need for a correction
- Opinion: any test method should minimize need for corrections to minimize uncertainty brought about by that correction

Procedural “Uncertainty”

- If we want EF to provide an estimate of the actual energy consumption of a unit...
 - How uncertain are...
 - Draw pattern
 - Water temperatures
 - Total usage
 - Ambient conditions
 - Etc.
- Opinion...EF is meant as a tool for relative comparisons between 2 different appliances that provide hot water to the customer.
- Problems arise when test method is biased towards different technologies and therefore prevents the end user from making a direct comparisons between appliances meant to deliver the same service.
 - Electric vs. Gas
 - Heat Pump vs. Electric Resistance
 - Tankless vs. Storage

Summary

- Classic uncertainty analysis of test procedure suggests EF's for electric storage water heaters can be confidently determined to ± 0.012
- Flexibility in procedures and correction factors bring about uncertainty in estimates of energy consumption
- The procedure used for the test will always lead to some uncertainty in applying the test results to actual consumption

What is the test procedure supposed to tell us?