2.19 Fuel Switching: Heat Pump Water Heater to Gas Water Heater

Measure Name	Fuel Switching: ~~DHW~~ Heat Pump Water Heater to Gas Water Heater
Target Sector	Residential
Measure Unit	Water Heater
Unit Energy Savings	~~4104~~ 2208 kWh
Unit Peak Demand Reduction	~~0.376~~0.203 kW
Gas Consumption Increase	21.32 MMBtu
Measure Life	13 years

Natural gas water heaters reduce electric energy and demand compared to heat pump water heaters. Standard heat pump water heaters have energy factors of 2.0 and a federal standard efficiency gas water heater has an energy factor of 0.594 for a 40gal unit.

2.19.1 Eligibility

This protocol documents the energy savings attributed to converting from a standard heat pump water heater with Energy Factor of 2.0 or greater to a standard natural gas water heater with Energy Factor of 0.594 or greater. The target sector primarily consists of single-family residences.

2.19.2 Algorithms

The energy savings calculation utilizes average performance data for available residential standard heat pump water heaters and natural gas water heaters and typical water usage for residential homes. Because there is little electric energy associated with a natural gas water heater, the energy savings are the full energy utilization of the heat pump water heater. The energy savings are obtained through the following formula:

$$\Delta kWh = \frac{\left\{\left(\frac{1}{EF_{HP,bl} \times F_{Derate}}\right) \times \left(HW \times 365 \times 8.3\frac{lb}{gal} \times (T_{hot} - T_{cold})\right)\right\}}{3413\frac{Btu}{kWh}}$$

Although there is a significant electric savings, there is an associated increase in natural gas energy consumption. While this gas consumption does not count against PA Act 129 energy savings, it is expected to be used in the program TRC test. The increased natural gas energy is obtained through the following formula:

$$Gas\ Consumption\ (MMBtu) = \frac{\left\{\left(\frac{1}{EF_{NG,inst}}\right) \times \left(HW \times 365 \times 8.3\frac{lb}{gal} \times (T_{hot} - T_{cold})\right)\right\}}{1,000,000\frac{Btu}{MMBtu}}$$

Demand savings result from the removal of the connected load of the heat pump water heater. The demand reduction is taken as the annual energy savings multiplied by the ratio of the average energy usage during noon and 8PM on summer weekdays to the total annual energy usage.

$$Demand\ Savings = EnergyToDemandFactor$$

The Energy to Demand Factor is defined below:

$$EnergyToDemandFactor = \frac{Average\ Usage_{Summer\ WD\ Noon\text{-}8}}{Annual\ Energy\ Usage}$$

The ratio of the average energy usage during noon and 8 PM on summer weekdays to the total annual energy usage is taken from load shape data collected for a water heater and HVAC demand response study for PJM[57]. The factor is constructed as follows:

1. Obtain the average kW, as monitored for 82 water heaters in PJM territory[58], for each hour of the typical day summer, winter, and spring/fall days. Weight the results (91 summer days, 91 winter days, and 183 spring/fall days) to obtain annual energy usage.
2. Obtain the average kW during noon to 8 PM on summer days from the same data.
3. The average noon to 8 PM demand is converted to average *weekday* noon to 8 PM demand through comparison of weekday and weekend monitored loads from the same PJM study[59].
4. The ratio of the average weekday noon to 8 PM energy demand to the annual energy usage obtained in step 1. The resulting number, 0.00009172, is the *EnergyToDemandFactor.*

The load shapes (fractions of annual energy usage that occur within each hour) during summer week days are plotted in Figure 2-9

[57] Deemed Savings Estimates for Legacy Air Conditioning and Water Heating Direct Load Control Programs in PJM Region. The report can be accessed online: http://www.pjm.com/~/media/committees-groups/working-groups/lrwg/20070301/20070301-pjm-deemed-savings-report.ashx

[58] The average is over all 82 water heaters and over all summer, spring/fall, or winter days. The load shapes are taken from the fourth columns, labeled "Mean", in tables 14,15, and 16 in pages 5-31 and 5-32

[59] The 5th column, labeled "Mean" of Table 18 in page 5-34 is used to derive an adjustment factor that scales average summer usage to summer weekday usage. The conversion factor is 0.925844. A number smaller than one indicates that for residential homes, the hot water usage from noon to 8 PM is slightly higher is the weekends than on weekdays.

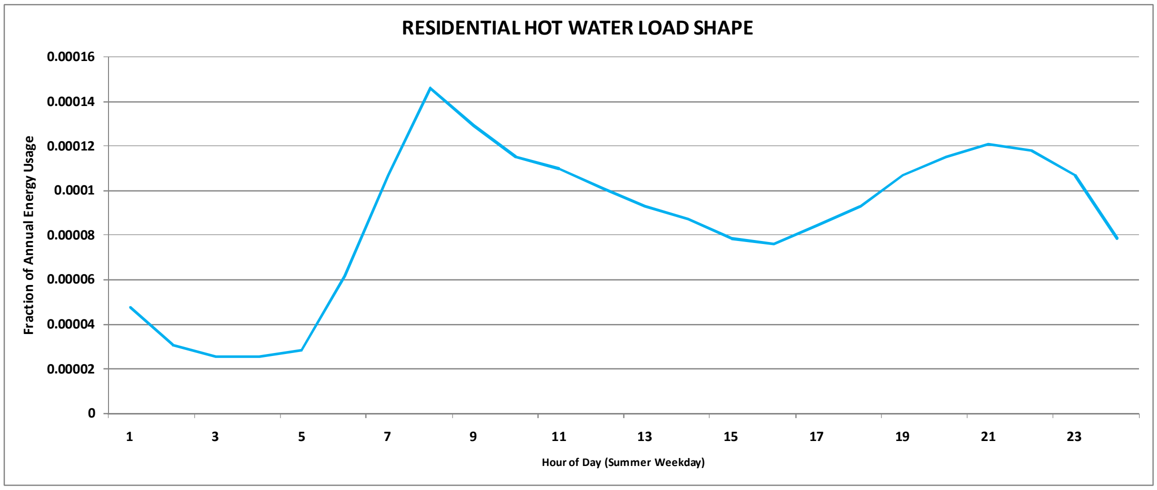

Figure 2-9: Load shapes for hot water in residential buildings taken from a PJM.

2.19.3 Definition of Terms

The parameters in the above equation are listed in Table 2-29.

Table 2-29: Calculation Assumptions for ~~Fuel Switching, Domestic Hot Water~~ Heat Pump Water Heater to Gas Water Heater

Component	Type	Values	Source
$EF_{HP,bl}$, Energy Factor of baseline heat pump water heater	Fixed	≥ 2.0	4
$EF_{NG,inst}$. Energy Factor of installed natural gas water heater	Variable	≥ 0.594	5
HW, Hot water used per day in gallons	Fixed	64.3 gallon/day	6
T_{hot}, Temperature of hot water	Fixed	120 °F	7
T_{cold}, Temperature of cold water supply	Fixed	55 °F	8
F_{Derate}, COP De-rating factor	Fixed	0.84	9, and discussion below
EnergyToDemandFactor	Fixed	0.00009172	1-3

Sources:

1. Deemed Savings Estimates for Legacy Air Conditioning and Water Heating Direct Load Control Programs in PJM Region. The report can be accessed online: http://www.pjm.com/~/media/committees-groups/working-groups/lrwg/20070301/20070301-pjm-deemed-savings-report.ashx
2. The average is over all 82 water heaters and over all summer, spring/fall, or winter days. The load shapes are taken from the fourth columns, labeled "Mean", in tables 14,15, and 16 in pages 5-31 and 5-32
3. The 5th column, labeled "Mean" of Table 18 in page 5-34 is used to derive an adjustment factor that scales average summer usage to summer weekday usage. The conversion

factor is 0.925844. A number smaller than one indicates that for residential homes, the hot water usage from noon to 8 PM is slightly higher is the weekends than on weekdays.

4. Heat pump water heater efficiencies have not been set in a Federal Standard. However, the Federal Standard for water heaters does refer to a baseline efficiency for heat pump water heaters as EF = 2.0 "Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters" US Dept of Energy Docket Number: **EE–2006–BT-STD–0129**.
5. Federal Standards are 0.67 -0.0019 x Rated Storage in Gallons. For a 40-gallon tank this is 0.594. "Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters" US Dept of Energy Docket Number: **EE–2006–BT-STD–0129,** p. 30
6. "Energy Conservation Program for Consumer Products: Test Procedure for Water Heaters", **Federal Register** / Vol. 63, No. 90, p. 25996
7. Many states have plumbing codes that limit shower and bathtub water temperature to 120 °F.
8. Mid-Atlantic TRM, footnote #24
9. Based on TMY2 weather files from DOE2.com for Erie, Harrisburg, Pittsburgh, Wilkes-Barre, And Williamsport, the average annual wet bulb temperature is 45 ± 1.3 °F. The wet bulb temperature in garages or attics, where the heat pumps are likely to be installed, are likely to be two or three degrees higher, but for simplicity, 45 °F is assumed to be the annual average wet bulb temperature.

2.19.4 Heat Pump Water Heater Energy Factor

The Energy Factors are determined from a DOE testing procedure that is carried out at 56 °F wet bulb temperature. However, the average wet bulb temperature in PA is closer to 45 °F[60]. The heat pump performance is temperature dependent. The plot in Figure 2-10 shows relative coefficient of performance (COP) compared to the COP at rated conditions[61]. According to the linear regression shown on the plot, the COP of a heat pump water heater at 45 °F is 0.84 of the COP at nominal rating conditions. As such, a de-rating factor of 0.84 is applied to the nominal Energy Factor of the Heat Pump water heaters.

[60] Based on TMY2 weather files from DOE2.com for Erie, Harrisburg, Pittsburgh, Wilkes-Barre, And Williamsport, the average annual wetbulb temperature is 45 ± 1.3 °F. The wetbulb temperature in garages or attics, where the heat pumps are likely to be installed, are likely to be two or three degrees higher, but for simplicity, 45 °F is assumed to be the annual average wetbulb temperature.

[61] The performance curve is adapted from Table 1 in http://wescorhvac.com/HPWH%20design%20details.htm#Single-stage%20HPWHs
The performance curve depends on other factors, such as hot water set point. Our adjustment factor of 0.84 is a first order approximation based on the information available in literature.

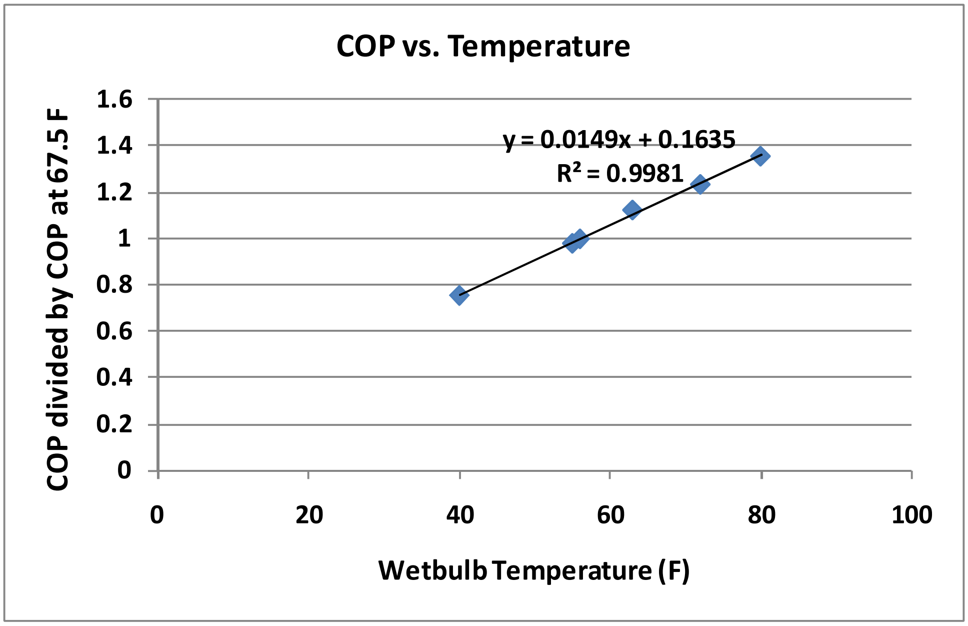

Figure 2-10: Dependence of COP on Outdoor Wet-Bulb Temperature

2.19.5 Deemed Savings

The deemed savings for the installation of a natural gas water heater in place of a standard heat pump water heater are listed in Table 2-30 below.

Table 2-30: Energy Savings and Demand Reductions for ~~Fuel Switching, Domestic Hot Water~~ Heat Pump Water Heater to Gas Water Heater

Heat Pump unit Energy Factor	Energy Savings (kWh)	Demand Reduction (kW)
2.0	2208	0.203

The deemed gas consumption for the installation of a standard efficiency natural gas water heater in place of a standard heat pump water heater is listed in Table 2-31 below.

Table 2-31: Gas Consumption for ~~Fuel Switching, Domestic Hot Water~~ Heat Pump Water Heater to Gas Water Heater

Gas unit Energy Factor	Gas Consumption (MMBtu)
0.594	21.32

2.19.6 Measure Life

According to an October 2008 report for the CA Database for Energy Efficiency Resources, a gas water heater's lifespan is **13 years**[62].

[62] DEER values, updated October 10, 2008
http://www.deeresources.com/deer0911planning/downloads/EUL_Summary_10-1-08.xls

2.19.7 Evaluation Protocols

The most appropriate evaluation protocol for this measure is verification of installation coupled with assignment of stipulated energy savings.

3.2.7 Calculation Method Descriptions By Project Classification

New Construction and Building Additions

For new construction and building addition projects, savings are calculated using ASHRAE 90.1-2007 as the baseline (kW_{base}) and the new wattages and fixtures as the post-installation wattage. The baseline, pursuant to ASHRAE 90.1-2007, can be calculated using either the ASHRAE 90.1-2007 Building Area Method as shown in Table 3-3, or the ASHRAE 90.1-2007 Space-by-Space Method as shown in Table 3-4. The new fixture wattages are specified in the Lighting Audit and Design Tool shown in Appendix C.

EFLH, CF and IF values are the same as those shown in Table 3-5 and Table 3-6.

Table 3-3: Lighting Power Densities from ASHRAE 90.1-2007 Building Area Method[122]

Building Area Type[123]	LPD (W/ft2)	Building Area Type	LPD (W/ft2)
Automotive facility	0.9	Multifamily	0.7
Convention center	1.2	Museum	1.1
Courthouse	1.2	Office	1.0
Dining: bar lounge/leisure	1.3	Parking garage	0.3
Dining: cafeteria/fast food	1.4	Penitentiary	1.0
Dining: family	1.6	Performing arts theater	1.6
Dormitory	1.0	Police/fire station	1.0
Exercise center	1.0	Post office	1.1
Gymnasium	1.1	Religious building	1.3
Health-care clinic	1.0	Retail	1.5
Hospital	1.2	School/university	~~0~~1.2
Hotel	1.0	Sports arena	1.1
Library	1.3	Town hall	1.1
Manufacturing facility	1.3	Transportation	1.0
Motel	1.0	Warehouse	0.8
Motion picture theater	1.2	Workshop	1.4

[122] ASHRAE 90.1-2007, "Table 9.5.1 Lighting Power Densities Using the Building Area Method."
[123] In cases where both a common space type and a building specific type are listed, the building specific space type shall apply.

Table 3-21: HVAC Baseline Efficiencies[153]

Equipment Type and Capacity	Cooling Baseline	Heating Baseline
Air-Source Air Conditioners		
< 5.41 tons	13.0 SEER	N/A
≥ 5.41 tons and <11.25 tons	11.2 EER	N/A
≥ 11.25 tons and < 20.00 tons	11.0 EER	N/A
≥ 20.00 tons and < 63.33 tons (IPLV for units with capacity-modulation only)	10.0 EER / 9.7 IPLV	N/A
≥ 63.33 tons (IPLV for units with capacity-modulation only)	9.7 EER / 9.4 IPLV	N/A
Water-Source and Evaporatively-Cooled Air Conditioners		
< 5.41 tons	12.1 EER	N/A
≥ 5.41 tons and < 11.25 tons	11.5 EER	N/A
≥ 11.25 tons and < 20.00 tons	11.0 EER	N/A
≥ 20.00 tons	11.5 EER	N/A
Air-Source Heat Pumps		
< 5.41 tons	13 SEER	7.7 HSPF
≥ 5.41 tons and < 11.25 tons	11.0 EER	3.3 COP
≥ 11.25 tons and < 20.00 tons	10.6 EER	3.2 COP
≥ 20.00 tons (IPLV for units with capacity-modulation only)	9.5 EER / 9.2 IPLV	3.2 COP
Water-Source Heat Pumps		
< 1.42 tons	11.2 EER	4.2 COP
≥ 1.42 tons and ≤ 5.41 tons	12.0 EER	4.2 COP
Ground Water Source Heat Pumps		
< 11.25 tons	16.2 EER	3.6 COP
Ground Source Heat Pumps		
< 11.25 tons	13.4 EER	3.1 COP
Packaged Terminal Systems (Replacements)[154]		
PTAC (cooling)	10.9 - (0.213 x Cap / 1000) ~~x~~ EER	
PTHP	10.8 - (0.213 x Cap / 1000) ~~x~~ EER	2.9 - (0.026 x Cap / 1000) COP
Packaged Terminal Systems (New Construction)[155]		
PTAC (cooling)	12.5 - (0.213 x Cap / 1000) ~~x~~ EER	
PTHP	12.3 - (0.213 x Cap / 1000) ~~x~~ EER	3.2 - (0.026 x Cap / 1000) ~~x~~ COP

[153] Baseline values from IECC 2009, after Jan 1, 2010 or Jan 23, 2010 as applicable.
[154] Cap represents the rated cooling capacity of the product in Btu/h. If the unit's capacity is less than 7,000 Btu/h, 7,000 Btu/h is used in the calculation. If the unit's capacity is greater than 15,000 Btu/h, 15,000 Btu/h is used in the calculation.
[155] Cap represents the rated cooling capacity of the product in Btu/h. If the unit's capacity is less than 7,000 Btu/h, 7,000 Btu/h is used in the calculation. If the unit's capacity is greater than 15,000 Btu/h, 15,000 Btu/h is used in the calculation.

Table 3-55: HVAC Baseline Efficiencies for Non-Residential Buildings

	Existing[170]		New Construction[171]	
Equipment Type and Capacity	**Cooling Efficiency**	**Heating Efficiency**	**Cooling Efficiency**	**Heating Efficiency**
Air-Source Air Conditioners				
< 5.41 tons	10.0 SEER	N/A	13.0 SEER	N/A
≥ 5.41 tons and <11.25 tons	10.3 EER	N/A	11.2 EER	N/A
≥ 11.25 tons and < 20.00 tons	9.7 EER	N/A	11.0 EER	N/A
≥ 20.00 tons and < 63.33 tons (IPLV for units with capacity-modulation only)	9.5 EER	N/A	10.0 EER / 9.7 IPLV	N/A
≥ 63.33 tons (IPLV for units with capacity-modulation only)	9.2 EER	N/A	9.7 EER / 9.4 IPLV	N/A
Water-Source and Evaporatively-Cooled Air Conditioners				
< 5.41 tons	12.1 EER	N/A	12.1 EER	N/A
≥ 5.41 tons and < 11.25 tons	11.5 EER	N/A	11.5 EER	N/A
≥ 11.25 tons and < 20.00 tons	11.0 EER	N/A	11.0 EER	N/A
≥ 20.00 tons	11.0 EER	N/A	11.5 EER	N/A
Air-Source Heat Pumps				
< 5.41 tons:	10.0 SEER	6.8 HSPF	13 SEER	7.7 HSPF
≥ 5.41 tons and < 11.25 tons	10.1 EER	3.2 COP	11.0 EER	3.3 COP
≥ 11.25 tons and < 20.00 tons	9.3 EER	3.1 COP	10.6 EER	3.2 COP
≥ 20.00 tons (IPLV for units with capacity-modulation only)	9.0 EER	3.1 COP	9.5 EER / 9.2 IPLV	3.2 COP
Water-Source Heat Pumps				
< 1.42 tons	11.2 EER	4.2 COP	11.2 EER	4.2 COP
≥ 1.42 tons and ≤ 5.41 tons	12.0 EER	4.2 COP	12.0 EER	4.2 COP
Ground Water Source Heat Pumps				
< 11.25 tons	16.2 EER	3.6 COP	16.2 EER	3.6 COP
Ground Source Heat Pumps				
< 11.25 tons	13.4 EER	3.1 COP	13.4 EER	3.1 COP
Packaged Terminal Systems				
PTAC (cooling)	10.9 - (0.213 x Cap / 1000) ~~x~~ EER	N/A	12.5 - (0.213 x Cap / 1000) ~~x~~ EER	N/A
PTHP	10.8 - (0.213 x Cap / 1000) ~~x~~ EER	2.9 - (0.026 x Cap / 1000) ~~x~~ COP	12.3 - (0.213 x Cap / 1000) ~~x~~ EER	3.2 - (0.026 x Cap / 1000) ~~x~~ COP

[170] ASHRAE 90.1-2004, Tables 6.8.1A, 6.8.1B, and 6.8.1D

[171] IECC 2009, Tables 503.2.3(1), 503.2.3(2), and 503.2.3(3)