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Memorandum

Date: November 7, 1996

To: Robert A. Zogg
C. Edward Barbour
Christopher Harmon
Kristie Thayer

cc:

From: Daniel Gaugel
Loc: 20-555
Ext: 6233

Subject: EEI/DOE Residential Economic Analysis
Re: 31186-00

Water Heating Performance Simulations

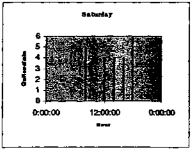
The residential economic analysis includes nine models of current electric water heating technologies. WATSIM, a water heating simulation model developed by the Electric Power Research Institute, served as the primary tool for performance representation. Simulations were generated for seven day periods in the Spring/Fall season and extrapolated to represent an entire year. The Spring/Fall entering water temperatures for each city are roughly equivalent to the average of the winter and summer seasons. Five climate zones were inspected:

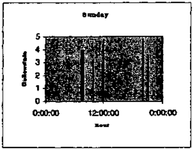
Climate Zone	Representative City	HDD	CDD	Fall/Spring Entering Water T(F)	Population (MM Households)[i]
1	Minneapolis, MN	> 7000	< 2000	45.8	8.7
2	Detroit, MI	5500-7000	< 2000	49.9	26.5
3	New York, NY	4000-5499	< 2000	57.6	22.5
4	Atlanta, GA	<4000	< 2000	62	17.8
5	New Orleans, LA	<4000	>2000	64.9	21.2

Water draw profiles were previously developed[ii] with the following method from experimental field data provided by the following electric utilities: Virginia Power, Central Hudson Gas and Electric, Northeast Utilities, and El Paso Electric Company. A seven day representative water draw profile was developed from the submetered data for average households (3.0 persons) containing an electric water heater. The average daily water consumption for 58°F (Climate Zone 3) entering and 135°F delivery water temperatures was determined to be 40 gallons. A high water draw profile was represented by scaling the daily water consumption by a factor of 2.0. Low draw patterns were not developed since residential buildings with low hot water consumption are generally not cost affective for high efficiency technologies. To represent the remaining climate zones, these profiles were scaled to reflect the effect of entering water temperature on amount of hot water needed to provide desired end use temperature. The water draws for the analysis are as follows:

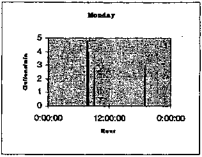
Climate Zone	Representative City	Average gal/day (medium draw)	Average gal/day (high draw)
1	Minneapolis, MN	50	100
2	Detroit, MI	45	90
3	New York, NY	40	80
4	Atlanta, GA	35	70
5	New Orleans, LA	32	64

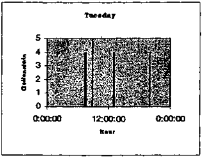
WATSIM simulations for heat-pump water heaters with dual element tanks revealed that a near match existed between the peak hourly draws in the profiles and the volume of water below the upper temperature sensor. These peak draws from the developed profiles caused a large uncertainty of annual estimated HPWH performance. The amount of water draw capable of shifting the energy input between the lower heat pump(COP~ 2.3-2.8) and the upper electrical element(COP = 1.0) in the tank was very minimal. Due to the fact that these draws would be used to estimate annual performance for various competing technologies, a minor reduction was made to the largest peaks in the profiles. The largest hourly demands were reduced and shifted to minimize the sensitivity in the model. Overall daily water heating consumption remained the same. The weekend draw profiles for New York, medium draw, are displayed below:

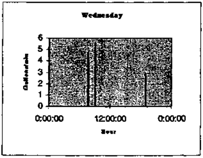


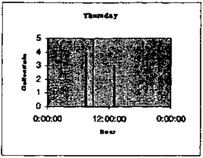


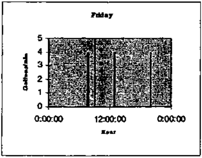
The weekday profiles for New York, medium draw, are displayed below:











The high-draw profiles retain these general shapes, with magnitudes scaled to reflect increased draw.

1) NAECA Standard Electric Resistance Water Heater

Three dual element tank configurations(50, 66, 80 gallons) were setup to resemble NAECA standard efficiency electric resistance water heaters. Their energy factors were estimated by simulating the DOE water heating test procedure(WATSIM). Exterior tank parameters such as pipe inlet/outlet insulation thickness were adjusted to arrive at a tank EF close to the standard EF for a 50 gallon tank. The tank diameter was increased to achieve 66 and 80 gallon storage capacities. The following table presents the comparison of the DOE Energy Factors:

Tank Size (gallons)	NAECA Standard EF*	DOE Test EF
50	.864	.86
66	.842	.84
80	.824	.83

* .93 - .00132*Vnominal(gallons)

2) NAECA Standard Gas Water Heater

The baseline gas water heater performance was determined with the NAECA standard Energy Factor for three tank sizes:

Tank Size (gallons)	NAECA Standard EF*
40	.544
50	.525
66	.495

*.62 - .0019*Vnominal(gallons)

Standby loads were determined such that:

$$\text{Energy Consumed} = \frac{\text{Water Heating Load(Btu)} + \text{Standby Load(Btu)}}{\text{Thermal Efficiency (.76)}}$$

The Energy Factor is defined as :

$$\text{EF} = \frac{\text{Water Heating Load(Btu)}}{\text{Energy Consumed(Btu)}}$$

The standby load was thus determined as:

$$\text{Standby Load} = \text{Water Heating Load}*\left(\frac{\text{Thermal Efficiency}}{\text{EF}} - 1\right)$$

The water heating loads used in the calculation of the standby loads were calculated for a 77°F temperature rise at 64.3 gallons/day. The water heating loads calculated for each climate zone and water draw were dependent on the region specific entering water temperature, average delivery temperature determined from the electric resistance model, and the previously mentioned daily water draws.

3) Add-On Heat Pump Water Heater

The Crispaire WH-6BX(nominal capacity = 6,000 Btuh) HPWH was modeled within WATSIM by scaling the electrical draw and heating capacity performance maps for the Crispaire R106K(nominal capacity = 12,000 Btuh) HPWH by 50%. The WH-6BX represents the current HPWH technology, but published performance curves are not available. Dr. Carl Hiller of EPRI recommended using 50% of the R106K to give a conservative estimate of the capabilities on the WH-6BX. The tank configurations used with the add-on heat pump water heater models are the same used for the electric resistance water heater.

4) High Efficiency Electric Resistance Water Heater

Water tank conservation measures were made with the electric resistance water heater input parameters to simulate a high efficiency electric resistance water heater. Heat traps were added, support ring material was changed from steel to plastic, and tank insulation thickness was increased from 1.5" to 3.0". The DOE Energy Factors and percent improved efficiencies over standard electric resistance water heaters are presented in the following chart:

Tank Size (gallons)	DOE Test EF	% Improvement over Standard ER
50	.93	8.14
66	.92	9.52
80	.91	9.64

Current typical high efficiency electric resistance water heater heaters have Energy Factors ranging from .94-.91 for storage volumes of 50-80 gallons.[iv]

5) Point-of-Use Water Heater

The implementation of point of use water heaters was estimated to save 20% in pipe thermal losses[v]. The energy consumption for this model was calculated as 80% of the electrical resistance water heater for each climate zone and water draw.

6) Solar Thermal Water Heater

Solar water heating systems modeled in this analysis consisted of a standard dual element electric resistance tank, pump, heat exchanger, valves, piping, supports, and the following collector configurations for each climate zone:

Climate	Tank Size (gallons)	# of Panel(s) - Size(ft)
Minneapolis	50	2 - 4x8
	80	2 - 4x8
Detroit	50	2 - 4x8
	80	2 - 4x8
New York	50	2 - 4x10
	66	2 - 4x10
Atlanta	50	1 - 4x10
	66	1 - 4x10
New Orleans	50	1 - 4x10
	66	1 - 4x10

Panel sizes were selected based on 3-4 person residences in each of the climate zones.[vi]

Since WATSIM is unable to model solar water heating systems, ESPRE[vii] was selected to estimate performance. Although this program uses different water draws and entering water temperature profiles than WATSIM, the ability of the system to collect energy was estimated with the following method.

Tank parameters and solar collector(American Energy Technologies AE Series) specifications were entered into ESPRE for the five cities, one in each DOE climate zones. Collector area was varied in the model for each climate to create a relationship between annual collected energy(Btu) and the product of collector area(ft^2) and annual solar flux(Btu/ft^2). By normalizing this relationship with the annual thermal water heating load, the relationship becomes dimensionless and useful for applying specific modeling conditions. Figure 1, displays the ESPRE model for Climate Zone 2 (Detroit).

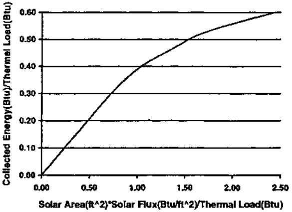


Figure 1. Climate Zone 2 Solar Panel Performance Model.

The collector areas used in this analysis were then applied to the model along with the solar insolation for the city and WATSIM generated thermal water heating loads to determine the amount of energy collected from the system.

The fraction of thermal load satisfied by the system was then calculated:

% Thermal Load Satisfied by System = Collected Energy(Btu)/Total Thermal Load(Btu)

The electric energy saved by the solar system was calculated by applying this fraction to the total annual energy consumption for the standard electric resistance water heater. A (1/25) hp pump assumed to run 8 hrs/day was also added to the system.

7) Multifunction, Full-Condensing Heat Pump

Performance simulation for the Nordyne Powermiser was accomplished by first calculating the seasonal thermal water heating load for each climate at their respective medium and high draws. Weekly thermal loads were taken from WATSIM simulations for the electric resistance water heater models. Seasonal water heating thermal loads for the cooling and heating seasons were then calculated by multiplying the weekly load by the fraction of the year devoted to heating and cooling, respectively.

Space conditioning models for an electric heat pump(7.4 HSPF, 10 SEER) were run in each climate zone with the Analysis Platform.™ The seasonal COPs for the heat pump were then calculated from the annual energy consumption and space heating/cooling loads.

The water heating energy consumption for the heat pump was then calculated for each climate and water draw:

$$\text{Water Heating kWh}_{\text{HEATING}} = \frac{\text{Hot Water Thermal Load}_{\text{HEATING}}\ \text{(Btu)}}{\text{Heat Pump COP}_{\text{HEATING}} * 3.412\ \text{(Btu/kWh)}}$$

$$\text{Water Heating kWh}_{\text{COOLING}} = \frac{\text{Hot Water Thermal Load}_{\text{COOLING}}\ \text{(Btu)}}{\text{Heat Pump COP}_{\text{COOLING}} * 3.412\ \text{(Btu/kWh)}}$$

8) Desuperheater

The energy consumption for a desuperheater water heater was estimated with the use of the Analysis Platform. Annual simulations for a desuperheater with an electric AC(3 ton, SEER=10) and standard electric resistance water heating systems were run for the climates and water draws specified for this analysis. The percent energy savings from desuperheater use were then calculated:

$$\%\ \text{Savings} = \frac{\text{Annual Energy Use(Electric Resistance Tank - Desuperheater)}}{\text{Electric Resistance Tank}} * 100$$

The following table presents the level of energy savings for each climate:

Climate	Tank Size (gallons)	Draw (gallons/day)	% Energy Savings w/ Heat Recovery
Minneapolis	50	50	8.8
	80	100	10.9
Detroit	50	45	11.0
	80	90	12.0
New York	50	40	13.6
	66	80	13.1
Atlanta	50	35	22.2
	66	70	19.2
New Orleans	50	32	29.1
	66	64	25.0

The annual energy use for the desuperheater system was calculated from these percentages and the standard electric resistance energy use from the WATSIM simulations:

$$\text{Annual Energy Use(kWh)} = \text{Energy Use ER WH} * (1 - (\%\ \text{Energy Savings}/100))$$

9) Drain Water Heat-Recovery System

The annual energy consumption for a Vaughn Gravity-Fed, Falling Film, Heat Recycling System (Model 3F60-1/2) with electric resistance tank was estimated by first determining the amount of drain water available for heat recovery from the water draws. The typical household percent of hot water originating from showers and running faucets was determined to be 56.9% from a published study from Lawrence Berkeley Laboratory.[ix] The annual energy savings for the GFX was calculated from the heat exchanger efficiency and the standard electric resistance energy consumption:

$$\text{Annual Energy Savings (kWh)} = f_{\text{Hot Water Available}}(.569) * \text{GFX Efficiency}(.60) * \text{Annual Energy Consumption, ER Tank}$$

Life-Cycle Cost Analysis

The life-cycle costs for the eight residential technologies were calculated for 7 and 30 years (typical home-ownership period and typical mortgage period, respectively) with a discount rate of 6%. The following formula was used:

LCC($) = Initial Installed Costs($) + Net Present Value(Annual Energy Costs($)) + Net Present Value(Annual Operation and Maintenance Costs($)) + Present Value(Capital Replacement Cost($)) - Present Value(Salvage($))

The following table gives the useful life spans assumed in the LCC analysis:

Technology	Useful Life Span (years)
Electric Resistance	10[x]
Natural Gas	9[x]
Add-On HPWH	15[xi]
Solar WH System	30[xii]
Point-of-Use	10[xiii]
High-Efficiency ER	18[xiii]
Multifunction, Full-Condensing HP	13[x]
Desuperheater	14[x]
Drain Water Heat Recovery System	30[x]

A straight-line depreciation was assumed for each technology from the time of installation to the end of the useful life span. Final salvage values for each technology are thus assumed to be negligible. For instances where the end of the life-cycle falls within the useful life of the technology(eg. 7 year life cycle for Electric Resistance, life span of 10 years), the present value of the technology determined from the straight-line depreciation is subtracted from the LCC.

The 30 year LCC analysis assumes that additional installations be required when the respective technologies reach the end of their useful life spans. The present value of the capital replacement are thus added to the LCC at the year of replacement. Depreciation for these technologies follow the same methodology as the initial installations.

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[i] <u>EPRI Commercial Water Heating Applications Handbook</u>, Abrams, 1992, Table 2-2.

[ii] <u>Housing Characteristics 1993</u>, DOE/EIA, June, 1995, p. 22.

[iii] <u>Technical Analysis of the Proposed DOE Electric Heat Pump Water Heater Efficiency Standard</u>, Arthur D. Little, August, 1994, for Gas Appliance Manufacturers Association, Sections 2.2-2.3.

[iv] <u>Consumers' Directory of Certified Efficiency Ratings</u>, GAMA, April, 1995.

[v] See Appendix B, Memorandum, Christopher Harmon, August 22, 1996.

[vi] <u>Solar Design Catalog</u>, AAA Solar Service and Supply, Inc., 1995-96 Edition.
See Appendix C, Memorandum, Christopher Harmon, August 26, 1996.

[vii] EPRI Simplified Program for Residential Energy, Ver. 2.1.

[viii] DOE Analysis Platform Building HVAC and Water Energy Usage Technical Model, Ver. 1.0.

[ix] <u>The Effect of Efficiency Standards on Water Use and Water Heating Energy Use in the U.S.: A Detailed End-use Treatment</u>, Lawrence Berkeley Laboratory, May, 1994, p. 7.

[x] <u>Appliance</u>, Dana Chase Publications, Inc., September, 1995, p. 89.

[xi] <u>EIA - Technology Forecast Updates</u>, Arthur D. Little, June 7, 1995, for EIA, pp. 8-9.

[xii] <u>Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts, & Television Sets</u>, Lawrence Berkeley Laboratory, November, 1993.

[xiii] ADL Estimate.

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Memorandum

Date: August 22, 1996

To: Bob Zogg
cc: Dan Gaugel
Kristie Thayer
Ed Barbour
W.P. Teagan
Detleph Westphalen

From: Christopher Harmon
Loc: 20 / 532
Ext: 6515

Subject: EEI / DOE Joint Water Heating Program
Re: Service Hot Water Piping - Thermal Losses

Introduction/Abstract

I have examined the thermal losses of the hot water distribution piping in a typical household (single-family, detached) and in a commercial building (hotel) for the purpose of quantifying the possible energy savings of point-of-use water heater applications. Thermal losses for the residence are approximately 15-20 percent of the heat energy supplied by the central water heater. Thermal losses for the hotel are approximately 40-60 percent of the supplied heat energy.

Residential

The "typical" house was defined to have one kitchen (sink, dishwasher), two full baths (shower, sink), and a laundry room. Although, piping diameters usually vary along the distance of a run, a non-insulated copper pipe with a nominal size of 3/4" was used for simplicity. Piping runs between the central water heater and the kitchen and bathrooms ranged from 30 - 45 ft. (the washing machine was assumed to be located near the water heater). Ambient, quiescent air was assumed to be 70°F and the hot water tank temperature was 120°F. The coefficient of heat transfer, h, was found to be 1.2 Btu / h•ft^2 and the heat loss of the pipe, q, was equal to 19.3 Btu / h•ft. This number correlates well with ASHRAE's estimation of 30 Btu / h•ft for the same copper pipe assuming 70°F ambient air and a water tank temperature of 140°F.

Percent thermal loss was determined using a "high" and "medium" daily water draw rate, 80 gal/day and 40 gal/day, respectively. The resulting percent thermal losses were 16 percent (1,400 kBtu/year) and 17 percent (760 kBtu/year) for the high and medium water draw profiles. Point-of-use water heaters will save more energy in absolute terms for the high water-use household. Yet, the percent energy savings per household would be nearly the same for both households with high and medium water draw profiles. Potential space conditioning impacts of piping losses were not taken into account in this analysis. If the lost heat is being dissipated into conditioned spaces, the heat would have beneficial effects during periods of heating and detrimental effects during periods of cooling.

Two types of thermal losses were defined, operational and standby. Operational losses occur *during* the period of hot water draws. Standby losses result when a volume of "dead" water sits in the piping runs during the intervals *between* hot water draws. The results illustrate that standby losses, as opposed to operational loses, accounted for the greatest portion of thermal losses. Standby loses represent 80 percent of the total thermal losses, due to typical double-peaked daily hot water draws, i.e. morning and early evening hot water use, regardless of water draw volumes.

A study by New Zealand researchers examined the energy savings from insulating copper tubing with 20mm fiberglass sleeves[1]. This study reported that insulation reduces thermal losses by an additional 5-7 percent of the total thermal energy.

Commercial

Modeling thermal piping losses in a commercial building, such as a hotel, is much more difficult than in a residence. Commercial buildings, such as hospitals and hotels, typically have circulating loops in order to have a continuous and immediate supply of hot water. In these systems, thermal losses are comprised only of operational loses. For this reason, insulation is common among service hot water systems found in hotels and hospitals.

This analysis examined a 200 room hotel, servicing guestrooms only (neglecting laundry, restaurant, etc.).The hot water draws in guestrooms consist of shower and sink use. Estimates were derived for a weekly, 80 percent occupancy rate with 25 percent double occupancy and 75 percent single occupancy. For simplicity, an insulated 4" nominal copper pipe was used. ASHRAE estimates that the heat transfer rate of a 4" fiberglass insulated (1/2") copper pipe is 48.4 Btu / h•ft assuming 70°F ambient air and a water tank temperature of 140°F.

Thermal loss estimates of 40-60 percent were determined using a total circulation loop ranging between 600 and 800 linear feet. Actual thermal losses were 254,000 kBtu/year for the 600 ft. circulation loop and 338,000 kBtu/year for the 800 ft. circulation loop. The true percent thermal loss is site-specific, corresponding to the length, diameter and structure of the piping distribution system, as well as the volume of the daily hot water draw in a commercial building. However, it appears that point-of-use/compact water heaters would result in significant energy savings. Their application would depend on their compatibility with the existing building/design and their installed cost as compared to a centrally located water heater.

[1] "Structure of Domestic How Water Consumption", Carrington, Warrington, and Yak, <u>Energy Research</u>, Vol.9, Num 1, Jan-March 1985, pp 65-75.

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Memorandum

Date: August 26, 1996

To: Bob Zogg
Ed Barbour
cc: Brian Nowicki
Dan Gaugel
Kristie Thayer
Lisa Frantzis

From: Chris Harmon
Ext: 6515

Subject: EEI / DOE Joint Water Heating Program
Re: Solar Water Heaters - Response to comments received on 8/1/96 from EE

Abstract

The purpose of this analysis was to produce accurate, documented estimates of solar-thermal electric water heating systems installed costs. The estimated installation costs in five cities: Atlanta, Minneapolis, New Orleans, New York and Detroit are found in Table 2.

Findings

The following is a response to the comments from Les Nelson, California Solar Energy Industries Association (SEIA). Reference is also made to a report he had sent to ADL, entitled: "Analysis of Various Water Heating Systems" prepared by the California Energy Commission (CEC) in May 1996.

- Table 1 (attached) compares the total installed costs for several types of water heate given by CEC versus those found in ADL's presentation, "Update on Current Electric Water Heater Market Situation" (July 18th EEI/DOE Meeting). Water heating systems examined by CEC include: integral collector storage (ICS) solar-electric, active solar-electric, electric resistance, gas and heat pump. All costs pertai to new construction. I found an acceptable correspondence between the electric and gas water heater installed costs (≅ ±10%). However, the solar-electric water heater installed costs differed by 20 percent or more.

- The CEC estimates were specific to the Sacramento, California area, which lies in th "Sunbelt Region". The CEC estimated that the total installed cost for an active sola electric system (40ft^2 of solar panels) is $2,447. ADL estimated that a similar installation in Atlanta, Georgia, located in the sunny "Southeast Region", costs roughly 18% more, or $3000.[1]

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[1] "Task I: Technologies & Potential Applications" Joint Electric Industry / DOE Meeting, July 18,1996.

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A/C	Air Conditioning
ADL	Arthur D. Little
AEO	Annual Energy Outlook (EIA/DOE)
AFUE	Annual Fuel Utilization Efficiency
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
Btu	British Thermal Unit
Btuh	Btu per Hour
COP	Coefficient of Performance
DOE	Department of Energy
EIA	Energy Information Administration
GAMA	Gas Appliance Manufacturers Association
HSPF	Heating Season Performance Factor
kW	Kilowatt
NAECA	National Appliance Manufacturers Association
NPV	Net Present Value
SEER	Seasonal Energy Efficiency Ratio
WATSIM	Water Simulation Analysis (software)
WH	Water Heater
yr	Year